AN ASSESSMENT OF SOCIO-ECONOMIC POTENTIAL OF CONSERVATION AGRICULTURE AND PREDICTION OF ITS FUTURE PERFORMANCE USING THE DSSAT MODEL FOR THE PANDAMATENGA VERTISOIS IN NORTHERN BOTSWANA

MASTER OF SCIENCE

IN AGRICULTURAL ENGINEERING

BY

KAPWEKE KANDONDI

NOVEMBER 2019

BOTSWANA UNIVERSITY OF AGRICULTURE AND NATURAL RESOURCES

BUAN

BOTSWANA UNIVERSITY OF AGRICULTURE AND NATURAL RESOURCES

AN ASSESSMENT OF SOCIO-ECONOMIC POTENTIAL OF CONSERVATION AGRICULTURE AND PREDICTION OF ITS FUTURE PERFORMANCE USING THE DSSAT MODEL FOR THE PANDAMATENGA VERTISOLS IN NORTHERN BOTSWANA

A dissertation submitted to the Department of Agricultural and Biosystems Engineering in partial fulfilment of the requirement for the award of Master of Science degree (MSc) in Agricultural Engineering (Soil and Water Engineering Stream)

By

Kapweke Kandondi

ID: 200900079

November 2019

Main Supervisor:

Prof. B. Kayombo

Co - Supervisors:

Dr. Davis S. Marumo

Mrs T. Mpuisang

Department of Agricultural and Biosystems Engineering

Botswana University of Agriculture and Natural Resource

CERTIFICATION

Benedict Kayombo 08/10/2020

Main Supervisor's Name and Signature   Date

Thembeka Mpusang 8/10/2020

Co-Supervisor's Name and Signature   Date

Davis Samunzala Marumo 08/10/2020

Co-Supervisor's Name and Signature   Date

.... Gilbert Gabolitloeloe 08/10/2020

Head of Department's Name and Signature   Date

APPROVAL

Benedict Kayombo [signature] 08/10/2020

Main Supervisor's Name and Signature .... Date

Thembeka Mpusay [signature] 8/10/2020

Co-Supervisor's Name and Signature .... Date

Davis Shimunzala Marumo [signature] 08/10/2020

Co-Supervisor's Name and Signature .... Date

Gilbert Gabonthloeloe [signature] 08/10/2020

Head of department's Name and Signature .... Date

Prof Khumbotsile Mmolawa [signature] 08/10/2020

Dean of faculty's Name and Signature .... Date

STATEMENT OF ORIGINALITY

This is to certify that the work contained in this dissertation was compiled by the author at Botswana University of Agriculture and Natural Resources between 2016 and 2019. It is original except where references are made and it will be not submitted for the award of any other degree or diploma of any University.

Kapueke Kandondi K.Kandondi 02/10/20

Author's Name and Signature Date

ACKNOWLEDGEMENT

Firstly, I would like to thank my heavenly Father who has been the source of my strength. Every problem that came my way during my study period, I overcame through His grace and mercies. I convey my sincere thanks to my main supervisor Prof. B. Kayombo for giving me constructive pieces of advice and guidance starting from the proposal writing to the completion of the research work. I thank him for his genuine and energetic encouragement, suggestion, insight and professional expertise to complete this work. I am also thankful to my co-supervisors Dr Davis S. Marumo and Mrs T. Mpuisang for their constructive insightful comments, suggestions and guidance at the time when the proposal was developed and for giving important comments and suggestions during dissertation writing.

I am also deeply grateful to the Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA) which funded this research under the coordination of my main supervisor Prof. B. Kayombo. Furthermore, my sincere thanks go to Prof. F. Pule – Meulenberg who coordinated the Mogae F.G scholarship that helped me financially to complete my studies. The support and cooperation of Pandamatenga officers from the Departments of Crop Production and Agricultural Research of the Ministry of Agriculture Development and Food Security, who provided relevant secondary data and facilitated field work, is highly appreciated. I would like also to express my gratitude to the sampled smallholder rainfed farmers for their cooperation during data collection. I acknowledge the Department of Metrological services (Gaborone) for providing me with weather data for Pandamatenga. The Agricultural Model Intercomparison and Improvement Project (AgMIP) is also appreciated for providing me with future weather climate data for Pandamatenga.

The hard work of Mr C. Sekhesa in soil analysis is highly appreciated. I also appreciate the work of Ms Boitumelo in field data collection. In addition, I wish to extend my gratitude to the BUAN Department of Agricultural and Biosystems Engineering staff and graduate students who provided advice during my studies. BUAN drivers' assistance with transport during data collection is highly appreciated. I would like to express my deepest thanks to my family especially my brother James Kandondi for his moral support and encouragement. Finally, I would like to give thanks to my friends for their encouragement and prayers during my study period.

DEDICATION

I dedicate this dissertation to all my family members and friends who were always supportive to me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

°C	Degrees Celsius
ADB	African Development Bank
AgMIP	Agricultural Model Intercomparison and Improvement Project
AGRA	Alliance for a Green Revolution in Africa
ASSP	Agriculture Services Support Project
BBF	Broad Bed and Furrows
BD	Bulk density
BUAN	Botswana University of Agriculture and Natural Resources
CA	Conservation Agriculture
CanESM2	Canadian Earth System Model, the Second Generation
CEC	Cation exchange capacity
cm	Centimetre
cm/hr	Centimetre per hour
CRS	Cowpea Rotated Sorghum
CS	Continuous sorghum
CSM	Cropping System Modelling
CT	Conventional Tillage
d	index of agreement
DAP	Anthesis date
DSSAT	Decision Support System for Agrotechnology Transfer
DUL	Drained Upper limit
E	Mean error
Ef	Modelling efficiency
FAO	Food and Agriculture Organization of the United Nations
g/cm^3	Grams per cubic metre
GCMs	Global Concentration Models
GDP	Gross Domestic Product
ha	Hectare
HadGEM2 - ES	Hadley Centre Global Environment Model, Version 2 Earth Systems

ICRISAT	International Crops Research Institute for the Semi-arid Tropics
IFAD	International Fund for Agricultural Development
ILCA	International Livestock Centre for Africa
ISPAAD	Integrated Support Programme for Arable Agricultural Development
kg	kilogram
Km^2	Kilometre squared
LL	Lower limit
MDAP	Maturity date after planting
MJ/m^2	Mega joules per meter squared
mm	Millimetre
MPI – ESM - LR	Max Planck Institute Earth System Model at Lower Resolution
MT	Minimum Tillage
NT	No Tillage
NT+M	No Tillage + Mulch
NTR	No tillage and rotation
R^2	Coefficient of determination
RCPs	Representative Concentration Pathways
RMSE	Root mean square Error
SAT	Saturation
SBUILT	Soil Built
SPSS	Statistical Package for Social Sciences
SSA	Sub Saharan Africa
TLU	Total Livestock Unit
UNDP	United Nations Development Programme
USDA-SCS	United States Department of Agriculture – Soil Conservation Service

ABSTRACT

This study was based in the Chobe District in Pandamatenga village in the northern region of Botswana. The main aim of the study was to assess the socio – economic potential of Conservation Agriculture (CA) technologies and to predict their future performance on sorghum grain yield using the Decision Support System for Agrotechnology Transfer (DSSAT) in the vertisols of Pandamatenga. A field experiment was conducted at the Department of Agricultural Research station at Pandamatenga during the 2015-2017 planting seasons. A randomized complete block design was used for the on-station field experimentation. The design had trial plots with four treatments, namely No tillage (NT), No tillage + mulch (NT+M), Minimum tillage (MT), and broad bed and furrow (BBF), with four replicates rotated between sorghum and cowpea. Sorghum grain yield results were analysed using the Statistical Analysis Software (SAS version 9.2). Analysis of variance and means were separated using Duncan's multiple range test at 5% confidence level. The DSSAT model was also evaluated using the experimental data and weather data for the growing period. The model was further used to predict the performance of these CA technologies in terms of sorghum grain yield in the future.

A structured questionnaire was used for the collection of the socio - economic and demographic characteristics of the sampled smallholder rainfed farmers. Farmers' perception and level of acceptance of CA technologies were also assessed in the study area. The socio - economic characteristics of the smallholder rainfed farmers included land holding size (ha), labour availability, livestock possession, education level, and farming experience. Demographic characteristics considered in this study were smallholder rainfed farmers' age, marital status, gender and average number of family members in the household. Descriptive statistics (means, percentages) from Statistical Package for the Social Sciences (SPSS) Version 22 (IBM Corp, 2013) were used for data analysis of socio – economic and demographic characteristics of smallholder rainfed farmers. The binary logistic regression model was also used to analyse the farmers probability of adopting CA practice given a set of the socio- economic variables.

The results have shown that age, gender and farm size had a significant influence on smallholder rainfed farmers' decision to adopt CA technologies in Pandamatenga region. Smallholder rainfed farmers had a positive perception and a high level of acceptance of CA technologies that were tried in their region. On average no tillage (594kg/ha) and no tillage plus mulch (560kg/ha) technologies were found to have the highest sorghum grain yield in different growing seasons in both continuous and cowpea- rotated- with- sorghum trials. The DSSAT crop model provided reasonable predictions of sorghum grain yield under NT, MT, NT+M and BBF on vertisols of Pandamatenga. Even though the sorghum grain yields will be decreased in the mid – century (2040-2070), however the model further predicted that sustained NT+M practice by smallholder rainfed farmers in Pandamatenga would increase sorghum grain yield production in the future as compared to other CA technologies which were evaluated.

Research, extension and planning agencies need to be sensitive to the age, gender and farm size of smallholder rainfed farmers when developing and disseminating agricultural technologies and strategies in the Pandamatenga area. No tillage mixed with mulch would be a suitable farming system for smallholder rainfed farmers for increased growth and enhancement of physical properties of vertisols. Thus, it is recommended that agricultural programmes should focus on the demonstration of no tillage mixed with soil surface cover to smallholder rainfed farmers in Pandamatenga. Modelling should be integrated in planning to assist smallholder rainfed farmers improve crop production to enhance food security sustainably.

Key words: Economic potential, conservation agriculture technologies, adoption, smallholder rainfed farmers, DSSAT model.

CHAPTER ONE

1. INTRODUCTION

1.1 Background on the Agricultural Sector

Rainfed Agriculture is the source of livelihoods for the majority of the population in Sub-Saharan Africa (SSA) (Rockström, 2000 as cited in Ngigi, 2009 and AGRA, 2014). Rainfed agriculture in SSA is characterized by low input and low output features such as extreme rainfall events variability, high frequency of dry spells and low fertilizer and pesticide use. Thus limited water and nutrients availability are key factors for low agricultural production in SSA (Dile *et al.*, 2013).

In Botswana, with an area of 582 000 km^2 and a population of over 2 million, about 70 percent of the population live in rural areas and derive their living from agriculture and other subsistence activities (UNDP, 2012). The country has a semi- arid climate with mean annual rainfall which varies from a maximum of over 650mm in the extreme north – eastern area of the Chobe District, to a minimum of less than 250mm in the extreme south – west of Kgalagadi District. The rainy season is in summer during the hot months of October to April and the dry season occurs during the months of May to September (Botswana Tourism Organization, 2013). Botswana is not well endowed with agricultural land. Of the 29,100 km^2 (or 5% of total land area) reported to be suitable for arable agriculture only less than 6,000 km^2 is under cultivation (IFAD, 2011).

At independence in 1966, agriculture contributed about 40 percent to the Gross Domestic Product (GDP). At present it only contributes 1.9 percent (Statistics Botswana, 2015). Agriculture plays an important role in rural development by providing food, employment and income for the majority of rural dwellers (Statistics Botswana, 2013). However, due to recurring droughts and outbreaks of pests and diseases, the performance of the sector has been poor, despite the financial support from the Government over the years (Statistics Botswana, 2012). Nevertheless, agriculture still remains a viable option for poverty reduction and employment creation because it is labour intensive (Statistics Botswana, 2014).

The agricultural sector is composed of traditional and commercial farmers, covering both crop and livestock production. Traditional farming is the most dominant in terms of numbers of people involved and the geographical coverage, with an average farm size of five hectares (Statistics

Botswana, 2013). Crop productivity is lower for subsistence agriculture across crop categories. For example in the 2013 cropping season, subsistence cereal yields ranged from 62 to 158 kilograms per hectare, compared with 704 to 1113 kilograms per hectare for the commercial sector (Statistics Botswana, 2013). The low subsistence crop productivity is due to low and erratic rainfall, and the low adoption of improved technologies (Seleka *et al.*, 2014 as cited in Seleka & Khaufelo, 2016). In the traditional sector maize, sorghum, millet and beans have been reported as the major crops in terms of area planted (Statistics Botswana, 2014). The beef industry is the only sub-sector that constantly remained a significant contributor to the agricultural GDP, accounting for about 80 percent of the output of agriculture (IFAD, 2011).

The agricultural sector has been identified as one of the areas that have a great potential to diversify the economy and create employment especially in rural areas. Therefore, programmes such as the Integrated Support Programme for Arable Agricultural Development (ISPAAD) have been supporting farmers in Botswana and this resulted in the expansion of rainfed cropped areas. However the yield gap between small – scale and commercial farmers is very large, where commercial farmers realized up to 2 tons per hectare for maize and sorghum as compared to an average of less than 0.2 tons per hectare among smallholder farmers under similar agro - ecological conditions (IFAD, 2011).

1.1.1 Background on the global distribution and uses of vertisols

Vertisols are dark- coloured clays which develop cracks when expanding and contracting with changes in moisture content. They shrink upon drying and swell upon wetting (Wubie, 2015). The global area under vertisols is estimated to be approximately 308 million hectares (USDA - SCS, 1994; Pal *et al.*, 2012). According to Pal *et al.* (2012) however, the reliability of this estimate remains uncertain because several countries have not yet been included in the inventory. In addition, the area under vertisols in a soil survey area may often be too small to resolve at the scale of map compilation (Coulombe *et al.*, 1996 as cited in Pal *et al.*, 2012).

Vertisol areas are located in Australia and India (80 million ha), Sudan (50 million ha) and the United States, China and Ethiopia (12-15 million ha) (Coulombe *et al.*, 2000 as cited in Buol *et al.*, 2003). Many of these soils are underutilised because they are difficult to manage, hard and cloddy when dry and very sticky when wet (Wubie, 2015). Vertisols occur in wide climatic zones, from the humid tropics to arid areas, but they are most abundant in the tropics and sub arid regions (Ahmad, 1996; Pal *et al.*, 2012).

The agricultural use of these soils ranges from grazing, collection of firewood, charcoal burning through smallholder post rainy season crop production (millet, sorghum and cotton) to small and large irrigated agriculture under cotton and wheat (Dagar *et al.*, 2016). These soils occur at low elevations but they also occur at higher elevations in the Ethiopian plateau (Pal *et al.*, 2012).

