NAMIBIA UNIVERSITY OF SCIENCE AND TECHNOLOGY

Conservation Agriculture: Analysing willingness to adopt, crop productivity, and the effects of socioeconomic factors in Northern Namibia

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TABLE OF CONTENTS

Declaration i
Retention and Use of Thesis ii
Table of Contents iii
List of Figures vi
List of Tables vii
List of Acronyms viii
Acknowledgements x
Dedication xi
Abstract xii
CHAPTER 1: General Introduction 1
1.1 Background 1
1.2 Problem Statement 4
1.3 Research Objectives 6
1.4 Significance of the study 6
1.5 Limitations of the study 7
1.6 Thesis outline 7
Chapter 2: Literature Review 8
2.1 Introduction 8
2.2 Agriculture and Food Production 8
2.3 Importance of soil carbon 9
2.4 Soil quality and land degradation 9
2.5 Consequence of climate change 10
2.6 Conventional Tillage System 11
2.7 Conservation Agriculture 12
2.7.1 Minimum mechanical soil disturbance 14
2.7.2 Permanent soil cover 14
2.7.3 Crop rotation 15
2.7.4 Weed management 16
2.7.5 A framework for understanding the adoption of CA 17
2.7.6 Socio-economic aspects of conservation agriculture 18
2.7.7 Challenges associated with conservation agriculture 19
2.7.8 Mechanisation of conservation agriculture 20
2.7.9 The role of policy and institutions 21

2. 8 Analysing conservation agriculture 21
2.8.1 Models 21
2.8.2 Multinomial logistic model 22
2.8.3 Analysis of Variance 23
2.8.4 Conditional logistic regression model 24
2.9 Summary 26
CHAPTER 3: Overview of the namibian agricultural sector 27
3.1 Introduction 27
3.2 Overview of the agricultural sector 27
3.3 Importance of the agricultural sector 29
3.4 Summary 31
CHAPTER 4: RESEARCH METHODS 32
4.1 Introduction 32
4.2 Description of the study area 32
4.2.1 Kavango West Region 33
4.2.2 Kavango East region 34
4.2.3 Zambezi region 34
4.3 Research design 35
4.3.1 Experimental choice 35
4.3.2 Randomised complete block design 36
4.4 Data collection 37
4.5 Data analysis 38
4.5.1 Multinomial logistic regression model 39
4.5.2 Analysis of Variance 40
4.5.3. Conditional logistic regression model 41
4.6 Summary 43
Chapter 5: Results and discussion 44
5.1 Introduction 44
5.2 Socio-economic Characteristics of the Respondents 44
5.2.1 Age 44
5.2.2 Household size 45
5.2.3 Area under conservation agriculture 45
5.2.4 Education 46
5.2.5 Composition of participating farmers 47
5.3 Socio-economic Factors influencing CA adoption 47

5.3.1 Introduction 47
5.3.2 Method of soil preparation 48
5.3.3 Crop diversification through intercropping 51
5.3.4 Crop rotation 54
5.3.5 Permanent soil cover materials 57
5.4 Evaluation of farmers' preference for CA and the trade-offs between CA and conventional practices 58
5.4.1 Introduction 58
5.4.2 Socio-economic characteristic comparison between regions 59
5.4.3 ANOVA analysis results 62
5.5 Willingness to Pay for the main activities of conservation agriculture 64
5.5.1 Introduction 64
5.5.2 Description of data used 64
5.5.4 Conclusion 63
5.6 Field Experiment 63
5.6.1 Introduction 63
5.6.2 Rainfall records 64
5.6.3 Crop yields 65
Chapter 6: Conclusions and Recommendations 82
6.1 Introduction 82
6.2 Conclusion 82
6.3 Recommendations 85
References 88
Appendices 116
Appendix 1: Questionnaire 116
Appendix 2: Experimental questionnaire virtual features 130

LIST OF FIGURES

Figure 2.1: An overview of integrated challenges majorly faced by the agriculture sector 11
Figure 2. 2: The vicious weed cycle can affect smallholder farmers' crop yields in developing countries. 17
Figure 3. 1: Namibia agricultural map 28
Figure 4. 1: Location of villages in the selected study areas..... 32
Figure 4. 2: On-farm experimental field plan design showing mouldboard plough and ripper strip plots 38
Figure 5. 1: Farmers' educational status 46
Figure 5. 2: The composition of interviewed farmers 47
Figure 5. 3: Gender of the interviewed farmers 60
Figure 5. 4: Educational level of the respondents per region 61
Figure 5. 5: Marital status of respondents 62
Figure 5. 6: Cumulative rainfall at research clusters during the 2016/2017 to 2017/2018 seasons 64
Figure 5. 7: Cumulative rainfall at research clusters during the 2018/2019 to 2019/2020 seasons 65
Figure 5. 8: Average maize biomass yield on different treatments 66
Figure 5. 9: Average maize grain yield on different treatments 67
Figure 5. 10: Average maize biomass yield across treatments within seasons 68
Figure 5. 11: Average maize grain yield across treatments within seasons 70
Figure 5. 12: Pearl millet biomass yield on different treatment 72
Figure 5. 13: Pearl millet grain yield on different treatment 73
Figure 5. 14: Average pearl millet biomass yield across treatments within seasons 74
Figure 5. 15: Average pearl millet grain yield across treatments within seasons 76
Figure 5. 16: Average cowpeas biomass yield across treatments over all seasons 77
Figure 5. 17: Average cowpeas biomass yield between treatments within seasons 78
Figure 5. 18: Average cowpeas grain yield across treatments over all seasons 79
Figure 5. 19: Average cowpeas grain yield between treatments within seasons 80

LIST OF TABLES

Table 3.1 Various Green Schemes and their size in hectares 30
Table 5. 1: Descriptive statistics summary of the respondents 44
Table 5. 2: Multinomial logistic regression result for the method of soil preparation 49
Table 5. 3: Multinomial logistic regression result for intercropping 52
Table 5. 4: Multinomial logistic regression result of crop rotation 55
Table 5. 5: Multinomial logistic regression result of mulching options 57
Table 5. 6: ANOVA analysis Table 63
Table 5. 7: Attributes and level used 65
Table 5. 8:Conditional logistical regression estimates for main activities of practicing conservation 61

LIST OF ACRONYMS

ACIAR	Australian Centre for International Agricultural Research
ADSWAC	Adaptation in Drought-stricken South-western African Communities
C	Carbon
CA	Conservation agriculture
CE	Choice Experiment
CH_4	Methane
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
CIRAD	Centre de cooperation International en Recherche Agronomique Pour le Developpement
CO_2	Carbon dioxide
CT	Conventional tillage
DCE	Discrete Choice Experiment
DCPP	Dry Land Crop Production Programme
FAO	Food and Agriculture Organization
GHGs	Greenhouse gases
GIZ	Gesellschaft für Internationale Zusammenarbeit
GLASOD	Global Assessment of Soil Degradation
GLM	Generalized Linear Models
GMCC	Green Manure Cover Crop
HA	Hectare
ICRAF	International Council for Research in Agroforestry
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
MAWF	Ministry of Agriculture, Water and Forestry
MAWLR	Ministry of Agriculture, Water and Land Reform
MLR	Ministry of Land and Resettlement
MNL	Multinomial Logit
N_2O	Nitrous Oxide
NAB	Namibia Agronomic Board
NCAF	National Conservation Agriculture Forum
NCATF	National Conservation Agriculture Task Force
NORAD	Norwegian Agency for Development Cooperation
NPC	National Planning Commission
NPK	Nitrogen, Phosphorus, and Potassium
NSA	Namibia Statistic Agency
NTA	National Training Authority
NUST	Namibia University of Science and Technology
RBD	Randomised Block Designs
RCBD	Randomised Complete Block Design
RUM	Random Utility Maximisation
SARE	Sustainable Agriculture Research and Education

SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	sub-Saharan Africa
UNDP	United Nations Development Programme
WTP	Willingness to Pay

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ABSTRACT

Farmers in the northern communal areas of Namibia practice mixed farming, which comprises livestock and crop production. However, various factors limit crop production. First, the soil is low in nutrients, leading to poor water-holding capacity, except in the Zambezi region. Second, irregular rainfall patterns occur between October and March, often resulting in crop failure due to the region's late rains or total water deficits. Third, soil pulverization and compaction caused by animal-drawn or heavy tractor mouldboards present a concern for crop production, especially in the northern regions where major staples such as maize and pearl millet are grown. Because of these challenges, some farmers were introduced to conservation agriculture in recent years; however, the adoption rate of this practice has been low. Therefore, this study aims to determine the factors that influence the practice of conservation agriculture by subsistence crop farmers in three regions: Zambezi, Kavango East, and Kavango West. The objectives are to identify the socio-economic factors that influence adoption, evaluate the trade-offs between conservation agriculture and conventional tillage, assess farmers' willingness to adopt conservation agriculture, and determine statistically significant differences in average yields between conventional (plough) and conservation (ripper) agriculture for both cereals and cowpeas.

The multinomial logistic model revealed that farmers' socio-economic factors significantly impact their use of basins as a tillage method over direct seeders. However, the education level of the household head, household size, weeding rate, and the practice of mono-cropping have a negative influence on the adoption of basins compared to direct seeders. Conversely, the practice of crop rotation positively influences the use of basins over direct seeders. Annual crop rotation is more positively associated with mono-cropping than intercropping cereals and cowpeas. Moreover, the educational level of the household head and the practice of crop rotation negatively affect the intercropping of cereals with groundnuts compared to intercropping cereals with cowpeas. Additionally, the gender of the household head and the household size positively influence the decision to rotate crops every two years rather than every cropping season. Conversely, the age of the household head negatively impacts the preference for rotating crops every two years compared to annual crop rotation.

The ANOVA analysis' rejection of the null hypothesis across all cases suggests that there is a statistically significant difference between continuing with the current farming practices (the base scenario) and adopting new, more sustainable and environmentally friendly initiatives. This indicates that respondents are aware of and can distinguish the benefits that new agricultural practices, like conservation agriculture, can offer in comparison to traditional methods. It reflects the respondents' understanding of the potential

improvements in sustainability and environmental friendliness that these new practices can bring to farming.

Conditional logistic regression estimates indicate that intercropping negatively influences the adoption of conservation agriculture. Farmers have shown the highest willingness to pay to avoid practicing intercropping. Crop rotation consistently increases the adoption of conservation agriculture, though willingness to pay varies from round to round. The time spent on the first soil preparation and the weeding rate have been identified as significantly influencing the practice of conservation agriculture in the second and sixth rounds for soil preparation and the second and fourth rounds for the weeding rate. Welch's t-test indicates that cereal crop biomass and grain yields were not statistically significantly different across treatments and seasons in pearl millets. However, there was a statistically significant difference in maize grain yields between treatments in the 2017/2018 cropping season. The study identified a statistically significant difference in cowpea biomass yield between treatments in the 2018/2019 cropping season. Thus, the study concludes that there is no statistically significant difference within treatments and seasons for pearl millet (grain and biomass yield), cowpeas (grain yield), and maize (biomass yield). The study recommends that stakeholders make concerted efforts to ensure that conservation agriculture's concept, objectives, and intended outcomes are well communicated and understood by all parties involved, especially the farmers implementing conservation agriculture. It is recommended that a National Conservation Agriculture Task Force (NCATF) be established to oversee, promote, mobilize, and coordinate various conservation agriculture activities across the country. There is a need for the Ministry of Agriculture, Water, and Land Reform (MAWLR) to hire special extension technicians specifically for disseminating information and coordinating, promoting, and implementing conservation agriculture activities in all regions. Adequate market access should be ensured for improved market participation.

Key words: conservation agriculture, conventional, sustainable, yield, fertility

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background

Agriculture plays a pivotal role in economic development, particularly within the rural economy, where most individuals are subsistence farmers who depend on agriculture for food and income generation (Lai et al., 2012). Approximately 67 percent of Namibia's population is estimated to reside in rural areas, with most of these individuals relying on smallholder crop production for their livelihoods (MAWF, 2015). In Namibia, a significant portion of the land is dedicated to agricultural use, with subsistence farming on state-owned land covering about 250,700 square kilometers, representing 30.4 percent of the total land area (Mendelsohn et al., 2002). The most prevalent form of agriculture in northern Namibia is small-scale farming, especially in communal areas, where farmers engage in mixed farming, including livestock and crop production (Kerdiles, Rembold, & Pérez-Hoyos, 2015).

Despite efforts toward achieving sufficient food production, self-sufficiency and food security remain elusive for many rural communities. This situation can be attributed to several factors. In the northern communal areas, the soil is typically nutrient-poor and exhibits inadequate water-holding capacity, except for the Zambezi region in the northeast (Krebs, 2014). Compounding this issue are the irregular rainfall patterns, predominantly occurring between October and March, often leading to inadequate crop production rainfall. Consequently, small-scale farming, relying on traditional cultivation methods, prevails among these rural communities.

Despite efforts to enhance food production, conventional agricultural practices, such as using animal-drawn mouldboards for ploughing, negatively impact soil porosity and moisture retention capacity, as Krebs (2014) highlighted. Moreover, conventional tillage methods often involve removing crop residue post-harvest, further depleting soil nutrients (Wang et al., 2020). Such practices have severely depleted vast tracts of land in Zimbabwe (Makwara, 2010). Von Hase (2013) observed that farmers frequently use rudimentary tools for planting, leading to overcrowded planting stations and subsequent competition among plants for limited nutrients, resulting in poor yields. The additional issues of mono-cropping and continuous cultivation without replenishing soil nutrients or organic matter exacerbate the decline in soil fertility and crop productivity (Grabowski & Kerr, 2014). Islam & Miah (2010) identify the loss of organic matter, high cropping intensity, improper crop sequencing, inefficient fertilizer use, and incorrect

management practices as key factors in soil fertility depletion. Krebs (2014) advocates for better soil management practices, especially those enhancing soil organic carbon.

Pearl millet, a crop of significant nutritional value widely cultivated in Africa, including Namibia, demonstrates the potential for resilience and productivity under appropriate conditions (Taylor, Barrion, & Rooney, 2010). In northern Namibia, rain-fed pearl millet production areas receive an average of 350–400 mm of rainfall annually, enabling yields of more than 400 kg/ha (Matanyaire, 1996). Namibia research stations have recorded pearl millet yields ranging from 1.5 to 1.75 tonnes/ha (Rohrbach et al., 1999; Ipinge, 2001, cited in Ashipala, 2013). However, a significant yield gap exists between farm-level (0.15–0.20 tonnes/ha) and research station (3.63–3.87 tonnes/ha) cultivation, as observed in the 1992/1993 season (Matanyaire, 1996). Moreover, yields have generally declined in recent years, averaging about 350 kg/ha in seasons with good rainfall and dropping to as low as 200 kg/ha in low rainfall seasons (Matanyaire, 1996; Krebs, 2014).

An alternative to traditional farming methods is Conservation Agriculture (CA), which represents a shift towards more sustainable agricultural technologies. For instance, adopting CA in the Omusati and Oshana regions of north-central Namibia has significantly increased pearl millet yields to approximately 2500–3000 kg/ha (Schlecter, 2014). Defined by its commitment to improved soil management, conservation agriculture encompasses a variety of practices centered around three core principles: (a) minimizing soil disturbance through methods like ripping instead of ploughing, (b) maintaining permanent soil cover by adding organic matter, and (c) implementing crop rotation, specifically alternating cereal crops with leguminous ones (Wagstaff & Harty, 2010). These practices provide a protective buffer for crops, especially under drought conditions (Palm et al., 2014), and offer a sustainable approach to agriculture applicable across different farming systems (Kassam et al., 2014).

The shift from traditional to conservation agriculture practices, focusing on soil moisture and nutrient conservation, results in enhanced yields and sustainable land use (Gebru, 2010). Krebs (2014) notes that transitioning from conventional to conservation tillage can significantly improve soil carbon levels. Moreover, incorporating organic matter, like kraal manure, into the soil enhances water retention, reduces erosion, and fosters crop growth (He et al., 2009; Krebs, 2014). Supporting this, a study in Zambia by Nyanga, Johnsen, and Aune (2011) found that maize yields per hectare were consistently higher on CA fields than those using conventional methods, particularly in seasons of low rainfall.

Rising environmental concerns have underscored the need for alternative approaches that reconcile development activities, including agriculture, with the imperatives of future investment and environmental sustainability (Mkomwa et al., 2017a; Xavier et al., 2020). Conservation agriculture emerges as a viable solution, offering the potential to effectively manage agroecosystems for enhanced and sustainable outputs, improved incomes, and increased food security, all while protecting the natural resource base and the environment. Echoing this perspective, Pittelkow et al. (2014) and Islam and Miah (2010) advocate for the widespread adoption of conservation agriculture to ensure sustainable agricultural productivity.

In Eastern and Southern Africa, CA has been actively promoted for over a decade as a strategy to enhance crop productivity, simultaneously facilitating soil and water conservation (Islam & Miah, 2010; Baudron, Thierfelder, & Gerard, 2015; Ngwira et al., 2020). Recognized as a sustainable approach, CA minimizes or reverses land degradation, stabilizes, and significantly increases long-term yields. An additional benefit of CA is its labour hours per unit of output efficiency, leading to higher net returns compared to CT practices (Ngwira, Thierfelder, & Lambert, 2012). Mkomwa et al. (2017a) further highlight CA's potential in climate change mitigation. Moreover, it supports nature conservation efforts by promoting adaptation and mitigation strategies, preserving biodiversity, ensuring the distribution of ecosystem services, and meeting societal needs (Mkomwa, Lugandu, Kuria, & Mutai, 2017b).

CA represents a distinctive approach encompassing conservation tillage and comprehensive crop residue management. This agricultural method safeguards soil fertility and bolsters land resilience against drought and other adverse climatic conditions (Akpalu & Ekbom, 2010). CA enhances water infiltration efficiency and reduces soil surface evaporation, leading to a corresponding decrease in runoff. One of the direct advantages of CA in dryland farming is improved precipitation utilization (Baudron et al., 2015; Gebru, 2010; Thierfelder & Wall, 2009). The practice of CA does not entirely shift away from conventional farming techniques (Kassam et al., 2014); instead, it seeks to recognize, integrate, and address the limitations associated with traditional practices by realigning them with CA principles through the adoption and dissemination of knowledge. For CA to effectively enhance crop productivity, it is essential to tailor it to specific regional conditions through a stakeholder-driven approach that leverages market opportunities, ensuring that the practice is affordable and meets farmers' needs (Pittelkow et al., 2014). The success of CA implementation should not be gauged merely by the level of tillage or the quantity of mulching

material applied but by its impact on reducing production costs, improving water retention, and controlling soil erosion (Baudron et al., 2015). This study aims to explore these critical factors relevant to northern Namibia. The study employed a range of models to assess the suitability of CA within Namibian rural crop farms. It aims to establish a baseline for how the government might strategize the broader application of CA to additional farmers and regions, highlighting its importance for policy development and implementation. This approach evaluates the current state of CA adoption. It provides insights into effective strategies for scaling up these practices, supporting the transition towards more sustainable agricultural systems in Namibia.

Using various models to evaluate the compatibility of CA in Namibia at the rural crop farm level is a strategic approach to understanding CA practices' multifaceted impacts and benefits. By assessing compatibility, the study examines the agronomic feasibility of CA and considers socio-economic and environmental factors that influence its adoption and sustainability.

1.2 Problem Statement

In Namibia, about 67 percent of the population are subsistence farmers who largely depend on crop production, with pearl millet and maize being the major crops. Agriculture contributes approximately 5–6% to the country's GDP (Matanyaire, 1996; Shifiona, Dongyang & Zhiguan, 2016). By 2031, Namibia's population is anticipated to grow from 2.2 million to 3 million, with the majority living in the northern areas (MAWF, 2015). The question arises whether the agricultural sector can produce sufficient food for the rapidly growing population. According to an analysis of the agricultural sector, there is a persistent shortage of staple foods, and most African states—including Namibia—are net importers of these foods (Mushendami, Biwa, & Gaomab II, 2008). Moreover, many factors militate against large-scale food production. These factors include drought, high temperatures, poor fertiliser application, and poor soil management (Johansson, 2016).

Namibia is susceptible to climate change risks and could face severe productivity losses due to extreme climate events (Shifiona et al., 2016). For instance, severe flooding has led to the loss of many crops, resulting in low grain production and food scarcity. The largest challenges to increasing the production of maize and pearl millet, which are crucial for Namibia's food security and economic development, include irregular rainfall patterns and declining soil fertility (Shifiona et al., 2016; Fortunato & Enciso, 2023). The

total production of pearl millet decreased from 44,450 tonnes in 2006/2007 to just 24,700 tonnes in 2012/2013, despite an increase in the area planted from 194,788 ha to 255,456 ha (NAB, 2013). Additionally, the quantity of pearl millet imported has increased significantly, indicating rising domestic demand (NAB, 2013; Shifiona et al., 2016).

Consequently, agriculturalists, environmentalists, and development experts, among others, have hailed CA as a 'win-win' approach in agriculture—benefiting both farmers by increasing crop yields and preserving the natural environment (Taapopi, Kamwi, & Siyambango, 2018; Remmer, 2020). The CA method, promoted since 2005, has boosted average mahangu (pearl millet) yields to 1,670 kg/ha in Namibia (Von Hase, 2013). However, the adoption of CA techniques across Africa remains low, with only a few exceptions, such as Southern Zambia, South Africa, and Ghana (Giller et al., 2009). With a fragile natural environment, Namibia has been subject to unsustainable agricultural practices over the past decades (Remmer, 2020). Although reductions in yields are observed, the response from subsistence farmers is minimal due to the currently insufficient application of various drought survival mechanisms, including CA, to permanently improve crop yields (Amukuhu, 2020; Shikangalah, 2020; Fortunato & Enciso, 2023). Namibia must apply and advance sustainable agricultural production methods, including CA. Understanding the background and the steps taken in the decision to implement CA and socioeconomic influences will hopefully aid ongoing and future CA projects in boosting adoption rates across Northern Namibia. Therefore, investigating the factors that affect the adoption of CA by communal farmers in northern Namibia is important.

1.3 Research Objectives

The study's main objective is to analyse the impact of various socio-economic factors on the adoption rate of CA by subsistence crop farmers in Namibia over the first three years of its introduction. The following specific objectives were established:

i. Examine the influence of socio-economic factors in sustainable conservation agriculture adoption
ii. Examine the trade-off between conservation and conventional agriculture practices
iii. Determine farmers' willingness to adopt conservation agriculture
iv. Determine the effect of conservation agriculture on crop yield

1.4 Significance of the study

Extreme climatic conditions, such as droughts and floods, are commonplace in Namibia, reducing productivity and increasing food insecurity. Given the significant impact of these changes on human life, it is crucial to enhance awareness at the grassroots level and reorient rural farmers and community members who are most vulnerable to these changes. Consequently, this study is pertinent in creating a conducive opportunity for stakeholders to comprehend the factors influencing the adoption rate of CA. Understanding the direction of adoption and farmers' perspectives will aid in prioritizing the acquisition of resources necessary to ensure the successful adoption of CA. The study aims to establish a comprehensive baseline of data that extension agencies and research organisations can utilise to strategise on addressing the issue of smallholder farmers adopting conservation agriculture. Furthermore, this research will be instrumental for government agencies and other stakeholders as the country reviews its comprehensive agricultural conservation policy and other related policies to enhance the socio-economic status of farmers and the wider society.

1.5 Limitations of the study

The experimental phase of this study was conducted directly in farmers' fields, which presented unique challenges. Notably, these fields were not enclosed by fencing, leading to significant crop damage and losses due to wildlife and livestock. Difficulties in crop-residue management compounded this issue in several instances; crop residue was lost to livestock invasion before data could be recorded. This residue loss directly undermines the CA principle of maintaining permanent soil cover, which is essential for the method's success. Another major hurdle was relying on all experimental fields on rainfall for crop production. Insufficient rainfall emerged as a significant challenge, casting doubts on the feasibility of valid experimental results under such conditions. Additionally, the experimental fields were plagued by outbreaks of pests and diseases, further complicating the study's execution.

Temporarily, livestock fencing was provided to address the challenge of unfenced crop fields. An option for dealing with low or poorly distributed rainfall is to use a seed variety with a short maturity period. The Okashana No. 2 (millet) variety was used in the Kavango West and Kavango East regions, while in the Zambezi region, seed ZMS606 (maize) from the Zam-seed company was used. The outbreak of pests and diseases was controlled with homemade remedies (chili mixed in water, crushed neem leaves boiled in water, ash, etc). The lack of residues in the field was addressed using alternative available materials, such as grass and bush mulch, where possible.

1.6 Thesis outline

The chapters of this study are systematically organised to guide the reader through the exploration of conservation agriculture, setting the theoretical framework and context for the study, which are presented in Chapter 2. An overview of the agricultural sector in Namibia, delineating the structure and performance of the sector to provide a backdrop against which the study's findings can be evaluated, is offered in Chapter 3. The study area and outlines of the research methodology employed, including the discussion on the design of the questionnaire and the data collection procedures, ensuring a transparent and replicable research process, are described in Chapter 4. Results and discussion on the key findings of the study highlighting the implications and significance of the research within the broader context of Namibia's agricultural sector are provided in chapter 5. Finally, the summary of findings, policy recommendations, and suggestions for further research, proposing additional questions that could significantly advance crop farming in Namibia, are part of Chapter 6.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter is devoted to a literature review of the theory and application of conservation agriculture. The regression models and their application are reviewed, and the chapter concludes with a summary.

2.2 Agriculture and Food Production

Agricultural production faces numerous challenges in sub-Saharan Africa (SSA), leading to insufficient food supply (Assefa, Jha, Reyes, & Worqlul, 2018). Sub-Saharan Africa has failed to keep pace with other developing and developed regions of the world in terms of generating enough food to feed its population, a consequence of poor agricultural productivity (Mazvimavi et al., 2010; Gracia-Romero et al., 2018; Ngango & Hong, 2021). The challenge for agricultural scientists today is to increase food production to meet the demands of the ever-growing population in many developing countries (Hobbs, 2007; Glick, 2012; Pittelkow et al., 2014; Dachraoui & Sombrero, 2019; Delgado et al., 2019). Increased uncertainty in agricultural production, arising from extreme climatic changes, leads to uncertainty in productivity (Jat et al., 2020a). This undoubtedly complicates the task of satisfying the constantly rising food demand a phenomenon that is difficult for stakeholders to manage (Soares et al., 2019). Consequently, the future of agricultural productivity is endangered by the detrimental impacts on agriculture's natural resource base, characteristic of the existing agricultural system focused on mechanical soil tillage, exposed soils, and continuous monocropping (Corsi, 2019). The decline in soil fertility, a form of degradation affecting large areas in sub-Saharan Africa, poses urgent global concerns due to its negative effects on agricultural production, food security, and livelihoods (Mkomwa et al., 2017b). In Namibia, as in many other Southern African nations, there is constant and growing pressure to increase food production and alleviate poverty among the rural population (Taapopi, Kamwi, & Siyambango, 2018). Thus, future food production necessitates the adoption of new management approaches that are both efficient and climate-smart (Akpalu & Ekbom, 2010; Antle, Stoorvogel, & Valdivia, 2013; Shikuku et al., 2016; Jat et al., 2020b). These approaches should include improved agronomic practices such as intercropping, row planting, and proper fertilizer application (Erkossa, Williams, & Laekemariam, 2018). Furthermore, the adoption of appropriate crop species and varieties, adequate planting techniques, and physical soil and water conservation

measures all contribute to achieving favorable outcomes (Ilukor, Bagamba, & Bashaasha, 2014; Baudron, Thierfelder, & Gerard, 2015; Slater, 2016; Erkossa et al., 2018; Ngwira et al., 2020).

2.3 Importance of soil carbon

It is widely acknowledged that soil organic carbon (SOC) is one of the crucial components of healthy soil (Mutua et al., 2014). Kabirigi et al. (2015), Farooq & Siddique (2015), and Kassam & Coates (2018) state that soil carbon is the primary determinant of the soil's capacity to store and release water, as well as to supply other nutrients essential for plant growth and the development of root systems. Soil microbes play a vital role in the transformation of organic carbon from straw into soil, whereas dissolved organic carbon is crucial for several soil processes, including its influence on the mobility and availability of soil nutrients (Ghaley et al., 2018; Cong et al., 2020). Soil organic carbon plays a pivotal role in maintaining soil structure and improving the physical conditions necessary for root penetration (Mutua et al., 2014). Hui et al. (2013) and Ngwira et al. (2020) have noted that excessive tillage in traditional farming practices leads to declines in soil fertility by altering the soil's nutrient and carbon content, thereby affecting its fertility and productivity. This indicates a loss of organic matter from the soil, which negatively impacts soil biology, water infiltration, and the overall structure of the soil (Derpsch et al., 2010; Crummett, 2019).

2.4 Soil quality and land degradation

Churchman (2010) and Moradi et al. (2020) highlight soil as an essential natural resource that encompasses minerals, carbon, water, air, and nutrients. Soil quality is defined by its capacity to interact with various elements of the ecosystem as a living system, according to Singh et al. (2021). Emphasizing the importance of soil quality is crucial for ensuring food safety, human health, and the development of sustainable agriculture (Wu, Liu, Huang, & Liu, 2019). The quality of soil is determined by its chemical, physical, and biological properties and their distribution throughout the soil profile (Coxhead & Oygard, 2008). Crucially, indicators such as pH, organic matter content, availability of nutrients to plants, porosity, grain size distribution, water permeability and retention capacity, depth of topsoil, and the presence of compounds harmful to plants are among the metrics scientists use to assess soil quality (Coxhead & Oygard, 2008; Nachtergaele, Biancalani & Petri, 2010; Pivato et al., 2017; Yang, Siddique, & Liu, 2020). Importantly, Corsi (2019) identified soil organic matter as the most reliable predictor of soil quality.