1.1.2 Local distribution and uses of vertisols in Botswana

In Botswana vertisols (black soils) are found in the Northern part, particularly in the Pandamatenga plains. Pandamatenga vertisols have a high content of clay. The soils are soft and plastic when wet and very hard and with deep cracks when dry (Arup - Atkins, 1990). Hence the workability of the soil is within a very narrow range moisture content. In addition, during increased rain seasons the area experiences floods which make accessibility to fields difficult during cropping season. The floods are caused by the high water retention capacity of the soil, as well as the very flat topography of the area which does not permit adequate water percolation and runoff, respectively (ADB, 2008).

Commercial agriculture is carried out in the central and southern plains of Pandamatenga, where a total of 25074 hectares have been demarcated. The production is centred on sorghum as the main crop. Other crops include maize, cotton and sunflower. Small scale dry land farming is also carried out in Pandamatenga plains. The major crops grown by these farmers are sorghum, maize and millet, inter – spaced with other crops such as beans, groundnuts and watermelons (Pardo *et al.*, 2012).

1.1.3 Potential of Conservation Agriculture on Vertisols management

To maximize production under these vertisols' unique properties, a systematic understanding of the properties and processes of these soils is crucial for the development and implementation of farming practices. This will keep them productive for the current and future generation.

Better management of vertisols, apart from enhancing crop production is also necessary in the protection of the environment (Wubie, 2015). This is because under the current conventional tillage system commonly used by farmers, the whole field is ploughed using either a mouldboard or disc ploughs followed by harrowing before seeding. This system destroys soil structure leading to problems related to soil degradation and compaction (Tapela *et al.*, 2007). Soil compaction is caused by high field machinery traffic as well as continuous cropping that results in an increased exposure of soils to high intensity storms.

To mitigate the physical constraints of vertisols properties, some organizations such as the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) and International Livestock Centre for Africa (ILCA) have been promoting alternative methods of crop production especially in vertisols. These farming systems such as conservation agriculture enhance productivity while conserving soil and water.

According to Food and Agriculture Organization (FAO) (2016), conservation farming or Conservation Agriculture (CA) is an approach to managing agro – ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resources base and the environment. Conservation Agriculture is characterized by three linked principles namely; continuous minimum mechanical soil disturbance, permanent organic soil cover and diversification of crop species grown in sequence and or associations.

Description of the three principles:

1. Minimum soil disturbance (minimum tillage with the aim to achieve no tillage or zero tillage). In CA crops are planted directly into unploughed soils. Minimum disturbance of the soil allows the retention of soil organic matter, which is lost through conventional tillage. This not only provides more nutrients for the growing crop, but also stabilizes the structure of the soil and makes it less vulnerable to crusting, compaction and erosion. Less

moisture is lost through evaporation that occurs in a conventional ploughed field. More carbon is sequestered in the soil and carbon dioxide emissions can be reduced in mechanized farming system as significantly less fuel is used than would be required for ploughing (FAO, 2010).

2. Permanent soil cover (with crop residues and cover crops) – Crop residues are retained in the field as mulch and / or cover crops are grown throughout the year. Covering the soil reduces the splash effect of raindrops. Once the energy of the drops has been dissipated the drops proceed to the soil without much harmful effect. This results in higher infiltration and reduced runoff, leading to less erosion. The residues also form a physical barrier that reduces the speed of wind over the surface and this leads to reduction of soil moisture evaporation. Additionally, insects, fungi, bacteria and other organisms living in this environment break down the mulch and incorporate it into the soil, improving soil fertility over the time (FAO, 2010).

3. Crop Rotation - Crops are planted in different associations and rotations with one another in both spatially and over time. Growing crops in mixtures or rotations helps to control pests and diseases by breaking their life cycles. Some crops help to suppress weeds and if legumes are used, they can also fertilize the soil through nitrogen fixation process. Soil structure is improved through penetration of different root systems into the soil and this also allows different crops of different root depth to draw nutrients and moisture from different soil layers (FAO, 2010).

Conservation Agriculture techniques are of great importance in semi-arid areas, because they constitute a field rain water conservation and soil fertility improvement strategy that enhances crop production and economic profitability (Araya *et al.*, 2016). A study conducted in Ethiopian vertisols showed that soil losses and run off were significantly higher in conventional tillage systems (Araya et *al.*, 2016). It was also found out that the gross margin was significantly higher in CA systems as compared to conventional tillage.

The introduction and adoption of CA in Zambia and Zimbabwe has significantly reduced the constraints of soil moisture to crop production (Thierfelder & Wall, 2010). It was found out that the infiltration rates were higher on CA plots as compared to conventional plots. This led to higher available soil moisture on CA plots. The increase in soil moisture enabled crops to overcome seasonal dry spells and reduces crop failure.

Conservation Agriculture has a potential for increasing improved yields regardless of the bad weather (Owenya *et al.*, 2011). It was also observed that CA was effective in the fight against hunger and poverty because of intercropping cereals with cover crops that produced three harvests instead of two (Owenya *et al.*, 2011). In Tanzania, farmers also experienced a reduction in time and labour requirement. This was brought about by reducing the number of operations during land preparation.

Conservation Agriculture technologies are experiencing increasing interest in many countries around the world (Derpsch & Friedrich, 2009). They are sustainable and offer economic alternatives as they conserve soil moisture, enhance soil fertility and reduce production costs (Derpsch *et al*, 2010). Also in sub Saharan Africa, CA is gaining momentum as the region struggles to address the worrying increase in population rates which is escalating the deterioration of agricultural land and increasing the scarcity of water (IFAD, 2011).

In Botswana the majority of the farmers practice conventional tillage where the field is ploughed several times and deeper in order to create a seed bed that is firm, granular and contains some moisture. The tillage system is conducted by using the soil invention mouldboard plough (Kethobile, 2006). This leads to high moisture loss through evaporation, especially when little rainfall is received. Also, this tillage system requires the highest level of energy input. Minimum tillage system which encourages the infiltration of rain water so that crop moisture requirements are adequately met is rarely used (Kethobile, 2006).

In the study area, some commercial and small holder farmers practise conventional tillage. In this tillage system equipment is used primarily to prepare the seedbed, control weeds and incorporate fertilizer and manure. The narrow range of optimum water content for tillage and the clotting nature of vertisols are challenges to this tillage system. Clods make it necessary to follow primary tillage operations with a cultivator to level the seedbed. As a result, more field operations are required and there is increased energy requirements (Tapela *et al.*, 2007). Consequently, on average cereal grain yields have been respectively hovering around 0.2 tons per hectare and 2.5 tons per hectare for small scale and large scale farmers respectively (Boitshepo, 2012).

However, the effectiveness of CA to address the above mentioned problems largely depends on the capacity of change agents and farmers in applying the actual formulae and techniques of the principles of CA to local context (Ngwira *et al.*, 2014). Short term to medium term potential benefits of CA have been assessed on farms. Conservation Agriculture generally results in increased yields especially after 3–5 years largely due to improved rainfall infiltration, reduction in number of labour hours and increased returns to labour, and reduction in risk of economic returns.

However, long term studies that report the long-term effects of CA on crop productivity and net economic returns including risks are lacking in Botswana and southern Africa as a whole. At the same time, traditional experiments aimed at deriving appropriate cropping practices for the wide variety of soil types and climatic conditions are time consuming and expensive (Ngwira *et al.*, 2014). According to Jones *et al.* (2003), the use of crop simulation models (CSMs) is often considered useful tool to simulate different soil and crop management and climatic scenarios for developing the most suitable and site-specific strategies. The Decision Support System for Agro-technology Transfer (DSSAT) is a collection of several such models, which connects the decision support system to crop simulation models (Jones *et al.*, 2003).

1.1.4 Description of the DSSAT cropping system model

The Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model (CSM) is a software package that simulate growth, development and yield of a crop on a uniform land under prescribed or simulated management as a function of crop phenotype, soil conditions, weather and crop management that takes place under the cropping system over time (Jones *et al.*, 2003). The DSSAT model is a collection of independent programs that operate together. These programs include crop simulation model at the centre, databases that describe weather, soil, experiment condition and measurements, and genotype information (Figure 1.1).

The software helps users to prepare inputs for each of the programs and compare simulation outcomes with observed data to achieve improved accuracy (Hoogenboom *et al.*, 2015). Programs contained in the DSSAT model also allow users to simulate options for crop management over a number of years to assess the risks associated with each option.

DSSAT was developed through collaboration among scientists at the University of Florida, the University of Georgia, University of Guelph, University of Hawaii, the International Centre for Soil Fertility and Agricultural Development, USDA-Agricultural Research Service, Universidad Politecnica de Madrid, Washington State University, and other scientists associated with the DSSAT Foundation (Hoogenboom *et al.*, 2015). Additionally the recent DSSAT 4.6 has algorithms which can simulate the influence of conservation agriculture practices such as crop residue cover and tillage on soil surface properties and plant development (Ngwira *et al.*, 2014).

In recent updates, of the software the DSSAT has separate program drivers called seasonal analysis sequence and rotational analysis, which has the ability to analyse and compare the different management options biophysically and economically to guide choice of the most efficient management options (Ngwira *et al.*, 2014). The structure of DSSAT is shown in Figure 1.1.

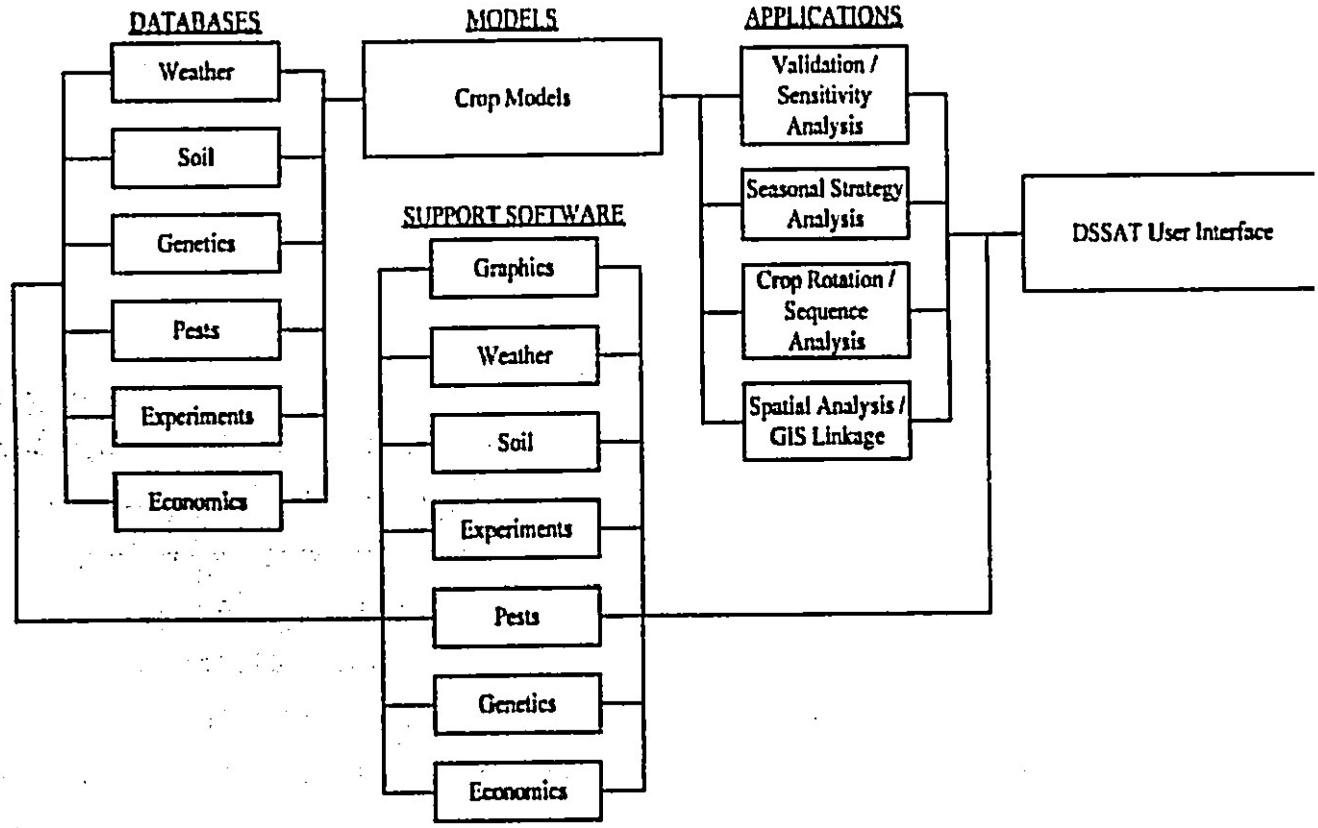

Figure 1. 1: Diagram of databases, applications, and support software components and their use with crop models for applications in DSSAT; (Jones *et al.*, 2003).

1.2 Problem statement

Vertisols such as those found in the Pandamatenga region have a high crop production potential. Farmers are however unable to manage these types of soils because of their unique properties that require a careful special management to translate their high potential fertility into successful crop production. The physical properties of these soils make them difficult to cultivate and present inherent problems of low infiltration rates, waterlogging and high erodibility. Furthermore, most farmers in Pandamatenga practice conventional tillage where the whole field is ploughed using a mouldboard and followed by harrowing. These repeated machinery operations are known to destroy soil structure. This leads to problems of soil degradation and compaction and result in an increased exposure of soils to high intensity storms (Tapela *et al.*, 2007). The long-term effect of which is the decline in crop yields. There is also scanty information on the impacts of conservation agriculture technologies in the Pandamatenga vertisols.

The adoption of agricultural technologies in developing countries including Botswana has attracted considerable attention because it can provide the basis for increasing production and income. Support programmes such as Integrated Support Programme for Arable Agricultural Development (ISPAAD) and Agriculture Services Support Project (ASSP) were established to help farmers adopt and implement improved agricultural technologies across Botswana. The Department of Agricultural Research is committed to develop appropriate and environmentally friendly agricultural technologies in support of sustainable and competitive agriculture to contribute to food security, poverty alleviation and socio-economic growth. However, the physical effectiveness and financial efficiency of different conservation agriculture technology measures have not been investigated under social and economic setting, soil types and climatic conditions of the Pandamatenga region and beyond. The extent to which conservation agriculture technologies have been adopted and the socio-economic factors that influence their adoption have not been documented. Finally, the future performance of some of these agricultural technologies has not been evaluated under future weather conditions and this can easily be achieved through modelling.

1.3 Significance of the study

Pandamatenga farms have been the focus of interest in arable agricultural development for a number of years, and it has more than 100 000ha of fertile black cracking clay soils, a potentially valuable resource in Botswana where good farmland is scarce (Arup - Atkins, 1990). Therefore, assessing the socio-economic potential of CA in the study area, where there is high rainfall intensity, high evapotranspiration during crop season and mostly shrinking and swelling vertisols is vital. Moreover, assessing the performance of these CA technologies on sorghum grain yield through modelling in the future climate is important. The use of models will help researchers to identify the best technologies to counter the effects of climate change since the traditional experiments are expensive and time consuming. The assessment may open viable opportunities in agriculture as the CA technologies offer sustainability of crop production through more effective management of soil and water. Information from this study will motivate smallholder rainfed farmers to adopt the CA technologies when high yields are experienced. The study will also help policy makers and development programmes to develop evidence - based future interventions aimed at benefiting smallholder rainfed farmers. There is also scanty information on CA in the Pandamatenga vertisols, so through this study it will help to contribute additional knowledge on vertisols management. Last but not least, the study will contribute to the enrichment of agricultural knowledge on vertisols management not only in Pandamatenga but in the Southern African region, since farming practices, soil conditions and climatic conditions in the agricultural sector are comparable across the region.

1.4 Purpose of the study

This study purports to fill the existing knowledge and information gap on the physical effectiveness and socio – economic potential of different CA technologies under soil types and climatic conditions of the Pandamatenga region. The study assessed the socio – economic potential of the following CA technologies namely no tillage (NT), no tillage plus mulch (NT + M), minimum tillage (MT), broad bed and furrow (BBF) and crop rotation on improving crop productivity. It also assessed the performance of these CA technologies in the future in terms of sorghum grain yield using the DSSAT model.

1.5 Objectives of the Study

This study intended to design and apply a methodology for improving crop productivity under social and economic setting, soil type and future climatic conditions of the Pandamatenga region.

The specific objectives of the study were:

1.5.1 To describe the socio economic and demographic characteristics of smallholder rainfed farmers in Pandamatenga region;

1.5.2 To assess smallholder rainfed farmers' perception and level of acceptance of conservation agriculture technologies in the Pandamatenga region;

1.5.3 To identify social and economic factors that influence smallholder rainfed farmers' decisions to adopt different conservation agriculture technologies in the Pandamatenga region;

1.5.4 To assess the potential of conservation agricultural technologies namely no tillage (NT), no tillage plus mulch (NT + M), minimum tillage (MT), broad bed and furrow (BBF) and crop rotation on improving sorghum yields;

1.5.5 To evaluate the DSSAT model in the prediction of yields of sorghum under conservation agricultural technologies and predict the yield during the mid – century.

1.6 Specific research questions to be addressed in this Study;

This study sought to provide answers to the following research questions:

1.6.1 What are the socio- economic and demographic characteristics of farmers engaged in rainfed agriculture in Pandamatenga region?

1.6.2 What are smallholder rainfed farmers' perceptions and level of acceptance of conservation agriculture technologies in the Pandamatenga region?

1.6.3 What social and economic factors influence smallholder rainfed farmers' decisions to adopt different conservation agriculture technologies in the Pandamatenga region?

1.6.4 What are the effects of conservation agriculture technologies on the yield of sorghum in the Pandamatenga region?

1.6.5 What are the implications of the DSSAT model on sorghum yield prediction and CA technologies using future projected weather data?

1.7 Hypothesis

1.7.1 There is no significant difference in the socio economic and demographic characteristics of smallholder farmers that adopt CA measures and non-adopters.

1.7.2 Smallholder rainfed farmers in Pandamatenga region have negative attitude towards CA technologies

1.7.3 Social and economic factors have no influence on smallholder farmers' decisions to adopt CA measures in the Pandamatenga region.

1.7.4 The conservation agriculture technologies have no potential to improve sorghum productivity in the Pandamatenga region.

1.7.5 The DSSAT model has the potential to predict sorghum yield and the best CA technology using future projected weather data.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Physical properties of Pandamatenga vertisols

Pandamatenga vertisols exhibit characteristics that are typical to similar soils found in other parts of the world. They are characterized by heavy textural features. The clay content is generally more than 50 percent and they have a very dark colour (Moganane *et al.*, 1990).

The bulk density of a vertisol has to be reported with the moisture content at which it was measured, because bulk densities decrease as the moisture content increases, due to the continuous expansion of vertisols on wetting. Bulk densities for the Pandamatenga vertisols range from 1.3g/cm^3 in the untilled top soil to 1.8g/cm^3 in the sub soil (Pardo *et al.*, 2012).

In the dry season, the vertisols form structures that are separated from each other by deep vertical cracks of various sizes at a depth of 50cm down. When dry they have a hard consistence but are plastic and sticky when wet, hence they have a workability within a narrow soil moisture range. Pandamatenga vertisols have a poor structure that is not well drained. The infiltration rates are assumed to be very high due to the cracks when the soils are dry and very low when the cracks are closing up. Initial rates on naturally occurring soils average to 22.7cm/hr while the final infiltrations average 0.3cm/hr (Moganane *et al.*, 1990). Vertisols have a relative high-water storage capacity in the root zone because of their depth and high clay content. On an average the available moisture for the vertisols can be approximately128mm/m (Joshua, 1991).

2. 2 Chemical properties of Pandamatenga vertisols

Soil chemical properties include the cation exchange capacity (CEC), soil reaction (pH), organic matter, macro and micro-nutrients. The CEC of the surface horizon of the Pandamatenga vertisols varies widely but is high in general averaging 41centi – mol per kg. In general, vertisols in Pandamatenga are neutral to moderately basic and non-saline.

In spite of the dark colours, they present a low organic carbon which is used to estimate organic matter, and it decreases with depth. Reasons for low carbon include high temperatures that promote organic matter decomposition (Tapela *et al.*, 2007) and little matter accumulation of plant residue due to low rainfall and frequent drought. Calcium and magnesium constitute the dominant bases in the exchange complex. As in the case in most tropical areas these vertisols are deficient in nitrogen, which is a limiting factor to crop growth. Available phosphorus in vertisols ranges from low to normal values of 22 mg kg^{-1} to 32 mg kg^{-1} (Pardo *et al.*, 2012).Vertisols contain copper, due to high amount of clay and due to the fact that they are derived from basic rocks which are well endowed (Pardo *et al.*, 2012).

2.3 Importance of Vertisols in Pandamatenga agriculture

Vertisols such as the ones found in the Pandamatenga region are considered good farming soils (Tapela *et al.*, 2007), but they have unique properties that require special management if full yield potential is to be realized. Vertisols are considered difficult to cultivate and in many areas of the semi-arid tropics they are underutilized (Wubie, 2015). Their advantages, however, include the fact that they are moderately fertile and have high capacities to store both nutrients and water. Under favourable climatic conditions and appropriate management, vertisols have proved to be productive and capable of producing a much greater contribution to food production (Pardo *et al.*, 2012).

2.4 The concept of conservation agriculture in Vertisols physical properties

Vertisols have great potential for agricultural production, but many, especially in the developing world, are underutilized due to a lack of understanding regarding their behaviour and management (Patil *et al.*, 2012). The physical constraints are related to their physical properties and moisture regimes (Wubie, 2015). Their heavy texture and the presence of expanding type clay minerals result in a narrow range between moisture stress and water excess (Deckers *et al.*, 2001). The swell-shrink nature of these soils leads to complex hydraulic behaviour, causing difficulties in managing them. In fact, management of these soils is one of the major challenges in increasing agricultural productivity (Patil *et al.*, 2012).

The physical properties of vertisols make them difficult to cultivate and present inherent problems of low infiltration rates, water logging and high erodibility. In combination with widespread chemical fertility decline, the physical problems represent a major constraint to the sustainable management of vertisolic lands (Deckers *et al.*, 2001). In addition to this problem most farmers in Pandamatenga practice conventional tillage where the whole field is ploughed using a mouldboard and followed by harrowing. These repeated operations of machinery destroy soil structure leading to problems of soil degradation and compaction and result in an increased exposure of soils to high intensity storms (Tapela *et al.*, 2007), the long term effects of which is the decline in crop yields.

Oicha *et al.* (2010) similarly stated that in Ethiopia conventional tillage includes a primary tillage followed by repeated secondary shallow tillage and these repeated operations cause moist soil to move to the surface favouring water loss by evaporation, exposing the soil to both wind and water erosion and causing structural damage. Soil erosion due to high tillage frequency and other soil management problems has seriously affected over 25% of the Ethiopian highlands (Kruger *et al.*, 1996; Oicha *et al.*, 2010). Nevertheless, there is evidence that substantial increases in crop yield could be obtained on vertisols if excess surface soil water is drained off and if appropriate cropping practices are used (Wubie, 2015). This is supported by Araya *et al.*, (2016), who stated that conservation agriculture has been practiced around the world to reduce cropland degradation and improve soil quality, thereby increasing crop productivity.

Conservation agriculture is an important alternative farming system in the control and improvement of the soil regimes in vertisols for increased crop production thus improving livelihoods (Araya *et al.*, 2016). Conservation Agriculture is a way of managing agro-ecosystems to achieve higher, sustained productivity, increased profits and food security while enhancing the environment. This is achieved through improved management and application of three key principles in conjunction with other good agronomic practices: Minimal soil disturbance, maintenance of a permanent soil cover with mulch or cover crops and practising crop associations or rotations (FAO, 2016).

Vertisols possess inherent poor structure which is greatly influenced by water regimes (Deckers *et al.*, 2001). Soil structure is the arrangement of soil particles and aggregates of sand, silt and clay and pores in the soil (Verhulst *et al.*, 2010). Soil structure is often expressed as the degree of stability of aggregates (Mohanty *et al.*, 2012). Soil structure stability is the soil's ability to maintain the arrangement of particles and pores when exposed to environmental stress (Verhulst *et al.*, 2010). Conservation agriculture minimizes stress due to conventional tillage, so the soil profile stays undisturbed and the aggregates and roots are not broken hence affecting positively the stability of aggregates (Federica, 2015). In addition, the undisturbed soil profile allows the retention of soil organic matter which provides nutrients for the growing crop and makes it less vulnerable to crusting, compaction and erosion (FAO, 2010).

McCarty *et al.* (1998) and Hati *et al.* (2015) further reported that for clay soils no tillage is a suitable management option which minimises sub-soil compaction and also induces natural structure formation through shrink-swell cycles. The maintenance of a permanent soil cover with mulch or cover crops also increased the stability of vertisols (Oicha *et al.*, 2010). Residues provide a constant food source for the soil fauna and flora and a habitation of many organisms. These organisms produce soil pores and their increased biological activity with crop residue retention enables the slow breakdown of the residues and incorporate these residues in the soil as organic matter (Wall & Thierfelder, 2013). Soil organic matter promotes aggregation through the linkage of clay-organic matter (Mohanty *et al.*, 2012).

In an experiment carried out in Central India to determine the stability of soil aggregates under different vegetation cover, Mohanty *et al.*, (2012) reported higher soil aggregates in different vegetative covers, than in soils under cultivated crops with no vegetative cover. Diversification also brings stability in soil fertility through cultivating legumes with cereals in rotation (Patil *et al.*, 2016).

During the rainy season, infiltration rates and hydraulic conductivity within vertisols control two important water balance components, intake and runoff. Poor drainage can be an inherent physical constraint for crop production on these soils during the rainy season when rainfalls are high. Also, in dry seasons, the little amount of moisture needs to be conserved. On a bare vertisolic surface, aggregates already weakened by tillage systems are broken down by the explosive impact of heavy raindrops. The dispersed soil particles block soil pores and seal the surface, thus impeding water infiltration. In conservation agriculture systems, the soil surface is protected from raindrops, resulting in high infiltration rates and reduced runoff leading to moisture availability to crops (Wall & Thierfelder, 2013).

Araya *et al.* (2012) evaluated the effects on runoff, soil loss and crop yield of newly developed CA versions of traditional tillage using local crop rotation systems, and found that permanent raised beds planting with retention of crop residues was beneficial for reducing runoff and soil loss. Federica (2015) similarly stated that residues captured rain and reduced the runoff and its speed consequently allowing more time for water to infiltrate, hence surface' s moisture was higher and more water was available in the soil. Verhulst *et al.* (2011) stated that this aspect was very important especially with prolonged drought periods.

In a study to improve water productivity in vertisols of semiarid India using conservation agriculture, Patil *et al.* (2016) found that conservation agriculture had a large impact on reducing surface runoff as compared to conventional practices. On average, CA practices (minimum tillage & crop residues) reduced runoff by 28 percent compared to conventional practices, thus enhancing soil water availability for plants uptake. Conservation agriculture through crop residues improved infiltration by restricting surface runoff and reducing surface sealing from rain drop impact.

Due to the presence of cracks at the beginning of the wet season vertisols have high initial infiltration rates which decrease drastically with increased wetting of the soil. As the infiltration rates are reduced more water runs off the land and leads to erosion. During crop growth, surface soil cover or mulching is effective in reducing the incidence of cracking, as residues form a physical barrier that reduces the speed of wind over the surface and this leads to the reduction of soil moisture evaporation (Bandyopadhyay *et al.*, 2003; Federica, 2015). Under CA practices more water goes into the soil (increased infiltration) and thus less water runs off the land. This leads to reduction in water erosion. Residues also protect the soil from the wind and the soil is not loosened by tillage in CA systems (Wall & Thierfelder, 2013).

2.5 Socio - economic potential of conservation agriculture on vertisols

A socio-economic assessment examines how a proposed development will change the lives of current and future residents of a community (Edwards, 2016) . There are many indicators that are used to measure the potential of socio-economic development depending on the type of the proposed development. For this study on the socio-economic potential of CA, it comprised how CA technologies from other studies have affected the livelihoods of farmers in terms of crop yields and food security status. It also included the economic factors that determined adoption of conservation agriculture.

2.5.1 Improved crop yields

Recent reviews of research in Latin America, Africa and Asia have concluded that conservation agriculture yields are approximately 20 – 120 percent higher than those in conventional agriculture (Derpsch *et al.*, 2010). Furthermore numerous studies [Mloza-Banda and Nanthambwe (2010), Sileshi *et al.* (2008), Boahen *et al.* (2007), Kaumbutho and Kienzle (2007), Nyende *et al.* (2007), Shetto *et al.* (2007), Haggblade and Tembo, (2003)] have conducted experiment to compare the yields of conservation agriculture systems to those of conventional farming systems as cited in Milder *et al.*, 2011). The general pattern from the researchers is that yields increased in both short term and long term as a result of conservation agriculture.

An assessment on the status and potential of no–tillage system in the Pandamatenga area revealed that Masedi farms were able to obtain yield levels of up to 5 tonnes per hectare and 2.8 tonnes per hectare for sorghum and cotton respectively due the use of fertilizers and adoption of no-tillage system as opposed to conventional tillage previously practiced by farmers who only harvested about 0.3 tonnes per hectare (Tapela *et al.*, 2007).