The current understanding of land degradation's extent, its trends, and the human contribution to this process remains limited (Safriel, 2016; Coxhead & Oygard, 2008; Yang et al., 2020). According to several studies (Cassman, 1999; Gregg & Izaurralde, 2010; Meseret, 2016; Muoni et al., 2019; O'Dell et al., 2020), soil degradation poses a significant environmental challenge that demands urgent attention. When considered in the context of food security and safety, it emerges as one of the most pressing socioeconomic and environmental challenges, posing a direct threat to human survival and well-being (Chan et al., 2017; Yang et al., 2020; Singh et al., 2021). Consequently, it is imperative to develop and implement comprehensive programs aimed at preserving, restoring, and safeguarding soil health.

Human activities such as unsustainable agricultural land use, soil acidification from intensive N-fertilizer use, native vegetation removal, frequent heavy machinery use, overgrazing, nutrient imbalances from intensive nutrient mining, and poor irrigation techniques are significant contributors to land degradation (Meseret, 2016; Cassman, 1999; Singh et al., 2021). Meseret (2016) underscores the imperative for farmers to protect and restore soil fertility to maintain farm productivity and meet food demands sustainably. However, a challenge emerges when inefficient land management practices lead to increased output losses, particularly for farmers with limited resources (Mkomwa et al., 2017a).

2.5 Consequence of climate change

The relationship between humans and the natural environment is undergoing significant changes due to global climate change, rendering previously stable climatic conditions uncertain and increasingly perilous (Findlater et al., 2018). Kragt and Bennett (2008) along with Ogunbode et al. (2018) have found a strong correlation between perceptions of abnormal weather changes, personal experiences of extreme weather events, and the acknowledgment of ongoing climate change. This shifting climate is believed to alter interactions among crops, pests, diseases, and weeds (Ball et al., 2005; Perkins & Nachmany, 2018; Soares et al., 2019), impacting these distinct phenomena in ways that challenge the ecosystem's resilience (FAO, 2020). It's crucial to acknowledge that climate change poses significant risks to plant-pollinator interactions, as many pollinators are vulnerable to increased heat and dryness. Recent projections indicate that the number of people facing food shortages—currently at 800 million—will increase by 189 million with a temperature rise of 2°C (FAO, 2020; Hepburn et al., 2020). Furthermore, Jat et al. (2020a) highlight that this rise in temperature is expected to affect pest presence and population dynamics adversely, as well as reduce the effectiveness of nutrient mineralization and fertilizer usage. Climate

simulation studies have shown that heat and drought lead to a non-linear decrease in maize yields within African maize-growing regions, posing significant risks to crop production (Schlenker & Lobell, 2010; Awala et al., 2019). Figure 2.1 summarizes the challenges faced by the agricultural sector, which is responsible for producing food for the growing human and livestock populations amid climate change. Climate change is anticipated to not only increase the frequency of extreme El Niño events but also intensify their severity. This is expected to result in increased cyclone activity and unpredictable rainfall patterns (Rubio, 2019; FAO, 2020).

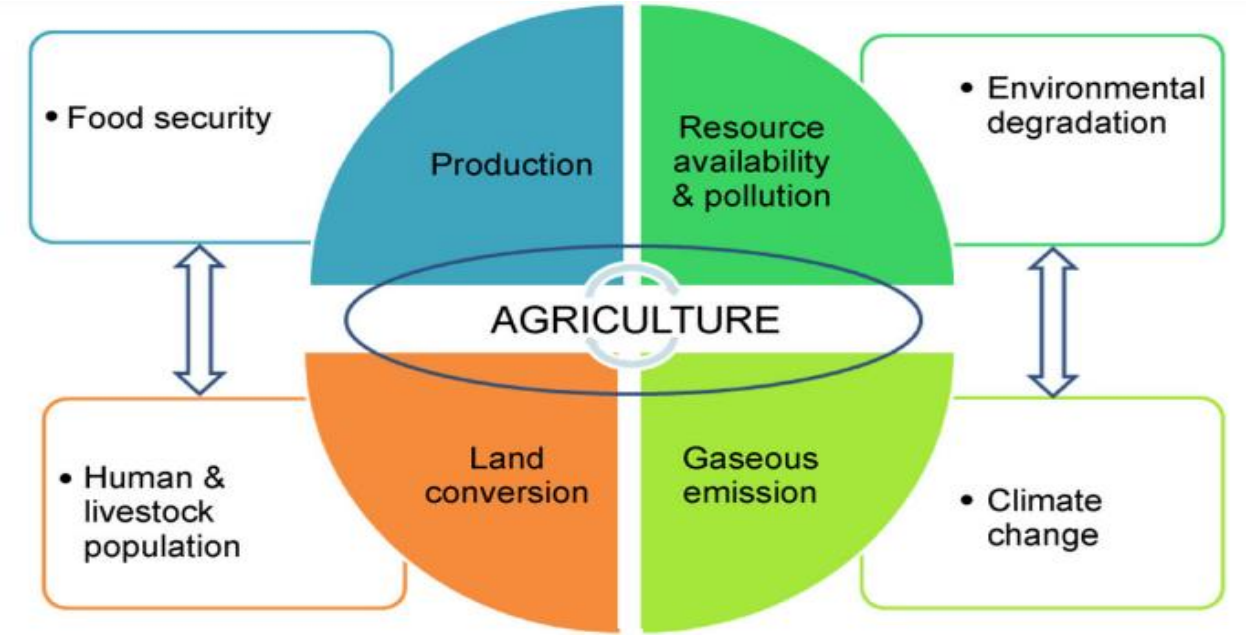


Figure 2.1: An overview of integrated challenges majorly faced by the agriculture sector
Source: Singh et al. (2021)

2.6 Conventional Tillage System

Tillage involves preparing the land for crop cultivation, which can include manual clearing or the use of mechanical systems for seedbed preparation and weed management during secondary cultivation (Rowen et al., 2020). Conventional farming, often characterized by monocropping and deep ploughing typically involving 20–30 cm of inversion tillage and the removal of crop residues has been associated with negative impacts on soil functions, although this is not invariably the case (Six, Elliott, & Paustian, 1999; Ghaley et al., 2018; Rowen et al., 2020). This type of land preparation involves soil tillage using a mouldboard plough to loosen the seedbed. This process aims to ensure uniform germination, eliminate

weeds, and release soil nutrients through mineralization and oxidation (Gracia-Romero, Vergara-Diaz, Thierfelder, Cairns, Kefauver, & Araus, 2018; Rowen, Regan, Barbercheck, & Tooker, 2020). However, the repeated passes of machinery required for land preparation activities, such as ploughing, harrowing, and seeding, can significantly damage the soil structure (Rasaily et al., 2012; Kassam & Coates, 2018; Hajer et al., 2020). The conventional crop production practices employed by farmers worldwide are extractive by nature, invariably leaving the ecosystem depleted. These practices result in diminished nutrient levels, lower soil organic matter (SOM), reduced biological activity, and decreased biodiversity (Rasaily, Li, He, Wang, & Lu, 2012; Caldeira, Bala, & Cao, 2013; Taner, Arisoy, Kaya, Gültekin, & Partigoc, 2015; Mitchell, Reicosky, Kueneman, Fisher, & Beck, 2019; Lv et al., 2019; Jat et al., 2020a). Therefore, it is clear that current traditional tillage systems contribute to significant land degradation. This degradation not only heightens the risk of future food insecurity but also accelerates emissions, diminishes carbon sinks, and leads to exceedingly low yields (Bryson, Dorsett & Purdon, 2002; He et al., 2009; Bai et al., 2009; Mutua et al., 2014; Su, Gabrielle, Beillouin, & Makowski, 2021).

However, some authors advocate for traditional tillage methods. Mutua et al. (2014) argue that conventional tillage improves the environment for biological activity by accelerating the decomposition of organic matter, as it brings organic materials into contact with soil organisms. Nonetheless, if decomposition outpaces the introduction of new organic matter, the soil's organic matter content will decline. This method benefits farmers by reducing the need for multiple weeding sessions, as traditional plowing buries the initial flush of weeds, allowing them to weed just once before their crops mature (IFAD, 2016).

2.7 Conservation Agriculture

Through mechanisms that enhance the soil's physical, chemical, and biological properties, CA aims to reduce the degradation of soil quality caused by conventional tillage practices (Fuhlendorf, Davis, Elmore, Goodman, & Hamilton, 2018; Kassam & Coates, 2018; Mitchell et al., 2019; Jat et al., 2020a). According to numerous studies (Hobbs, 2007; Chiputwa et al., 2011; IFAD, 2016; Griscom et al., 2017; Sims et al., 2018; Su et al., 2021), the CA system is well-recognized for providing beneficial environmental externalities, such as increased biodiversity, enhanced carbon sequestration, and improved soil quality due to an increase in soil organic matter. CA is a method for enhancing soil fertility that involves minimal soil disturbance, an increase in crop residue retention, more varied crop rotations, a decrease in excessive

pesticide and fuel use, and integrated weed management (Wall, 2007; He et al., 2009; Farooq & Siddique, 2015; Bell et al., 2019; Gracia-Romero et al., 2018; Kassam & Coates, 2018; Kidane, Lambert). According to Mutua et al. (2014), it is an approach that emphasizes the soil as a living body, necessary to sustain life on earth.

The advantages of CA over conventional tillage, including time, fuel, and labor savings, along with favourable economic returns, have made it increasingly appealing to farmers in the modern era. These benefits are identified as key factors driving its attractiveness (Derpsch et al., 2010). To support both small- and large-scale farmers in sustainably increasing food production, CA is becoming more widely accepted worldwide and is being utilized as an alternative to traditional agricultural technologies (Mkomwa et al., 2017a; Kassam et al., 2018). The CA system has been successfully implemented in regions with annual rainfalls as low as 250 mm, including Western Australia and Northern China, and in areas with much higher annual rainfall, reaching up to 2000 mm in Brazil and Chile, and even 3000 mm per year (Derpsch et al., 2010). Despite its inception in the 1970s, it took approximately 20 years for CA to become widely adopted in South America and other regions (He et al., 2010; Friedrich et al., 2012). While CA is increasingly recognized for its soil conservation benefits (Sims, Corsi, Gbehounou, Kienzle, Taguchi, & Friedrich, 2018; Fonteyne et al., 2020), a significant number of farmers remain unfamiliar with its practices and advantages (Sims, Corsi, Gbehounou, Kienzle, Taguchi, & Friedrich, 2018; Fonteyne et al., 2020). In the early 1990s, the adoption of CA began to revolutionize farming systems in Argentina, Southern Brazil, and Paraguay. During this period, many international organizations started to show interest in promoting CA (Farooq & Siddique, 2015). The initiative to introduce and promote CA in Africa commenced a bit earlier, with Sasakawa Global (2000) being the first non-governmental organization (NGO) to introduce CA to Eastern Africa in the late 1980s (Mkomwa et al., 2017b). Throughout the 1990s, the development of CA increasingly caught the attention of other parts of the world, drawing involvement from development and international research organizations, including the Food and Agriculture Organization (FAO), World Bank, IFAD, GIZ, NORAD, CIRAD, ACIAR, and the CGIAR system (Friedrich et al., 2012; Kassam et al., 2018). In 1999, the Selian Agricultural Research Institute (SARI) in Tanzania commenced CA research with support from the German Technical Cooperation Agency (GTZ/GIZ). The awareness and adoption of CA soon spread to other parts of Africa, including South Africa, Zambia, Zimbabwe, and Mozambique, as well as to Asia, notably in Kazakhstan, India, Pakistan, and China. This expansion was significantly influenced by farmers, policymakers, and research projects from various countries who participated in study tours in Brazil, witnessing CA's success first hand (Friedrich et al., 2012; Kahimba et al., 2014; Kassam

et al., 2018). In recent years, there has been a growing interest in CA crop production systems across the globe (Friedrich et al., 2012). During the 1980s, facing economic sanctions, Zimbabwe—then known as Rhodesia—adopted CA as a necessity to reduce machinery wear and fuel costs (Mazvimavi, Ndlovu, Nyathi, & Minde, 2010; Chiputwa, Langyintuo, & Wall, 2011). Moreover, in response to climate change and the escalating issue of soil degradation, CA is now being widely promoted throughout sub-Saharan Africa (SSA) as a strategy for implementing climate-smart agriculture (Derpsch, Friedrich, Kassam, & Hongwen, 2010; FAO, 2017; Hermans, Dougill, Peacock, Eze, & Thierfelder, 2021). As such, CA serves as a mechanism to weatherproof agriculture, making it more resilient and 'climate-smart.' This enables agricultural systems to buffer against climate variability, offering a viable solution to pressing challenges such as drought, unstable crop yields, sustainability of agricultural systems, and escalating production costs. These are the primary reasons why many agricultural scientists are advocating for the promotion of CA in sub-Saharan Africa (Kassam et al., 2018; Steward et al., 2018; Chiputwa et al., 2011; Abdulai, 2016; Bennett & Roth, 2018; Veloso, Angers, Chantigny, & Bayer, 2019; Jat et al., 2020b; Ngwira et al., 2020).

2.7.1 Minimum mechanical soil disturbance

This term refers to a no-till method characterised by permanent, minimal soil disturbance, encompassing practices such as no-till weeding and direct sowing. For planting, the disturbed area must not exceed 15 cm in width or 25% of the cultivated area, ensuring minimal disruption for crop establishment (Kassam et al., 2018). Attracted by the superior protection and nourishment that perennial crops offer without the need for tilling, an increasing number of farmers are transitioning from annually sown row crops to these varieties (Mitchell et al., 2019). In their study, Wang et al. (2020) found that tillage and residue management significantly affect the composition of soil microbial communities. Therefore, Corsi (2019) concluded that mechanical soil disturbance, such as ploughing, affects soil aggregate dynamics and interferes with vital biological processes. One of the most important drivers of minimum soil tillage is the possibility of seeding the crop at the right time (Wall, 2007; Nyagumbo et al., 2017). Thus, the key to success with this system lies in having the correct soil moisture at the time of seeding (Naresh et al., 2014).

2.7.2 Permanent soil cover

Crop residues constitute a protective ground cover, including manure, sawdust, seaweed, litter, stubble, sand, pebbles, and other natural products (Mohaiuddin et al., 2020). The residues are left on the soil

surface to protect the topsoil, thereby reducing some of the negative effects of heat stress on crops (Thierfelder & Wall, 2009; Kassam et al., 2012; Farooq & Siddique, 2015; Steward et al., 2018b; Sims et al., 2018; Komarek, Thierfelder, & Steward, 2021). Residue decomposition releases nutrients to the soil, and increasing amounts of surface residues are expected to improve soil nutrient content, at least in the long term (FAO, 2001; Ranaivoson et al., 2019; Paustian et al., 2020; Adetunji et al., 2020). When no-tillage is combined with crop residues, this practice can benefit yields in rainfed crop production systems in dry environments (Ranaivoson et al., 2019; Rodenburg, Büchi, & Haggar, 2020). In CA, the use of a dense cover crop, followed by its successive, thick residue cover, reduces soil moisture losses and traps nutrients. This promotes greater productivity in subsequent crops (McHugh et al., 2007; Bahri et al., 2019; O'Dell et al., 2020). Cover crops may include any plant, though legumes or non-legume grasses are mostly recommended for their effectiveness (Adetunji et al., 2020; Ortega et al., 2020).

There is competition for the alternative uses of crop residues, which may limit their availability as mulching material, especially in areas where animals are an essential component of the system and communal grazing rights are in effect after the crop harvest (Wall, 2007). Additionally, open grazing policies granted by traditional authorities mean individual farmers do not have exclusive rights to the residues on their land. Efforts by farmers to conserve these residues for their own use can lead to violent confrontations (Wall, 2007; Delgado et al., 2019). An area with less than 30% cover does not meet the requirements for CA, according to Kassam et al. (2018). This criterion makes the successful establishment of a system that provides sufficient soil cover for the subsequent crop increasingly challenging in areas characterized by low productivity (Wall, 2007).

2.7.3 Crop rotation

A well-planned crop rotation system is a crucial component of proactive management strategies aimed at reducing weed pressure, as well as the associated time and costs of weed control over the long term (Farooq & Siddique, 2015; Sims et al., 2018). Crop rotation offers significant advantages by interrupting the life cycles of weeds, insects, pests, and pathogens, making them more susceptible to natural predators. Additionally, it introduces allelochemicals that inhibit the development of these agricultural nuisances (Derpsch et al., 2010; Chiputwa et al., 2011; Yang et al., 2020). Studies have indicated that the increased diversity inherent in cropping systems that incorporate legumes may enhance their ability to maintain functionality under conditions of heat stress (Burke et al., 2009; Komarek et al., 2021). Research

has demonstrated that rotating different plant species in the same area can significantly alter soil acidity dynamics (Tiecher, Calegari, Caner, & Rheinheimer, 2017). It is advisable not to follow low-residue crops with other low-residue crops; instead, slow-growing crops should precede weed-suppressing crops due to their higher vulnerability to weed competition (Sims et al., 2018). Moreover, opting for crop rotation over intercropping as a diversification strategy has been shown to have markedly beneficial effects on reducing pests and diseases (Lark et al., 2020). A study by Mhlanga, Cheesman, Maasdorp, Mupangwa, and Thierfelder (2015) revealed that plots where maize was rotated with leguminous cover crops yielded higher grain outputs compared to those under cereal monocropping and rotations with non-leguminous cover crops in most seasons. Additionally, crop rotation was found to significantly enhance habitat quality for both functional and intrinsic biodiversity, as well as improve nutrient regulation and cycling (Ghaley et al., 2018).

2.7.4 Weed management

Weed pressure poses a significant threat to the sustainability of conservation agriculture, particularly for farmers who refrain from using herbicides for weed control (Sims et al., 2018; Mazvimavi et al., 2010). The challenges of managing weed pressure, alongside issues of weed resistance and the potential for crop yield losses, can deter farmers from adopting conservation practices like direct seeding (Lindwall & Sonntag, 2010; Sims et al., 2018; Fonteyne, Singh, Govaerts, & Verhulst, 2020). Therefore, accurately identifying and effectively controlling weeds is essential for ensuring profitable crop production (Bishop-Sambrook et al., 2004; Sims et al., 2018; Ranaivoson et al., 2019; Tibugari, Chiduza, & Mashingaidze, 2020). Labour savings are a significant advantage when herbicide application replaces manual weeding efforts (Bell et al., 2019; El-Shater et al., 2020). On average, conservation agriculture plots require 2 to 3 weeding operations per season, in contrast to plots managed with conventional draft tillage, which may need more (Mazvimavi et al., 2010). Consequently, there's a pressing need to develop and provide support for smallholder farmers to effectively manage weed control (Mhlanga, Cheesman, Chauhan, & Thierfelder, 2016).

Utilising crop residues or mulch can significantly reduce the need for weeding, offering an alternative to mechanical hoeing (Sims et al., 2018). However, small-scale farmers face vulnerabilities that may lead to a detrimental cycle of weed proliferation, poverty, and migration, as illustrated in Figure 2.2 (Sims et al., 2018). Among various weed control methods within conservation agriculture, chemical management,

particularly using herbicides, is deemed the most effective (Farooq & Siddique, 2015; Sims et al., 2018). The introduction of glyphosate-resistant crops has facilitated easier weed control, contributing to a widespread adoption of minimum and no-tillage systems in certain areas (Zulu-Mbata, 2016; Sims et al., 2018; Pardo & Martinez, 2018). However, in Africa, the cost and accessibility of herbicides place them out of reach for many smallholders (IFAD, 2016). Moreover, the potential adverse effects of herbicides, including those classified as mild (class III) or moderate (class II) hazards, raise concerns for human health and environmental safety (Sims et al., 2018). Consequently, hand weeding remains the most favoured weed control method among smallholder farmers (Tibugari et al., 2020).

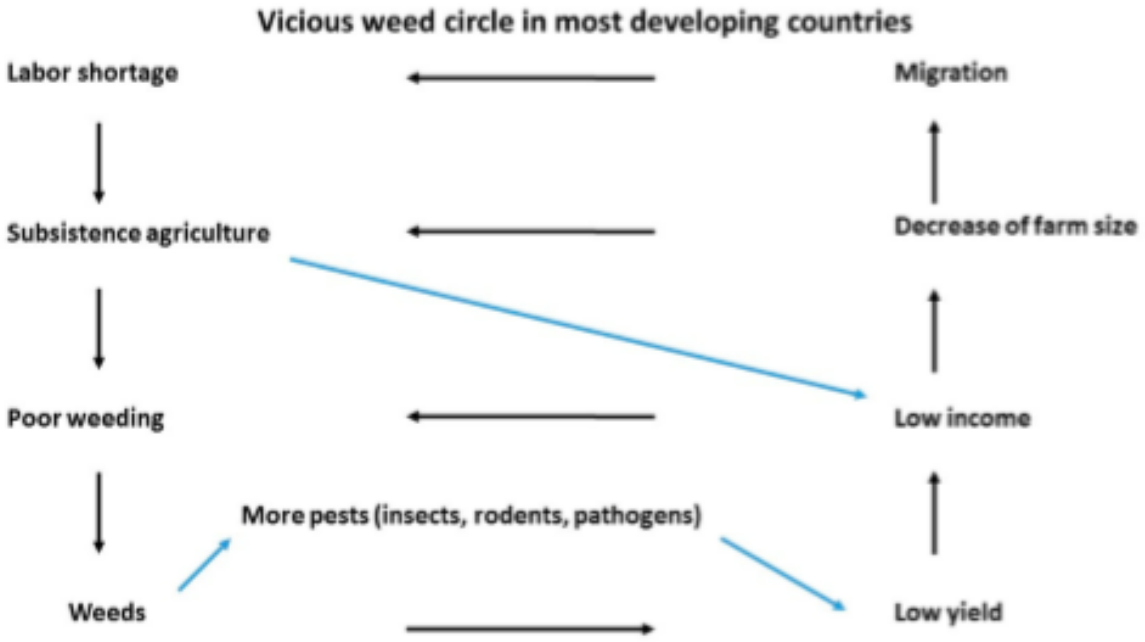


Figure 2. 2: The vicious weed cycle can affect smallholder farmers' crop yields in developing countries. Source: Adapted from Sims et al. (2018)

2.7.5 A framework for understanding the adoption of CA

Adapting to climate change necessitates agricultural systems that enhance resilience, support mitigation efforts where possible, and boost productivity and incomes sustainably (Friedrich et al., 2012; FAO, 2017; Ngango & Hong, 2021). Transitioning to conservation agriculture demands significant skill development among farmers and requires investment in new equipment, marking a substantial shift from conventional farming practices (FAO, 2001; Chiputwa et al., 2011; He, Zhang, & Wang, 2014; IFAD, 2016). Many farmers neglect practices that actively conserve soil, leading them into a cycle of poverty and hunger as soil quality

deteriorates (Taapopi et al., 2018). The rate of adoption of conservation agriculture is not a straightforward measure of its biophysical or socioeconomic benefits; however, it is often used as an indicative metric of success (Findlater et al., 2018; Hermans, Whitfield, Dougill, & Thierfelder, 2020). Consequently, researchers distinguish between partial and comprehensive adoption in the promotion, monitoring, and evaluation phases of CA research to gain accurate insights (Findlater et al., 2019).

The adoption and spread of CA reflect a narrative unique to each country, revealing the specific circumstances and timings of its initiation (Kassam & Coates, 2018). In parts of China, the impetus for CA was to combat air pollution resulting from the burning of straw. Conversely, in much of Latin America, the adoption of CA was driven by the prohibitive costs associated with traditional land preparation methods (IFAD, 2016). The United States saw the adoption of CA in response to the devastating dust bowls that affected vast swathes of the mid-west during the 1930s (Friedrich et al., 2012; Giller, Hijbeek, Andersson, & Sumberg, 2021). Meanwhile, in Brazil, Argentina, and Paraguay, where no-till farming emerged in the 1970s and 1980s, it was primarily soil erosion that spurred the move towards CA (Kassam & Coates, 2018; Hermans et al., 2020). In Madagascar, the introduction of CA in the early 2000s was a response to challenges such as poor soil fertility, inadequate soil moisture due to erratic rainfall, and intense weed infestations, all of which contributed to low rice yields (Ranaivoson et al., 2019). Meanwhile, research in South Africa reveals that farmers' decision to adopt CA is largely driven by the need for survival, indicating the crucial role of CA in ensuring food security and livelihoods (Findlater et al., 2018).

2.7.6 Socio-economic aspects of conservation agriculture

The literature reveals a low adoption rate of CA among smallholder farmers in Sub-Saharan Africa (SSA), with only 8% of farmers adopting the complete CA package (Hermans et al., 2020; Rodenburg et al., 2020). In Zambia, a study examining the bivariate relationships between CA adoption and various household characteristics found positive correlations with the age and education level of the household head, as well as household size, farm size, and income level (Abdulai, 2016; Zulu-Mbata, 2016). Recent increases in the adoption of CA are largely attributed to enhanced policy support and the allocation of more resources towards promoting CA. This is achieved through participatory dissemination and scaling approaches (Kassam & Coates, 2018; Cassman, 1999). The significance of local knowledge in this process cannot be overstated. Incorporating local insights into the evaluation of CA's impact ensures that the analysis is deeply rooted in the specific agricultural context (Hermans et al., 2021). The introduction of locally

customised minimum-till tine planters, which allow for the simultaneous and precise application of seeds, fertilizer, and herbicide, has reportedly led to improved performance and reduced input costs compared to older planting equipment (Findlater et al., 2018). Additionally, CA practices, including basin and direct seeding systems, have been shown to generate higher yields compared to conventional tillage methods typically used by farmers (Kidane et al., 2019).

Smallholder farmers are often risk-averse, and the adoption of CA is negatively influenced by its increased labour demands and the necessity to utilise fertilizer and herbicide inputs (Mhambi-Musimwa, 2009; Grabowski & Kerr, 2014; Abdulai, 2016; Michler et al., 2018). It has been observed that farmers are more inclined to adopt technologies that offer immediate benefits in terms of yield and income (Ngwira et al., 2020). Indeed, the observation that the returns of CA can be low in the initial years, especially for maize, aligns with the general challenges faced by smallholder farmers when adopting new agricultural practices (Michler et al., 2018). This initial period of lower returns, combined with added risks and costs associated with CA practices, understandably contributes to smallholders' reluctance to fully embrace CA without clear, immediate benefits.

2.7.7 Challenges associated with conservation agriculture

The challenges highlighted in Southern Africa regarding the adoption of CA underscore the complexity of integrating agricultural innovations into existing farming systems. The competition for crop residues, often used as livestock feed, and the challenges of weed control illustrate the multifaceted barriers to fully adopting CA practices. These barriers are not merely technical but also socio-economic, as they reflect the needs and practices of local communities (Hobbs, 2007; Wall, 2007; Derpsch et al., 2010; Friedrich et al., 2012; Grabowski & Kerr, 2014; Kassam et al., 2018; Hajer et al., 2020; Su et al., 2021). The initial reduction in yields following the switch from conventional to CA practices can indeed be a significant barrier to its adoption, particularly for smallholder farmers who rely on each harvest for their immediate livelihood (Rodenburg et al., 2020; Mhlanga & Thierfelder, 2021). This transition period poses a risk that many may be unwilling or unable to take, especially without assurances of short-term gains to offset their investments and risks. Furthermore, the full benefits of CA, including its potential for carbon sequestration and improvement in soil health, may not be realized if the three core principles of CA minimum soil disturbance, permanent soil cover, and crop rotation are not fully implemented (O'Dell et al., 2020). This highlights the need for a comprehensive approach to adopting CA, one that includes support and incentives for farmers during the initial transition period.

The labour-intensive nature of CA underscores a critical challenge in its adoption, particularly in sub-Saharan Africa where a significant portion of farm labour is manual. Given that 70% of labour on farms in the region is provided by human effort (IFAD, 2016), the capacity of households to engage in and expand CA practices is directly tied to their available labour force. Labour constraints are exacerbated in households affected by HIV/AIDS, chronic illnesses, or those led by children, making the implementation of CA even more challenging (Mazvimavi et al., 2010). These conditions not only limit the labour available for initial CA practices, such as establishing cover crops or constructing basins for water conservation but also restrict the potential for scaling up operations to increase food production and improve livelihoods. This observation highlights a significant challenge in the widespread adoption of CA - its sustainability and continuity beyond initial external support phases. Countries with highly mechanized and high-input agricultural systems have seen the greatest adoption of CA, as these contexts can more easily accommodate the initial costs and changes in practice that CA requires (Pittelkow et al., 2014; Findlater et al., 2018). The reliance on free inputs and technical advice to encourage adoption during pilot studies or initial implementation phases reveals a dependency issue. Once the support is withdrawn, the incentive for farmers to continue with CA practices diminishes, leading many to revert to their conventional farming systems (Zulu-Mbata, 2016). This situation underscores the importance of ensuring that CA is not only economically viable for farmers in the long term but also compatible with their existing farming operations and capabilities.

2.7.8 Mechanisation of conservation agriculture

In sub-Saharan Africa, difficult chores such as preparing the soil, clearing the land, and weeding are done by hand with simple agricultural implements (Bishop-Sambrook et al., 2004). The two basic forms of CA field operations under smallholder systems in sub-Saharan Africa will likely remain hand-hoe pitting and ox-drawn furrow openers (IFAD, 2016). One major need for this system is the development and availability of equipment that allows for the good germination of crops planted into soil that is not tilled (Hobbs, 2007). Farmers in Zambia have indicated that the available services and mechanization in the market promote conventional tillage rather than minimum tillage (Zulu-Mbata, 2016). However, industries in other nations develop equipment to meet their farmers' needs and ensure that CA is properly implemented (Derpsch et al., 2010; Friedrich et al., 2012; Mutua et al., 2014). In China, the most significant

CA machinery is the no-tillage seeder, which plays a crucial role in the application and expansion of conservation tillage (He et al., 2010).