Similar results have been reported from field studies incorporating permanent raised bed planting system in northern Ethiopia (Araya *et al.*, 2011). CA practices had the ability to reduce soil loss and improved soil fertility thus increasing crop productivity and avoiding further degradation.

Patil *et al.* (2016) also reported high yields in CA as compared to conventional agriculture in a three-year experiment at the International Crops Research Institute for the Semi- Arid Tropics, Patancheru, India. The long-term simulation results showed that CA helped reducing water stress in dry areas and reduced the risks of crop failure, with maize yield being enhanced by 46 percent in low rainfall years compared to conventional system.

A study by Hati *et al.* (2015) in vertisols of central India, however reported no significant difference in yield under three tillage (CT, MT and NT) systems.

2.5.2 Conservation agriculture and food security

Conservation agriculture if practiced correctly has the potential to improve food security and nutritional status for farming households (Harford & Le Breton, 2009).

Rusinamhodzi *et al.* (2012) evaluated the suitability of maize-legume intercropping to alleviate socio-economic constraints faced by smallholder farmers in central Mozambique. They found out that maize yield in the within-row intercropping treatment was larger than in sole crop in both planting seasons. The highest maize yield was 5.8 tonnes per hectare while in sole maize it was 2.6 tonnes per hectare. It was concluded that maize-legume intercropping had a potential to reduce the risk of crop failure, improve productivity, income and increase food security in vulnerable production systems.

Corbeels *et al.* (2014) meta–analysed crop responses to conservation agriculture in sub-Saharan Africa, and found that the weighted mean difference between CT and CA was 166kg/ha. Higher crop grain was observed under no tillage and rotation (NTR) relative to CT. Higher crop grain yield observed under no tillage plus NTR relative to CT was attributed to combined effects of multiple factors such as increased nitrogen inputs from biological nitrogen fixation in the case of legumes and enhanced water infiltration.

Jumbe & Nyambose (2016) identified factors that influenced the adoption and contribution of CA on household food security using household-level data collected in 2010 from Central Malawi. They found that CA adopters had more than 50 percent higher maize production than non-adopters. Overall results showed consistently that CA adopters were better off than non-adopters in various aspects such as maize production, per capita maize requirements and meal frequency.

2.6 Household socio - economic determinants of CA technologies adoption in Pandamatenga region

The response of farmers to CA is measured by the rate of adoption of the practice, and the decision to adopt is a function of several factors including socio-economic factors; and adoption meant the process by which a particular farmer is exposed to, considers and finally practices an innovation (Jumbe & Nyambose, 2016). For this study, the household socio-economic variables that influence household adoption included; age, gender and marital status of smallholder rainfed farmer, average number of family members in a household, total land holding size, livestock possession, labour availability, herbicide price and education level.

Age is assumed to be a determinant of adoption of new technology. Older farmers are assumed to have gained knowledge and experience over time and are better able to evaluate technology information than younger farmers (Jumbe & Nyambose, 2016). Gender and marital status of smallholder rainfed farmer are two of the determinants of CA.

To optimize the benefits of conservation agriculture, especially at the community and national levels, the technology should be practised by many farmers and on a large proportion of the cultivated land (FAO, 2010). Land related variables influence farmers' adoption behaviour, as land holding is an important unit where agricultural activities take place. Concerning land holding, different studies reported its effect positively. For example, a study carried out by Fadare *et al.* (2014) reported that farm size contributed positively in farmers' adoption of improved maize varieties. Bazezew (2015) conducted a study on adoption of CA practice in Ethiopia and found out that farm size was positively related to the adoption of agricultural practice. Similarly, Jumbe & Nyambose, (2016) reported positive relationship of farm size with adoption.

Livestock holding is an important indicator of household's wealth position. Livestock is also an important source of income, which enables farmers to invest on adoption of improved agricultural technologies. In most cases, livestock holding has positive contribution to household's adoption of agricultural technologies. Similar results were reported by Kassie *et al.* (2012) and Bazezew (2015).

Labour availability in the farm household was also found to affect positively adoption of the agricultural technologies (Ngombe *et al.*, 2014). Similar results were reported by Mlenga &

Maseko (2015), that the number of people contributing to agricultural labour was found to positively influence adoption of CA. On contrary, a study by (Jumbe & Nyambose, 2016) reported that labour was not an important factor for CA adoption. The other important factor for sustainable use of technologies is the supply of herbicides. Lack of inputs negatively affected the adoption of CA among women in Malawi (Chisenga, 2015). Education is believed to increase farmer's ability to obtain and analyse information that helps them to make appropriate decision. Fadare *et al.* (2014) and Bazezew (2015) indicated positive relationship between education and adoption. (Jumbe & Nyambose, 2016) also indicated that education enhanced the adoption of CA.

2.7 The DSSAT Cropping System Model (CSM)

DSSAT and its crop simulation models have been used for many applications ranging from on-farm and precision management to regional assessments of the impact of climate change. It has been in use for more than twenty years by researchers, educators, consultants, extension agents, growers, and policy and decision makers in over 100 countries worldwide (Hoogenboom *et al.*, 2015).

Many of these applications have been done to study management options at study sites, including fertilizer, irrigation, pest management, tillage and chemical applications. An important aspect of many of these studies is a consideration that weather influences the performance of crops, interacting in complex ways with soil and management. Researchers have thus applied these models to study uncertainty in crop production associated with weather variability and the associated economic risks that farmers face under such climate variability.

In a study to determine alternative production activities through yield prediction of several crops under use of organic and inorganic farming in Rwanda using the DSSAT model, Bidogeza *et al.* (2012) reported that the crop model showed acceptable and realistic predictions, although detailed experimental data were missing to verify model performance.

Liu *et al.* (2013) evaluated the ability of the DSSAT cropping system model with the CROPGRO soybean and CSM-CERES-Maize to predict crop yield and root zone soil water dynamics for a soybean –maize rotation under conventional tillage and conservation tillage practices in China. It was concluded that the DSSAT – CSM model provided reasonable predictions of crop yield and root zone water dynamics.

Similarly, DSSAT modelling system in rainfed semi-arid Spain was studied under combined effect of tillage system and cereal-legume rotations on crop yield and soil quality by Soldevilla-Martinez *et al.* (2013) who concluded that the DSSAT-CERES model performed relatively well in modelling barley biomass and yield in the experimental field. It was further emphasised that the use of models to simulate combinations of tillage systems and crop rotations constitute a powerful tool in assisting decision making to identify efficient system management options, increasing yields and decreasing environmental impacts, in specific -climatic conditions.

In Malawi, Ngwira *et al.* (2014) used and evaluated the DSSAT modelling of conservation agriculture maize in response to climate change. They concluded that the calibration and validation of the DSSAT model could be used for decision making to choose specific CA practices especially for no till and crop residues retention, as the simulated results showed the effects of CA were successful for no till and crop residue retention as compared to conventional tillage.

In Egypt, Harb *et al.* (2016) investigated the effect of tillage system, fertilizer rates and cereal legume rotation on crop yield and soil quality. The results showed that the calibration indexes (RMSE, D-STAT and r-squared) had excellent and good simulation for both seed yield and harvest index, and that the crop-model could correctly reproduce the observed yield.

Waffa & Benoit, (2015) used the DSSAT model to simulate and estimate wheat yield prediction under two climatic conditions for adaptation and mitigation. They concluded that the use of the model provided an efficient method for evaluating impact of climate change on wheat production.

In another study by Msongaleli *et al.* (2014) the DSSAT model was used to evaluate and simulate sorghum yield under current and future climate. The results showed that crop simulation models showed their applicability as tools for assessing impacts of climate change on sorghum yields.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the study Area

The study was based at Pandamatenga village. Pandamatenga region lies in the northern part of Botswana between latitude 18° 32' South, and longitude 25° 38' East and it covers an area of 280, 380 ha. The village is about 100km South of Kasane in the Chobe District. The Pandamatenga farms (in Figure 3.1) cover only 25,074 ha of this total land area (Tapela *et al.*, 2007).

3.2 Socio - economic environment

According to the housing and population census of 2011, the population of Pandamatenga village is 1798 people exclusive of associated localities. Pandamatenga village has 909 females and 889 males. This implies slightly higher female labour force for the farms (Statistics Botswana, 2011).

The government provides the basic services and amenities based on the size of the settlements (CAR, 2009). Facilities such as health posts do exist in the village. The village is connected to the national electricity grid. Lined telephone is connected to the area. Main source of water is borehole. Pandamatenga village is linked to Kasane, 100km to the North and Francistown about 400km to the South by a good tarred road. The village has one primary school, a post office and a police station and some government offices for various services (CAR, 2009).

The climate for the Chobe district and Pandamatenga in particular is semi–arid characterized by hot and moist summers and dry mild winters. Rainfall is derived from convective processes and its highly variable even over small distances and averages 600 mm annually, thus making Pandamatenga one of Botswana's least arid areas. Almost all rain falls between October and April, with December, January and February being the peak months. A substantial proportion of this rain, falls in short duration of high intensity storms, thus, leading to high run–on into some farms, which become flooded instantly. Maximum temperatures range between 26°C to 34°C and are experienced between October to March. Minimum temperatures range between 11°C to 20°C and are experienced between November and July. The vegetation is extensive grassland savannah in association with Mophane (*Colophospermum mopane*) and acacia species (CAR, 2009).

The Pandamatenga plains are underlain by basalt which occurs at the base of the black cotton soils. This basalt occurs subordinately with the sandstones. This basalt is mostly exposed around Pandamatenga village and extends eastwards across the border into Zimbabwe (CAR, 2009). The area is dominated by vertisolic clay soils, which are potentially good farming soils. The soils are characterized by very high clay contents dominated by expanding lattice clay minerals which give them their physical and chemical properties. The area is generally flat with a gentle slope and rain water flows following natural drainage routes (Tapela *et al.*, 2007).

Farmers in the area are classified as traditional (subsistence) and large-scale farmers. The smallholder farmers practice livestock farming, mixed cropping, broadcasting of seeds and depend on family labour for farm operations. Smallholder farm size varies between 6 and 15 ha. Arable farming under this system is nevertheless constrained by floods and crop damage due to wildlife. The large-scale farmers hire labour inputs, use kraal manure, fertilisers, pesticides, improved seeds and mechanize their operations. Farm size is between 300 and 1,000 ha (Government of Botswana, 2005). The large-scale farmers are also constrained by floods due to vertisolic soil properties. Large scale cereal production in Pandamatenga region contributes significantly to both local and national economy of Botswana. Commercial agriculture in the study area also provides farm employment for the locals. Crops cultivated in the area include sorghum, maize, sunflower, cotton, cowpeas/beans and millet.

Tourism is also a source of employment in the village in which locals are hired as waiters, guides, administration officers and cleaners. Informal sectors also contribute to family income. These include, tuck shops, selling of traditional beer, small scale tailoring and carpentry (CAR, 2009).

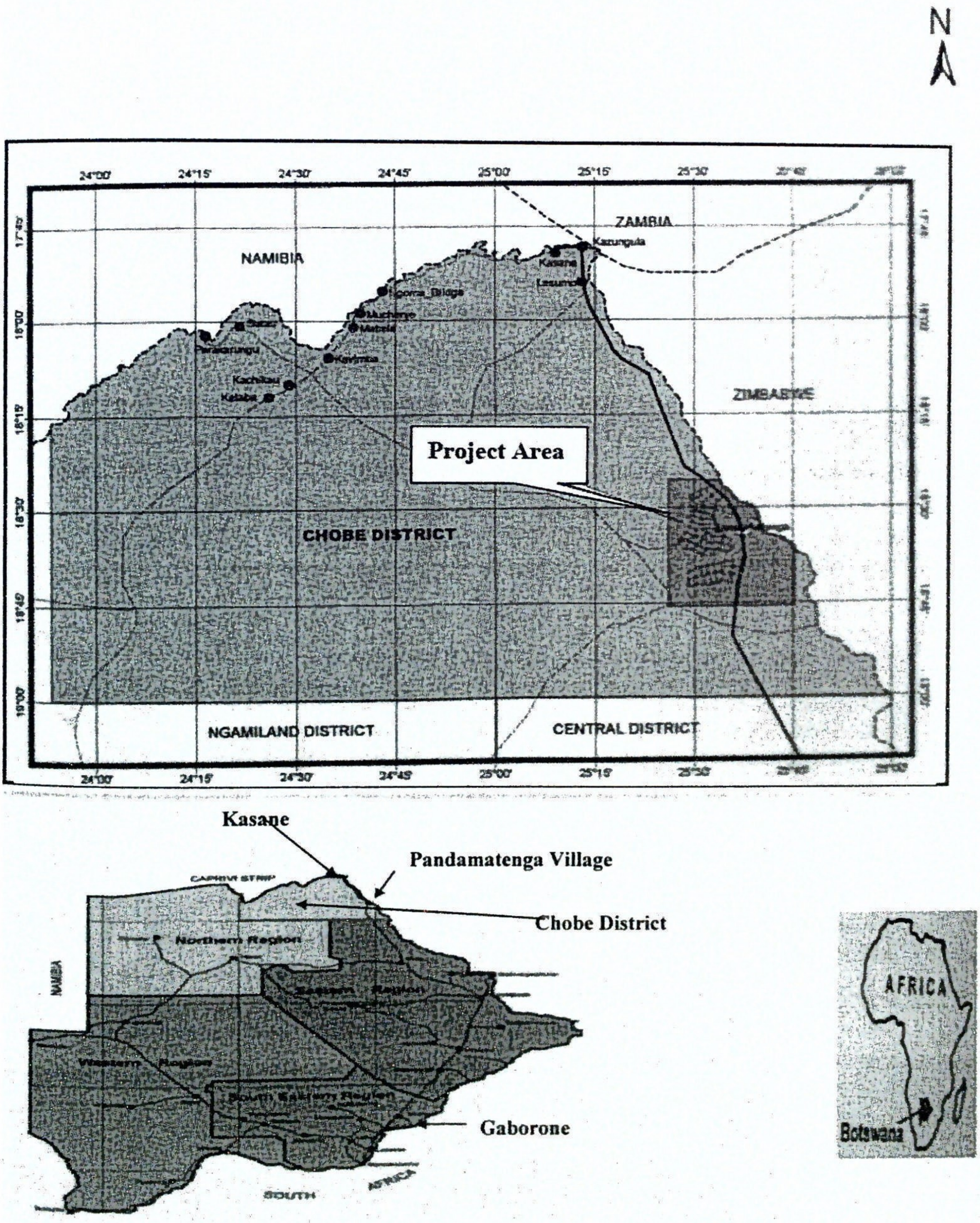

Figure 3.1: Map of Pandamatenga farms in the Chobe District

METHODOLOGICALLY FRAME WORK

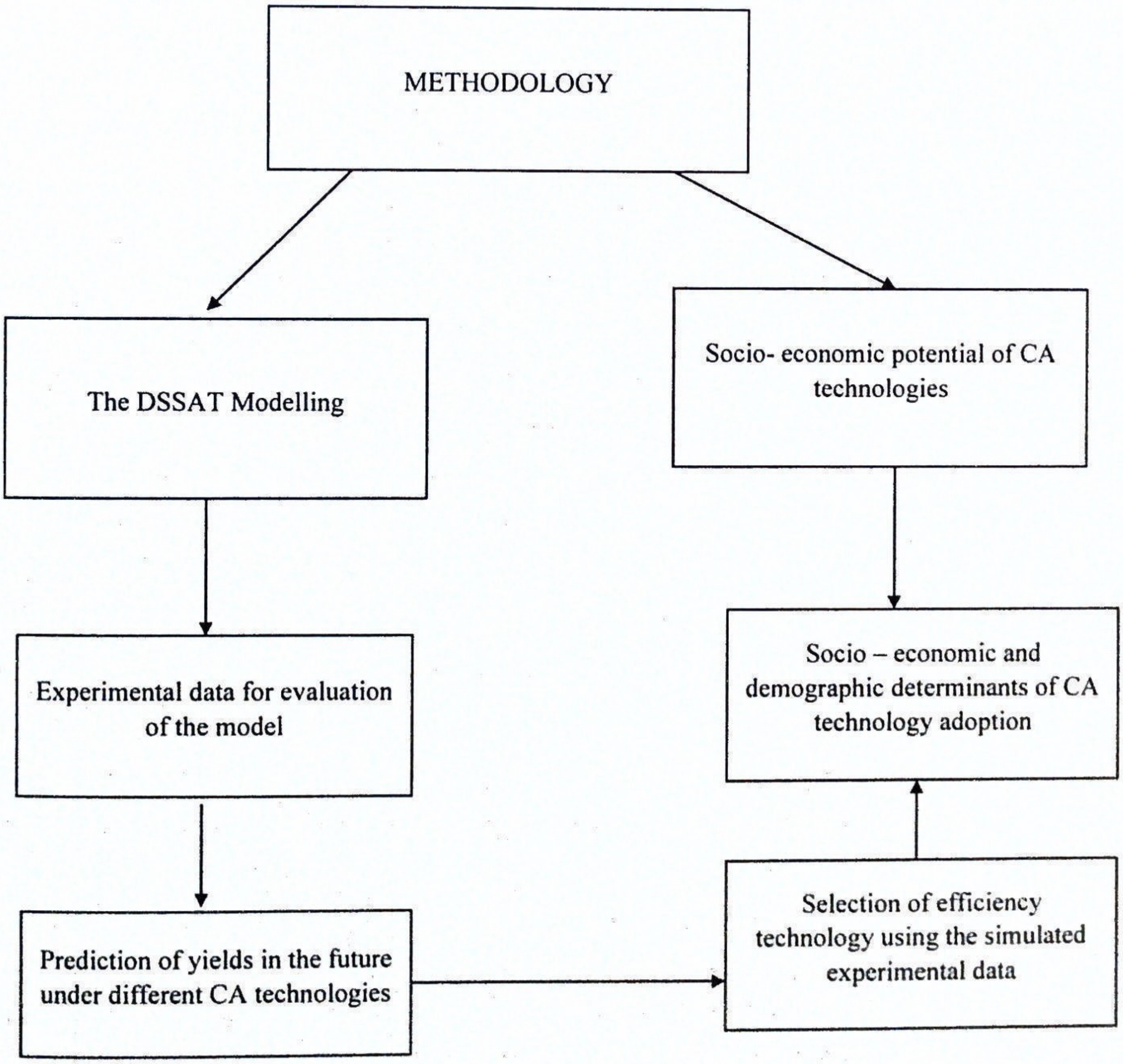

Figure 3. 1: Methodologically frame work for the research work

3.3 Experimental design

The study used the descriptive research method to obtain all the necessary information in order to achieve some of the above stated objectives as shown in (Figure 3.2). Descriptive research is used to describe characteristics of a population or phenomenon being studied and what exists with respect to variables or conditions in a situation.

The field experiment was conducted at the Pandamatenga Agricultural Research station under rainfed conditions during 2015-2017 growing seasons. A randomized complete block design was used for the field experimentation with plot dimensions of 20m * 7.5m. Blocking was included to cater for variation of slope and soil fertility in the plot layout. The design was subjected to the on-station trial plots with three treatments, namely No Tillage + Mulch (NT+M), Minimum Tillage (MT) and Broad Bed and Furrow (BBF) and No tillage as a control with four replicates rotated between sorghum and cowpea. Sorghum variety *Segaolane* and cowpea variety *Tswana* were used for the experiment as they are the common crops grown by smallholder farmers in Pandamatenga. The planting dates were on the month of February in 2015 and 2016 while in 2017 the planting date was on the month of March.

3.4 Population of the study and sampling techniques

The target population for the study included smallholder rainfed farmers in the Pandamatenga region. A list of smallholder rainfed farmers was obtained from the Department of Crop Production at Pandamatenga. Simple random sampling by the use of a random number table was used to select 50 smallholder rainfed farmers from the population list. Each farm household was treated as a sampling unit. In this study, sample size was determined by taking different factors such as research cost, time, human resource, and availability of transport facility. Furthermore, farmers were categorized into adopters and non-adopters of Conservation Agriculture (CA) technologies. In this study, a smallholder rainfed farmer was considered as an adopter of CA technologies if he/she had practiced at least one or more of the following agricultural technologies (no tillage, minimum tillage, no tillage plus mulch and broad bed and furrow) on his / her farm during the 2015/16 and 2016/17 cropping seasons. Conversely, a non – adopter of CA technologies referred to a smallholder rainfed farmer who had been practising conventional agriculture in the specified cropping seasons.

3.5 Data Types and data Sources

In this study, both qualitative and quantitative data were collected from primary and secondary sources to attain the stated objectives. Primary data were obtained from both the smallholder rainfed farmers and from the field experiment. Secondary data were obtained from reports and field records provided by the Departments of Crop Production and Agricultural Research of the Ministry of Agriculture Development and Food Security.

3.6 Methods of data collection for various specific objectives

The activities for data collection were divided into two phases. Phase one involved a formal visit and consultation of the Extension Officers at the Department of Crop Production in Pandamatenga to obtain the list of smallholder rainfed farmers in the study area. Simple random sampling was then done to obtain the sample number of smallholder rainfed farmers to be included in the study from the given list. Another visit was made to the Department of Agricultural Research station at Pandamatenga to collect sorghum grain yield, days to flowering and days to maturity from the experiments which were done at the farms. Phase two involved individual household survey of the selected smallholder rainfed farmers in the study area.

3.6.1: Specific objective one:

To describe the socio - economic and demographic characteristics of smallholder rainfed farmers in Pandamatenga region.

According to Jumbe & Nyambose (2016) farmers' socio - economic and demographic characteristics are expected to have a great influence on agricultural development. After the selection of the sampled number of the smallholder rainfed farmers, they were visited for face- to-face interviews. Structured interviews were used to collect the socio - economic and demographic characteristics of the smallholder rainfed farmers. The interviews were conducted using a structured questionnaire (Appendix 2.1) containing relevant questions which were answered by the respondents with the help of the researcher.

The socio - economic characteristics of the smallholder rainfed farmers included the following: land holding size (ha), labour availability, livestock possession, education level and farming experience. Demographic characteristics considered in this study were smallholder rainfed farmers' age, marital status, gender and average number of members in the household. These variables were selected because most literature on agriculture technologies adoption, consider that the decision to adopt agricultural technologies is affected by the characteristics of the farmer.

3.6.1.1 Data Analysis

Descriptive statistics (means and percentages) from Statistical Package for the Social Sciences (SPSS) Version 22 (IBM Corp, 2013) were used for data analysis. The t- test was used to compare the percentage differences of means of the continuous variables between adopters and non-adopters of CA technologies. Whereas the percentage difference of means for the categorised variables between adopters and non - adopters were compared using the Chi – square test. Both tests were set at 5% level of significance.

3.6.2 Specific objective two:

To assess smallholder rainfed farmers' perception and acceptance of CA technologies in the Pandamatenga region.

In order to capture the perception of farmers towards CA technologies, interviews were conducted using a structured questionnaire (Appendix 2.1) comprising of CA issues such as benefits, constraints, and adoption problems. The respondents were asked to indicate their level of agreement with a given statement using a 5-point ordinal Likert scale ranging from "strongly agree" to "strongly disagree".

3.6.2.1 Data analysis

Descriptive statistics (percentages, median and interquartile range) from Statistical Package for the Social Sciences (SPSS) Version 22 (IBM Corp, 2013) were used for the Likert scale data analysis.

3.6.3 Specific objective three:

To identify social and economic factors that influence smallholder rainfed farmers' decisions to adopt different CA technologies in the Pandamatenga region.

The literature indicated that several socio - economic variables play a role in determining the willingness and ability of farmers to invest in agricultural technologies. This study examined the influence of total land holding size, livestock possession, labour availability, herbicide price, education level on smallholder rainfed farmers' decision to adopt CA technologies in the Pandamatenga region. The socio-economic variables were collected through one-on-one interviews with selected smallholder rainfed farmers using a structured questionnaire.

3.6.3.1 Data Analysis

The response to questions such as whether a smallholder rainfed farmer has used conservation agriculture technologies (NT, NT + M, MT, BBF and crop rotation) or not could be yes or no, which is a typical case of dichotomous dependent variable. Hence a binary logistic regression model was used to estimate the farmer's probability or the odds of adopting CA practice given a set of socio-economic variables. Chi–square and likelihood estimation were used to test the significance of association between dependent and independent variables and the overall significance of the model.

3.6.3.1.1 Logistic Regression Analysis

According to Thomas (1996),the logistic distribution for the adoption decision of CA can be specified as:

$$P_i = \frac{1}{1+e^{-zi}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Pi is the probability of adopting CA for the ith farmer and ranges from 0 to 1.

e represents the base of natural logarithms and Zi is the function of a vector of n explanatory variables and expressed as;

$$z_i = \beta_0 + \sum \beta_i X_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where β_0 is the intercept and $\beta_i$is a vector of unknown slope coefficients. The relationship between Pi and X_i (and *Xi* is the independent variable) which is non-linear, can be written as follows:

$$P_i = \frac{1}{1+e^{-\beta 0+\ \beta i X i+\cdots \beta n X n}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The slopes tell how the log-odds in favour of adopting the technology changes as independent variables change. If Pi is the probability of adopting given technologies, then 1-Pi represents the probability of not adopting and can be written as:

$$1 - Pi = \frac{1}{(1+e^{-zi})} = \frac{e^{-zi}}{1+e^{-zi}} = \frac{1}{1+e^{zi}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Dividing equation (1) by equation (4) and simplifying gives:

$$\frac{P_i}{1-P_i} = \frac{1+e^{zi}}{(1+e^{-zi})} = e^{z} - \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Equation (5) indicates simply the odd-ratio in favour of adopting the technologies. It is the ratio of the probability that the farmer will adopt the technology to the probability that he will not adopt it. Finally, the logit model is obtained by taking the logarithm of equation (5) as follows:

$$L_i = L_n\left[\frac{P_i}{1-P_i}\right] = z_i = \beta_0 + \beta_1X_1 + \beta_2X_2 + \cdots \beta_nX_n \quad \ldots (6)$$

Where Li is log of the odds ratio, which is not only linear in X, but also linear in the parameters: Thus, if the stochastic disturbance error term Ui is taken into account, the logistic model becomes:

$$z_i = \beta_0 + \beta_1X_1 + \beta_2X_2 + \cdots \beta_nX_n + U_i \quad \ldots (7)$$

Thus, the empirical model estimated in this study was specified as:

$$z_i = \beta_0 + \beta_1AGE + \beta_2GENOFF + \beta_3EXP + \beta_4\,EDUOFF + \beta_5LABPO + \beta_6\,TLTLU + \beta_7FSIZE + \beta_8HERBCDPR + \varepsilon \quad \ldots (8)$$

Where;

z_i is the logit, that is, the natural log of the odds of the smallholder rainfed farmer's decision to adopt CA technology given his / her set of explanatory socioeconomic factors.

Adoption of CA is a dichotomous decision variable represented by a value of 1 if a smallholder rainfed farmer is an adopter (practiced at least one of the stated technologies in the 2015/16 and 2016/17 cropping seasons) and a value of 0 otherwise (practised conventional tillage in the specified cropping seasons).

AGE: Represented the age of the smallholder rainfed farmer in the Pandamatenga region at the time of the survey, measured in years. As the age of the farmer increases, the probability of using conservation agriculture is likely to increase. This is because, older people are often more experienced and knowledgeable than the younger ones. Thus, age is expected to have a positive influence on farmers' decision to adopt CA technologies in the study area.

GENOFF: Referred to gender of the smallholder rainfed farmer, which was measured as a dummy variable, coded with 1 if the farmer was a male and 0 if female. Males are in a better position to attend extension meetings in traditional set – ups and thus have more access to information on new agricultural technologies. Thus, adoption was expected to be higher among males compared to females.

EXP: Represented farming experience, the number of years the smallholder rainfed farmer has been farming, measured as a continuous variable. Experienced farmers are more perceptive of conservational benefits and hence are more receptive to new innovations. Farming experience is expected to positively influence farmers' decision to adopt conservation agriculture.

EDUOFF: Represented the education level of the smallholder rainfed farmer. It was measured as a dummy variable, coded with 1 if the farmer was literate (can only read and write), and 0 if illiterate. Exposure to education increases the ability of farmers to obtain, process and use information relevant to the adoption of new technology, thus level of education was expected to positively influence farmers' decision to adopt CA.

LABPO: Labour availability: It referred to the number of active family members between the age of 15 and 65. It was measured as a continuous variable. A household with larger number of workers per hectare (unit) is more likely to be in a position to try and continue to use a potentially profitable innovation thus it is expected to positively influence farmers' decision to adopt CA.

TLTLU: Livestock possession: This variable was defined in terms of Total Livestock Unit (TLU), it was measured as a continuous variable. Livestock is a source of income which enable households that have large number of livestock to invest on adoption better than others who have less, thus it is expected to positively influence farmers' decision to adopt CA.

FSIZE: Total land holding size: In this study, farm size is defined as total farm size owned by the household head in hectares. It was a continuous variable, measured by the number of hectares of the farm. Farmers with large hectarage under crop production have a greater incentive to invest in conservation agriculture. Farm size is expected to have a positive influence on household decision to adopt CA.