2.7.9 The role of policy and institutions

The constraints hindering the acceleration of CA adoption at the farmer level have been identified as a lack of proper information, inadequate knowledge dissemination, insufficient demonstrations, vague policies, lack of institutional support, and the necessity for long-term hard work (Giddings et al., 2002; Farooq & Siddique, 2015; IFAD, 2016; FAO, 2017; Bennett & Roth, 2018; Ogunbode et al., 2018). Research and development projects being implemented in sub-Saharan Africa often lack the capacity to quantify the long-term effects of CA due to their short duration and the absence of longitudinal research trends (Mhlanga & Thierfelder, 2021). Ideally, policy support should facilitate the creation of accessible input markets, strengthen extension support for farmers, establish links to credit facilities, and improve access to output markets (FAO, 2001; Chiputwa et al., 2011; Mazvimavi et al., 2010; Kassam et al., 2018). Establishing strong linkages among research organizations, academic institutes, and extension services is crucial for the successful launch of any technology (Farooq & Siddique, 2015). Consequently, policy measures aimed at improving household welfare, such as investing in rural education and enhancing access to information from extension services and farmers' peers, have been identified as effective solutions for adopting new technologies (Abdulai, 2016; Tukker & Ekins, 2017).

2. 8 Analysing conservation agriculture

2.8.1 Models

This section focuses on the literature review concerning the multiple statistical models used to assess the research objectives of this study. The models to be discussed are the multinomial logistic model, analysis of variance, and conditional logistic regression. Each model will be defined and references to where the model has been applied, as well as which objectives it has attained in different studies, will be explored. Furthermore, the advantages and disadvantages of these models will be briefly discussed in this section.

2.8.2 Multinomial logistic model

The Multinomial Logistic Regression model is an important method for categorical data analysis (El-Habil, 2012). It is used to analyse the probability of category membership on a dependent variable based on multiple independent outcomes (Deb & Trivedi, 2006a; Dixit et al., 2015; Hwang, 2016). A multinomial logistic model is appropriate when regressors vary across individuals (Fox & Anderson, 2006; Gujarati, 2015). It focuses on the individual as the unit of analysis and uses the individual's characteristics as explanatory variables (Hoffman & Duncan, 1988; Deb & Trivedi, 2006b). Like binary logistic regression, multinomial logistic regression uses maximum likelihood estimation to evaluate the probability of categorical outcomes (El-Habil, 2012; Lawin & Tamin, 2018). The application of the multinomial logistic model in various fields of engineering and health sciences has established this technique as a fundamental tool for data analysis and subsequent decision-making processes (Llinas & Carreno, 2012). The main advantage of the multinomial logistic regression model is its simplicity in estimating and interpreting the resulting choice probabilities (Sarrias & Daziano, 2017). The multinomial logit model's shortfall is that it suffers from the limitation of assuming independence of irrelevant alternatives (Alvarez & Nagler, 1998). Another limiting aspect of this model is its handling of unobserved heterogeneity (Doherty et al., 2011).

The model has been utilised in numerous studies, some of which are discussed here. One study utilised multinomial logistic regression to ascertain and predict the extent to which licensed Texas saltwater anglers were willing to substitute fishing at one location for another. This study explored the relationship between specialization variables (behaviour, skill/knowledge, and commitments) and anglers' willingness to substitute (Hyun & Ditton, 2006). Another study conducted by Stratton et al. (2005) at the Institute for the Study of Labour in Bonn, Germany, modeled college students' stop-out and dropout behaviour. Multinomial logit specification was used to model students' choices among continuous enrollment, but returning within a year (stop-out). In another study, multinomial logistic regression explored the heterogeneity in activity-travel behaviours of older people in the United States, thereby modeling the transportation system of the aging population (Zhang, Konduri, & Enam, 2020). In Chile, a study examined the perceptions of citizens and companies regarding the effects of the COVID-19 pandemic on the development of their activities and lifestyles. This research aimed to understand how the current economic scenario is perceived in terms of employment, the economy, and government performance (Umana-Hermosilla et al., 2020).

In Malaysia, a study utilized multinomial logistic regression to assess the impact of the smoke-free Melaka city project. Awareness of the campaign significantly influenced discussions with family and friends about the implementation of smoke-free homes and vehicles (Aziz et al., 2016). Another study proposed a five-category typology of homicides based on the geographical relationship between the victim's residence, the offender's residence, and the location of the homicide (Tita & Griffiths, 2005). This study utilized the multinomial logistic model to examine the effects of various interactional, motivational, and situational characteristics of homicides on the type of homicide. In Jakarta, another study analysed the factors influencing students' learning difficulties in statistics and economics courses using the multinomial regression method. The goal was to categorize the characteristics of economic education related to students who face learning difficulties in statistics, focusing on several aspects, including gender, regional origin, monthly tuition allowance, and learning patterns (Abdillah et al., 2020).

2.8.3 Analysis of Variance

Analysis of Variance (ANOVA) is a statistical tool used to detect differences between the means of experimental groups (Schwenke, 1997; Hidalgo, 2007; Martin & Larson, 2008; Sawyer, 2009; Ardelean, 2017). Mathematically based on linear regression and general linear models, ANOVA quantifies the relationship between dependent and independent variables (Long & Freese, 2001; Gelman, 2004; Sawyer, 2009; Kesavulu et al., 2018). It is commonly employed to analyse the statistical significance of multiple factors in a model, especially useful in field experiments (Schwenke, 1997; Natoli, 2017; McIntosh, 2018). While numerous statisticians have enhanced the ANOVA model, making it a staple in almost every statistical package and accessible to researchers across experimental sciences, its widespread recognition surged after being featured in Fisher's 1925 seminal work, “Statistical Methods for Research Workers” (Martin & Larson, 2008). The model presupposes that the sampled populations are normally distributed and share the same standard deviation (Mu, 2006). Notably, the mathematical integrity of ANOVA is considered robust against deviations from normality, especially with sufficient sample sizes (Sawyer, 2009). A fundamental aspect of ANOVA is its ability to dissect the data set variance into components of statistical signal and noise, culminating in the calculation of the F score (Martin & Larson, 2008).

Fisher and Mackenzie (1923) pioneered the development of ANOVA, leveraging extensive long-term field weather data and notes. They aimed to estimate and compare the relative contributions of various factors—such as weather conditions, soil fertility, weed cover, and manure treatments—to the observed

variations in crop yields. Similarly, Mhlanga et al. (2016) applied ANOVA in their research on weed emergence. Their study focused on determining the effects of crop rotations on weed emergence, specifically examining the impact of maize cover crop rotations in contrasting arable soils of Zimbabwe under conservation agriculture practices at each testing site. In their study, "Contribution of cover crops to the productivity of maize-based conservation agriculture system in Zimbabwe," Mhlanga et al. (2015) employed ANOVA to compare the effects of different treatments on various agricultural outcomes. Specifically, they analysed treatment impacts on weed density, biomass yield, and the contribution of green cover crops to the availability of plant nutrients, as well as the yields of maize grain and biomass. This approach allowed for a comprehensive evaluation of how cover crops can enhance the productivity of maize-based conservation agriculture systems.

2.8.4 Conditional logistic regression model

Conditional logistic regression, an advanced form of logistic regression, enables researchers to accommodate the matched, clustered, or longitudinal characteristics of data (Wang & Powers, 2020). It calculates estimates of regression coefficients for an independent variable within specific strata (Sun et al., 2010). This model delineates the probability of selecting between two or more options based on the attributes defining those choices (Long, 2004; Hauber et al., 2016; Lee, Lynch, & Krischer, 2020). The connection between models of individual behaviour and observed choices at the population level becomes crucial when decision-makers face qualitative alternatives (McFadden, 1974; Hoffman & Duncan, 1988; Ackerman, 2008; Hauber et al., 2016). The conditional logit model excels in scenarios where the regressors, or independent variables, vary across different choices (Gujarati, 2015). It has emerged as a standard approach for analysing matched case-control data, addressing the potential sparse data biases inherent in traditional logistic regression analyses (Greenland, Schwartzbaum, & Finkle, 2000; Kuo, Duan, & Grady, 2018).

The conditional logit model is subject to certain limitations, notably its assumption of uniform preferences across all individuals (Hoffman & Duncan, 1988; Hauber et al., 2016; Crespo-Cebada et al., 2020). This model overlooks the possibility of unobserved, systematic differences in respondents' preferences (Hauber et al., 2016). Additionally, it does not support the calculation of an R-squared measure for assessing absolute goodness of fit, a metric familiar to many researchers (Que, 2015; Hauber et al., 2016).

Incorporating a cost coefficient into a choice experiment allows researchers to determine the marginal substitution rate between any non-cost attribute and the cost attribute, which reflects the willingness to pay (WTP) (Kragt & Bennett, 2009; Berendsen et al., 2015). Specifically, the ratio of an attribute's coefficient to the price coefficient can reveal the WTP for that attribute (Train, 2003; Mc Morrow et al., 2018). Essentially, WTP represents the monetary value of a good or service to an individual under particular conditions (Gunatilake et al., 2007). Willingness to pay (WTP) measures are invaluable for several reasons. Firstly, they offer direct insights to policymakers about the value individuals place on certain goods or services, which can guide pricing strategies (Hanley et al., 2003). Secondly, WTP provides a practical means for comparing and prioritizing various goods and services based on their desirability (Hole & Kolstad, 2010). Willingness to pay (WTP) estimates can be obtained from discrete choice models, which are calculated using either discrete choice experiments (DCEs) or revealed preference data (Hole & Kolstad, 2010). Discrete choice experiments are grounded in Lancaster's theory, positing that the value of a good is determined by its attributes or characteristics, rather than merely by the quantity consumed (Mc Morrow et al., 2018). According to this approach, when faced with various options, respondents will choose the one that maximizes their utility (or well-being), based on the levels of the option's attributes (Mc Morrow et al., 2018; Vass, Rigby & Payne, 2018). Given the complexities involved, including relatively small sample sizes and the need for additional parameters to estimate more complex models, a conditional logit model is often employed to analyse the data from DCEs (Mc Morrow et al., 2018).

The model has found applications in numerous studies worldwide, as illustrated below: Kallas et al. (2007) utilised a hybrid conditional logit model in Spain to reveal that urban residents exhibit higher willingness to pay (WTP) for global agricultural services. In another study, Kennelly et al. (2014) applied the conditional logistic model within the framework of discrete choice experiments to model student preferences for different assignment designs. They demonstrated the utility of calculating WTP for various attribute levels through the estimation of attribute level parameters, offering valuable insights for educational design. In their study, Mc Morrow et al. (2018) utilised a conditional logit model to explore preferences for hypothetical medical clinic visits, defined by various quality levels. By asking respondents to choose among different options in a series of scenarios, the study effectively quantified preferences for specific clinic attributes. Importantly, incorporating a monetary attribute allowed for the estimation of respondents' willingness to pay for different hospital clinic appointments or alterations in non-monetary attributes. Berendsen et al. (2015) sought to understand the specific goals and financial needs of business owners to design an effective microfinance product for ING Bank. This study underscores the

model's utility in real-world applications, particularly in financial product development and market analysis. By focusing on Romanian urban microfinance product, the research addresses a critical gap in access to financing, illustrating how conditional logit models can aid in tailoring financial solutions to meet specific market needs. Jumamyradov et al. (2023) pushed the model's capabilities further by investigating its performance under preference heterogeneity. By simulating discrete choice experiments, they examined how omitted variance and correlations affect estimates of coefficients, willingness to pay (WTP), and decision predictions. Their findings that the conditional logit model's estimates and true choice probabilities align closely, regardless of underlying preference structures, validate the model's accuracy and reliability in capturing complex decision-making processes.

2.9 Summary

The literature revealed that conservation agriculture is a broader topic covering several topics of different dimensions. Different countries adopted conservation agriculture with different motives depending on the countries' situations. Although conservation agriculture is a fairly new tillage system in Namibia, the literature review revealed that the system started a long time ago across the world, and extensive research has been conducted in Africa and the rest of the world. Despite many advantages and praise conservation agriculture received across many works of literature conducted, the adoption rate remained low, especially in low-mechanized countries. This triggered a question of whether conservation is an appropriate technology that poor-resourced farmers can harness at a village level. In addition, the literature review disclosed that many research and experiments happened in controlled environments or research stations where sufficient funds were made available. The chapter reviewed the econometric methods used in analysing related studies. The literature revealed that different models can be applied to achieve different objectives.

CHAPTER 3: OVERVIEW OF THE NAMIBIAN AGRICULTURAL SECTOR

3.1 Introduction

This chapter provides an overview of the agricultural sector in Namibian. Namibia's agricultural sector is diversified and consists of crop and livestock enterprises.

3.2 Overview of the agricultural sector

Namibia features a dualistic agricultural sector comprised of a commercial sub-sector (on freehold land) and a communal sub-sector (on state-owned land), which are primarily separated by a veterinary cordon fence (FAO, 2016). Commercial farmland occupies approximately 44% of the total land area, supporting 10% of the population (NTA, 2013). Rain-fed crop production is limited to the communal areas in the north-central and north-eastern regions (UNDP, 2012). Crop production accounts for 24% of the agricultural output value, while the livestock sector contributes more than 70% (NTA, 2013). According to Mendelsohn (2006), many people residing in a narrow zone that stretches across the north from the Omusati region in the west to the Zambezi region in the east engage in a small-scale mixed farming system, as depicted in Figure 3.1.

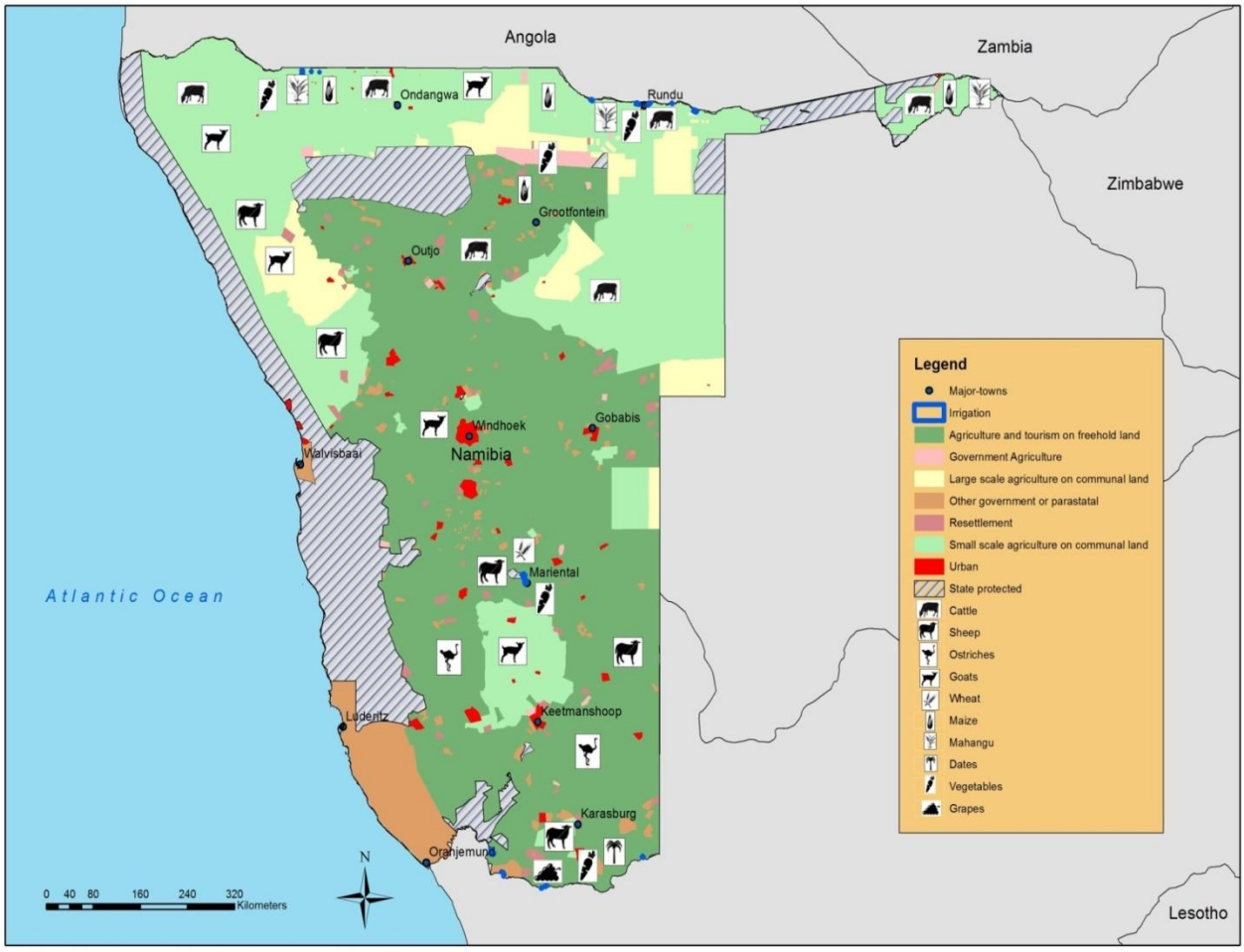


Figure 3. 1: Namibia agricultural map
Source: Adapted from NTA (2013)

Given its arid conditions, agriculture and food production in Namibia are significantly hindered by highly variable climatic conditions and inherently poor soils (Msangi, 2014; FAO, 2016; FAO, 2020; O'Dell et al., 2020). Furthermore, only 8% of the country receives an average annual rainfall exceeding 500 mm, which is considered the minimum for dryland cropping (NTA, 2013; Keja-Kaereho & Tjizu, 2019). Unique challenges to the industry, especially in rural areas, include severe drought leading to water shortages, which in turn cause animal deaths and crop failures (Msangi, 2014; FAO, 2016; MAWF, 2018; FAO, 2020). Despite commendable efforts, Namibia's agricultural sector continues to suffer from low yields, a situation attributed to low levels of inputs, limited cultivated areas, and other factors (Simasiku & Sheefeni, 2017). The country's arid conditions and the impact of severe, prolonged droughts counteract the government's efforts to boost agricultural productivity (Nyambe & Belete, 2018; Nangolo & Alweendo, 2020).

Furthermore, increasingly unpredictable rainfall patterns and the presence of unstable soils with limited water-holding capacity have exacerbated the drought conditions (ICRAF, 2012).

In regions that receive better rainfall and are deemed more fertile, the land has often been farmed for decades, leading to a significant depletion of its original nutrient value (NTA, 2013). Consequently, these dryland crop production areas have experienced massive reductions in harvests. As a result, the production of millet and maize has declined by 56 percent and 77 percent, respectively (MAWF, 2018). In 2016, the performance of millet production by region showed that Oshikoto had the highest yield, producing 6,865 tonnes, followed by Omusati with 4,627 tonnes. In contrast, Zambezi only produced 328 tonnes of millet (MAWF, 2018). The lower millet production in Zambezi can be attributed to the local farmers' preference for maize, leveraging the region's comparatively better rainfall and soil fertility than other areas.

3.3 Importance of the agricultural sector

Poverty, unemployment, and significant social inequalities present ongoing challenges in Namibia. With a Gini coefficient of 0.57, it ranks among the most unequal countries globally (Finke et al., 2020). Agriculture plays a crucial role in the country, not only as a key driver of job creation, poverty reduction, and food security but also as a significant contributor to national foreign exchange earnings (Mushendami et al., 2008; Shapi, 2017; MAWF, 2018). The sector stands as one of Namibia's largest sources of employment, providing around 167,242 jobs (Nangolo & Alweendo, 2020). Moreover, smallholder farming is fundamental in supplying food and fostering economic growth, particularly benefiting the 75% of the world's impoverished population living in rural settings (Michler et al., 2018). Agricultural development can make food both accessible and affordable for the rural and urban poor (Shapi, 2017). As countries evolve from primarily agricultural economies to ones with a broader industrial and service base, agriculture remains vital in driving and supporting economic transformation (Otero et al., 2019). This underscores the sector's potential in poverty eradication (FAO, 2016). Therefore, through comprehensive agricultural redevelopment, we could see significant improvements in food security, alongside reductions in poverty and malnutrition (Shapi, 2017).

Agricultural development plays a pivotal role in making food accessible and affordable for both rural and urban populations, thereby serving as a key factor in boosting economic output and reducing poverty

(Shapi, 2017; Mushendami et al., 2008). Recognizing this, the Namibian government has identified enhancing the productivity of the country's agricultural resources as a primary strategy for mitigating poverty and improving food security. Consequently, Cabinet Decision No. 18th/06.08.02/004 endorsed a program aimed at boosting food production through irrigation schemes, known as Green Scheme Projects (Shapi, 2017). Namibia's Green Scheme Projects were launched with the dual goals of enhancing job opportunities and increasing food production via irrigation. Currently, the country hosts eleven Green Scheme Projects, which differ in scope, size, and focus. Together, these projects cover a total of 4,282.6 hectares under irrigation, as detailed in Table 3.1.

Table 3.1 Various Green Schemes and their size in hectares

Schemes	**Hectare under production**	**Hectares under commercial**	**Hectares under Medium farmers**	**Hectares under Small farmers**	**Orchard Hectares**	**Not under production**	**Total**
Etunda	963	483	120	300	60	300	1263
Hardap	154.6	60	94.6				154.6
Kalimbeza	150	141		9		79	229
Mashare	150	150					150
Musese	450	450				550	1000
Ndonga Linena	580	421		160		419	1000
ORIP	195	125		70		405	600
Shadikongoro	390	300		90		200	590
Sikondo	590	320	270			240	830
Shitemo	420	420				580	1000
Vungu-Vungu	240	180		60		585	825
Total	4282.6	3050	484.6	689	60	3358	7641.6

Source: Adapted from Shapi (2017)

3.4 Summary

This chapter has provided an overview of the Namibian agricultural sector, examining its crucial role in contributing to the national economy through the balance of payments, job creation, and ensuring food security. Despite its positive impacts, the sector is hindered by a range of challenges, including underdeveloped infrastructure, the effects of climate change, poor soil fertility, and the absence of effective trading policies and strategies. However, the sector holds significant potential for expansion, provided there is a commitment to substantial investment. The initial investments in green scheme projects demonstrate that further efforts can be made to mitigate unemployment and reduce food prices in Namibia.

CHAPTER 4: RESEARCH METHODS

4.1 Introduction

The description of the study area, the research designs a framework of approaches and processes that guide the investigation is described and presented in this chapter. Following a description of the data collection technique and the data analysis model, the process used to select a representative sample of the population under study is discussed.

4.2 Description of the study area

The Kavango West, Kavango East, and Zambezi regions in Namibia's north and northeast were the study sites. The three regions differ in terms of their attributes, locations, and types of vegetation, which was one of the reasons conservation agriculture was tested there. Each region had two villages chosen for the 2016–2017 growing season, as seen in Figure 4.1. A cluster of six farmers was developed in each community.

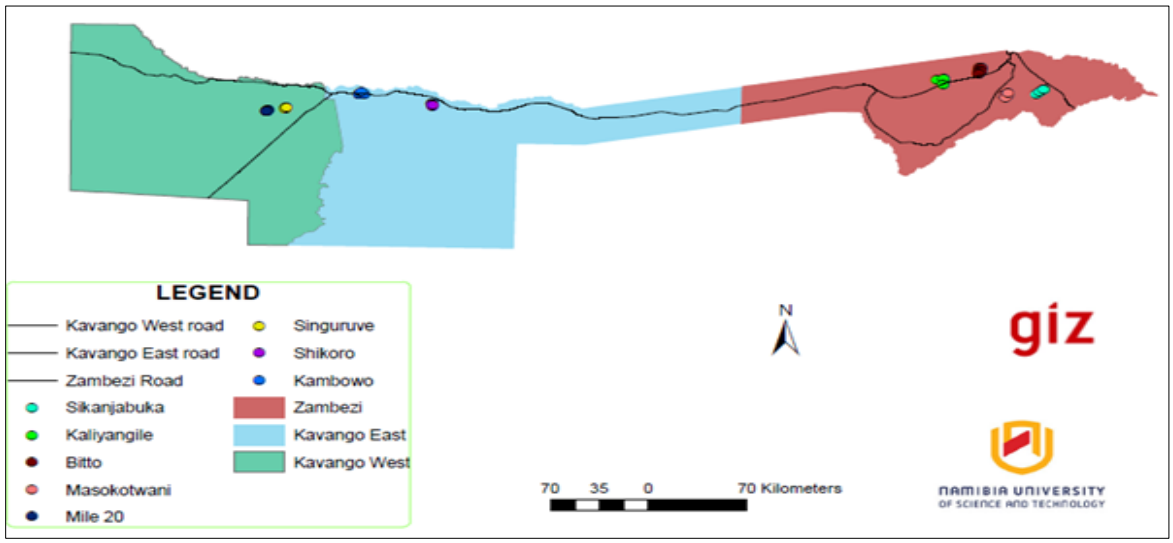


Figure 4. 1: Location of villages in the selected study areas
Source: Author's compilation

Figure 4.1: Location of villages in the selected study areas

A brief description of each region is presented below to appreciate the geo-political dynamics of the regions.

4.2.1 Kavango West Region

One of Namibia's fourteen regions, Kavango West, has a total size of 23,166 km². The region was established in 2013 due to the division of the Kavango Region into two regions, and as of 2011, it had 86,529 inhabitants (NSI, 2014). Kavango West shares a northern boundary with the Angolan province of Cuando Cubango. It shares boundaries with the following areas: Kavango East to the east, Otjozondjupa to the south, Oshikoto to the west, and Ohangwena to the northwest. Eight constituencies make up the Kavango West Region: Kapako, Musese, Tondoro, Nkurenkuru, Mankumpi, Mpungu, Ncamangoro, and Ncuncuni. Most of Kavango West is flat and situated at a height of roughly 1,100 meters (ADSWAC, 2021).

4.2.2 Kavango East region

The Kavango East Region has a total size of 25,576 km² and 136,823 inhabitants as of 2011 (NSI, 2014). According to MLR (2015), the region is bordered to the north by the Kavango River and Angola, to the east by the Zambezi Region and Botswana, to the west by the Kavango West Region, and to the south by the Otjozondjupa Region. There are six constituencies in the Kavango East Region: Mashare, Mukwe, Ndiyona, Ndonga Linena, Rundu Rural, and Rundu Urban. Crop and livestock farming account for 60% and 26% of the primary agricultural activities carried out by households in the Kavango East Region (MLR, 2015). Although the region's poor soil conditions are one of the biggest obstacles for crop producers, pearl millet, also known locally as "mahangu," is the predominant crop farmed by community farmers (MLR, 2015). The biggest potential for the area is having access to a reliable water source like the Kavango River. The eastern section of the region has a lot of wildlife, which makes it quite desirable and profitable for tourism.

4.2.3 Zambezi region

Until 2014, the Zambezi region was officially referred to as the Caprivi region (Nyambe & Belete, 2018) after Leo Caprivi, a German chancellor who negotiated the Anglo-German Treaty that gave the Germans access to the area and the Zambezi River. The area was mostly neglected administratively until independence, as it became apparent that the Zambezi River could not provide a navigable link to Tanzania and the Indian Ocean due to its rapids and the Victoria Falls (Kiesel, 2019).

In the Zambezi region, as in other northern parts of Namibia, traditional leaders govern rural communities. A person governed by a system like this has the legal right to farm the land, but selling it is against the law (Nyambe & Belete, 2018). Therefore, because there are no title deeds to the land, it cannot be utilized as collateral security in financial transactions that require security, as it is not private property.

The area is 14,785 km², and the population was 90,596 in 2011 (NSI, 2014). The Zambezi region is divided into eight political constituencies: Kabbe South, Kabbe, Katima Rural, Katima Urban, Linyanti, Sibbinda, Judea Lyaboloma, and Kongola.

The Zambezi region benefits from having Namibia's highest precipitation and lowest water shortage rates (Kiesel, 2019). The common agronomic crops in the Zambezi region are maize, pearl millet, and sorghum.

However, maize dominates other crops because most farmers who grow maize at a large scale, especially in the flood-plain area, are farming for commercial purposes. The soils are heavy with high clay content in areas regularly flooded, such as hydromorphic and organic clay soils (Teweldemedhin et al., 2015).

4.3 Research design

This study used two research methods: experimental choice and a randomised complete block design. Each method is briefly described below.

4.3.1 Experimental choice

Experimental choice is a type of survey tool used in experimental economics and has been utilized in market research to learn about consumer preferences for items and features that are not yet available on the market (Lancaster, 1966; Carson et al., 1994; Greiner, 2015; Cash, Stankovic, & Storga, 2016). Based on choice experimentation, experimental choice was used to elicit consumer preferences (Hanley, Mourato, & Wright, 2001). This allows customers to choose from pre-designed options (Sandor & Wedel, 2002; Das, 2014; Pecorari, Borin, & Sbaizero, 2017). In a choice set, there is a choice between various proposed situations and the base scenario, which is always the case (Rolfe et al., 2004). The likelihood that a decision-maker will pick a certain alternative is calculated under the probabilistic choice theory assumption, making the choice experiment a strong paradigm for discrete choice analysis (Train, 2009; Wittink, 2011; Klingen, Van Lerberghe, & Tulenko, 2012; Sherman et al., 2012). A choice experiment aims to estimate economic values for the qualities of economic goods or services with several features (Rolfe et al., 2004; Holme, Adamowicz, & Carlsson, 2017). Furthermore, choice experiments provide ex-ante information that can be used to enhance agricultural technology development by taking into account the preferences and needs of local farmers and thereby improve research and extension programs before they are deployed or scaled up (Weisburd, Petrosino, & Mason, 1993; Vega & Alpízar, 2011; Lambrecht et al., 2013; Cerulli, 2014). Notwithstanding its significance, Holme, Adamowicz, and Carlsson (2017) observed the following shortfalls with choice experimental research.

Respondents may experience considerable trouble when considering options with many attributes in new choice situations. Requiring respondents to evaluate complex trade-offs may result in poorly understood behavioural reactions, such as using decision heuristics, which may not represent how they would make genuine market decisions. In general, customers under study are expected to select the option that

provides them with the highest level of satisfaction (Carson et al., 1994). Satisfaction, which is inherently an unobservable or latent variable, provides a useful framework for linking observed decisions to attribute levels.