HERBCDPR: Herbicides price: This variable was measured on five-point scale based on farmers' perception as very expensive, expensive, moderately expensive, less expensive and not expensive. It was measured as categorical variable. It was hypothesized that the higher the perceived price of herbicide, the lower the likelihood of using CA.

3.6.4. Specific objective four:

To assess the potential of CA technologies [namely no tillage (NT), no tillage plus mulch (NT + M), minimum tillage (MT), broad bed and furrow (BBF) and crop rotation] on improving sorghum yields.

The on-station research trials and accompanying field records provided by the Department of Agricultural Research at Pandamatenga were used as the data source for this objective. A Randomized complete block design of trial plots with four treatments (NT, MT, NT + M and BBF), and four replicates rotated between sorghum and cowpea was used. A field book was used to record all relevant variables (sorghum grain yield, anthesis date and days to maturity) for three consecutive cropping seasons between the years 2015 and 2017.

3.6.4.1 Data analysis

Data on sorghum grain yield in (kg/ha) were analysed using the Statistical Analysis Software computer package version 9.2 (SAS Institute, 2002-2008). Analysis of variance and means were separated using Duncan's multiple range test at 5% confidence level.

3.6.5 Specific objective five:

To evaluate the DSSAT model in the prediction of yields of sorghum under CA technologies and predict the yield during the mid – century.

3.6.5.1 The DSSAT model methodology

3.6.5.1.1 Model inputs:

3.6.5.1.1.1 Daily weather data from the Experimental site for the duration of the growing season (2015 to 2017)

The weather data for Pandamatenga Department of Agricultural Research was used. The required minimum weather data for the DSSAT model includes daily solar radiation (MJ/M^2), daily maximum and minimum air temperature (°C) received by the crop canopy and daily precipitation (mm). The daily weather data for this study (2015-2017) was collected from the Department of Metrological services in Gaborone (appendix Table 1). The data was formatted and input into the DSSAT model using the weatherman software.

3.6.5.1.1.2 Soil data for the experimental site

The soil profile input included wilting point water content, field capacity, saturated water content, (cm/cm^3), bulk density (g/cm3), soil organic matter content (%), saturated hydraulic conductivity (m/day), soil pH, clay and silt particle size (%). The bulk density and volumetric water content were measured from the experimental site at 5cm depth. The other soil data for the same experimental site was obtained from the DSSAT soil database. The above data were used to construct the model soil profile.

The DSSAT soil profile data also required a sorghum root distribution (i.e. factor from 0 to 1). The sorghum growth factor was estimated using the following relationship; Root growth factor = EXP (-0.02 * layer centre) where layer centre is the depth from the soil surface to the centre of the soil layer in question (Wilkens *et al.*, 2004) . Other soil data information that was needed in the model includes:

Location of the experimental site (country), latitude and longitude of the experimental site, soil data source and soil classification and the colour of the upper horizon that was used to approximate the albedo. The albedo for the vertisols of Pandamatenga was 0.09 corresponding to the black colour of the soils (appendix Table 4). The drainage coefficient was approximated from soil description based on classification. The drainage of the vertisols is poor which gives a drainage coefficient of 0.5 (appendix Table 5). The runoff curve number 84 for cropland soils was approximated from the four hydrological soil group (appendix table 6), from the runoff potential group and from the slope of the site using information in appendix Table 7. When all the necessary soil data information was entered, the soil profile for Pandamatenga vertisols was generated (appendix Table 2).

3.6.5.1.1.3 Crop data

The crops that were used in simulating the growth were sorghum and cowpeas. The DSSAT model required the following crop data for simulation; crop name, cultivar, plant density and harvested grain yield. Furthermore, inputs on crop management practices included date of start of simulation, sowing dates, tillage type and tillage implement used, seed type, depth of sowing, row spacing, rotations, amount and type of fertilizer and manure application, kind and amount of residue applied (appendix Table 3).

3.6.5.1.2 Statistical evaluation of the model

Model calibration

Model calibration or parameterization is the adjustment of parameters so that simulated values compare well with observed ones (Harb *et al.*, 2016). For crop growth models the calibration involves determining genetic coefficient for the cultivar to be grown in a location. For this study calibrated sorghum genetic coefficients from another previous study were used, so the model was not calibrated. To evaluate model performance, simulated and measured crop yields and anthesis dates were compared by changing the soil data initial conditions in the model and analysed by using the following statistics; the Root Mean Square Error (RMSE), Mean Error (E), Modelling Efficiency (EF), index of agreement (d), and linear regression with the coefficient of determination R^2, (Willmott *et al.*, 1985; Yang, *et al.*, 2014a). A paired t- test was used to detect whether the mean error, E, was significantly different from zero (Liu *et al.*, 2013). Statistical evaluation was conducted using EasyGrapher v4.6 software (Yang *et al.*, 2014) .

The above statistics were calculated as follows;

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n}(S_i - M_i)^2/n} \quad \text{......} \quad (9)$$

RMSE is a measure of accuracy to compare the simulated and observed data. The value of RMSE equal to zero indicates the goodness of fit between predicted and observed data.

$$\text{Mean Error, E} = \frac{1}{n}\sum_{i=1}^{n}(S_i - M_i) \quad \text{......} \quad (10)$$

E determines if model predictions tend to underestimate (negative) or overestimate (positive) the measurements.

$$\text{EF} = 1 - \frac{\sum(S_i-M_i)^2}{\sum(S_i-\bar{S})^2} \quad \text{......} \quad (11)$$

EF is a relative measure of error, EF =1 correspond to a perfect match of modelled output with the observed data, EF = 0 indicate that the model predictions are as accurate as the mean of the observed data, whereas an efficiency of less than zero occurs when the observed mean is a better predictor than the model.

$$\text{d} = 1 - \frac{\sum_{i=1}^{n}(S_i-M_i)^2}{\sum_{i=1}^{n}(|S_i'|+|M_i'|)^2} \quad \text{......} \quad (12)$$

The d statistic ($0 \leq d \leq 1$) is used primarily to determine the relative "degree of agreement" (or alternatively, relative "degree of error" between simulated and measured values, with d = 0.0 indicating no agreement (i.e. complete randomness) and d = 1.0 indicating perfect agreement or zero error.

Where S_i and M_i are the ith simulated and measured data, respectively, n is the number of values, $S_i' = S_i - \bar{M}$ and $M_i' = M_i - \bar{M}$, $\bar{M}$ is the average of the measured values.

3.6.5.1.3 Prediction of sorghum grain yield under CA technologies using mid-century weather data (2040 -2070)

The DSSAT model was further used to predict sorghum grain yield using mid – century weather data. The methodology of developing the future weather climate was obtained from the (AgMIP) under the Representative Concentration Pathways (RCP) 4.5 and RCP 8.5 climate scenario for Pandamatenga area (Crespo 2015). The future weather data were used to create the weather data file in the DSSAT model for yield prediction in the future. The RCP 4.5 hot and dry weather data were extracted from the Canadian Earth System Model, the second generation (CanESM2). While hot and wet (RCP 4.5) the weather data were extracted from Hadley Centre Global Environment Model, version 2 Earth Systems (HadGEM2 -ES). Furthermore, RCP 8.5, hot and dry weather data were generated from Max Planck Institute Earth System Model at Lower Resolution (MPI -ESM - LR). The soil and crop management conditions were kept the same as in 2015 – 2017. RCP 4.5 refers to the intermediate emissions which consist of lower energy intensity, strong reforestation programmes and decreasing use of croplands and grasslands due to increased yield. While RCP 8.5 consist of high emissions with a future of no policy changes to reduce emissions (Stocker 2014).

CHAPTER FOUR

4. RESULTS

4.1 Adoption of conservation agriculture technologies

The adoption rate of conservation agriculture technologies among the sampled farmers in Pandamatenga was very low. Minimum tillage was the type of CA that was mostly practiced by adopters (Figure 4.1). The average sorghum grain yield for adopters was 1 ton/ha and for non/adopters it was around 0.35 ton/ha (Table 4.1).

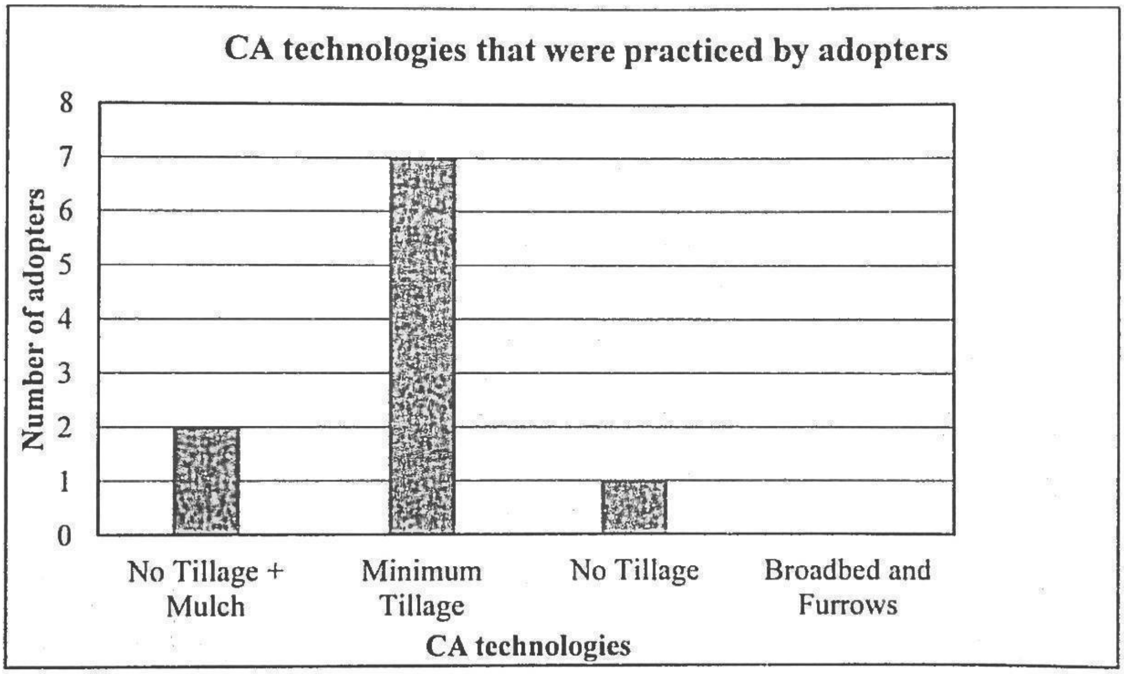

Figure 4. 1: Conservation agriculture technologies that were practiced by adopters in Pandamatenga region

Table 4. 1: Levels of sorghum grain yield under farmers' farming conditions

Farmers	Yield (ton/ha)
Adopters	1
Non -adopters	0.35

4.2 Socio - economic and demographic characteristics of smallholder rainfed farmers in Pandamatenga region.

Table 4.2 presents summary statistics, comparing adopters and non-adopters of conservation agriculture technologies. The mean age for adopters and non-adopters was estimated at 53 and 47 years respectively and the percentage difference of the mean age was statistically insignificant at 5% with a t –value of 1.229.

There was also no significant statistical difference in the average number of family members in the household between adopters and non-adopters of CA technologies. Furthermore, the percentage difference of means for labour potential between adopters and non-adopters of CA technologies was not statistically significant. The average number of years in farming (that is, farming experience) for adopters and non-adopters were estimated at 9 and 8 years, respectively. The percentage difference was not significant at 5% level of significance (Table 4.2).

It can be seen from Table 4.2 that gender of smallholder rainfed farmers between adopters and non-adopters of CA technologies was such that, on average, 76% of the adopters were male. Likewise, 35% of the non-adopters were male. Results revealed that percentage difference (of 54%) between male adopters and non-adopters of CA was statistically significant at 5% level of significance.

Table 4.2 also indicates that 67% of the adopters were married while only 9% of the non-adopters were married. The percentage difference (86%) of married smallholder rainfed farmers between the two groups was statistically significant at 5% level of significance.

The education level, measured in terms of average number of smallholder rainfed farmers who were able to read and write between adopters and non-adopters was statistically significant at 5% level of significance. Almost 86% of the adopters were able to read and write compared to 65.2% for non – adopters. There was also a significant statistical difference in number of livestock owned expressed as Total Livestock Unit (TLU) between adopters and non-adopters at 5% level of significance. The average number of livestock owned by adopters was estimated at 5.6 TLU and 1.4 TLU for non-adopters, with a percentage difference of 75%. Finally, the mean land size between adopters and non-adopters was 16.7 ha and 7.2 ha, and the percentage difference of the means was statistically significant at 5% level (Table 4.2).

able 4.2: Socio - economic and demographic characteristics of adopters and non-adopters conservation agriculture practices in Pandamatenga region

Characteristics	Adopters	Non-adopters	% Difference	T-Statistics	Chi² test	P-Value
Average age of participant (years)	53	47	11	1.229		
Gender of participant (% of male participant)	76	35	54		7.591	0.006**
Marital status of participant (% of married participant)	67	9	86		16.482	0.001*
Average number of members in the household (family size)	5.3	5.4	2	-0.112		
Education level of participant (% of participant who are able to read and write)	85.7	65.2	24		11.780	0.00
Labour Potential (Average number of adults work in the field)	1.2	1.83	54	-1.365		
Average number of livestock (TLU)	5.6	1.38	75	2.309**		
Mean household land size (ha)	16.7	7.20	57	2.654**		
Average number of years in farming (farming experience in years)	9.1	8.43	7	0.317		

** Significant at 5%

4.3 Smallholder rainfed farmers' perceptions and level of acceptance of CA technologies in the Pandamatenga region

Table 4.3 presents a summary of farmers' perception toward CA in the study area. Only twenty – three percent of the smallholder rainfed farmers had full knowledge about CA while forty – three percent were not aware about CA technologies and thirty – four percent were uncertain. From the descriptive statistics, most of the smallholder rainfed farmers were not certain about knowing CA technologies.

Forty – six percent of smallholder rainfed farmers were in agreement that CA technologies could be beneficial to them as it increases yield and income while 41 % were uncertain because they had not practiced CA to see its benefit (Table 4.3).

In preventing soil erosion, 64% of the smallholder rainfed farmers were uncertain. The response of farmers to CA technologies being labour intensive was that more than 50% of them were in agreement. Almost 91% were in agreement that lack of farming implements was a limiting factor in CA. For the incorporation of CA in the future, smallholder rainfed farmers showed positive attitude towards adopting the technology as 77% responded with "agree" (Table 4.3).

Table 4. 3: Summary on farmers' perceptions toward conservation agriculture in the study area

Statement	Farmers' Agreement Score		
	Agree	Disagree	Neutral
I have full knowledge of CA technologies	10 (23%)	19 (43%)	15 (34%)
CA technologies can be beneficial to farmers	20 (46%)	6 (14%)	18 (41%)
Advantages of CA			
Increase yield	20 (46%)	6 (14%)	18 (41%)
Increase income	20 (46%)	6 (14%)	18 (41%)
Prevent soil erosion	10 (23%)	6 (14%)	28 (64%)
Disadvantages of CA			
Labour intensive	24 (55%)	9 (21%)	11(25%)
Lack of farm implements are limiting factors in CA	40 (91%)	2 (5%)	2 (5%)
Having tried CA in the farm, will you continue to adopt	34 (77%)	7 (16%)	3 (7%)

4.4 Social and economic factors influencing smallholder rainfed farmers' decisions to adopt different CA technologies in the Pandamatenga region

Binary logit regression model was used to estimate the natural log of the odds of farmers' decision to adopt CA technologies given selected socio-economic variable.

Table 4.4 presents socio-economic variables, the logistic regression estimates, odds ratios and significance values at 1% and 5% levels of significance. Results showed that the Log-Likelihood function was statistically significant at 1% level of significance. This suggests that when variables are taken together, they strongly influence farmers' decision to adopt conservation agriculture technologies in the study area. Likewise, $\chi2$ statistic of 34.284 showed that the overall model was significant at 1% level signifying fitness of the model. This shows that the explanatory variables were relevant in explaining smallholder rainfed farmers' decision to adopt CA technologies in the study area.

Table 4.4 shows that age, gender of participants, and farm size were statistically significant factors in influencing smallholder rainfed farmers' decision to adopt CA technologies in the study area. Age of participants positively influenced the odds of smallholder farmers' decision to adopt CA technologies in the study area. An increase in age of a farmer by one year, for instance, will increase the odds of adopting a CA practice by 1.045. The negative sign of the coefficient on this variable implied a negative association between gender and farmers' decision to adopt CA technologies. Male farmers were 0.063 times less likely to adopt CA technologies than females in Pandamatenga region.

Farm size positively influenced the odds of smallholder rainfed farmers' decision to adopt CA technologies in the study area and was statistically significant at 5% level of significance. An increase in the size of land by one ha, for instance, would increase the odds of adopting a CA practice by 1.306. Farming experience and total livestock owned were found to have positive association with farmer's decision to adopt CA technologies but their respective individual influences were not significant at both 1% and 5% levels of significance (Table 4.4).

As for the farming experience, an increase of one year, for instance, will raise the odds of adopting by 1.018. An increase in livestock units will raise the odds of adopting CA by 1.645. Education level, labour potential and herbicides price were found to have a negative association with farmer's decision to adopt CA but their respective individual influences were also not statistically significant at both 1% and 5% levels of significance (Table 4.4).

Variables	Coefficients	Std. Error	Sig.	Odds ratio
Constant	-3.135	2.439	0.199	0.043
AGE	0.311	0.213	0.034**	1.045
GENOFF	-2.757	1.316	0.036**	0.063
EXP	0.018	0.092	0.845	1.018
EDUOFF	-2.217	1.662	0.182	0.109
LABPO	-0.653	0.582	0.262	0.520
TLTLU	0.498	0.316	0.115	1.645
FSIZE	0.267	0.131	0.042**	1.306
HERBCDPR	-0.007	1.699	0.997	0.993
Log - Likelihood	26.622			
X^2	34.284			
Probability of X^2	0.000***			

Table 4. 4: Binary logit model estimates (Estimated Log Odds and Odds Ratios)

Source Model output: *** Significant at 1%, ** Significant at 5%

4.5 Effects of CA technologies on the yield of sorghum in the Pandamatenga region

4.5.1 Weather data for Pandamatenga Department of Agricultural Research Station

The weather data for the study area is shown in Figure 4.2. The month of February had the highest amount of rainfall in all the growing seasons. The highest temperatures were experienced in January and October.

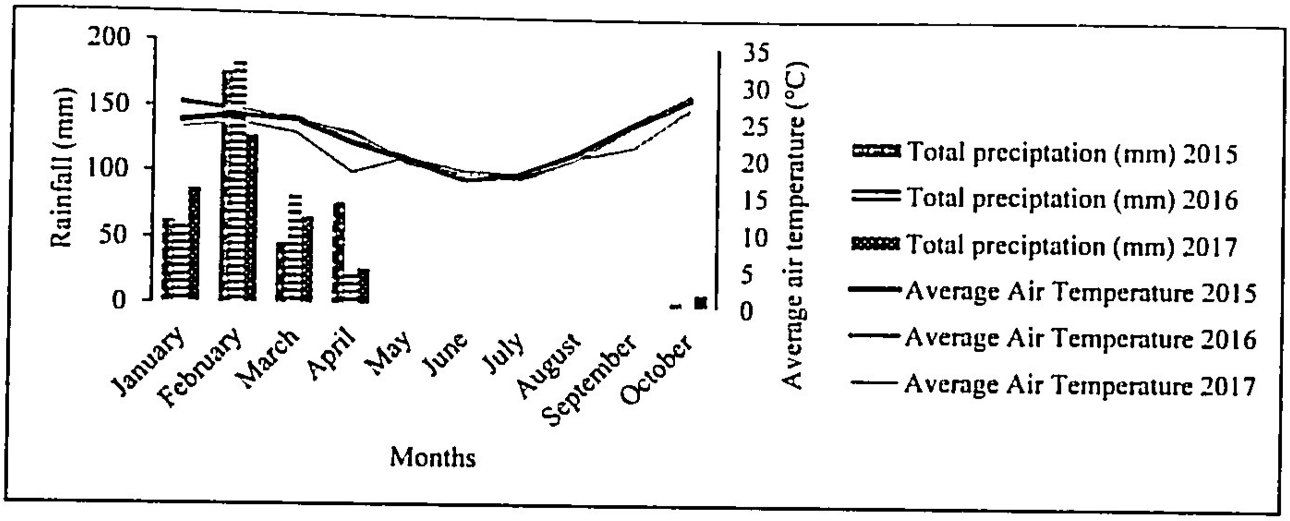

Figure 4. 2: Average air temperature (°C) and total rainfall amount (mm) for the growing seasons (2015 to 2017)

4.5.2 Soil sampling and analysis

Bulk density was greatest in BBF and least under NT+M during 2016 growing season (Table 4.5). In 2017, the bulk density was slightly higher in NT+M and least in MT. Across the growing seasons only NT+M showed a slight increase of the bulk density from1.240g/cm^3 to 1.267g/cm^3 whereas it showed a decrease in other practices. Volumetric water content was also highest in BBF and least under MT in 2016 growing season (Table 4.4). NT + M had the lowest value of volumetric water content in 2017 growing season. In all the practices the volumetric water content showed an increase from 2016 to 2017 growing season (Table 4.5).

Table 4. 5: Selected soil physical parameters that were collected from the field trials during 2016 and 2017 growing seasons at 0-5cm depth

Conservation agriculture practice	Growing seasons			
	2016		2017	
	Bulk density (g/cm^3)	Volumetric water content (cm^3/cm^3)	Bulk density (g/cm^3)	Volumetric water content (cm^3/cm^3)
No Tillage	1.320	0.127	1.261	0.270
Minimum Tillage	1.267	0.140	1.242	0.278
No Tillage + Mulch	1.240	0.113	1.267	0.249
Broad bed and Furrows	1.362	0.141	1.259	0.278

4.5.3 Effect of CA practices on continuous sorghum grain yield

Table 4.6 shows that sorghum grain yield was highest in 2016 cropping season as compared to 2015 and 2017 growing seasons. The continuous sorghum grain yields for 2015 growing season were not significantly different among CA practices. Although not significant, NT+M had the highest amount of sorghum grain yield in 2015. In 2016 growing season the sorghum grain yield was highest in NT (1313kg/ha) but not significantly different from NT+M and BBF. However, the yield was significantly lower in MT (893kg/ha). Sorghum grain yields were not significantly different among the treatments in 2017. No tillage had the highest sorghum grain yield (340kg/ha) in 2017 growing season (Table 4.6).

Table 4. 6: Sorghum grain yield (kg/ha) for the different treatments under continuous sorghum

Treatments	Years		
	2015	2016	2017
	Grain yield (kg/ha)		
No tillage	222a	1313a	340a
Minimum Tillage	231a	893b	260a
No Tillage + Mulch	260a	1153a	112a
Broad bed and furrows	169a	1113a	258a

Difference letters within a column indicate significant difference between values at $P \leq 0.05$

4.5.4 Effect of CA practices on cowpea rotated sorghum grain yield

In 2015 growing season, NT +M had the highest grain yield followed by MT and NT had the lowest amount of yield. No tillage plus mulch had the highest yield again in 2016 while BBF had the lowest amount of grain yield. In 2017 growing season however, BBF had the highest amount of grain yield as compared to NT+M which experienced the least amount of grain yield. In all the cropping seasons there was no significant difference among the treatments (Table 4.7).

Table 4. 7: Sorghum grain yield (kg/ha) for the different treatments under cowpea rotated sorghum

Treatments	Years		
	2015	2016	2017
	Grain yield (kg/ha)		
No tillage	128a	1313a	247a
Minimum Tillage	133a	1260a	223a
No Tillage + Mulch	240a	1403a	165a
Broad bed and furrows	131a	1117a	327a

Different letters within a column indicate significant difference between values at $P \leq 0.05$

4.5.5 Comparison of continuous– and cowpea-rotated sorghum grain yields

Table 4.8 shows that in 2015 the grain yield varied. The difference between the grain yield for cowpea rotated sorghum and continuous sorghum was statistically significant under minimum tillage at 0.05 level in 2016 growing season. While the other three practices were not significant (Table 4.8). In 2017 the difference between the grains yields for cowpea rotated sorghum and continuous sorghum was not statistically significant in all the conservation practices. BBF had the highest amount of grain yield under cowpeas rotated sorghum while NT+M had the least in both cowpea rotated sorghum and continuous sorghum (Table 4.8).

Table 4.8: Comparison of sorghum grain yield (kg/ha) for continuous sorghum and cowpea rotated sorghum

Years		Conservation agriculture technologies			
2015	Cropping systems	NT	MT	NT+M	BBF
	Cowpea rotated sorghum	128	133	240	131
	Continuous sorghum	222	231	260	169
2016	F -value	1.734ns	2.160ns	0.036ns	0.924ns
	Cowpea rotated sorghum	1313	1260	1403	1117
	Continuous sorghum	1313	893	1153	1113
2017	F -value	3.85ns	9.035*	3.200ns	0.713ns
	Cowpea rotated sorghum	247	223	165	327
	Continuous sorghum	340	260	112	258
	F -value	0.380ns	0.171ns	0.287ns	0.281ns

*: P≤ 0.05; Ns = Not significant

4.6 Crop modelling

4.5.1 Evaluation of the DSSAT model in predicting sorghum grain yield under CA technologies

After all the inputs were entered into the model, the model was evaluated to obtain simulated data that were close to experimental data. The statistical indexes in Table 4.9 were used to determine the performance of the model.

The mean value of days after planting simulated for anthesis (56 days) was slightly higher compared to the mean of observed values (54 days). Values of standard deviation for simulated and observed anthesis were the same (Table 4.9). The evaluation process revealed that the model predicted days to flowering for sorghum grain yield very well as the RMSE value was fairly low (Table 4.9). This index indicates that the model works well in simulating the anthesis, that is, one of the most important phases for sorghum growth. The E value (0.5 days) indicated a small and statistically insignificant anthesis overestimated by the model.

The coefficient of determination R^2 indicated that 90% of the total variation was explained by the model. Values of the modelling efficiency index (EF = 0) indicated that the model predictions were as accurate as the mean of the observed data, although the index of agreement showed poor model data agreement (Table 4.9).

The mean and standard deviation of estimated maturity days was the same as that for the observed data (132 days) (Table 4.9). Days to maturity were predicted by the model very well as they had a low value of RMSE (0.01 days). The E at (0) was relatively low indicating that there was no overestimate or under estimate of the model to the data. The coefficient of determination R^2 explained about 99% of the total variation. Values of the modelling efficiency index (EF = 0) indicated that the model predictions were as accurate as the mean of the observed days to maturity, although the index of agreement showed poor model data agreement.

The mean value of simulated sorghum grain yield (1137kg/ha) was less than the observed sorghum yield (Table 4.9). Values of standard deviation for simulated sorghum grain yield were higher respect to observed yield. It further showed that sorghum grain yield was perfectly evaluated as it was indicated by the lower value of RMSE (0.15). Ninety-nine percent of the total variation was explained by the model (R^2 = 0.99). Values of the modelling efficiency index (EF = 0.99) and of the index of agreement (d-index = 0.98) confirmed the good concordance between values observed and values estimated by the CSM-CERES-Sorghum model (Table 4.9).

Table 4. 9: Statistical indexes for the evaluation of CSM-CERES-Sorghum

Statistical indexes		Yield (kg/ha)		Anthesis (DAP)		Maturity (MDAP)	
		OBS	SIM	OBS	SIM	OBS	SIM
Mean	M	1143	1137	54	56	132	132
Standard Deviation	SD	155	158	0	0	0	0
Maximum	MAX	1313	1311	54	56	132	132
Minimum	MIN	893	881	54	56	132	132
Number of samples	N	16	16	16	16	16	16
Root Mean Square Error	RMSE	0.15		0.03		0.01	
Mean Error	E	1.6ns		0.5ns		0	
Modelling Efficiency	Ef	0.99		0		0	
Index of agreement	d	0.98		0		0	
Coefficient of Determination	R^2	0.99		0.90		0.99	

Anthesis: (DAP=day to flowering after planting) and maturity (MDAP =days to maturity after planting, ns: not significant, OBS: observed yield, SIM: simulated yield

4.5.2 Simulated yields versus observed yields

Grain yields obtained by the model were closer to mean yields obtained in the four treatments in the three experimental years (Figure 4.3). In 2015 for NT and MT, simulated sorghum grain yield was the same as for observed yield. Whereas in NT + M simulated sorghum grain yield was slightly more than observed sorghum grain yield. While in BBF observed sorghum grain yield was also slightly more than simulated sorghum grain yield. In 2016 growing season all the treatments sorghum grain yields had a positive difference except in continuous NT. The results in 2017 growing season showed that the sorghum grain yield was underestimated in all the treatments except in NT (Figure 4.3).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the study Area

The study was based at Pandamatenga village. Pandamatenga region lies in the northern part of Botswana between latitude 18° 32' South, and longitude 25° 38' East and it covers an area of 280, 380 ha. The village is about 100km South of Kasane in the Chobe District. The Pandamatenga farms (in Figure 3.1) cover only 25,074 ha of this total land area (Tapela *et al.*, 2007).