Another shortfall in using choice experiments is the possibility of a moral hazard – respondents might act contrary to their stated responses (Wittink, 2011). This phenomenon may occur because the respondent is unsure of how they would actually react or because they believe they are expected to respond in a certain way.

4.3.2 Randomised complete block design

The Randomised Complete Block Design (RCBD) is the second experimental design employed in this study. The RCBD is a standard biostatistical experimental design that groups similar experimental units into blocks or replicates (Kutubi, 2020). The randomised complete block design is one of the most-used layouts in field experiments (Anwaar et al., 2019). Randomisation is therefore applied to protect the experimental unit from unaccounted externalities that may affect the results (Lorenzen, 1984; Wilk, 1995; Festing, 2014). A randomised complete block design is an experimental design that compares *t* treatments in *b* blocks and is used to account for spatial factors in the field to control variance in an experiment (Kutubi, 2020). The blocks are made up of *t* identical experimental units. Within each block, treatments are randomly distributed to experimental units, with each treatment appearing precisely once. As the experiment is set up, randomization ensures no favouritism is displayed toward the practice being evaluated (Rzewnicki, 1992; Tsingati et al., 2019). This is consistent with Pilla, Kitska, & Loader (2005), who observed that the randomisation approach removes any bias in favour of certain treatments, while the blocking allows superfluous variation to be absorbed into block effects. The strategy broadens the generality of the study findings in addition to reducing experimental error (Lorenzen, 1984; Dafaallah, 2019). Because of the increased number of degrees of freedom for the error source of variation, the loss of information attributable to missing data is minor compared to other designs.

However, the design has drawbacks: accuracy may be lost if experimental units are not homogeneous and blocking is not used to decrease variance. This is because blocking removes degrees of freedom from the error variation estimate (Ogunsanya & Sulaimon, 2016). Unless the experimental units are uniform, it is the least efficient design. Furthermore, RCBDs are less adept at addressing certain statistical concerns,

such as substantial variability among research participants. When data are characterised by significant variability or imbalance, the researcher's ability to discern the genuine impact of the intervention is compromised (Ariel & Farring, 2010). RCBD has been proven acceptable for treatments with less than ten in a single block, making it unsuitable for treatments with more than ten in a single block (Anwaar et al., 2019). As a result, experts in advanced nations question the ability of RCBD to handle large field trials (Anwaar et al., 2019).

4.4 Data collection

The data for the experimental choice were collected using a structured questionnaire administered through a face-to-face survey approach in the third year of a four-year conservation agriculture pilot project. The data collection interviews started on July 11th, 2019, in the Kavango West region, continued through the Kavango East region, and interviews were concluded on October 16th , 2019, in the Zambezi region. The data were collected from three types of farmers who participated in the pilot project: research cluster farmers, lead farmers, and follower farmers. A total of 169 farmers, representing 51% of the eligible potential respondents, were interviewed across the three regions for this purpose. The survey focused on farmers' socioeconomic factors and agricultural characteristics. The objective is to emphasize identifying the elements that affect farmers' capacities for decision-making regarding the adoption of conservation agriculture.

Data for the Randomized Complete Block Design were collected from the experimental research plots of research-cluster farmers only. On-farm data, such as labour, rainfall, and production outputs, were collected across the three regions. Data collection commenced from the beginning of the pilot project in the 2016/2017 cropping season and continued until the end of the pilot project in the 2019/2020 cropping season. To facilitate and ensure a smooth data collection process, interns (students) were recruited at each cluster. Each cluster consisted of six farmers with an experimental research plot of 0.3 ha. Figure 4.2 shows the layout plan of an experimental research plot used to test the impact of treatments on yields between conventional and conservation agriculture tillage systems.

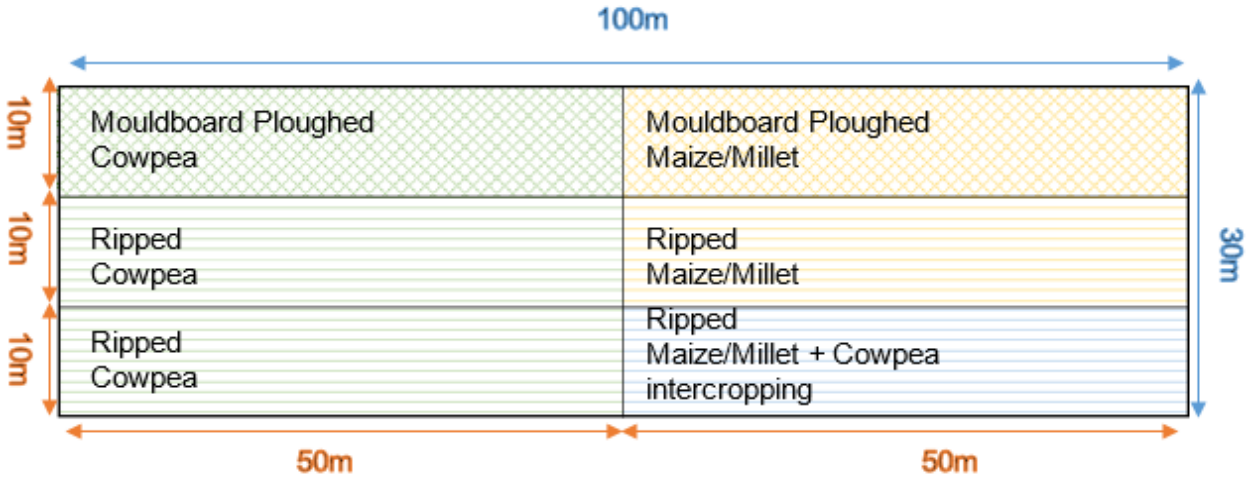


Figure 4. 2: On-farm experimental field plan design showing mouldboard plough and ripper strip plots
Source: Author's compilation

CA and Conventional Tillage (CT) were used as the tillage treatments, and the cropping systems evaluated were (i) mono-cropped maize/pearl millet and (ii) maize/pearl millet intercropped with leguminous crops. Pearl millet was the major cereal crop in the Kavango East and Kavango West regions; maize was the main cereal crop in the Zambezi region; and cowpea was the leguminous crop in both regions. Research cluster farmers were provided with all inputs; however, they were assisted in managing the research plots accordingly. All the crops were grown under rain-fed conditions. The approach of providing research cluster farmers with all necessary inputs and assisting them in managing their research plots under rain-fed conditions was strategic for several reasons. It ensured that the experimental variables were controlled as much as possible, allowing for a clearer comparison between CA and CT systems. By standardizing inputs—such as seeds, fertilizers, and any other agronomic supports—the study aimed to isolate the effects of tillage and cropping system choices on productivity, sustainability, and soil health.

4.5 Data analysis

This study has four objectives, and different models and statistical software were used to analyse these objectives. The first objective was analysed using a multinomial logistic regression model, with STATA version 13 as the statistical software. The analysis of variance (ANOVA) model was used to analyse the study's second objective, with IBM SPSS Statistics version 29.0.1.0 (142) as the statistical software. A conditional logistic regression model was used to analyse the third objective, with STATA version 13 as

the statistical software. Lastly, ANOVA was used to analyse the fourth objective of the study, with R version 4.1.3 as the statistical software. The model's specifications and how the collected data fit the model are discussed:

4.5.1 Multinomial logistic regression model

The study modelled CA arrangements as a multinomial selection process, wherein the three principles of CA are analysed in relation to the socio-economic characteristics of farmers through regression. The multinomial logistic regression modelling approach was employed to explore the relationship between exogenous factors of interest and the tillage methods with which farmers are familiar. However, in the context of multinomial logistic regression, the dependent variables such as the tillage methods, the choice of intercropping, and the choice of crop rotation are categorical, representing the different categories of choices that individual farmers prefer, rather than continuous variables. The study used individual farmers' socio-economic attributes and farm characteristics as independent variables to analyse the influence of socio-economic factors in making conservation agriculture an attractive option for small-scale crop farmers in the northern regions of Namibia.

Following Long & Freese (2014), the multinomial equation can be writer as:

$$ln\Omega_{m|b}(X) = ln\frac{Pr(y=m|X)}{Pr(y=b|X)} = X\beta_{m|b} \qquad for\ m = 1\ to\ J \qquad (1)$$

Where b is the base outcome, sometimes called the reference category. As $ln\Omega_{b|b}(X) = ln1 = 0$, it follows that $\beta_{b|b} = 0$. That is, the log odds of an outcome compared with itself is always 0.

These J equations can be solved to compute the probabilities for each outcome:

$$\Pr(y = m \mid X) = \frac{\exp\,(X\beta_{m|b})}{\sum_{j=1}^{J} \exp\,(X\beta_{j|b})} \qquad (2)$$

The probabilities will be the same regardless of the base outcome b that is used. For example, suppose that you have three outcomes and fit the model with alternative 1 as the base. Were one would obtain estimates $\hat{\beta}_{2|1}$ and $\hat{\beta}_{3|1}$ with $\beta_{1|1} = 0$.

$$\Pr(y = m \mid X) = \frac{\exp(X\beta_{m|b})}{\sum_{j=1}^{J} \exp(X\beta_{j|1})} \quad 3$$

An alternative set up of the model with base outcome 2, would generate an estimate $\hat{\beta}_{3|2}$ and $\hat{\beta}_{3|2}$, with $\beta_{2|2} = 0$. The probability equation would expressed as:

$$\Pr(y = m \mid X) = \frac{\exp(X\beta_{m|2})}{\sum_{j=1}^{J} \exp(X\beta_{j|2})} \quad 4$$

The estimated parameters are different because they estimate different scenarios but produce the same predictions. By default, mlogit, (a STATA command for multinomial logit) sets the base outcome to the alternatives with the most observations in the estimation sample.

4.5.2 Analysis of Variance

Analysis of variance (ANOVA) is used in this study to analyse two different objectives. The first objective is to evaluate farmers' preferences for CA and the trade-offs between CA technologies and conventional practices. This objective utilized experimental choice data, presenting farmers with a scenario from which they could choose from a list of options, each offering variations of alternatives. The response variable (Y) for this objective is the projected soil condition in 10 years under the base scenario (a condition in 10 years without new initiatives) compared to the condition in 10 years with CA initiatives. The indicators used in the base scenario include "*no mulching*," "*ploughing as a type of soil preparation," "mono-cropping*," and "*no crop rotation*." ANOVA analysis was employed to determine whether farmers could continue farming under the base scenario for the next 10 years or if they are willing to implement new initiatives. If farmers choose to stick with the base scenario, it implies that they may not be aware that continuing without adopting new initiatives is likely to result in environmental harm to their crop fields. If farmers choose an alternative to the base scenario, it suggests they are aware of the potential environmental harm their crop fields are likely to suffer in 10 years without the implementation of CA initiatives. Therefore, the hypothesis testing for this objective is formulated as follows:

H_0: There is no statistically significance difference between the base scenario and new initiative alternatives

Eleven new initiatives were provided as possible selection options (from B to K), matched with the base scenario as option A. To facilitate easier selection, questions 31 and 35 in the questionnaires (Appendix 1) were transformed into graphic presentations with features that resemble alternatives.

The last objective analysed with ANOVA aimed to assess the effect of conservation agriculture on crop yield. This analysis involved comparing the grain and biomass yields of a cereal crop (either maize or pearl millet) and a leguminous crop (cowpeas). The data for this analysis were collected from the experimental research plot, as depicted in Figure 4.2. Consequently, conventional (mould-plough) sub-plots were compared with conservation agriculture (ripped) sub-plots and conservation agriculture (ripped) sub-plots that were intercropped.

Following Greenwood (2022), mathematically, ANOVA can be specified as:

$$X_{ij} = u_i + \varepsilon_{ij} \qquad 5$$

Where

X are the individual data points ($i\ and\ j$ denote the group and the individual observation)
u are the population means of each group
ε is the unexplained variation and parameters of the model
Thus, each data point (X_{ij}) is its group mean plus error

4.5.3. Conditional logistic regression model

The variables in the conditional logit model are choice-specific attributes, not individual-specific characteristics. Thus, variation in the attributes of conservation agriculture within farmers' choice sets drives the estimates. To estimate the conditional logit model, data are organized as pairwise combinations of each farmer i with each village j with observations stratified by individual into groups of j. Using these combinations, the conditional logit model consists of j equations for each i, each equation describing one of the alternatives. This format accommodates match-specific variables based on the interaction of individual i with village j. The conditional logit model calculates the probability of a farmer being in each

of the stratum villages, relative to all other alternatives, with the dependent variable set to one for the chosen alternative. Following Hanley, Mourato, and Wright (2001), the indirect utility function for each respondent i $(\cup)$ can be decomposed into two parts: a deterministic element (V), which is typically specified as a linear index of the attributes (X) of the j different alternatives in the choice set, and a stochastic element (e) which represents unobservable influences on individual choice. This is shown in equation (6):

$$\cup_{ij} = V_{ij}(X_{ij}) + e_{ij} = bX_{ij} + e_{ij} \qquad 6$$

Thus, the probability that any particular respondent prefers option g in the choice set to any alternative option h, can be expressed as the probability that the utility associated with option g exceeds that associated with all other options, as stated in equation (7):

$$P\left[\left(\cup_{ig} > \cup_{ih}\right)\forall_{h \neq g}\right] = P\left[\left(V_{ig} - V_{ih}\right) > \left(e_{ih} - e_{ig}\right)\right] \qquad 7$$

To derive an explicit expression for this probability, it is necessary to know the distribution of the error terms $\left(e_{ij}\right)$. A typical assumption is that they are independently and identically distributed with an extreme value distribution:

$$P\left(e_{ij} \leq t\right) = F(t) = \exp(-\exp(-t)) \qquad 8$$

The above distribution of the error term implies that the probability of any alternative g being chosen as the most preferred can be expressed in terms of the logistic distribution stated in equation (9). This specification is known as the conditional logit model:

$$P\left(\cup_{ig} > \cup_{ih}, \forall h \neq g\right) = \frac{\exp\left(\mu V_{ig}\right)}{\sum_j \exp\left(\mu V_{ij}\right)} \qquad 9$$

Where μ is a scale parameter inversely proportional to the standard deviation of the error distribution. This model can be estimated by conventional maximum likelihood procedures, with the respective log-likelihood function stated in Equation (10), where y_{ij} is an indicator variable that takes a value of one if respondent i chooses option j and zero otherwise.

$$logL = \sum_{i=1}^{N} \sum_{j=1}^{J} y_{ij}\ log \left[\frac{\exp\ (V_{ij})}{\sum_{j=1}^{J} \exp\ (V_{ij})} \right] \quad 10$$

Socio-economic variables can be included along with the choice set attributed in the X terms in equation (6), but since they are constant across choice occasions for any given individual, they can only be entered as interaction terms, i.e., interested with choice-specific attributes.

Once the parameter estimates have been obtained, a WTP compensating variation welfare measure that conforms to demand theory can be derived for each attribute using the formula given by equation (11), where V° represents the entity of the initial state and V' represents the utility of the alternative state. The coefficient gives the marginal utility of income and is the coefficient of the cost attribute.

$$WTP = b_y^{-1}\ ln \left\{ \frac{\sum_i \exp\ (V_i')}{\sum_i \exp\ (V_i^{\circ})} \right\} \quad 11$$

The above formulae can be simplified to the ratio of coefficients given in equation (12), where b_c is the coefficient on any of the attributes. These ratios are often known as implicit prices.

$$WTP = \frac{-b_c}{b_y} \quad 12$$

Choice experiments are consistent with utility maximization and demand theory, at least when a status quo option is included in the choice set.

4.6 Summary

An overview of the study area, aiming to present a snapshot of its geographical context and the profile of farmers involved in the research was provided in this chapter. It outlines the research design, detailing the econometric models and software tools employed for data analysis. Furthermore, it discusses the data collection methods and the types of data utilized. The chapter concluded with the specification of the mathematical formulas of the models applied in the study.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Introduction

The results and findings of this study are discussed in this chapter. First, the socio-economic characteristics of the respondents and participants who contributed to the data collection through interviews or experimental field research clusters are examined. Second, an analysis of the impact of socio-economic factors on making CA an attractive option for farmers is conducted. The third section assesses the farmers' preferences for CA and the trade-offs between CA technologies and conventional practices. The fourth section explores the farmers' willingness to adopt CA practices, and the fifth section focuses on the experimental field performance hosted by the cluster farmers in different regions to compare the actual yields of cereal and leguminous crops.

5.2 Socio-economic Characteristics of the Respondents

A total of 169 farmers were interviewed for this study; 31 percent of the respondents are from the Kavango East region, 27 percent are from the Kavango West region, and 43 percent are from the Zambezi region. Table 5.1 summarises the descriptive statistics of the respondents.

Table 5. 1: Descriptive statistics summary of the respondents

Characteristic	Number of Respondents	Minimum	Maximum	Mean	Std. deviation
Age	169	28	86	52	11.94
Household size	169	1	59	10	7.62
Area under CA	169	.01	4	0.69	0.68

Source: Author's compilation

5.2.1 Age

The youngest participating respondent is 28 years old, and the eldest is 86. The variable "age" was used as a proxy for years of experience in farming. Age can both stimulate and hinder the acceptance of changes

in agricultural practices (Hartog et al., 2011). It is assumed that older farmers would have a lower probability of adopting CA than younger ones, because elderly farmers are more accustomed to the conventional farming system. On average, the respondents were 52 years old across the three regions. This figure indicates that the respondents across the three regions were sufficiently experienced, having spent many years in farming. On the other hand, having respondents with an average age of 52 is considered advantageous because these farmers possess vast experience and are a valuable source of information. They can provide insightful accounts of how farming practices have evolved from the past to the present.

5.2.2 Household size

Household size is an important indicator of the availability of farm labour in the community because the household size determines the size of the labour force that works in the crop field. However, in other studies, the variable of economically active members was used as a proxy for labour availability instead of using family size (Ntshangase et al., 2018). This is because of the realization that a larger family size does not necessarily translate into more family labour being available in the household. Thus, children, people with disabilities, and older people may be excluded from the list, and only the physically active members of the household should be considered. The study found an average of 10 persons per household among the interviewed farmers. In the modern world or urban life, this average number may be perceived as large; however, in rural communities, this is considered a normal size because grandparents, parents, siblings, nieces, nephews, and cousins can all be found living in one household.

5.2.3 Area under conservation agriculture

The interviewed farmers revealed that they had practiced CA on areas ranging from 0.01 ha to 4 ha. This range is a good indication that farmers have engaged in CA to varying extents. Typically, farmers start with a small area and, upon observing the benefits, are likely to increase the area under conservation agriculture in subsequent seasons. On average, farmers have utilized 0.69 ha for CA, which is close to the 1 ha minimum size recommended for every lead farmer to prepare under CA per cropping season.

5.2.4 Education

Respondents were asked to indicate their educational status, and this variable is an important social factor that can influence the adoption of CA. The assumption was that the rate of technology adoption increases with more years of schooling. A more-educated person is expected to appreciate new ideas better and quicker than a less educated person (Ntshangase et al., 2018). Educated farmers are more likely to be employed and earn higher wages than less educated farmers; thus, they can afford to buy the implements needed to switch from one tillage method to another. As indicated in Figure 5.1, the respondents who had completed primary education constitute the majority of the sample, at 46 percent. In contrast, those who had completed tertiary education represent the minority, at 5 percent. Lead farmers with education levels ranging from primary to tertiary dominate the rest of the group. This suggests that most lead farmers are either retired members of the workforce or farmers with additional roles within their communities. Typically, these farmers possess literacy skills and often act as representatives of their respective communities.

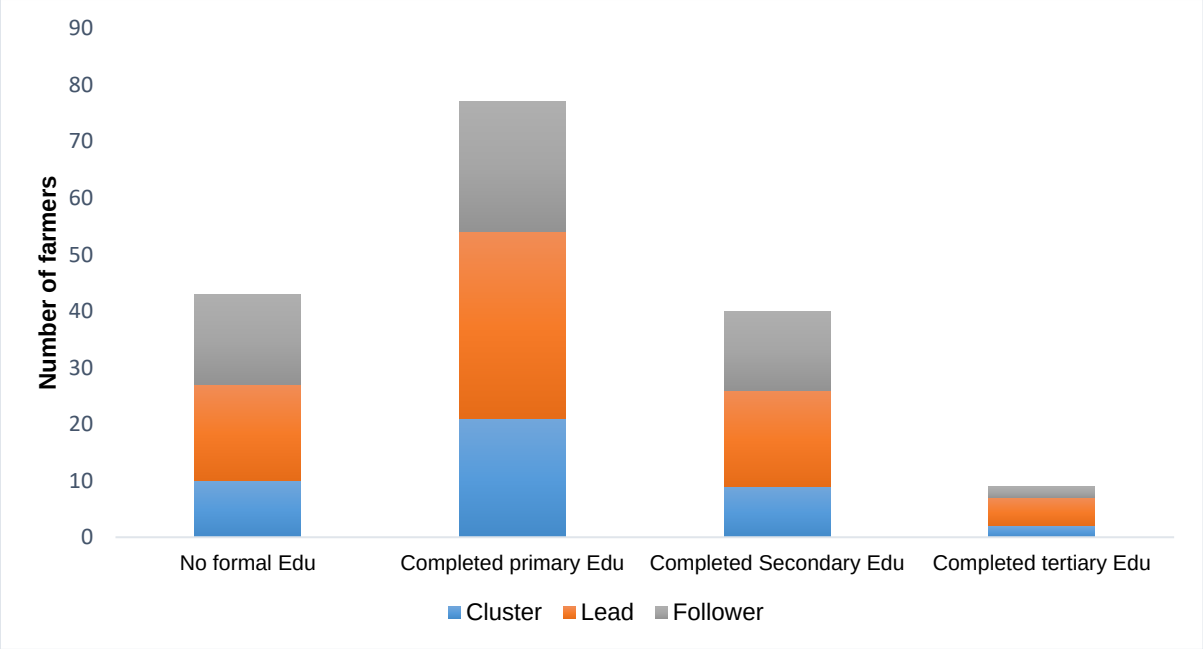


Figure 5. 1: Farmers' educational status
Source: Author's compilation

Twenty-five percent of the farmers surveyed had never attended formal school. As farming is their primary livelihood, many of these farmers are wholly dedicated to it, unlike individuals who have

completed formal schooling and can seek employment or fulfil other societal obligations. Furthermore, motivated by the prospect of increased yields, they are willing to adopt any technology believed to enhance their productivity. Moreover, because their focus is solely on farming, these farmers are more likely to notice any changes that occur when one tillage method is replaced by another.

5.2.5 Composition of participating farmers

Among the farmers participating across the three regions, 46.2 percent were Lead farmers and 32.5 percent were 'Follower' farmers, according to the study which was conducted in seven research clusters across these regions, as indicated in Figure 5.2. This group is comprised of 24.9 percent of the participating farmers. All Cluster farmers were interviewed, thanks to the assistance of student assistants who helped in the enumeration exercise.

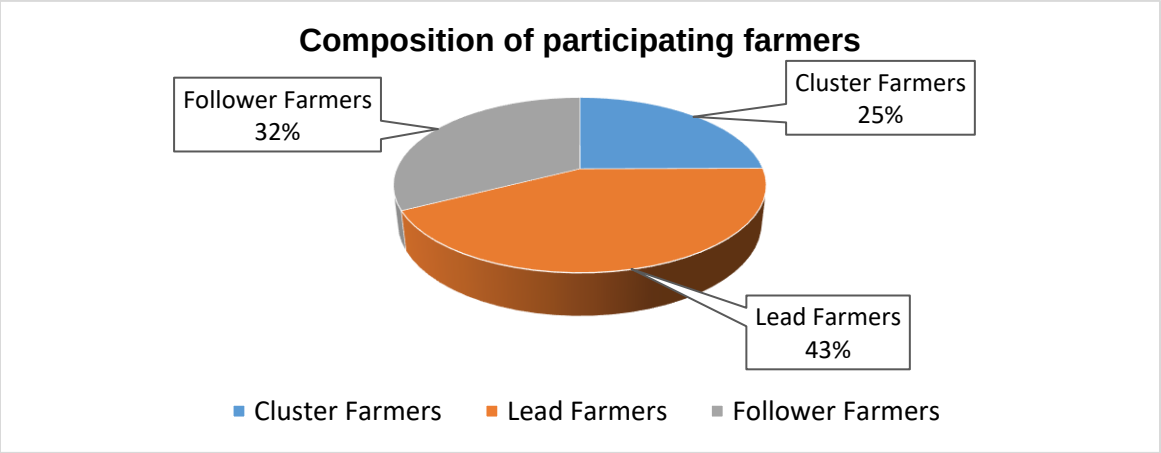


Figure 5. 2: The composition of interviewed farmers
Source: Author's compilation

Farmers from clusters formed the third group of participants in the study. Beyond providing survey data, these cluster farmers also contributed to conducting the CA field experiments, generating the on-farm research data used to assess crop productivity.

5.3 Socio-economic Factors influencing CA adoption

5.3.1 Introduction

This section presents the results related to socio-economic factors influencing the adoption of CA. The methods of soil preparation, crop diversification through intercropping, crop rotation, and maintaining permanent soil cover via mulching are highlighted as critical CA principles that determine farmers' responses to CA practices.

5.3.2 Method of soil preparation

Farmers were presented with four different tillage systems (plough, direct seeder, ripper, and basin), taking into account their socio-economic status. Therefore, these tillage systems are considered as four distinct outcome variables. The objective is to determine the preferred tillage system based on the farmers' socio-economic characteristics. The choice model was analysed using STATA software, wherein the direct seeder system was selected as the reference outcome group; thus, all other outcomes are compared against this baseline.

Therefore, given that the parameter estimates are relative to the reference group, the interpretation of the multinomial logit model output indicates that for a unit change in a predictor variable, the logit of the outcome (compared to the reference group) is expected to change by its respective parameter estimate, assuming all other variables in the model are held constant. Table 5.2 presents the multinomial logit model output for the plough relative to the direct seeder.

5.3.2.1 Plough relative to direct seeder

Ploughing is a tillage method well-known among farmers, with many having practiced it for decades. Twenty-three percent of the respondents identified ploughing as their preferred method of tillage. The impact of significant socio-economic variables on the preference for ploughing, as compared to the base method (direct seeder), is detailed in the second column of Table 5.2.

The multinomial logit model reveals that, with all other variables held constant, the increase in crop rotation after two years is the only socio-economic variable that significantly affects the preference for a plough over a direct seeder, showing statistical significance at the 1% level. Specifically, a one-unit increase in the frequency of rotating crops after two years is associated with a 19.07 unit decrease in the multinomial log-odds of choosing a plough over a direct seeder. This suggests that farmers are less inclined to opt for crop rotation after a two-year interval when they have access to ploughing compared to direct seeding as a method of soil preparation.

Table 5. 2: Multinomial logistic regression result for the method of soil preparation

Variables	Plough		Ripper		Basin	
	Coeff	z-stat	Coeff	z-stat	Coeff	z-stat
Constant	0.320	1.303	-0.221	1.131	-6.242	4.646
gendhh	-0.301	0.489	-0.586	0.447	-1.511	1.261
agehh	-0.0139	0.019	-0.00658	0.018	-0.114	0.088
eduhh	0.0387	0.293	0.366	0.243	-1.733***	0.587
hhsize	0.00401	0.026	-0.0208	0.023	-0.336*	0.177
monocrop	-1.612	1.115	-16.20***	0.561	-14.73***	2.077
annually	-0.118	0.499	0.164	0.484	15.47***	0.954
biannual	-19.07***	0.877	-1.177	1.465	19.40***	1.556
w5hrs	0.679	0.467	0.970**	0.425	-15.87***	1.571
Wald chi2(24)	416.49					
Prob>chi2	0.0000					
Pseudo R2	0.1037					
Observations	169					

*** p<0.01, ** p<0.05, * p<0.1

The base (reference) category is the direct seeder

Source: Author's compilation

5.3.2.2 Ripper relative to direct seeder

Ripping, as one of the tillage methods, was familiar to and had been practiced by the farmers interviewed over the last four years of the study period. Literature reviews, including findings from USAID in 2018, indicate that switching from conventional to conservation tillage methods can improve soil structure, reduce CO_2 emissions, and increase soil organic carbon content. To facilitate this practice, participating farmers were provided with the *Magoye* ripper for free use (Lead and Research Cluster farmers), while Follower farmers were permitted to borrow the ripper from their Trainer (Lead farmers). Among the survey respondents, 36 percent identified the ripper as their preferred tillage method, making it the second most popular choice after the direct seeder (the base category). The impact of socio-economic variables on the preference for the ripper tillage method, in comparison to the direct seeder, is presented in the third column of Table 5.2.

The multinomial logit model reveals that with all other variables held constant, a unit increase in *mono-cropping* and an increase in weeding specifically, *weeding twice for 5 hours per hectare* are associated with significant changes in the preference for a ripper over a direct seeder. These changes are significant

at the 1% and 5% levels for the two socio-economic variables, respectively. This analysis suggests that an increase in *mono-cropping* by one unit would decrease the log odds of preferring a ripper to a direct seeder by 16.20 units, assuming all other factors remain unchanged. This outcome indicates farmers' awareness that continuous mono-cropping, when using a ripper compared to a direct seeder, may forego the benefits of nitrogen fixation provided by leguminous crops. Furthermore, the model predicts that if farmers were to double the weeding effort to 5 hours per weeding session per hectare, the log odds of choosing a ripper over a direct seeder would increase by 0.970 unit, with all other variables in the model held constant.

5.3.2.3 Basin relative to the direct seeder

The basin method involves using a hoe for soil preparation; it is an ancient technique that was popular before the introduction of the plough. This method remains a common tillage system among farmers, especially those who do not have access to a plough or draught oxen. In the study area, farmers still use this system for the initial soil preparation, for sowing cowpeas when intercropping with a cereal crop, or when planting groundnuts. Only two percent of the respondents interviewed indicated that they had chosen the basin as their preferred tillage method. The interpretation of significant variables related to the basin tillage method, in comparison to the base method (direct seeder), is presented in the fourth column of Table 5.2.

The multinomial logit model's estimates reveal that an increase in the *education level of the household head, household size, mono-cropping, annual crop rotation, crop rotation after two years, and weeding twice for 5 hours per weeding per hectare* significantly affect the preference for using a basin over a direct seeder, with all other model variables held constant. Specifically, the model indicates that an additional year of education for the household head decreases the likelihood of preferring the basin method over direct seeding by 1.733 units, assuming no changes in other factors. The observed decrease in preference for the basin tillage method as the *education level of the household head* increases can be attributed to the correlation between education and income. A higher level of education typically leads to increased income levels, enhancing the farmer's ability to purchase more advanced farming equipment. Such tools accelerate farming operations, making the manual and time-intensive basin method less appealing. Similarly, an increase in *household size* by one unit is estimated to reduce the probability of choosing the basin method over direct seeding by 0.336 unit, all else being equal. This suggests that larger households,

with their higher food requirements, may necessitate the expansion of cultivated land to meet increased demand. Since the basin method is more suited to smaller fields, its utility diminishes as the need for larger scale cultivation grows. The multinomial logit model's findings indicate that an increase in *mono-cropping* significantly decreases the preference for the basin tillage method over direct seeding by 14.73 units, assuming all other variables remain constant. Conversely, the model suggests that increasing the practice of *rotating crops annually* by one year is associated with a 15.42 unit increase in the likelihood of preferring the basin method over direct seeding, with all other factors held constant. Furthermore, the coefficient for rotating crops every two years shows an even more substantial increase in preference for the basin method, with an expected increase of 19.40 units in the probability of choosing basin tillage over direct seeding. The multinomial logit model's estimates show that increasing the intensity of *weeding to twice for 5 hours per weeding per hectare* annually would decrease the probability of preferring the basin method over direct seeding by 15.87 units, assuming all other variables in the model remain constant.

The analysis indicates a marked preference among farmers for the basin tillage system over direct seeding. This suggests a strategic opportunity to engage younger and more educated farmers, who are likely to be more receptive to conservation agriculture practices. These farmers are typically more aware of the detrimental effects of using deep mouldboard plough on soil health. Moreover, they possess a sophisticated understanding of soil dynamics, including how different tillage systems affect soil structure and quality. It was also observed that mono-cropping has a statistically significant and negative impact on the adoption of rippers. Focusing on these informed groups could accelerate the adoption of sustainable agricultural practices, promoting soil conservation and enhancing farming efficiency. Therefore, to fully realize the benefits of conservation agriculture, launching an awareness campaign is essential. Educating farmers through mass media can play a pivotal role. Such a campaign would help farmers grasp and value the principles behind conservation agriculture, fostering a deeper understanding of its long-term advantages for soil health and agricultural sustainability.

5.3.3 Crop diversification through intercropping

Farmers were presented with four distinct intercropping configurations; mono-cropping, cereal/cowpeas, cereal/round nuts, and cereal/groundnuts taking into account their socio-economic statuses. These four intercropping options constituted the outcome variables in the analysis. The study aimed to regress these outcomes against the farmers' socio-economic factors to identify which option most effectively elucidates

the relationship between farmers' intercropping choices and their socio-economic factors. In this analysis, STATA uses *cereal intercropped with cowpeas* as the reference category. Consequently, the model estimates for *mono-cropping, cereal intercropped with roundnuts*, and cereal intercropped with groundnuts are all evaluated relative to *cereal intercropped with cowpeas*. Given this framework, the parameter estimates from the multinomial logit model indicate how a unit change in a predictor variable is expected to affect the log odds of choosing a specific intercropping option over the reference group (cereal/cowpeas), assuming all other variables in the model are held constant. Table 5.3 presents the multinomial output.

Table 5. 3: Multinomial logistic regression result for intercropping

Variables	Mono-cropping		Cereal/roundnuts		Cereal/groundnuts	
	Coeff	z-stat	Coeff	z-stat	Coeff	z-stat
Constant	-15.380***	2.453	0.339	1.966	-1.119	-1.472
gendhh	-0.946	0.859	-0.327	0.644	1.124**	0.461
agehh	-0.001	0.035	0.014	0.029	-0.005	0.016
eduhh	0.104	0.597	-0.940*	0.480	-0.348	0.248
hhsize	-0.056	0.072	0.019	0.028	-0.012	0.025
none	-0.116	1.405	-15.490***	1.336	1.222	1.456
annually	13.64***	0.996	-1.532	1.189	0.600	1.086
aftoneyr	13.73***	1.320	-0.533	1.172	1.467	1.144
Wald chi2(24)	1634.4					
Prob>chi2	0.0000					
Pseudo R2	0.077					
Observations	169					

*** p<0.01, ** p<0.05, * p<0.1
The base (reference) category is the cereal/cowpeas
Source: Author's compilation

5.3.3.1 Mono-cropping relative to cereal intercropped with cowpeas

Only four percent of the interviewed farmers identified monocropping as their preferred farming practice, citing its less time-consuming nature during seeding and weeding phases. The impact of significant socio-economic variables on the preference for monocropping, relative to the baseline practice of intercropping cereals with cowpeas, is detailed in Table 5.3's second column. The multinomial logit analysis identified three predictors that are statistically significant at the 1% level.

The *constant term* represents the multinomial logit estimate for preferring mono-cropping over the intercropping of cereal and cowpeas when all predictor variables in the model are set to zero. Specifically,

with the predictors at zero, the log odds of choosing mono-cropping relative to intercropping cereal with cowpeas are expected to decrease by 15.38 units.

The *Annually* parameter represents the multinomial logit estimate for the preference of monocropping over intercropping cereal with cowpeas when comparing annual crop rotation to biennial rotation, with all other variables in the model held constant. Specifically, the log odds of preferring monocropping over intercropping cereal with cowpeas are 13.64 units higher for farmers practicing crop rotation annually compared to those rotating crops every two years, assuming no change in other predictor variables. The *Aftoneyr* parameter in the multinomial logit model assesses the preference for monocropping over cereal intercropped with cowpeas, comparing the practice of skipping a year in crop rotation to rotating crops every two years, while controlling for other variables in the model. Specifically, the log odds of preferring monocropping over intercropping with cowpeas are 13.73 units higher for farmers who skip a year in their crop rotation schedule compared to those who rotate crops biennially, assuming all other factors in the model remain constant.

5.3.3.2 Intercropping of cereal with round nuts relative to intercropped cereal with cowpeas

Approximately eight percent of the interviewed farmers expressed a preference for intercropping cereal with roundnuts as an effective farming practice. The analysis of this preference, in comparison to the base case of intercropping cereal with cowpeas, is summarised in the third column of Table 5.3. Within this analysis, two predictors emerged as statistically significant, with one showing significance at the 10% level and the other at the 1% level.

The *Eduhh* variable in the multinomial logit model represents the effect of the household head's education level on the preference for intercropping methods. Specifically, an increase of one year in the education level of the household head is associated with a decrease of 0.940 units in the multinomial log-odds of preferring intercropping cereal with round nuts over intercropping cereal with cowpeas, assuming all other variables remain constant. Additionally, the *None* variable compares the preference for not practicing crop rotation to practicing crop rotation every two years for the choice of intercropping cereal with round nuts over cereal intercropped with cowpeas, with all other model variables held constant.
The coefficient for *No crop rotation* in the multinomial logit model indicates that, compared to practicing crop rotation every two years, the absence of crop rotation is associated with a decrease of 15.49 units in

the multinomial log-odds of preferring intercropping cereal with round nuts over intercropping cereal with cowpeas, when all other variables in the model are held constant. This means that farmers who do not practice crop rotation are significantly less likely to prefer intercropping cereal with round nuts to intercropping cereal with cowpeas than those who skip crop rotation for two years.

5.3.3.3 Intercropping of cereal with groundnuts relative to intercropping cereal with cowpeas

Thirty-one percent of farmers who participated in the interview revealed preferring intercropping cereal with groundnuts as a good farming practice. The analysis output of the significant socio-economic variable(s) on intercropping cereal with groundnuts option as a preferred practice in relation to the base (intercropping of cereal with cowpeas) is displayed in the fourth column of Table 5.3 above. Only one predictor was found to be statistically significant at 5% significance level and will be interpreted accordingly.

Gendhh – The multinomial logit variable indicating the gender of the household head as a significant factor in the preference for intercropping cereal with groundnuts over cereal with cowpeas reveals interesting insights into gender dynamics in agricultural practices. This result shows that when the household head is male, there is a slightly increased likelihood, by 0.327units, of preferring to intercrop cereal with groundnuts compared to intercropping cereal with cowpeas, holding all other variables constant. This preference could reflect underlying gender-based differences in decision-making, access to resources, or perceptions of agricultural practices. This reveals that male households are less likely than female households to prefer intercropped cereal with groundnuts to intercropped cereal with cowpeas. The reason could be that male-headed households have alternative means to generate income from livestock sales and prefer less intercropped cereal with groundnuts meant for income generation by female-headed households. The male-headed household will rather prefer intercropped cereal with cowpeas because cowpeas are grown for home consumption more than for income generation.

5.3.4 Crop rotation

Farmers were presented with four different crop rotation options (*None, annually, after1year, and after2years*) with special reference to their socio-economic status. Hence, all four crop rotation options represent four outcome variables, which were regressed with the farmer's socio-economic factors, to determine the option that best explains the relationship between the outcomes and the socio-economic

factors in making CA an attractive option to farmers. In this instance, STATA treats *annually* as the reference group and therefore estimated a model for none, after1year, and after2years relative to annually. Therefore, since the parameter estimates are relative to the reference group, the interpretation of the multinomial logit output will be that for a unit change in the predictor variable, the logit of outcome relative to the reference group is expected to change by its respective parameter estimate given the variables in the model are held constant. The multinomial result for crop rotation is presented in Table 5.4.

Table 5. 4: Multinomial logistic regression result of crop rotation

Variables	None		After1year		After2years	
	Coeff	z-stat	Coeff	z-stat	Coeff	z-stat
Constant	1.878	5.048	0.870	1.396	-11.680***	2.720
gendhh	0.036	0.932	-0.318	0.472	15.470***	0.583
agehh	-0.019	0.053	-0.057***	0.021	-0.169***	0.054
eduhh	-1.403	1.243	0.033	0.285	-0.079	0.659
hhsize	-0.192*	0.114	0.052*	0.028	0.107**	0.052
Wald chi2(24)	803.79					
Prob>chi2	0.0000					
Pseudo R2	0.1228					
Observations	169					

*** p<0.01, ** p<0.05, * p<0.1
The base (reference) category is annually
Source: Author's compilation

5.3.4.1 No crop rotation relative to crop rotation every year

Only four percent of farmers who participated in the interview indicated preferring no crop rotation as a good farming practice. The interpretation of the significant socio-economic variables on no crop rotation option as a preferred practice in relation to the base (crop rotation every year) is displayed in the second column of Table 5.4. Only one variable was statistically significantly different at 10% significance level.

Household size – The result shows that if a farmer's household size score were to increase by one point, the multinomial log-odds for preferring no crop rotation to crop rotation every year would be expected to decrease by 0.192 unit while holding all other variables in the model constant. As household size increases, the probability of having *no crop rotation* decreases because the household size will eventually translate into labour units available to work in the crop field. Household members will assist in opening

up new rows during soil preparation, seeding, and weeding process, making it easier to implement crop rotation.

5.3.4.2 Crop rotation after skipping one year relative to crop rotation every year

Fifteen percent of farmers who participated in the interview indicated preferring crop rotation after skipping one year as a good farming practice. The interpretation of the significant socio-economic variables on crop rotation after one year option as a preferred practice in relation to the base (crop rotation every year) is displayed in the third column of Table 5.4 above. The result shows that two variables are statistically significant at 1% and 10% significance level, respectively.

Age of the household head - The result shows that if the age of the household head score were to increase by one point, the multinomial log-odds for preferring crop rotation after skipping one year to crop rotation every year would be expected to decrease by 0.057 units while holding all other variables in the model constant. However, if the **household size** score for crop rotation after skipping one year relative to crop rotation every year, given that the other variables in the model are held constant, were to increase by one point. The multinomial log-odds for preferring crop rotation after skipping one year to crop rotation yearly would be expected to increase by 0.052 units.

5.3.4.3 Crop rotation after skipping two years relative to crop rotation every year

Only three percent of farmers who participated in the interview indicated preferring crop rotation after skipping two years as a good farming practice. The results show that four variables are statistically significant at 1% and 5% significance level.

Gendhh The result shows that male household headed relative to female household headed is 15.470 units more for preferring crop rotation after skipping two years relative to crop rotation every year, given all other predictor variables in the model are held constant. This reveals that male households are more likely than female households to prefer crop rotation after skipping two years to crop rotation every year. **Agehh**-. If the age of the household head score were to increase by one point, the multinomial log-odds for preferring crop rotation after skipping two years to crop rotation every year would be expected to decrease by 0.169 units while holding all other variables in the model constant. However, the **household**

size score for crop rotation after skipping two years relative to crop rotation every year, given that the other variables in the model are held constant, were to increase by one point. The multinomial log-odds for preferring crop rotation after skipping two years to crop rotation yearly would be expected to increase by 0.107 units.

The analysis shows that farmers in the regions are more responsive to crop rotation after skipping two years option relative to rotating annually.

5.3.5 Permanent soil cover materials

Farmers were presented with four different mulching options (None, grass, stalks, and leaves) with special reference to their socio-economic status. Hence, all four mulching options represent four outcome variables, which were regressed with the farmer's socio-economic factors, to determine the option that best explains the relationship between the outcomes and the socio-economic factors in making CA an attractive option to farmers. In this case, *stalks* **were** used as the reference group. The multinomial result of the mulching option is presented in Table 5.5.

Table 5. 5: Multinomial logistic regression result of mulching options

Variables	None		Grass		Leaves	
	Coeff	z-stat	Coeff	z-stat	Coeff	z-stat
Constant	-3.936*	2.203	0.031	1.046	-2.937	2.114
gendhh	0.064	0.807	0.394	0.423	0.928	0.842
agehh	-0.014	0.036	-0.003	0.015	0.008	0.031
eduhh	1.022**	0.473	0.118	0.234	0.448	0.391
hhsize	-0.032	0.046	-0.125***	0.045	-0.156	0.113
Wald chi2(24)	26.45					
Prob>chi2	0.0093					
Pseudo R2	0.0693					
Observations	169					

*** p<0.01, ** p<0.05, * p<0.1
The base (reference) category is annually
Source: Author's compilation

5.3.5.1 Other mulching relative to stalks

Only five percent of farmers who participated in the interview preferred no mulching as a good farming practice. The interpretation of the significant socio-economic variables on no mulching option as a preferred practice in relation to the base (mulching with stalks) is displayed in the second column of Table

5.5. Two variables are statistically significant at 10% and 5% significance, respectively. The result shows that more experienced farmers with larger family sizes would prefer either grass or no mulch relative to the stalk. Mulch with leaves is the least preferred option amongst the farmers.

5.4 Evaluation of farmers' preference for CA and the trade-offs between CA and conventional practices

5.4.1 Introduction

Experimental research was carried out with the purpose of determining farmers' preferences in conservation agriculture and the conventional tillage system. This was carefully done by selecting variables that farmers are familiar with and experience on a yearly basis. Farmers were experiencing crop yield reductions due to increased pressure on the soil, aiming to satisfy the often conflicting environmental, economic, and social goals, without undertaking corrective actions to sustainably utilize this precious natural resource called soil. Over the years, farmers have noticed changes in their crop fields, affirming that there is a depletion of organic matter and crucial crop nutrients occurring. As a result, farmers have noticed the need to conduct farming differently. Consequently, various farming practices have been introduced as corrective measures, initiated by the farmers themselves. Some farmers have abandoned old crop fields to establish new ones, while others delay soil preparation by waiting for the grass to establish first. This allows them to bury it when ploughing as green manure and as part of organic matter.

It is necessary to strike a balance between the economic effects of altered soil management and the environmental and social benefits of protecting natural resources. Although environmental changes and direct market impacts on soil are relatively easy to monitor, little is known about the non-market values associated with protecting crop fields. Therefore, obtaining more information about community preferences for alternative natural resource management options is necessary to support efficient decision-making. This section focuses on experimental research aimed at assessing farmers' understanding of the socio-economic contributions of two different tillage systems, considering their ability to elicit the non-market values of crop fields.

5.4.2 Socio-economic characteristic comparison between regions

Socio-economic comparisons between regions are essential for several reasons, as they provide valuable insights into the differences and similarities in economic, social, and cultural conditions. These comparisons help inform policymaking, resource allocation, and development planning. Hence, their comparisons are vital for understanding the diverse needs and conditions of different regions, leading to more informed, equitable, and effective policies and actions. In this regard, by exploring the differences in characteristic it helps the researcher to understand how farmers are making choices when given an option to choose between tillage systems.

Gender - the study found that a total in total 47 females were interviewed, 24 female respondents came from Zambezi region, 16 females from Kavango West and only 7 females from Kavango East region. Most respondents were males constituting 72 percent of the total interviewed respondents. 48 male respondents came from Zambezi region, followed by 45 male respondents from Kavango East region, and only 29 males were from Kavango West, the summary of gender between the regions is displayed in Figure 5.3. Gender plays a role at the household level because it tells who a decision-maker is. In most cases, male household head are the one in charge of making the final decision.

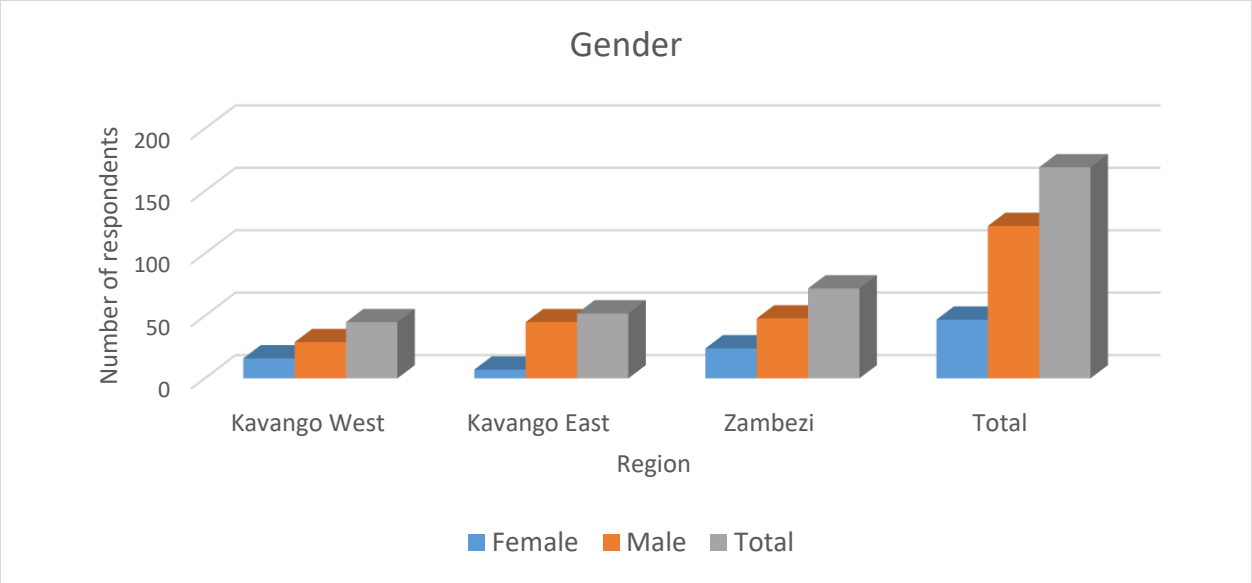


Figure 5. 3: Gender of the interviewed farmers
Source: Author's compilation

Education background - Kavango East region had a higher number of respondents with no formal education with 12 percent of the total interviewed respondent, Kavango West has 8 percent and 5 percent from Zambezi. Having no formal education is expected to influence the adoption rate of new farming techniques, access to information and resources negatively. The farmers who had not received any formal education, highlighting their reliance on external information providers for insights into innovative farming techniques (Shobhit, 2024). Education creates a favourable attitude towards new practices because an educated farmer understands the possible beneficial effects of modern agricultural technologies such as improved crop varieties better than the illiterate one (Paltasingh, 2016). As shown in Figure 5.4, Zambezi region has the highest number of respondents who completed secondary school amounting to 15 percent compared to only 4 and 5 percent for Kavango East and Kavango West respectively. None of the respondents from Kavango West has completed tertiary education and only 2 and 4 percent from Kavango East and Zambezi region respectively has completed tertiary education.

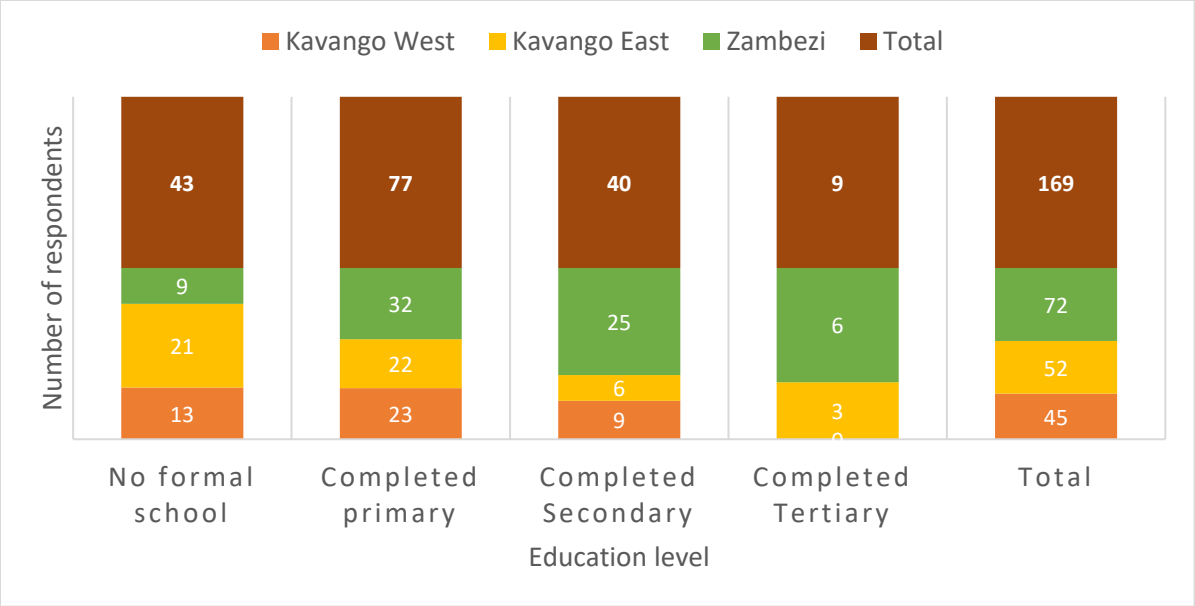


Figure 5. 4: Educational level of the respondents per region
Source: Author's compilation

Marital status is a socio-economic variable that is critical in determination of the level and magnitude of conflicts arising from hereditary process and which affects good agricultural practices in farming (Ngeywo et al., 2015). Most respondents were married with 28 percent from Zambezi region, 25 percent from Kavango East and 18 percent from Kavango West. Only a small amount of about 3 percent in total indicated divorced or separated. This is an indication that overall farmers in the three regions have stable relationship and work together for the common course of their families. The statistics on marital status across the three regions are shown in Figure 5.5.

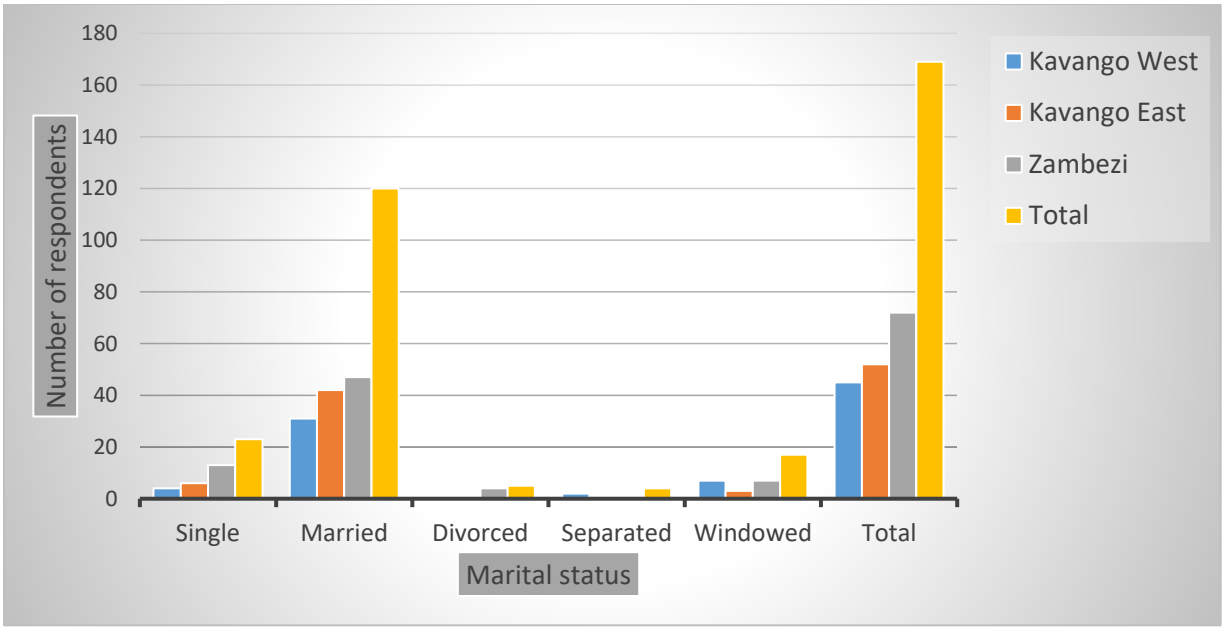


Figure 5. 5: Marital status of respondents
Source: Author's compilation

5.4.3 ANOVA analysis results

The response variable (Y) in this objective is the soil condition projected over a period of 10 years under two scenarios: the status quo scenario (representing conditions in 10 years without new initiatives) and the scenario with initiatives of conservation agriculture (CA). The indicators used in the status quo scenario include no mulching, ploughing as the method of soil preparation, mono-cropping, and no crop rotation. The analysis was conducted using version 29.0.1.0 (142) of IBM SPSS Statistics.

ANOVA analysis was used to determine whether farmers would choose to continue farming under the status quo scenario for the next 10 years or if they are willing to take action to implement new initiatives. If farmers opt for the status quo scenario, it implies that they are not aware that the conditions projected in 10 years without implementing new initiatives are likely to cause environmental harm to their crop fields. Conversely, if farmers choose the alternative option over the status quo scenario, it indicates that they are aware of the environmental harm that the crop

fields are likely to suffer in 10 years if initiatives of conservation agriculture (CA) are not implemented.

Hence, the hypotheses for this objective are: There is no statistically significant difference between the status quo scenario and the new initiative alternatives.

Eleven new initiatives were provided as possible selective options (from B to K), matched with the status quo scenario as option A.

Table 5. 6: ANOVA analysis Table

Option	Sum of squares	df	Mean Square	F	P- Value
Option B	2.467 (32.326)	1 (167)	2.467 (0.194)	12.742	< .001
Option C	9.271 (32.326)	1 (167)	9.271 (0.194)	47.896	< .001
Option D	0.342 (20.960)	1 (167)	0.342 (0.126)	2.723	.101
Option E	5.320 (35.686)	1 (167)	5.320 (0.214)	24.894	< .001
Option F	3.249 (36.266)	1 (167)	3.249 (0.217)	14.962	< .001
Option G	2.462 (39.360)	1 (167)	2.462 (0.236)	10.448	< .001
Option H	5.028 (36.298)	1 (167)	5.028 (0.217)	23.133	< .001
Option I	0.878 (27.453)	1 (167)	0.878 (0.164)	5.343	.022
Option J	5.890 (35.577)	1 (167)	5.890 (0.213)	27.647	< .001
Option K	1.018 (32.000)	1 (167)	1.018 (0.192)	5.313	.022

Sums of squares, df, and mean square of between groups and sums of squares, df, and mean square of within groups in parenthesis

Source: Author's compilation

The ANOVA output, as indicated in Table 5.6 above, analysed the status quo scenario option against other alternative options. All alterations are statistically significant, indicating that all selections in the analysis have rejected the null hypothesis statement, except for option D, which is not statistically significantly different from option A. This demonstrates that the respondents fully understand the difference between conventional and conservation tillage systems. In this

case, farmers are aware that if they continue ploughing their crop fields, soil fertility will continue to decline, and crop yields will further deteriorate.

This situation is one that farmers are not happy with; therefore, they are willing to opt for other management strategies likely to improve soil fertility status for better yields. The reason why option B is not statistically significant may be attributed to the tedious work associated with this type of soil preparation. Although many farmers without access to modern tools praise the basin tillage approach, it necessitates physical labour, especially during sowing and weeding. Farmers may not prefer the basin tillage system if the area exceeds 2 hectares; it is only practical if the farmer is preparing small areas of 2 hectares or less.

Therefore, farmers are advised to be proactive in taking initiatives to manage their crop fields. Adopting climate-smart agricultural methods that increase farm productivity and profitability, help farmers adapt to the effects of climate change, and mitigate those effects may be a good starting point. Conservation agriculture, which is practiced locally, is one example of a climate-smart practice. It aims to preserve soil moisture, maintain crop residues for soil fertility, disturb the soil as little as possible, and diversify through rotation or intercropping.

5.5 Willingness to Pay for the main activities of conservation agriculture

5.5.1 Introduction

The results of conditional logistic model for the willingness to pay for the main activities of conservation agriculture that farmers are likely to undertake to improve the soil fertility of their crop fields is discussed in this section.

5.5.2 Description of data used

A face-to-face interview was conducted to investigate six main conservation agriculture practices: intercropping, crop rotation, the timing of first soil preparation per hectare, the cost of soil preparation per hectare, frequency and duration of weeding per hectare, and the application of mulching materials. Respondents were presented with the attributes and levels in both a textual and visual format (see

Appendix 2). The attributes and levels (Table 5.7) were selected based on a literature review, discussions with extension officers in the study area, general discussions with some farmers, and expert consultations. Respondents were presented with three amendment alternatives in each choice set and asked to choose their most preferred option. The first option represents 'no new initiative'; this option is well-recognised as a baseline scenario that would lead to a continuation of the current trend of soil fertility degradation over the next ten years. The second and third options differ, with each incorporating new initiatives aimed at restoring and contributing to the improvement of soil quality.

Table 5. 7: Attributes and level used

Attribute	**Levels**
Intercropping	Monocropping Cereal & Groundnut Cereal & Barbarnut Cereal & Cowpeas
Crop rotation	No rotation Rotating every cropping season Rotating after skipping one cropping season Rotating after skipping two cropping seasons
Frequency & duration of weeding/Ha	1 Weeding @ 4 Hours/Ha 2 Weeding @ 2 Hours/Ha 2 Weeding @ 3 Hours/Ha 2 Weeding @ 5 Hours/Ha
Mulching materials	No mulching Grass Cereals' stalks Tree branches & leaves
Time of first soil preparation/Ha	2 Hours, 2 Hours & 30 min, 3 Hours, 4 hours
Cost of soil preparation/Ha	N$250, N$300, N$400, N$500

Source: Author's compilation

5.5.3 Regression results and welfare estimates

The results of the conditional logistic model's willingness-to-pay estimates are presented in Table 5.8. The majority of the attribute coefficients show positive effects, suggesting that respondents have a stronger preference for conservation agriculture options that provide more substantial improvements in enhancing soil fertility and, consequently, better crop yields. The conditional logistic regression model was run to

explore the selected attributes that may have influenced the farmers' decisions about whether or not to pay for the main activities that drive conservation agriculture, bringing changes to the fertility status of their crop fields. The regression output and its associated willingness-to-pay (WTP) levels will be discussed; however, only the significant attributes will be mentioned.

Intercropping statistically significantly influences the willingness to pay for adopting conservation agriculture; however, it has a negative coefficient. This indicates that respondents are satisfied with walking away from practicing intercropping as one of the main activities of conservation agriculture that promotes crop diversification.

Table 5. 8:Conditional logistical regression estimates for main activities of practicing conservation agriculture in WTP stated preference

	1st Round		2nd Round		3rd Round		4th Round		5th Round		6th Round	
Attribute	Coeff.	WTP1	Coeff.	WTP2	Coeff.	WTP3	Coeff.	WTP4	Coeff.	WTP5	Coeff.	WTP6
Cost	0.199		-0.380		-0.813***		-0.312		0.303		0.310	
	(0.235)		(0.238)		(0.260)		(0.229)		(0.192)		(0.192)	
Intercro	-0.668**	3.35	0.033	0.09	-0.490**	-0.60	0.254	0.82	0.238	-0.78	0.021	-0.07
	(0.263)		(0.209)		(0.232)		(0.192)		(0.181)		(0.191)	
Rotation	0.198	-0.99	0.708***	1.86	0.348*	0.43	0.872***	2.79	0.795***	-2.62	0.853***	-2.75
	(0.229)		(0.200)		(0.209)		(0.188)		(0.174)			
Time	0.144	-0.72	-0.524**	-1.38	0.066	0.08	-0.238	-0.76	-0.128	0.42	-0.791***	2.55
	(0.235)		(0.233)		(0.189)		(0.223)		(0.207)		(0.251)	
Wrate	0.037	-0.19	-0.788***	-2.07	-0.351	-0.43	-0.791***	-2.53	-0.117	0.39	0.144	-0.46
	(0.225		(0.256)		(0.230)		(0.247)		(0.200)		(0.197)	
Mulch	0.078	-0.39	0.138***	2.99	0.848	1.04	0.667*	2.14	0.240	-0.79	0.201	-0.65
	(0.190)		(0.164)		(0.165)		(0.168)		(0.178)		(0.181)	

Note: 1% (***), 5% (**) and 10% (*) significance levels. Standard errors are reported in parentheses.
Source: Author's compilation

In the second round, the regression analysis revealed that **crop rotation** positively influences willingness to pay. On average, respondents are willing to pay N$1.86 more to ensure they practice crop rotation, thereby improving soil fertility. This indicates that respondents understand the importance of rotating crops, especially when a leguminous crop is involved in the rotation process. This practice involves breaking life-circle of

pest and common diseases that will likely affect crops. The **time spent on first soil preparation per hectare** is an attribute that negatively influences willingness to pay. On average, respondents are willing to pay N$1.38 less for spending more time on soil preparation per hectare. This suggests that farmers prefer a quicker method of soil preparation. Farmers have the option to use oxen or hire private or public tractors; however, factors such as affordability, availability, and the type of implements available on these tractors will influence their choices. Other attributes that negatively influence willingness to pay include the **frequency and weeding rate**. On average, respondents are willing to abandon the practice of conservation agriculture if it involves more frequent and extended hours of weeding. They are willing to pay N$2.07 less for every unit increase in the frequency and weeding rate per hectare. **Mulching** is an attribute that positively influences willingness to pay. On average, respondents are willing to pay N$2.99 more for every unit increase in the application of mulching material on the crop field. In the third round of choices, the study revealed that the **cost of soil preparation** significantly, but negatively, influences willingness to pay. **Intercropping** significantly influences willingness to pay; just like in the first round, the respondents prefer walking away from intercropping. However, in the third round, on average, respondents are willing to pay N$0.60 less per hectare to avoid intercropping. Similarly, **crop rotation** significantly and positively influences willingness to pay, just as it did in the second round. On average, respondents are willing to pay N$0.43 more to practice crop rotation. This demonstrates the consistency in how respondents value crop rotation as a key activity in implementing conservation agriculture.

In the fourth round, it is interesting to note that **crop rotation** significantly and positively influences willingness to pay. On average, respondents are willing to pay N$2.79 more to ensure crop rotation, recognising its benefits. Similar to the findings in the second round, the **frequency and weeding rate** significantly and negatively influence willingness to pay. This indicates that respondents prefer not to engage in activities with numerous occurrences and extended weeding hours per hectare. On average, respondents are willing to pay N$2.62 less for every unit increase in frequency and weeding rate per hectare. In the fifth and sixth rounds, **crop rotation** continues to significantly and positively influence willingness to pay. However, contrary to expectations, on average, respondents are willing to pay N$2.62 and N$2.75 less for practicing crop rotation in the fifth and sixth rounds, respectively. This may indicate a misunderstanding, as it contradicts the positive influence mentioned. Additionally, **the time spent on first soil preparation** per hectare emerges as a second attribute that is statistically significant, negatively influencing the willingness to pay to adopt conservation agriculture in the sixth round. However, the estimated coefficient is negative, indicating that respondents are better off not adopting conservation

agriculture if it requires more time spent on soil preparation per hectare. On average, respondents are willing to pay N$2.55 more to avoid any increase in time spent on soil preparation per hectare.

5.5.4 Conclusion

In conclusion, the conditional regression output displayed consistency in the statistical significance and direction of the influences of the attributes across several rounds. This revealed that intercropping, time spent on first-season soil preparation, and the frequency and weeding rate consistently negatively influenced the willingness to pay for the adoption of conservation agriculture. Investment in training farmers on appropriate crop diversification, with an emphasis on cropping time, is necessary. Furthermore, introducing appropriate mechanical tools and equipment to ease the workload and reduce the time spent on soil preparation and weeding will likely favour the adoption of conservation agriculture among respondents in the study area.

Crop rotation and mulching consistently demonstrated statistical significance and positively influenced the willingness to pay for adopting conservation agriculture. This suggests that respondents in the study area recognize the importance of these practices and are willing to invest more to implement conservation agriculture.

5.6 Field Experiment

5.6.1 Introduction

This section presents the results of on-farm data collected from field experiments conducted in the research plots of research cluster farmers over four consecutive cropping seasons. It will detail rainfall records, as well as grain and biomass yield for pearl millet, maize, and cowpeas. The research experiment, firstly, aimed to ascertain the compatibility of conservation agriculture within beneficial farming environments by being conducted directly in farmers' fields. Secondly, it served as a pilot study to identify potential challenges farmers might encounter when implementing the conservation agriculture tillage method. Thirdly, the experiment acted as a training exercise, exposing farmers in the villages to the principles of comprehensive conservation agriculture and its practical implementation.

5.6.2 Rainfall records

All cluster research farmers were equipped with rain gauges to record the rainfall at their respective locations. The recorded rainfall data are illustrated in Figure 5.6 and Figure 5.7. Rainfall patterns showed sporadic variations throughout the experimental period from 2016/2017 to 2019/2020.

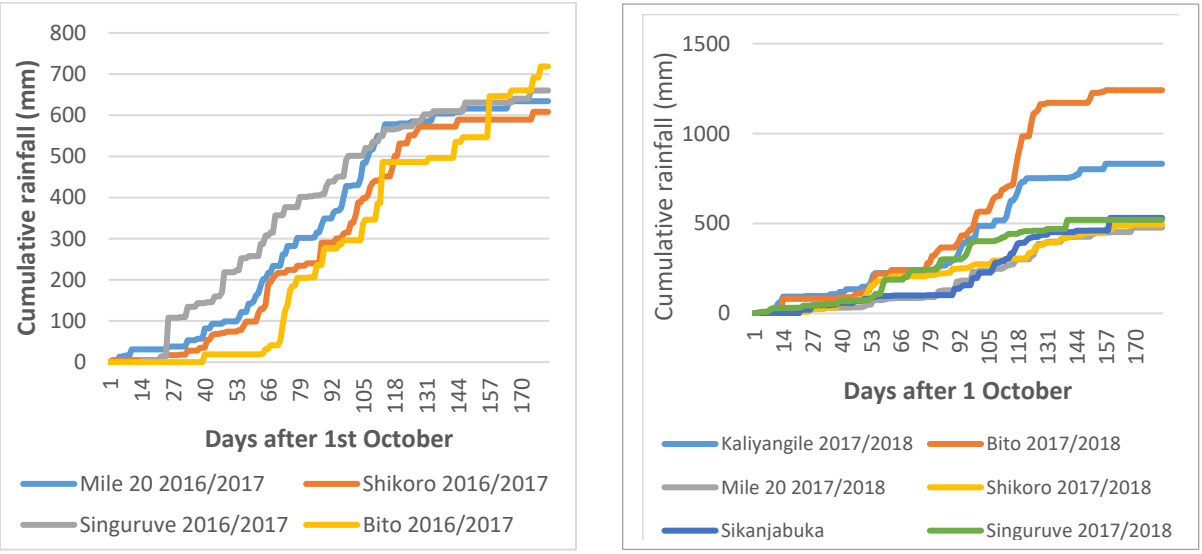


Figure 5. 6: Cumulative rainfall at research clusters during the 2016/2017 to 2017/2018 seasons
Source: Author's compilation

The rainfall figures varied from cluster to cluster. The records show that in the 2016/2017 season, rainfall was generally fair across all clusters, with a maximum cumulative rainfall exceeding 600 mm. In the 2017/2018 season, the Zambezi region experienced good rainfall, with the Bito cluster receiving more than 1000 mm

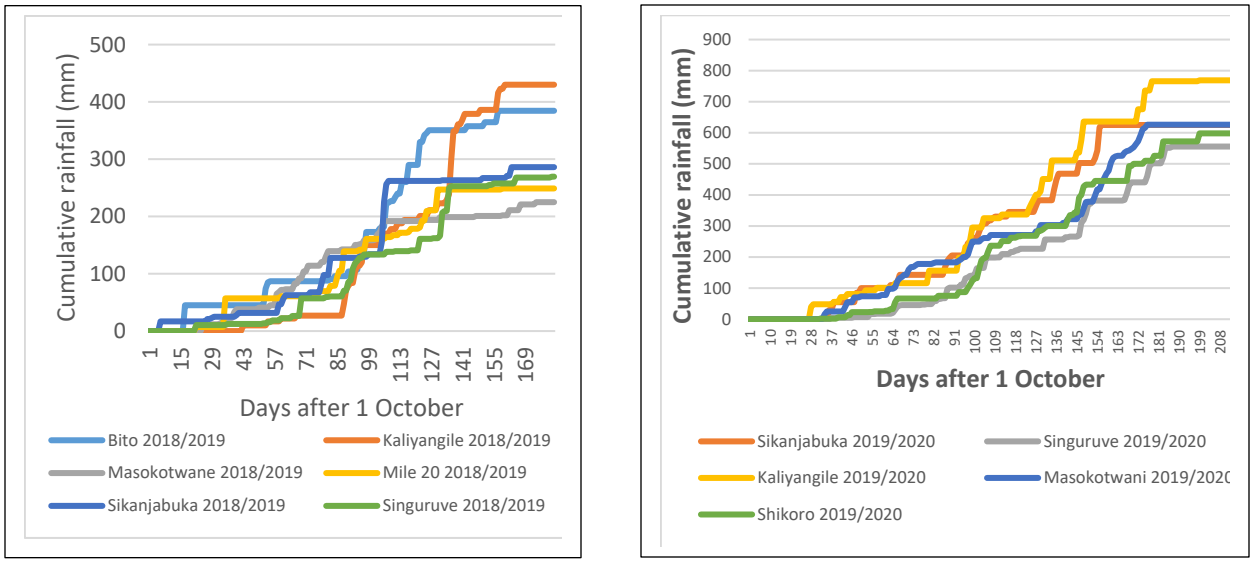


Figure 5. 7: Cumulative rainfall at research clusters during the 2018/2019 to 2019/2020 seasons
Source: Author's compilation

The 2018/2019 rainy season was one of the most challenging periods encountered during the research, marked by the shortest recording span of only 169 days. This season was noted as the severest drought, which the Head of State deemed a national disaster, leading to the declaration of a state of emergency due to the widespread poor rainfall across the country. In contrast, the 2019/2020 season was relatively favourable, showcasing a normal rainfall distribution pattern. The Zambezi region received almost 800 mm of rain, indicating a recovery. Notably, the last recorded season had the longest duration of 208 days, suggesting an extended and beneficial wet period for the crops.

5.6.3 Crop yields

In the Zambezi region, all research clusters planted Maize ZM606, whereas in the Kavango East and Kavango West regions, Pearl millet (Okashana No.2) was the chosen crop. Participating farmers from both regions underwent a week-long training tailored to the research objectives. Upon completion of the growing season, both grain and biomass yield for these crops were meticulously recorded following established harvesting protocols. To compare the mean yields of biomass and grain across maize, pearl millet, and cowpeas, Welch's t-test was employed. The analysis, including ANOVA tests, was conducted using R statistical software version 4.1.3. The significance of differences between various treatments across four cropping seasons was determined using the p-value from Welch's t-test as the initial analytical

step. Subsequently, a second test was conducted to assess whether there were differences in average yields within each cropping season.

5.6.3.1 Maize yield

The first test aimed to assess whether a statistically significant difference exists in the biomass yields of maize when comparing conventional tillage methods (plough) with conservation tillage (ripper) and the intercropping of maize and cowpeas (ripper). According to Figure 5.8, no statistically significant differences were observed in maize biomass yields, measured in kg/ha, between these tillage practices across the four cropping seasons.

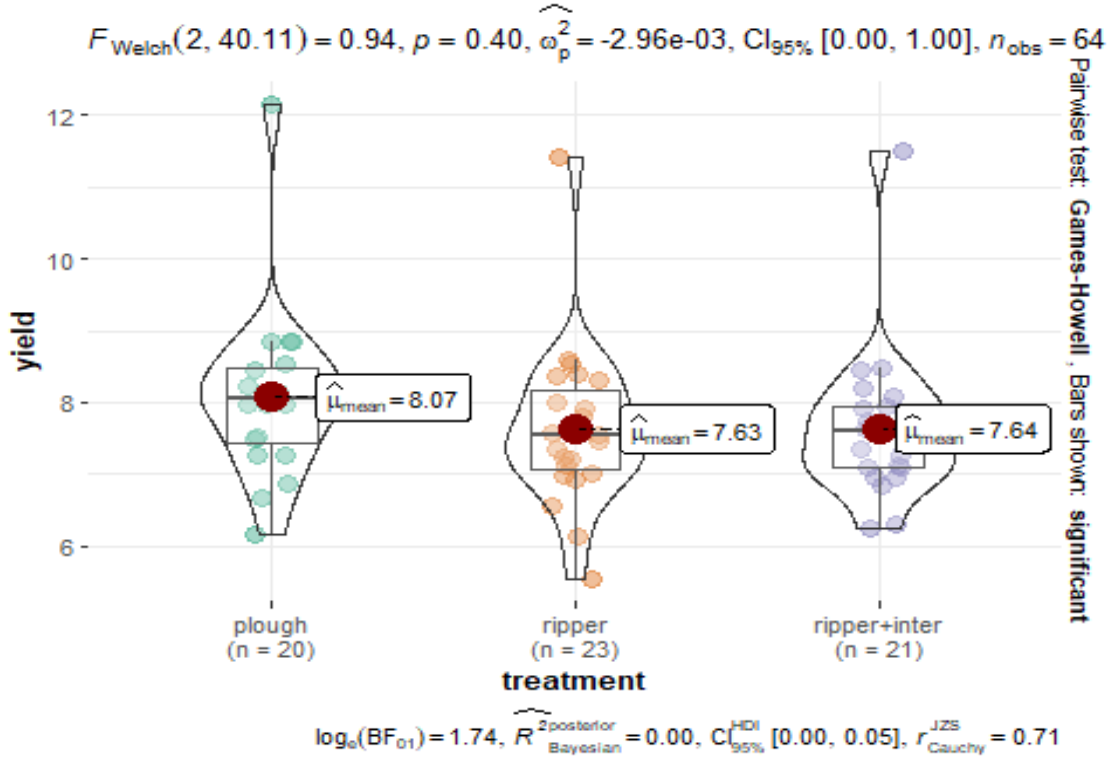


Figure 5. 8: Average maize biomass yield on different treatments
Source: Author's compilation

The ANOVA test revealed no statistically significant difference between the maize biomass yields achieved between conventional and conservation tillage, with $P > .05$; hence, the study accepted the null hypothesis. This result indicates that there is no difference in terms of the biomass of maize over four seasons.

A similar test was done to determine any significant difference in maize grain yields, and the results are displayed in Figure 5.9.

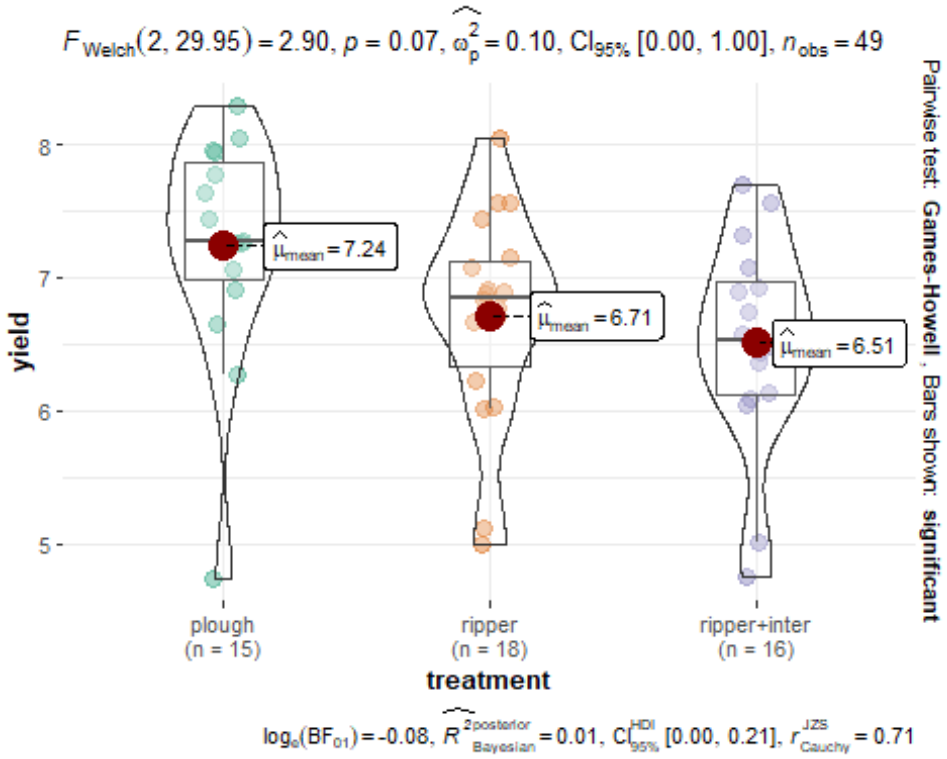


Figure 5. 9: Average maize grain yield on different treatments
Source: Author's compilation

The maize grain yield, on average, over the four cropping seasons was found to be statistically significant between conventional and conservation tillage at 10 percent; hence, the study rejected the null hypothesis.

The second test aimed to identify any statistically significant differences in the average biomass yields of maize across different cropping seasons, thereby capturing seasonal variations. According to the findings, illustrated in Figure 5.10, there were no statistically significant differences in maize biomass yields across the study's seasons. This observation aligns with the understanding that the full advantages of Conservation Agriculture (CA) may not be immediately apparent, as it often takes several years for the benefits to manifest fully. Early years of transition might yield discouraging results, leading some farmers to abandon this technology (Hobbs, 2007). Notably, data for the 2019/2020 cropping season were not included due to the absence of harvest data, a consequence of movement restrictions imposed nationwide in response to COVID-19 Regulations aimed at controlling the virus's spread.

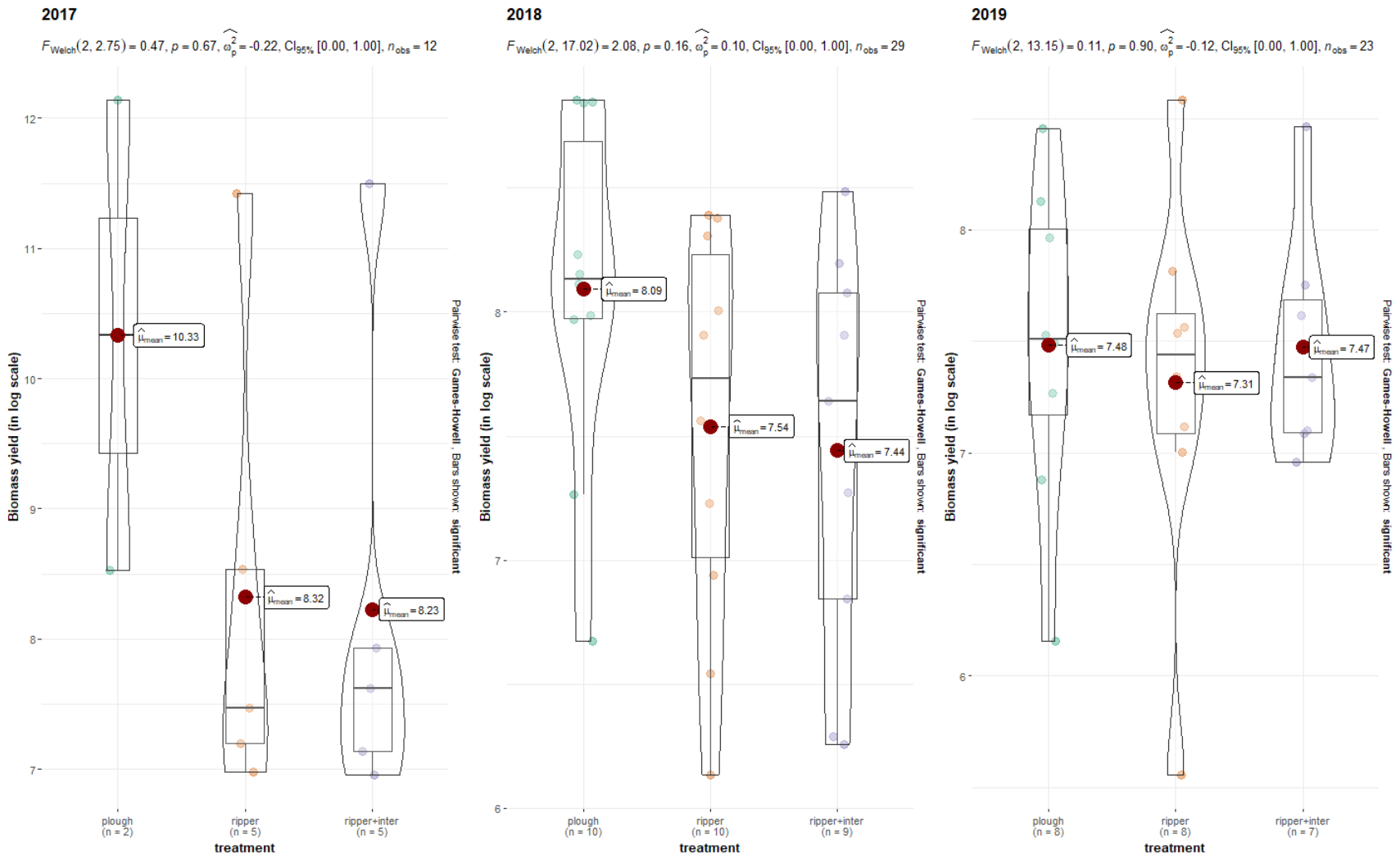


Figure 5. 10: Average maize biomass yield across treatments within seasons
Source: Author's compilation

In the second season, the analysis demonstrated a statistically significant difference in the average grain yield of maize, leading to the rejection of the null hypothesis which posited no significant difference in average grain yields across different tillage systems. As illustrated in Figure 5.11, the difference was significant with a *p*-value of < .0058. The results indicated that traditional ploughing yielded, on average, higher grain than both the ripper (maize) and the ripper intercropped with cowpea (maize & cowpea) for the 2018 season. This variation in yield could be attributed to the favourable rainfall the Zambezi region experienced during the first two seasons, which is depicted in Figure 5.6. Notably, the Zambezi region, the primary location for the maize cultivation in this study, received abundant rainfall, with certain areas exceeding 1000 mm

The analysis revealed that the maize grain yield was consistently higher in ploughed sections compared to those prepared with a ripper, as evidenced by the data presented in Figure 5.11. This disparity in yield can be attributed to several factors. Notably, ripper lines suffered from rat attacks, which targeted the maize seeds, necessitating replanting in many cases. This led to delayed establishment and poorer growth of crops in ripper lines compared to those in ploughed sections, where conditions were more conducive for germination and early growth due to a softer, weed-free seedbed. Additionally, the intercropped areas reported lower average grain yields compared to mono-cropping with the ripper. This reduction is likely due to the competition between maize and cowpeas for moisture and nutrients, impacting the overall yield of maize in these intercropped sections

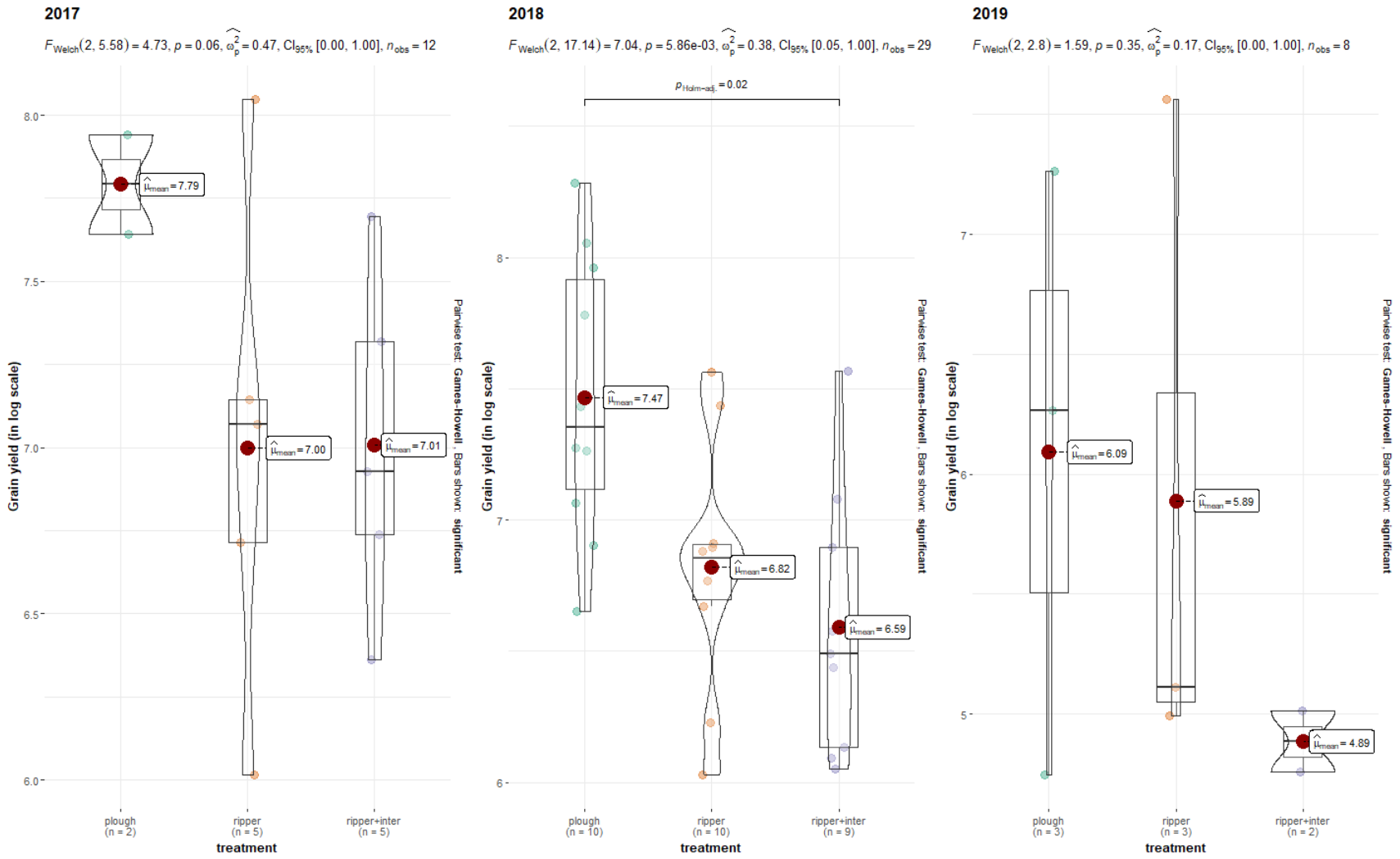


Figure 5. 11: Average maize grain yield across treatments within seasons
Source: Author's compilation

5.6.3.2 Pearl millet yield

In the Kavango East and Kavango West regions, pearl millet (Pennisetum glaucum) is used as a cereal crop; thus, its data were analyzed separately from that of maize. However, the same analytical procedures applied to maize were also followed for pearl millet. The tests indicated no statistically significant difference in the biomass of pearl millet produced using conventional and conservation tillage methods over the four seasons, as shown in Figure 5.12. Consequently, the study accepted the null hypothesis, which states, “There is no statistically significant difference in the biomass yield of pearl millet from conventional and conservation tillage systems”.

The average biomass yield showed no statistically significant difference because the experiment period was short, and the benefits of conservation agriculture were not yet realized in such a brief time. Farmers who participated in this study did not successfully implement all three principles; the different treatments did not show any differences over the first four cropping seasons. The principle of permanent soil cover was not applied accordingly, as farmers faced challenges in sourcing crop residues to use as mulching materials. This was because livestock grazed on the crop residues from the previous season. Thus, farmers only successfully carried out two of the principles, and the third principle of permanent soil cover was not implemented due to the scarcity of mulching materials.

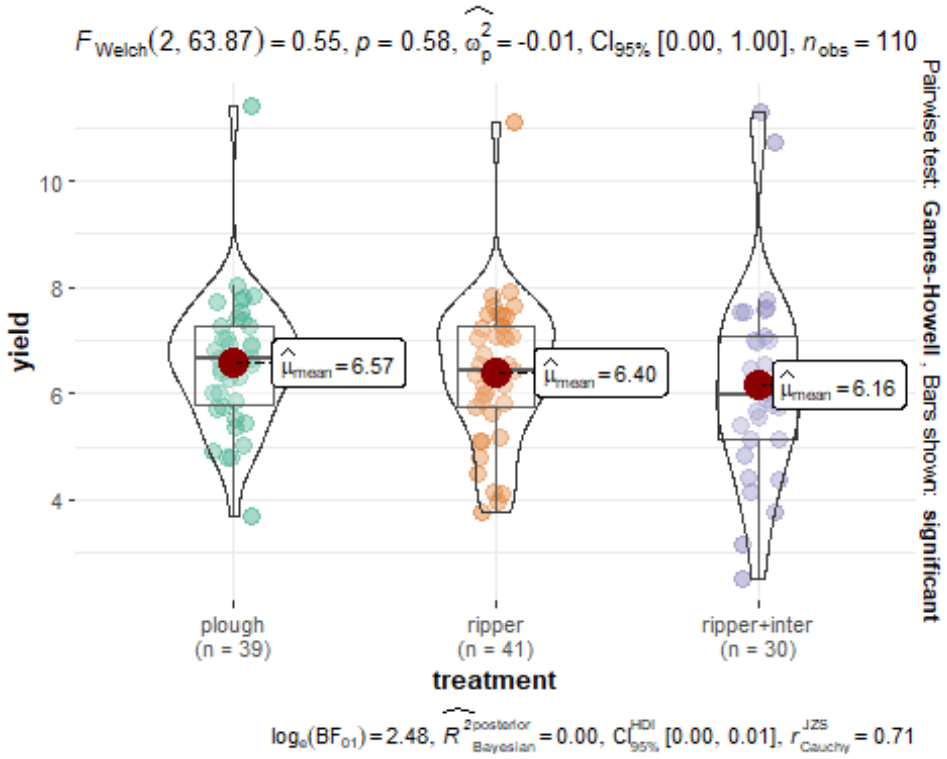


Figure 5. 12: Pearl millet biomass yield on different treatment
Source: Author's compilation

Similar to the analysis of pearl millet biomass, a test was conducted to determine if there was any significant difference in pearl millet grain yields over the four cropping seasons, with the results displayed in Figure 5.13. The analysis revealed no statistically significant differences in grain yields between the treatments across the four seasons. The factors contributing to the lack of significant differences in average grain yields among different tillage treatments over the four seasons mirror those that influenced the insignificant average biomass yields of pearl millet.

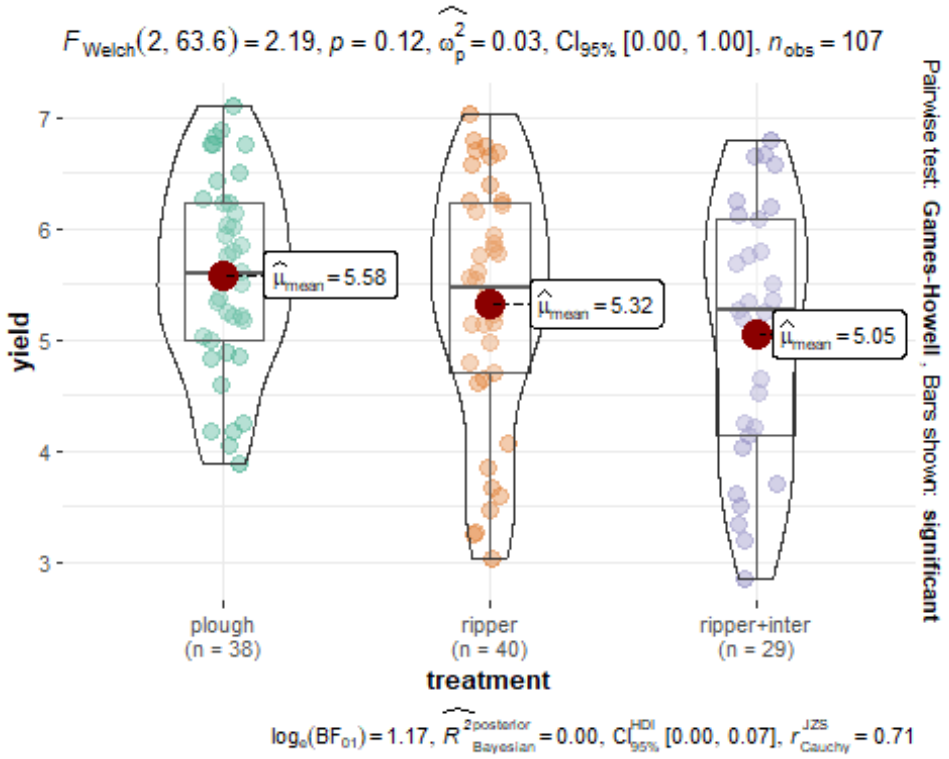


Figure 5. 13: Pearl millet grain yield on different treatment
Source: Author's compilation

The analysis aimed to determine if there was a statistically significant difference in the average biomass of pearl millet within each cropping season across different tillage treatments. It revealed no statistically significant differences, as all P-values were greater than 0.05, as shown in Figure 5.14. Consequently, the study accepted the null hypothesis. This confirms that while the primary benefits of conservation agriculture are economic and environmental (Pramanik et al., 2014), these advantages are realized only after consistent application of its principles over time. The long-term benefits, influenced by the amount of residue retained, rainfall, and soil type, may take four to five years or more to manifest (Loss et al., 2015).

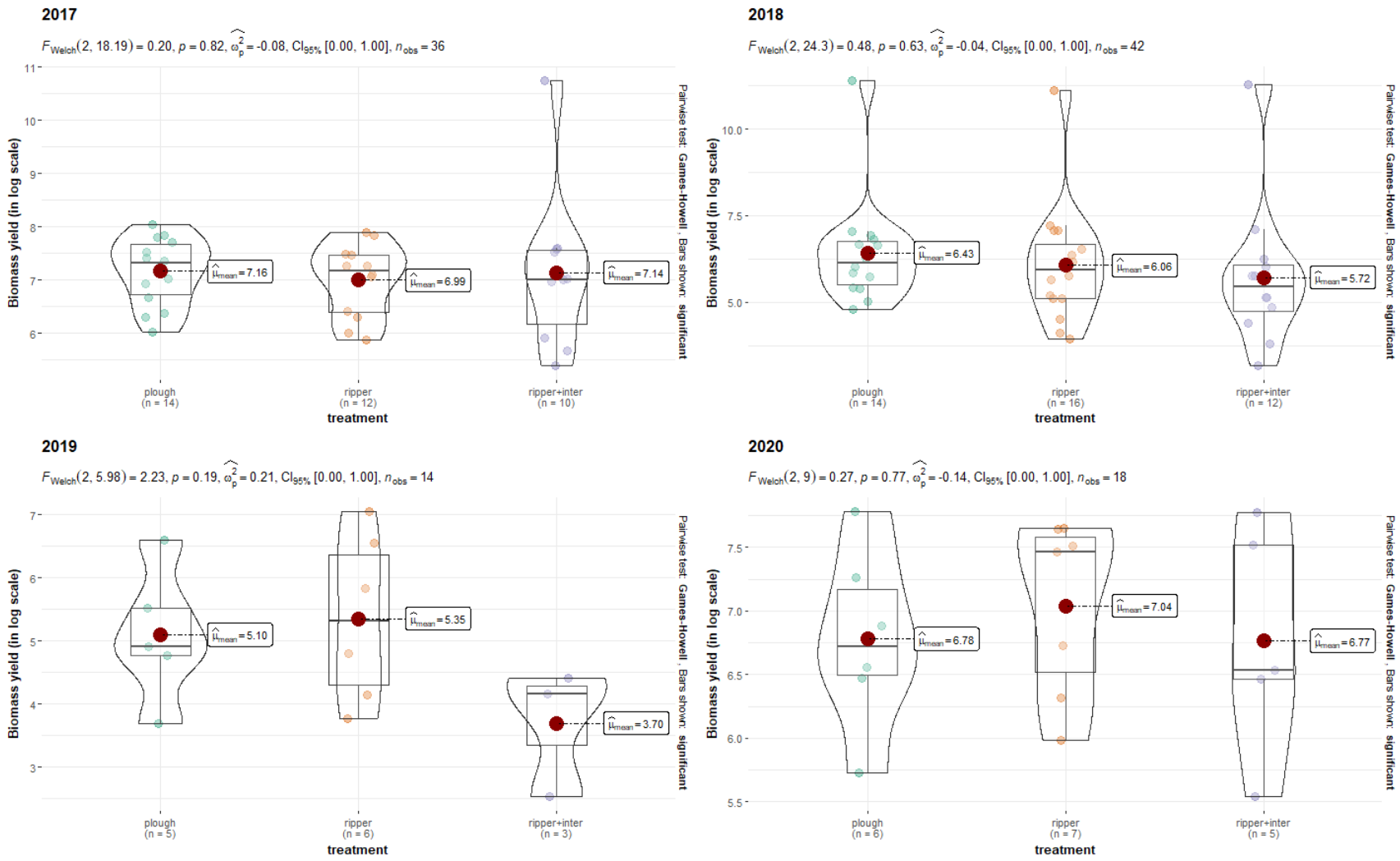


Figure 5. 14: Average pearl millet biomass yield across treatments within seasons
Source: Author's compilation

The final analysis on cereal crops aimed to determine if there was a statistically significant difference in the average grain yields of pearl millet. This analysis found no significant differences in most seasons, leading to the failure to reject the null hypothesis, except for the year 2019. In 2019, the study rejected the null hypothesis at the 10 percent level, as illustrated in Figure 5.15. The reasons for the generally insignificant differences are similar to those discussed earlier regarding the average biomass yields of pearl millet. However, the significant difference observed in 2019 is attributed to the crop's drought tolerance. Despite receiving low rainfall in Kavango East and Kavango West, farmers still managed to harvest grain, highlighting the resilience of pearl millet under adverse conditions. The significant difference observed can be attributed to the substantial variance in grain yield among the different farming methods: sole-cropping with plough, sole-cropping with ripper, and intercropping pearl millet with cowpeas using a ripper. The low rainfall contributed to insufficient moisture for the crops, impacting their grain yield. Consequently, the sole-cropped areas, both ploughed and ripped, achieved better yields compared to the intercropped sections. This is because, in the intercropped areas, the two crops competed for the limited moisture available, resulting in lower yields.

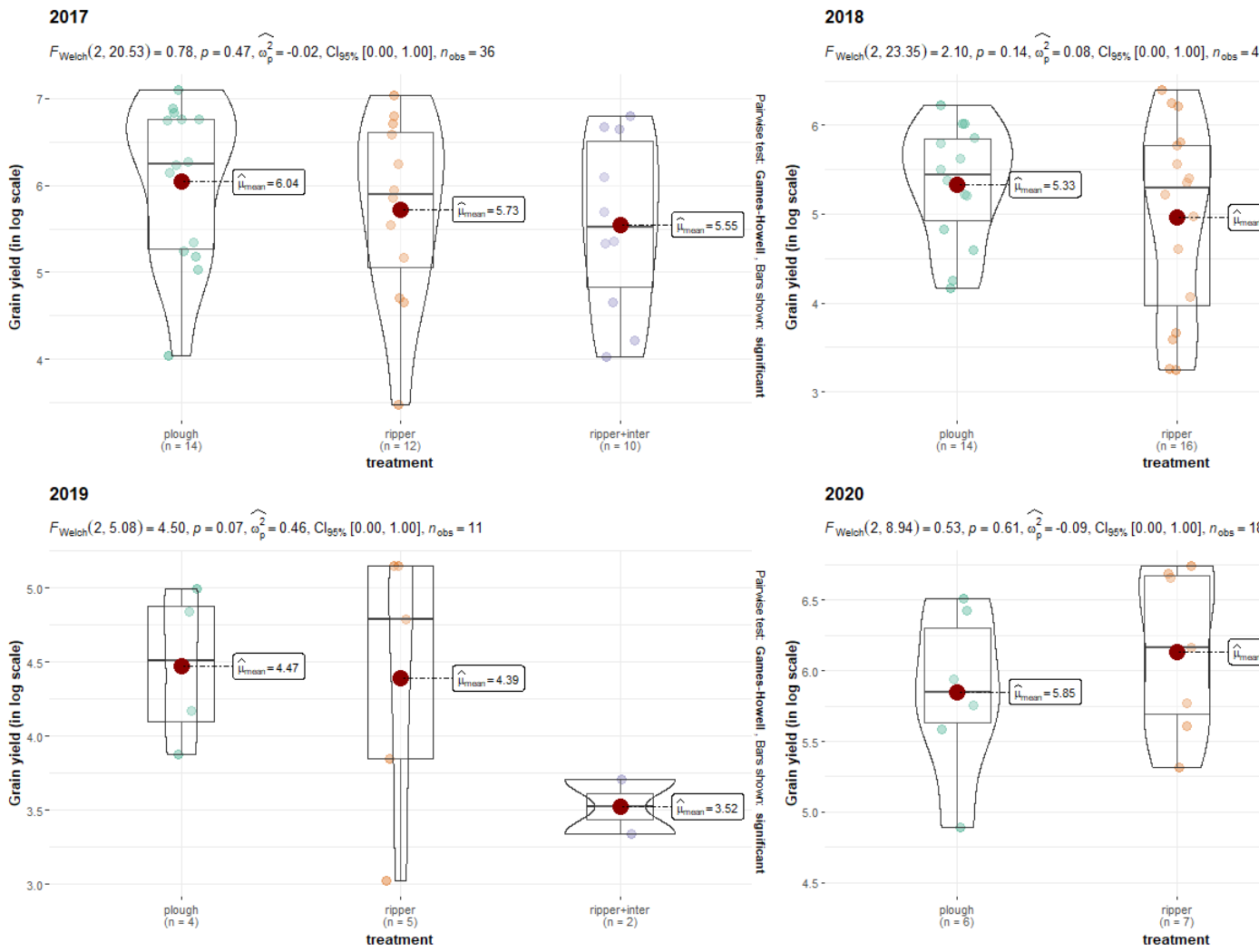


Figure 5. 15: Average pearl millet grain yield across treatments within seasons
Source: Author's compilation5.6.3.2 Cowpeas

Cowpeas were selected as a rotational crop with cereal crops (maize and pearl millet) for three primary reasons. First, cowpeas are leguminous crops capable of fixing nitrogen into the soil through N-fixing rhizobia bacteria that live in the root nodules. Second, cowpeas serve as a green manure cover crop (GMCC), covering and protecting the soil surface during the growing season while also suppressing weed establishment. Third, cowpeas are an edible crop that provides farmers with a valuable source of protein.

The initial analysis aimed to determine if there was a statistically significant difference in the average biomass yields of cowpeas over the years between ploughed (conventional) and ripped (conservation) tillage systems. With P > .05, the study accepted the null hypothesis, aligning with expectations. This outcome is attributed to the timing of biomass collection, which occurs as the cowpeas begin to dry

up. The period between the cessation of pod production and the harvesting affects the calculated biomass weight, as more moisture is lost the longer the wait.

Figure 5.16 clearly shows no difference between average biomass yields of cowpeas between plough and ripper over the four cropping seasons. The study indicates that an average of 5.55 kg/ha of biomass was harvested in both treatments.

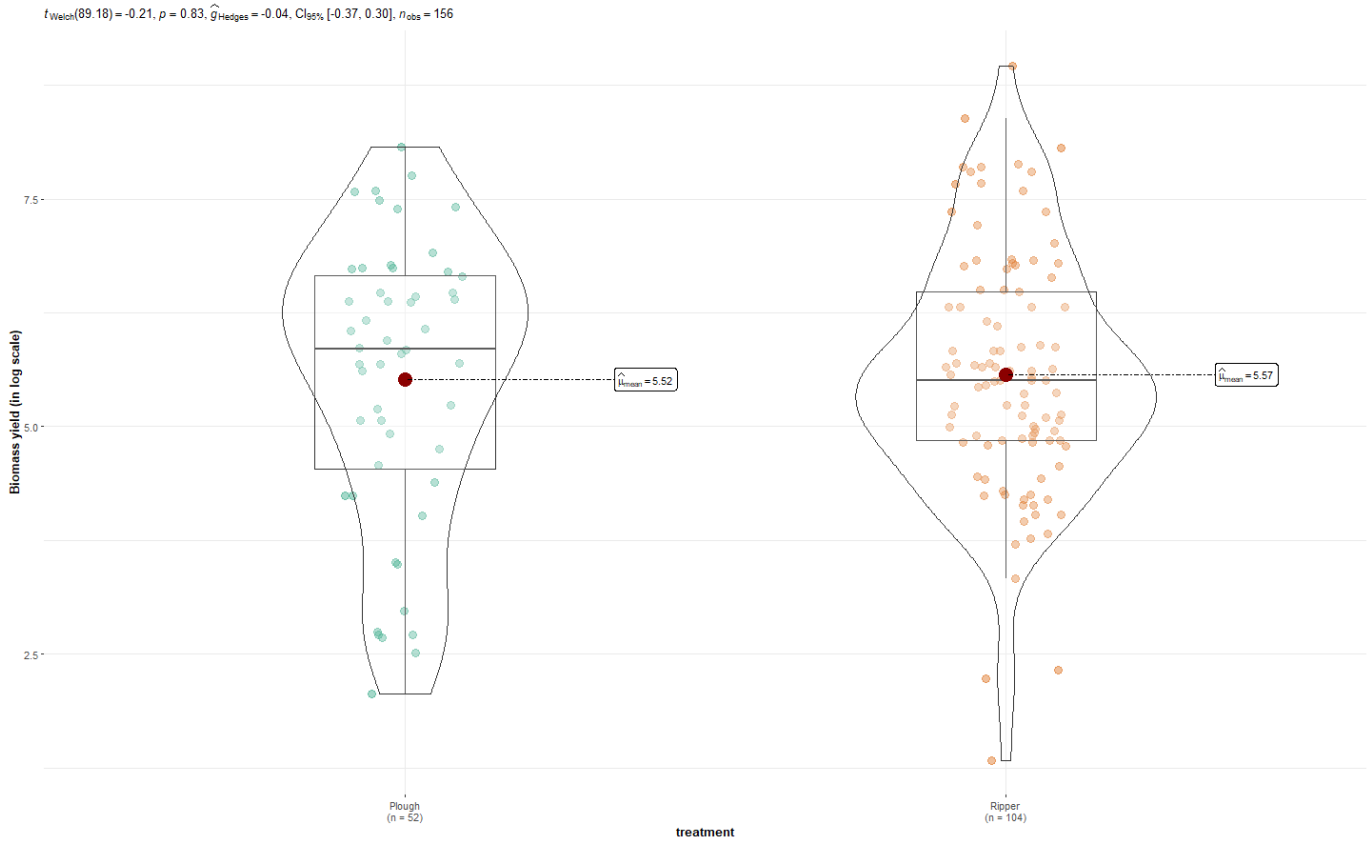


Figure 5. 16: Average cowpeas biomass yield across treatments over all seasons
Source: Author's compilation

The second analysis focused on identifying any statistically significant differences in average biomass yield between treatments across different seasons. The results showed no statistically significant differences except for the 2019 season, where P < .05, as illustrated in Figure 5.17. The significant difference observed in 2019 can be attributed to the rainfall pattern: the season began with favourable rainfall that persisted until around day 155, starting on October 1st, as detailed in Figure 5.7. This weather condition allowed cowpeas to develop a good canopy cover and thrive until the cessation of rain.

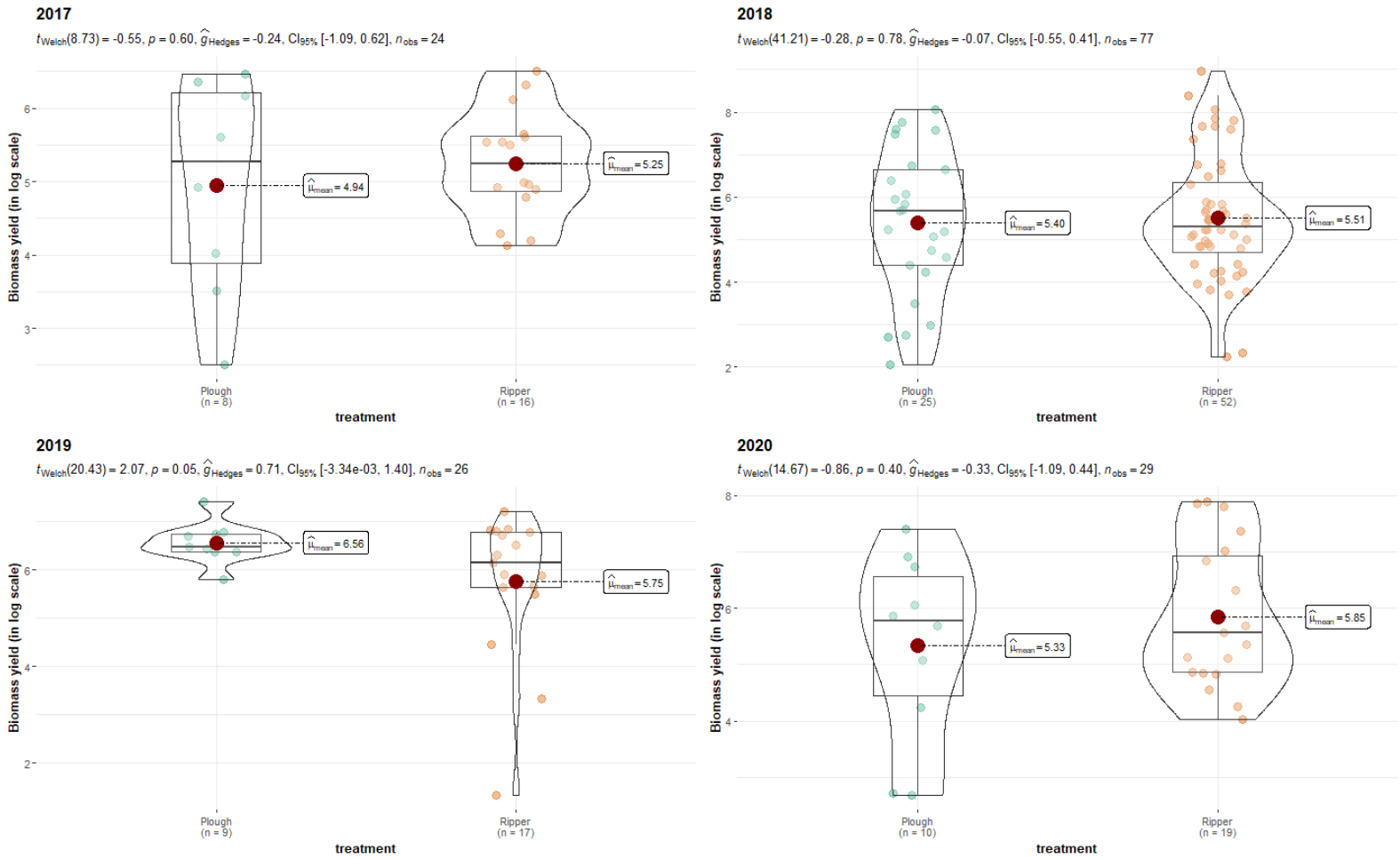


Figure 5. 17: Average cowpeas biomass yield between treatments within seasons
Source: Author's compilation

An analysis was conducted to evaluate the differences in grain yield of cowpeas across the four cropping seasons, with the results presented in Figure 5.18. Despite indicating that P > .05, suggesting no overall statistically significant difference across seasons, a closer examination reveals a significant difference at the 10% level between the average grain yield from the ploughed (conventional) and ripped (conservation) plots. Specifically, the plots managed with a ripper yielded an average of 6.43 kg/ha, compared to 5.96 kg/ha from the ploughed plots

The last analysis conducted was to determine if there was a statistically significance difference in average grain yield between treatments within seasons. No statistical significant difference was found within seasons, as shown in Figure 5.19; thus, the study failed to reject the null hypothesis in all seasons.

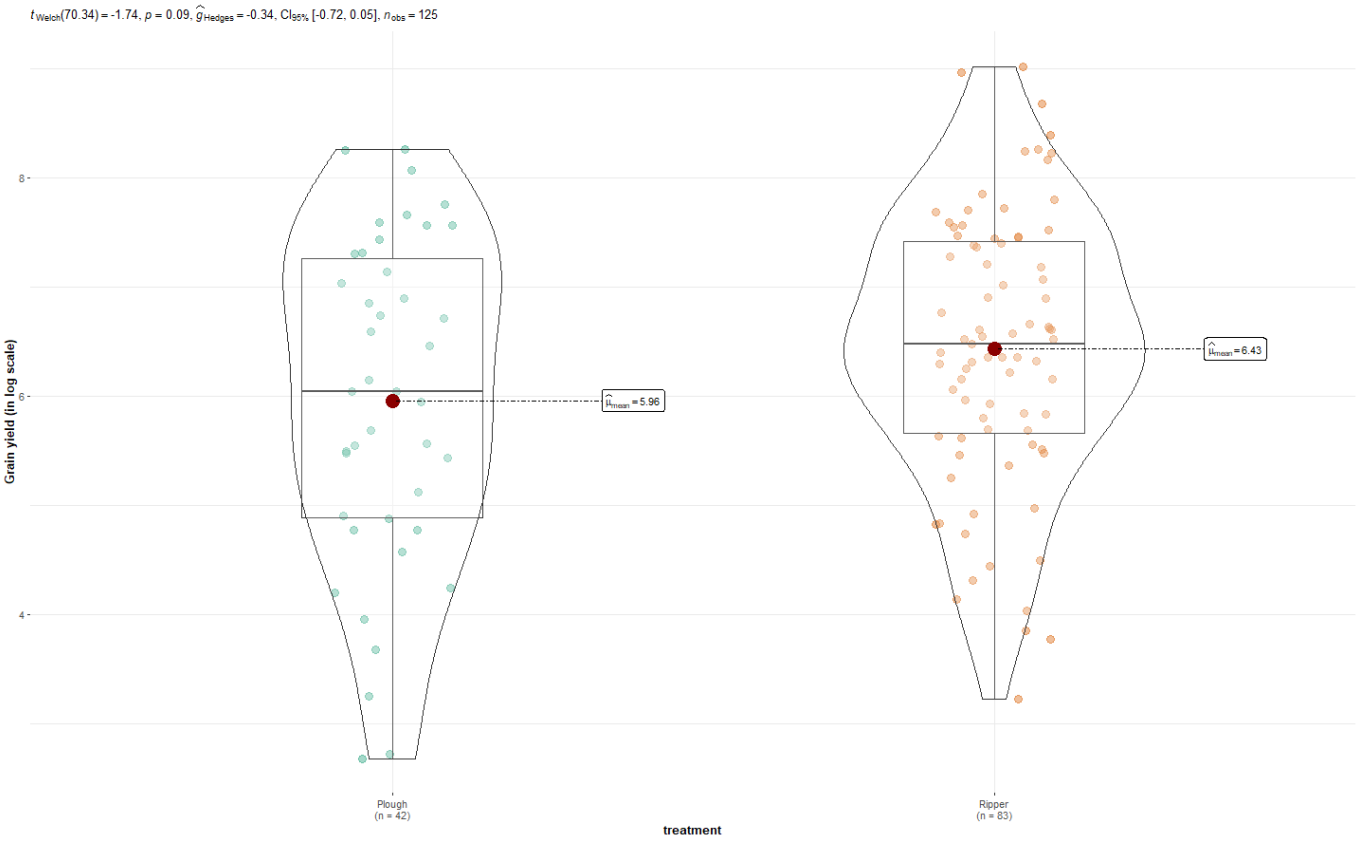


Figure 5. 18: Average cowpeas grain yield across treatments over all seasons
Source: Author's compilation

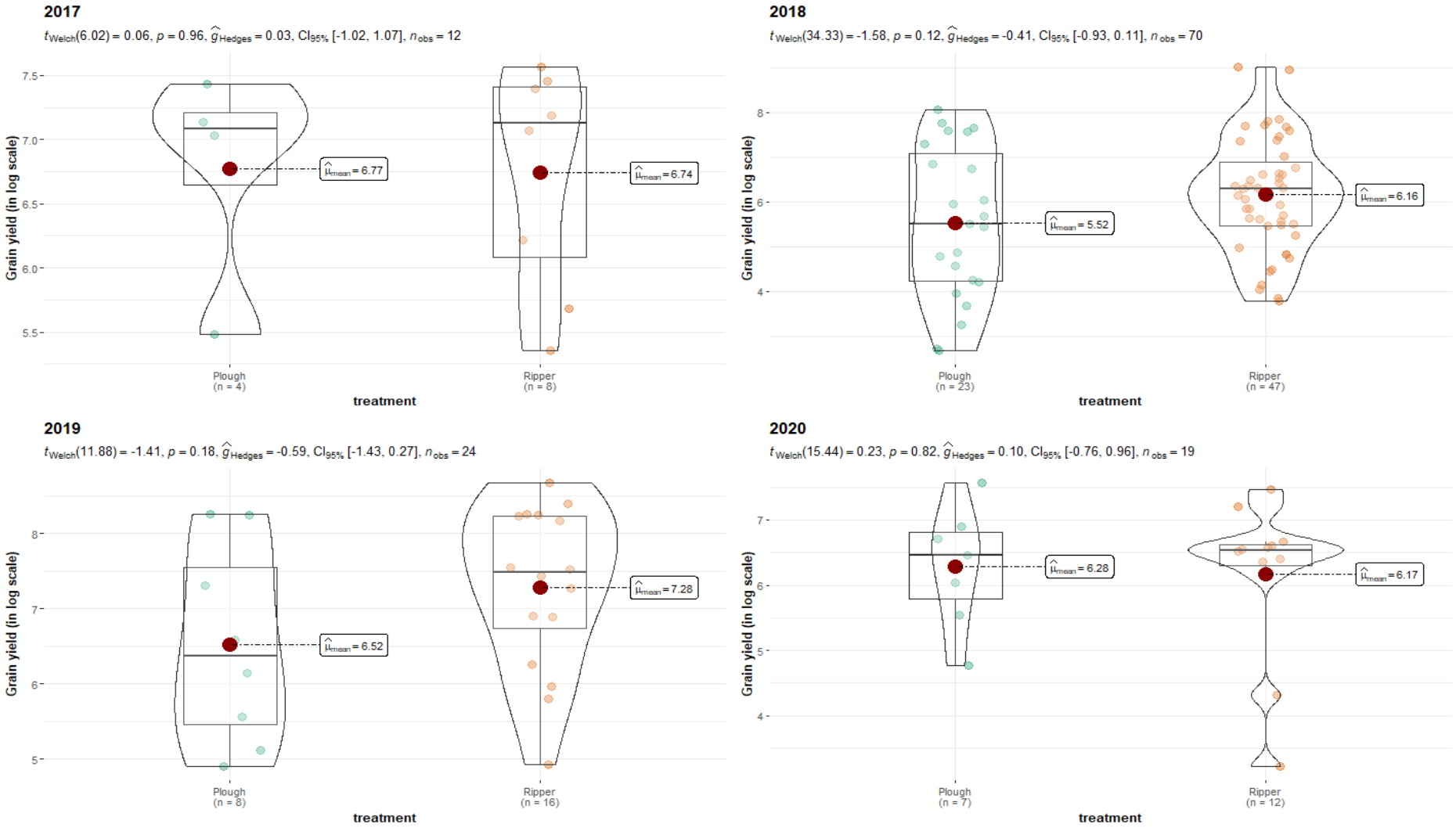


Figure 5. 19: Average cowpeas grain yield between treatments within seasons
Source: Author's compilation

5.6.3.3 Conclusion

The study concludes that there is no statistically significant difference in the average yields of cereal and legume crops between the two primary tillage systems examined: conventional and conservation agriculture. This conclusion applies to both biomass and grain yields. However, significant variations observed in specific seasons highlight the need for further research to examine the long-term performance of these treatments with a larger sample size. At this juncture, it's crucial to note the challenges encountered by farmers in implementing the third principle of conservation agriculture, which pertains to maintaining permanent soil cover. Throughout the four cropping seasons, none of the farmers were able to secure sufficient mulching materials to cover their entire research plots adequately. This shortfall is particularly significant within the context of conservation agriculture, as the presence of organic matter and the protection it offers to soil microorganisms play a critical role in the system. Such protection is vital because it enhances the presence and activity of microorganisms in the soil, thereby improving nutrient conversion and ultimately benefiting crop health and yield.

Management plays a crucial role in agricultural research, a fact underscored by farmers' experiences across various research clusters. The decision to plant crops early, aligned with the onset of rainfall, significantly influences plant growth and development, leading to improved yields. Furthermore, soil conditions in regions like Kavango West and Kavango East are notably depleted, necessitating comprehensive strategies for soil rehabilitation. In this context, Conservation Agriculture (CA) emerges as a vital approach for soil restoration. However, achieving noticeable improvements in soil health through CA is a gradual process. It is essential for stakeholders to persist in conducting CA trials at the farm level to demonstrate its benefits to farmers. Success in these experiments, particularly observed over an extended period, is critical to convincing farmers of CA's efficacy. Consequently, long-term experiments are indispensable for substantiating the advantages of CA and encouraging its adoption among farmers.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The conclusions regarding the different objectives and results of this study, as well as their implication for policy recommendations. The conclusion and recommendations provided are limited to the results obtained from the analysis of the data used for this study.

6.2 Conclusion

The study concluded that socio-economic factors significantly influence the attractiveness of Conservation Agriculture (CA), with basin tillage being preferred over the direct seeder among the farmers studied. This preference underscores the characteristics of the respondents, who are primarily subsistence farmers reliant on traditional and modest farming tools. The majority utilise oxen-drawn ploughs for tilling and hand hoes for weeding or cultivating post-emergence of their crops. Not all farmers have access to oxen-drawn ploughs, leading to a situation where those without must wait for others to complete their ploughing before they can rent or borrow the equipment. Consequently, this arrangement often results in delays, forcing these farmers to commence their planting season two to four weeks later than ideal. The utilization of tractors provided by both government and private entities under the Dry Land Crop Production Programme (DCPP) indeed offers essential soil preparation services. However, the availability of these tractors is limited, and they are consistently outstripped by the demand from a large number of interested farmers. This imbalance results in significant waiting times for the tractor services, often delaying soil preparation until nearly mid-cropping season. To mitigate these delays and avoid hindering the soil preparation process, farmers turn to the tools that are immediately available to them. Among these, hand hoes used to prepare basins represent the most practical and readily accessible option, allowing farmers to proceed with their planting activities without undue delay.

The study's findings highlight that the practice of annual crop rotation and the decision to rotate crops after one year significantly affect mono-cropping, especially when compared to the baseline practice of intercropping cereals and cowpeas. This underscores the need for increased awareness among farmers about the benefits of intercropping. The investigation revealed that farmers tend to evaluate their agricultural practices based on the immediate returns from mono-cropping versus those from intercropping. However,

there's potential for this perspective to shift favourably towards intercropping if it is consistently applied over a longer period.

Moreover, the study identifies gender as a crucial socio-economic factor influencing the choice of intercropping combinations, particularly the preference for intercropping cereals with groundnuts over cereals with cowpeas. This trend is observed as the number of households headed by males increases, with a significant emphasis placed on groundnuts as a cash crop to generate income. These insights suggest that both the promotion of intercropping and the recognition of gender dynamics are vital for encouraging more sustainable and economically beneficial farming practices.

To enhance the adoption of conservation agriculture, findings from the multinomial logistic model reveal that several factors are pivotal: the gender of the household head, the age of the household, and the size of the household significantly affect decisions regarding the rotation of crops after two years compared to rotating crops every cropping season. Specifically, as household heads age increase, there is a noticeable decline in the practice of rotating crops after extended periods, as opposed to annual rotation. This trend might be attributed to older household heads losing interest or perhaps lacking the physical ability to adhere to more demanding rotational schedules.

Conversely, larger household sizes and an increase in male-headed households are associated with a higher likelihood of implementing crop rotation after every two years compared to annual rotation. Female heads of households, often being more stationary at their homesteads due to domestic responsibilities or lack of external employment, are better positioned to manage and implement crop rotation schedules. Additionally, they may view this practice as a sustainable strategy to enhance soil fertility and crop yields over time. The presence of a larger family also implies more available labour to assist with the demands of setting up and managing crop rotation, making it a more feasible option.

Based on these insights, the study suggests a practical approach for farmers interested in adopting conservation agriculture: begin with a small, manageable area and gradually expand as they become more accustomed to the practices and start to observe the benefits. This phased approach allows for easier adaptation to conservation agriculture practices, making it more sustainable and less overwhelming for farmers, especially those with limited resources or knowledge of these methods.

In addition, the results of multinomial logistic regression indicated that household size negatively influences the use of grass relative to crop stalks as a mulching material option. This suggests that, regardless of household

size, farmers are not motivated to collect grass for use as mulching material to increase organic matter in their crop fields. This lack of motivation is attributed to the challenges of transportation and the time required for the activity. Although the household size may be large, if the majority of household members are school-going children, it can be challenging to collect grass for use as mulching material compared to using crop stalks already present in the crop field.

ANOVA analysis, used to test the relationship between the base scenario and alternative options, rejected the null hypothesis in all cases except for option D, which was not statistically significant. Therefore, the study concluded that farmers understand the impacts of continuing with conventional tillage methods versus adopting conservation agriculture. Although the respondents chose among various options with varied attributes, the analysis verified that they could clearly distinguish between the base scenario and the alternative options. Thus, the study concluded that respondents are recognizing the advent of climate change. This recognition signals that awareness of land and water resource degradation among farmers and policymakers is indeed increasing.

The results of the conditional logistic regression indicated that intercropping negatively influences the adoption of conservation agriculture, with farmers expressing minimal eagerness to practice intercropping. Consequently, the study found that crop rotation, one of the core principles of Conservation Agriculture, consistently enhances its adoption, although willingness to pay for it varies from one round to another. Additionally, the study discovered that the time invested in initial soil preparation and the rate of weeding significantly affect the practice of conservation agriculture, particularly in the second and sixth rounds for soil preparation, and in the second and fourth rounds for weeding. This suggests that farmers prefer methods that reduce the time required for soil preparation and decrease the rate of weeding, making conservation agriculture more appealing to them.

The study found no statistically significant differences in the yields of cereal crop biomass and grains across treatments and seasons for pearl millets. However, a statistically significant difference was observed in the maize grain yields between treatments during the 2017/2018 cropping season. For the 2018/2019 season, cowpea biomass yields varied significantly between treatments, potentially due to the favorable rainfall in the 2016/2017 season. In contrast, the 2017/2018 season experienced less favorable rainfall, which did not substantially benefit the crops as anticipated, leading to inconclusive data regarding the performance of conservation agriculture versus conventional tillage methods. Therefore, the study ultimately concluded that

within the treatments and across the seasons, there was no statistically significant difference in the yields of pearl millet (both grain and biomass), cowpeas (grain yield), and maize (biomass).

6.3 Recommendations

The study emphasizes the importance of ensuring that all stakeholders, especially farmers, thoroughly understand the concept, objectives, and desired outcomes of conservation agriculture. This understanding is crucial from the outset as it serves as a key motivational factor, encouraging farmers to adopt a tillage system they comprehend fully. To support this, the Ministry of Agriculture, Water and Land Reform (MAWLR), via the Dry Land Crop Production Programme (DCPP), should expand its provision of the necessary machinery and equipment to satisfy the growing demand for these services. Furthermore, the study advocates for a nationwide campaign to raise awareness about the three core principles of conservation agriculture, aiming to educate farmers across the country. This campaign should employ various formats to ensure widespread outreach. Firstly, theoretical explanations should be broadcasted through national radio networks in multiple domestic languages, aiming to reach farmers across all regions. Practical demonstrations should be organized on agricultural demonstration plots in each of the constituencies across the 14 regions, allowing farmers to witness the principles of conservation agriculture in action. Additionally, the campaign should leverage printed and visual media. Educational materials, including newsletters, booklets, and newspapers, should detail the significance of each conservation agriculture principle. Complementing these, visual media education via television channels and short video clips, suitable for distribution through WhatsApp groups and other relevant social media platforms, will enhance understanding and adoption among farmers.

Beyond the commendable annual National Conservation Agriculture Forum (NCAF), the study suggests the establishment of a National Conservation Agriculture Task Force (NCATF). This task force would play a critical role in overseeing, promoting, mobilizing, and coordinating conservation agriculture activities nationwide. It proposes the creation of a coordinating body at the regional level, which would convene biannually: once with national coordinators post-harvest and again with all stakeholders during the NCAF sessions. The NCATF should comprise members from a diverse range of institutions, all with a vested interest in crop farming, to ensure comprehensive and well-coordinated implementation efforts. Moreover, the task force is tasked with designing and formulating progressive indicators. These indicators would serve as benchmarks for monitoring awareness, perceptions, and the adoption rates of conservation agriculture practices. The NCATF should be established as a binding entity, complete with an operational budget and accountability measures for its tasks. It is imperative that the task force offers precise guidance to the regional representatives of the Directorate of

Agricultural Production Extensions and Engineering Services (DAPEES). This includes providing detailed feedback on the outcomes of each cropping season, ideally shared during the annual National Conservation Agriculture Forum (NCAF) meetings. Moreover, the NCATF coordinators at the regional level need to possess a deep understanding of technical and operational matters, and be well-acquainted with the local soil, weather, and social conditions. Beyond promoting and mobilizing conservation agriculture activities, the task force's responsibilities should encompass conducting and overseeing research-based initiatives. These efforts are crucial for generating primary data, which in turn should inform recommendations and advisory services. To truly capture the efficacy and outcomes of conservation agriculture research trials, it is essential that these activities are monitored over extended periods, surpassing five years. This long-term approach will enable the task force to provide robust, evidence-based guidance and support the ongoing evolution of conservation agriculture practices.

The study strongly suggests that the Ministry of Agriculture, Water and Land Reform should appoint specialized extension technicians dedicated to the dissemination of information, coordination, promotion, and hands-on implementation of conservation agriculture activities across all regions. Alternatively, a new Directorate with special focus on Conservation Agriculture must be created in the Ministry of Agriculture, Water and Land Reform to act as a bridge of DAPEES and DARD. However, the Directorate must be equipped with resources to enable it to carry out National implementation and monitoring activities. To further encourage and accelerate the adoption of conservation agriculture practices, the Ministry could organize an annual regional competition. This competition would recognize and reward farmers who have successfully implemented conservation agriculture techniques and achieved higher yields as a result. The competition must come with well-crafted promotional packages to incentivise farmers who participates in Conservation Agriculture. Additionally, the study underscores the importance of conducting long-term experimental research on the various principles of conservation agriculture. Such research should aim to evaluate the impacts of these practices on crop yield and soil properties comprehensively. This approach will not only provide empirical evidence to support the efficacy of conservation agriculture but also guide future policy and practice to enhance sustainable agriculture.

To expedite the adoption of the conservation agriculture tillage system, it is essential for stakeholders in the agricultural sector to ensure the availability and affordability of appropriate farming equipment, such as rippers and direct seeders, in local markets. Making these tools accessible will significantly lower the barriers to adoption for farmers, facilitating a more widespread uptake of conservation agriculture practices.

Further research is recommended to determine whether there is a statistically significant difference in the time allocation for activities between the conventional tillage system and the conservation agriculture tillage system. Additionally, a comparative study on the costs associated with conventional tillage versus conservation agriculture should be conducted to ascertain if significant financial differences exist. These studies will provide crucial insights into the efficiency and economic viability of conservation agriculture practices compared to traditional methods, informing stakeholders and guiding policy decisions.

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APPENDICES

Appendix 1: Questionnaire

1. GENERAL INFORMATION

Questionnaire no: _____

Q1. Name of enumerator: _____

Q2. Date of interview (DD/MM/YYYY):_____

Q3. Checked by (supervisor's name) _____

Q4.Region_____.Q5. Constituency: _____

Q6. ADC: _____ Q7.Village:_____

Q7 Type of farmer: [1] Cluster research farmers ☐ [2] Lead farmer ☐ [3] Follower farmers ☐

GPS coordinates

Q8.Latitude:_____Decimal Degrees (*Format:* +/- Dd.Ddddd)

Q9. Longitude: _____Decimal Degrees (*Format:* +/- Dd.Ddddd)

Q10. Altitude: _____Meters above the sea level

2. RESPONDENT INFORMATION

Q11. Name of respondent: _____

Q12. Gender of respondent: [1] Male ☐ [2] Female ☐

Q13. Age of respondent (in years): _____

Q14. Is the respondent head of the household? [1] Yes ☐ [2] No ☐

If NO continue from Q15, BUT if YES, skip to Q18.

Q15. Name of household (HH) head: _____

Q16. Gender of HH head: [1] Male ☐ [2] Female ☐

Q17. Age of HH head (in years): _____

Q18. Marital status of HH head: _____ [1] Single ☐ [2] Married ☐ [3] Divorced ☐ [4] Separated ☐ [5] Widowed ☐

Q19. Educational level of HH head: _[1] No formal education ☐ [2] Completed primary [3] Completed secondary [4] Completed Tertiary ☐

Q20. Educational level of spouse: _[1] No formal education ☐ [2] Completed primary [3] Completed secondary [4] Completed Tertiary ☐

3. HOUSEHOLD CHARACTERISTICS

Q21. Household size (total number of household members) _____

Total number of members aged	Male	Female
Below 10 years		
10 to 13 years		
14 to 65 years		
Above 65 years		

	Question		Coded Response		Codes
Q22	What proportion of your household income out of 10 comes from the following sources?	*NOTE: Shares sum to 10à (a + b + c + d + e + f + g + h + i = 10)	Income share out of 10 stones a. Working for other farmers _____ b. Crop sales _____ c. Livestock sales _____ d. Brewing_____ e. Remittances _____ f. Non-farm employment _____ g. Pension._____ h. Renting farm tools or animals to others _____ i. Other (Describe): _____	Primary earner a. _____ b. _____ c. _____ d._____ e. _____ f. _____ g. _____ h. _____ i. _____	ßEarner Code 1 = Respondent 3 = Respondent's spouse 5 = Respondent's daughter(s) 7 = Respondent's son(s) 9 = Other (describe)

4. CA PRINCIPLES AWARENESS AND PRACTICE

(Enumerators: give a chance for the respondents to answer questions and then if necessary, prompt them using the codes below the table)

Q23. CA Principles awareness (Codes A) Which CA principle are you aware of?	Source of information about the CA Codes B	Have you ever tried the CA principle? 1.Yes 2.No	If tried, CA principle, who made the decision. **1.** Household head **2.** Spouse **3.** Other specify	Year first used YYYY	Still using it? 1.Yes 2.No	If stopped using it, give reasons – Rank 3 Codes C	If aware and never used it, give reasons – Rank 3 Codes D	Current level of use (Area in hectares)
Name Code								

Codes A	Codes B	Codes C		Codes D
1. Basin tillage	1. extension officer	1. Low productivity or profitability relative to conventional practices	7. Livestock feed shortage	1. Lack of skill to use technologies
2. tractor Ripping	2.NGOs		8. Other, specify……..	2. Told by fellow farmers that it is not increasing yields
3. animal ripping	3.Research institution		-99. Not applicable	3. Lack of cash
4. Direct seeding (animal/ tractor drawn planter)	4. Community Based Organizations (CBO)	2. Lack of Equipment		4. Lack of equipment
	5.Radio	3. Lack of herbicides		5. Labor shortage
		4. Labor shortage		

5 . Cereal legume rotation

6. Cereal legume intercropping

7. residue retention

8. live mulching

6. Other, specify……

5. Cash constrained

6. Increase pest & disease

6. Livestock feed shortage

7. Other, specify……..

-99. Not applicable

5. EXPERIMENTAL CHOICE

Q24. When preparing your soil for the first time in the season what duration of time do you prefer spending per hectare?

24. (a) 4 hours/ha ☐
24. (b) 2 hours/ha ☐
24. (c) 3 hours/ha ☐
24. (d) 2Hour & 30 Minutes ☐

Q25. How much are you willing to pay for your firs soil preparation of the season?

25. (a) N$ 400 ☐
25. (b) N$ 250 ☐
25. (c) N$ 300 ☐
25. (d) N$ 500 ☐

Q26. What frequency and duration of weeding/hectare do you prefer?

26. (a) 1 Weeding @ 4 Hours/weeding ☐
26. (b) 2 Weeding @ 5 hours/weeding ☐
26. (c) 2 Weeding @ 3 hours/weeding ☐
26. (d) 2 Weeding @ 2 hours/weeding ☐

Q27. When doing mulching what type of mulching materials do you prefer using?

27. (a) No mulching ☐
27. (b) Grass ☐
27. (c) Stalks ☐
27. (d) Tree branches & leaves ☐

Q28. When preparing your soil for the first time in a season what type of soil preparation do you prefer?

28. (a) Ploughing ☐

28. (b) Direct seeding ☐

28. (c) Ripping ☐

28. (d) Basin ☐

Q29. When seeding which combination of crops will you prefer to intercrop?

29. (a) Mono-cropping ☐

29. (b) Maize & Cowpeas ☐

29. (c) Maize & Barbarnut ☐

29. (d) Maize & Groundnut ☐

Q30. When doing crop rotation, after how many cropping season do you rotate your crops?

30. (a) No rotation ☐

30. (b) Every season ☐

30. (C) After one cropping season ☐

30. (d) After two cropping season ☐

In the next questions, we ask you to make some choices between alternative future options for practicing CA. The practicing of CA can have an influence in the way crop fields are managed. Alternative principles of CA will have different impacts on soil fertility and yield per hectare (ha). Option A is the same in each choice question. This option represents the condition of the fields that would occur in 10 years' time if conventional tillage would continue. This option involves no additional costs and no new management initiatives.

Please carefully consider each of the following three options in practicing CA. Suppose that options A, B and C are the only options available. Choose which option you prefer (check one box only).

Features	Duration of soil preparation/ha	Cost of soil preparation/ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now	3 hours	N$400	1 weeding @ 4 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A	4 hours	N$ 500	2 weeding @ 5 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option B	2 hour 30 minutes	N$ 300	2 weeding @ 3 Hours/weeding	Grass	Ripping	Maize/millet & groundnut	Every cropping season
Option C	2 hours	N$ 250	2 weeding @ 2 Hours/weeding	Stalks	Direct seeding	Maize/millet & Barbarnut	One cropping season

Q31. Which of these three options would you choose?

Option A ☐

Option B ☐

Option C ☐

The next four questions are similar to the previous one, except that the levels of the features in options for change are different in each question. Remember to consider each question separately.

Please carefully consider each of the following three options for practicing CA. Suppose that option A, D and E are the only available options. Which one would you choose?

Features	Duration of soil preparation/ha	Cost of soil preparation/ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now	3 hours	N$400	1 weeding @ 4 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A	4 hours	N$ 500	2 weeding @ 5 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option D	2 hours	N$ 250	2 weeding @ 3 Hours/weeding	Tree's branches&leaves	Basin	Maize/millet & groundnut	one cropping season
Option E	2 hour 30 Minutes	N$ 300	2 weeding @ 2 Hours/weeding	Grass	Ripping	Maize/millet & cowpeas	Two cropping season

Q32. Which of these three options would you choose?

Option A ☐

Option D ☐

Option E ☐

Please carefully consider each of the following three options for practicing CA. Suppose that option A, F and G are the only available options. Which one would you choose?

Features	Duration of soil preparation/ha	Cost of soil preparation/ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now	3 hours	N$400	1 weeding @ 4 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A	4 hours	N$ 500	2 weeding @ 5 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option F	3 hours	N$ 300	2 weeding @ 5 Hours/weeding	Grass	Ripping	Maize/millet & barbarnut	one cropping season
Option G	2 hour 30 Minutes	N$ 250	2 weeding @ 4 Hours/weeding	Tree's branches&leaves	Direct seeding	Maize/millet & cowpeas	Every cropping season

Q33. Which of these three options would you choose?

- Option A ☐
- Option F ☐
- Option G ☐

Please carefully consider each of the following three options for practicing CA. Suppose that option A, H and I are the only available options. Which one would you choose?

Features	Duration of soil preparation/ha	Cost of soil preparation/ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now	3 hours	N$400	1 weeding @ 4 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A	4 hours	N$ 500	2 weeding @ 5 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option H	2 hours	N$ 250	2 weeding @ 3 Hours/weeding	Tree's branches&leaves	Direct seeding	Maize/millet & cowpeas	Two cropping season
Option I	2 hour 30 Minutes	N$ 300	2 weeding @ 4 Hours/weeding	Stalks	Basin	Maize/millet & groundnut	One cropping season

Q34. Which of these three options would you choose?

- Option A ☐
- Option H ☐
- Option I ☐

Please carefully consider each of the following three options for practicing CA. Suppose that option A, J and K are the only available options. Which one would you choose?

Features	Duration of soil preparation/ha	Cost of soil preparation/ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now	3 hours	N$400	1 weeding @ 4 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A	4 hours	N$ 500	2 weeding @ 5 Hours/weeding	No mulching	Ploughing	Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option J	2 hours	N$ 400	2 weeding @ 3 Hours/weeding	Stalks	Direct seeding	Maize/Millet & groundnut	Every cropping season
Option K	2 hour 30 Minutes	N$ 300	2 weeding @ 2 Hours/weeding	Tree's branches&leaves	Ripping	Maize/millet & cowpeas	Two cropping season

Q35. Which of these three options would you choose?

- Option A ☐
- Option J ☐
- Option K ☐

Q36. a. When answering Questions Q31 to Q35, did you always choose option A (no new initiatives)?

Yes ☐ Go to Q36.b

No ☐ Go to Q.37

Q36. b. If you answered "Yes", which of the following statements most closely describe your reason for doing so? (Please tick one box only)

b. i. I prefer conventional tillage without any initiative ☐

b. ii. I prefer conservation agriculture with initiative, but it favors weeds ☐

b. iii. I prefer conservation agriculture with initiative, but it favors rodents ☐

b. iv. I didn't know which option was best, so I continued with the current methods ☐

b. v. I have some other reason, (Please specify) ☐

……

……

Q37. When choosing to support new initiatives (option B to K), which of the following statement best describes your main reason for doing so? (Please tick one box only)

Q37. (a) I always chose the option that had the lowest costs ☐

Q37. (b) I was looking at the option requiring the least time for soil preparation ☐

Q37. (c) I was looking at the option requiring the least time for weeding ☐

Q37. (d) I was looking at the option that achieved good combination of crops ☐

Q37. (e) I was looking at the option that result in easy soil preparation ☐

Q37. (f) I was looking at the option with available mulching material type ☐

Q37. (g) I was looking at the option with least rotational cycle ☐

Q37. (h) Some other reasons, (Please specify) ☐

……

……

Q38. In making your choices in question Q31 to Q35, were all the features (costs, time, intercropping, mulching, soil preparation method and rotation of crop) equally important to you?

Yes ☐ No ☐

Q39. Please tick the feature(s) you took into account when making your choice (Tick as many as apply)

a. Costs ☐	b. Time to prepare land ☐	c. Mulching ☐
d. Time to weed ☐	e. Intercropping ☐	f. Rotation ☐
g. Soil preparation method ☐		

Thank you for your time! Your effort in completing this survey is very valuable to us!

Appendix 2: Experimental questionnaire virtual features

Question 31

Features	Duration of soil preparation /ha	Cost of soil preparation /ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now			1 weeding @  per Weeding			Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A			2 weeding @  per weeding			Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option B			2 weeding @  Hours/weeding			Maize/Millet & groundnut	Every cropping season (No skipping a season)
Option C			2 weeding @  Hours/weeding			Maize/millet & Barbarnut	One cropping season (Skipping one season)

Question 32

Features	Duration of soil preparation /ha	Cost of soil preparation /ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now	🕐🕐🕐		1 weeding @ 🕐🕐🕐🕐 per Weeding			Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A	🕐🕐🕐🕐		2 weeding @ 🕐🕐🕐🕐 per weeding			Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option D	🕐🕐		2 weeding @ 🕐🕐🕐 Hours/weeding			Maize/Millet & groundnut	Every cropping season (No skipping a season)
Option E	🕐🕐◗		2 weeding @ 🕐🕐🕐 Hours/weeding			Maize/millet & cowpeas	Two cropping season (Skipping two season)

Question 33

Features	Duration of soil preparation /ha	Cost of soil preparation /ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now			1 weeding @  per Weeding			Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A			2 weeding @  per weeding			Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option F			2 weeding @  Hours/weeding			Maize/Millet & Barbarnut	One cropping season (Skipping one season)
Option G			2 weeding @  Hours/weeding			Maize/millet & cowpeas	Every cropping season (No skipping season)

Question 34

Features	Duration of soil preparation /ha	Cost of soil preparation /ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now			1 weeding @  per Weeding			Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A			2 weeding @  per weeding			Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option H			2 weeding @  Hours/weeding			Maize/Millet & cowpeas	Two cropping season (Skipping two season)
Option I			2 weeding @  Hours/weeding			Maize/millet & groundnut	One cropping season (Skipping one season)

Question 35

Features	Duration of soil preparation /ha	Cost of soil preparation /ha	Frequency & Duration of weeding/ha	Type of mulching	Type of soil preparation	Combination of crops	Rotational period
Condition now	🕐🕐🕐		1 weeding @ 🕐🕐🕐🕐 Per Weeding			Mono-cropping	No rotation
Condition in 10 years without new initiatives							
Option A	🕐🕐🕐🕐		2 weeding @ 🕐🕐🕐🕐 per weeding			Mono-cropping	No rotation
Condition in 10 years with initiatives of CA							
Option J	🕐🕐		2 weeding @ 🕐 Hours/weeding			Maize/Millet & groundnut	Every cropping season
Option K	🕐🕐◗		2 weeding @ 🕐🕐 Hours/weeding			Maize/millet & cowpeas	Two cropping season (Skipping two season)