3.2 Socio - economic environment

According to the housing and population census of 2011, the population of Pandamatenga village is 1798 people exclusive of associated localities. Pandamatenga village has 909 females and 889 males. This implies slightly higher female labour force for the farms (Statistics Botswana, 2011).

The government provides the basic services and amenities based on the size of the settlements (CAR, 2009). Facilities such as health posts do exist in the village. The village is connected to the national electricity grid. Lined telephone is connected to the area. Main source of water is borehole. Pandamatenga village is linked to Kasane, 100km to the North and Francistown about 400km to the South by a good tarred road. The village has one primary school, a post office and a police station and some government offices for various services (CAR, 2009).

The climate for the Chobe district and Pandamatenga in particular is semi–arid characterized by hot and moist summers and dry mild winters. Rainfall is derived from convective processes and its highly variable even over small distances and averages 600 mm annually, thus making Pandamatenga one of Botswana's least arid areas. Almost all rain falls between October and April, with December, January and February being the peak months. A substantial proportion of this rain, falls in short duration of high intensity storms, thus, leading to high run–on into some farms, which become flooded instantly. Maximum temperatures range between 26°C to 34°C and are experienced between October to March. Minimum temperatures range between 11°C to 20°C and are experienced between November and July. The vegetation is extensive grassland savannah in association with Mophane (*Colophospermum mopane*) and acacia species (CAR, 2009).

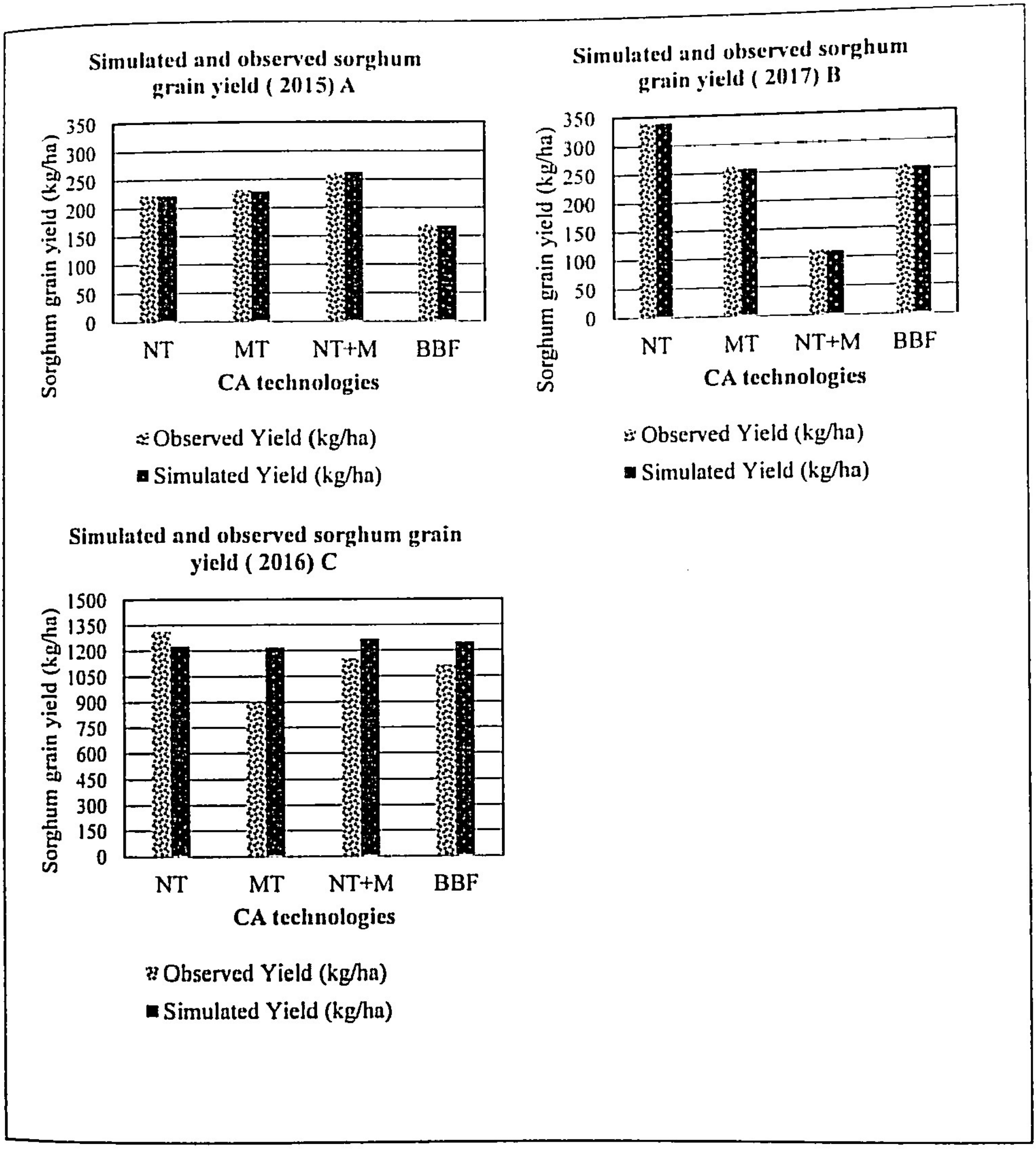

Figure 4.3: Comparison of simulated and observed sorghum grain yield under each CA technology for three cropping seasons

4.5.3 Prediction of sorghum grain yield under CA technologies using mid-century weather data (2040 -2070)

4.5.3.1 Climate change projections in mid – century (2040-2070)

According to the forecasted weather data both the maximum and minimum air temperatures in Pandamatenga will be increased beyond the present conditions under RCP 4.5, hot and dry climate conditions (Figure 4.4). Maximum temperatures will be increased by 3°C while minimum temperatures will be increased by 2°C.

An increased amount of rainfall will be experienced in the RCP 4.5, hot and dry climate in the months of January, October, November and December while in February, March and April the amount of rainfall will be decreased (Figure 4.4).

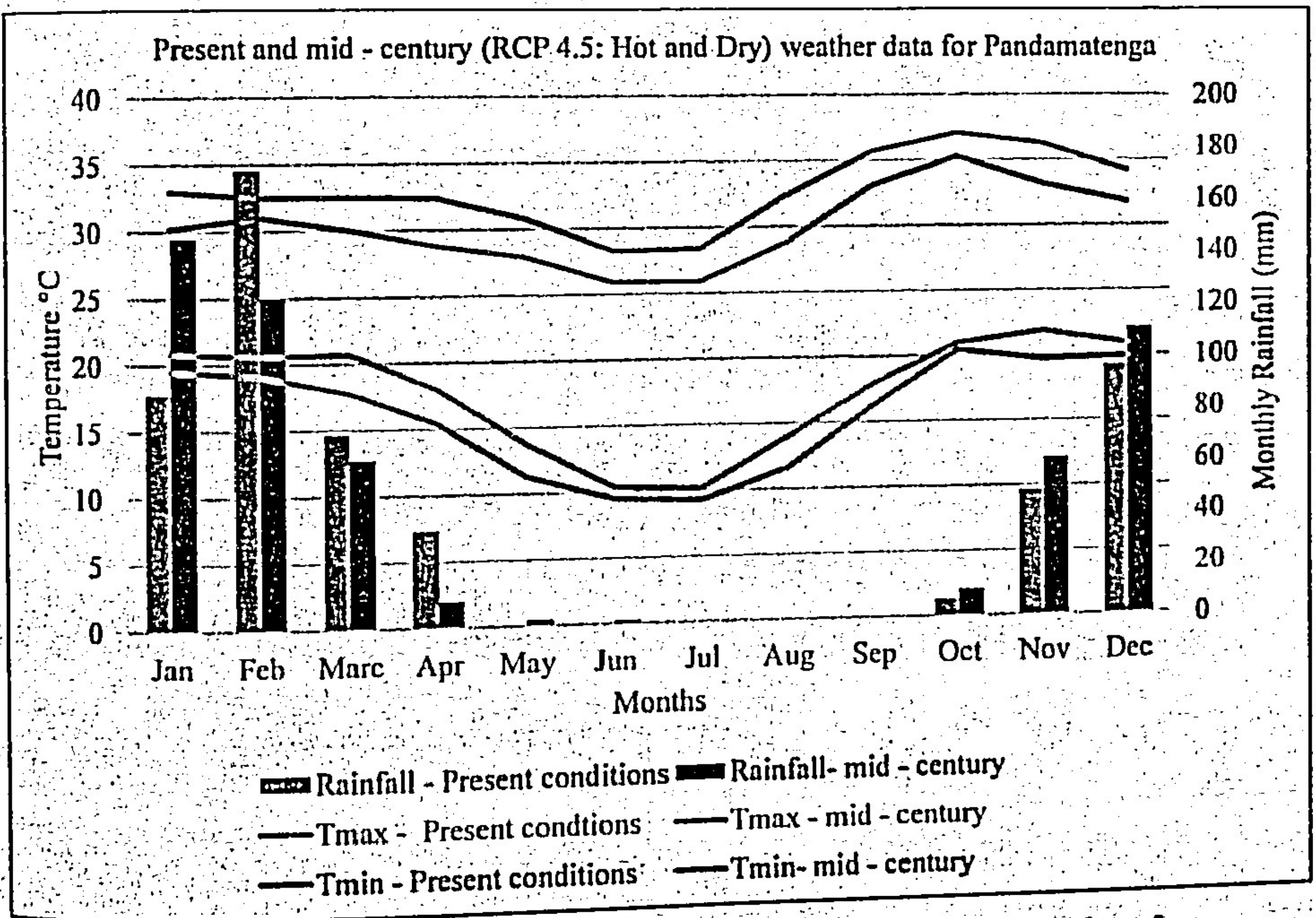

Figure 4. 4: Present and mid – century (RCP 4.5 Hot and Dry) weather data for Pandamatenga Department of Agricultural Research Station

4.5.3 Prediction of sorghum grain yield under CA technologies using mid-century weather data (2040 -2070)

4.5.3.1 Climate change projections in mid – century (2040-2070)

According to the forecasted weather data both the maximum and minimum air temperatures in Pandamatenga will be increased beyond the present conditions under RCP 4.5, hot and dry climate conditions (Figure 4.4). Maximum temperatures will be increased by 3°C while minimum temperatures will be increased by 2°C.

An increased amount of rainfall will be experienced in the RCP 4.5, hot and dry climate in the months of January, October, November and December while in February, March and April the amount of rainfall will be decreased (Figure 4.4).

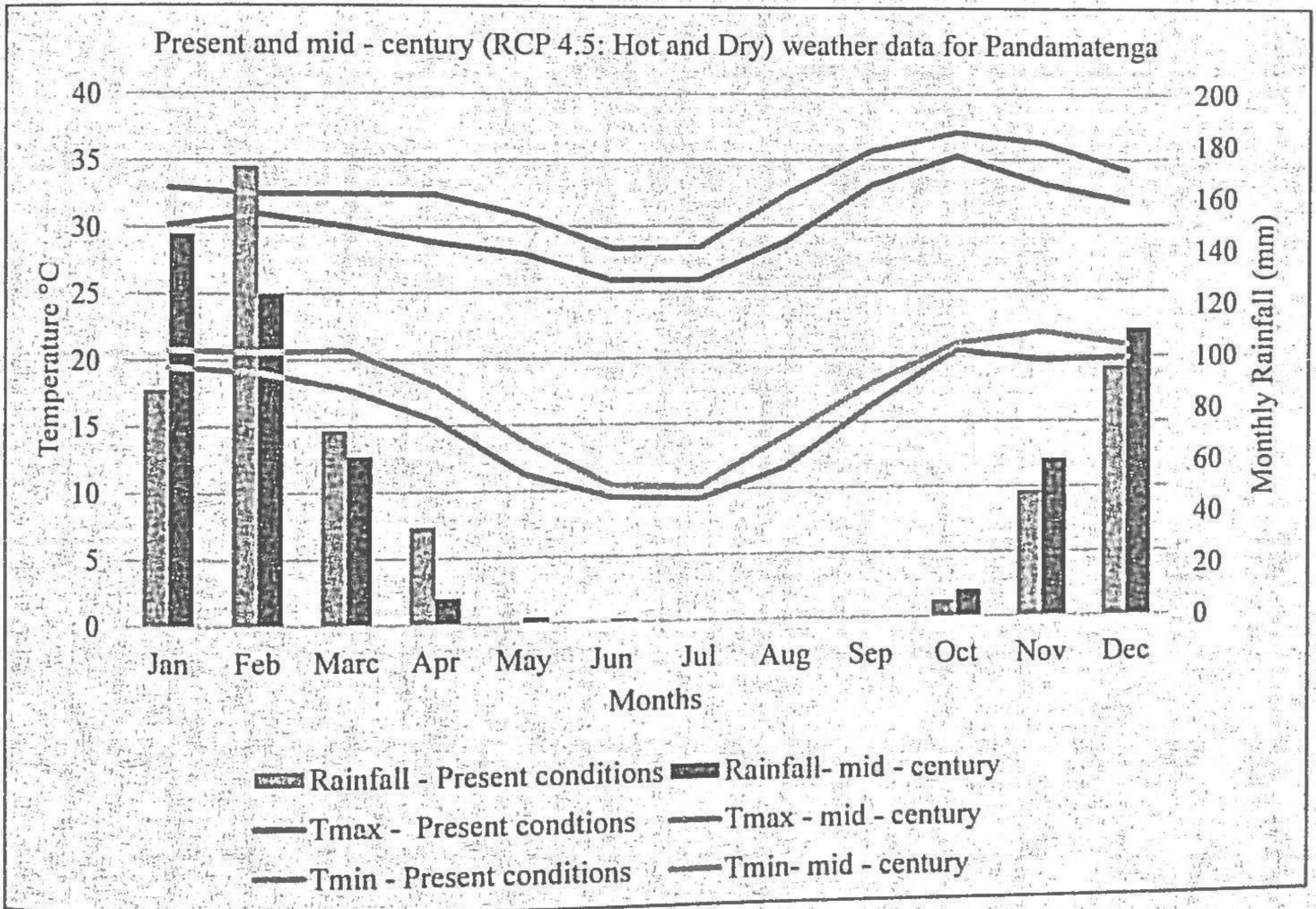

Figure 4. 4: Present and mid – century (RCP 4.5 Hot and Dry) weather data for Pandamatenga Department of Agricultural Research Station

Under RCP 4.5, hot and wet climate conditions both maximum and minimum temperatures will be decreased by 2°C (Figure 4.5). An increased amount of rainfall will be experienced in the RCP 4.5, hot and wet climate conditions in the months of January, October, November and December while in February, March and April the amount of rainfall will be decreased (Figure 4.5).

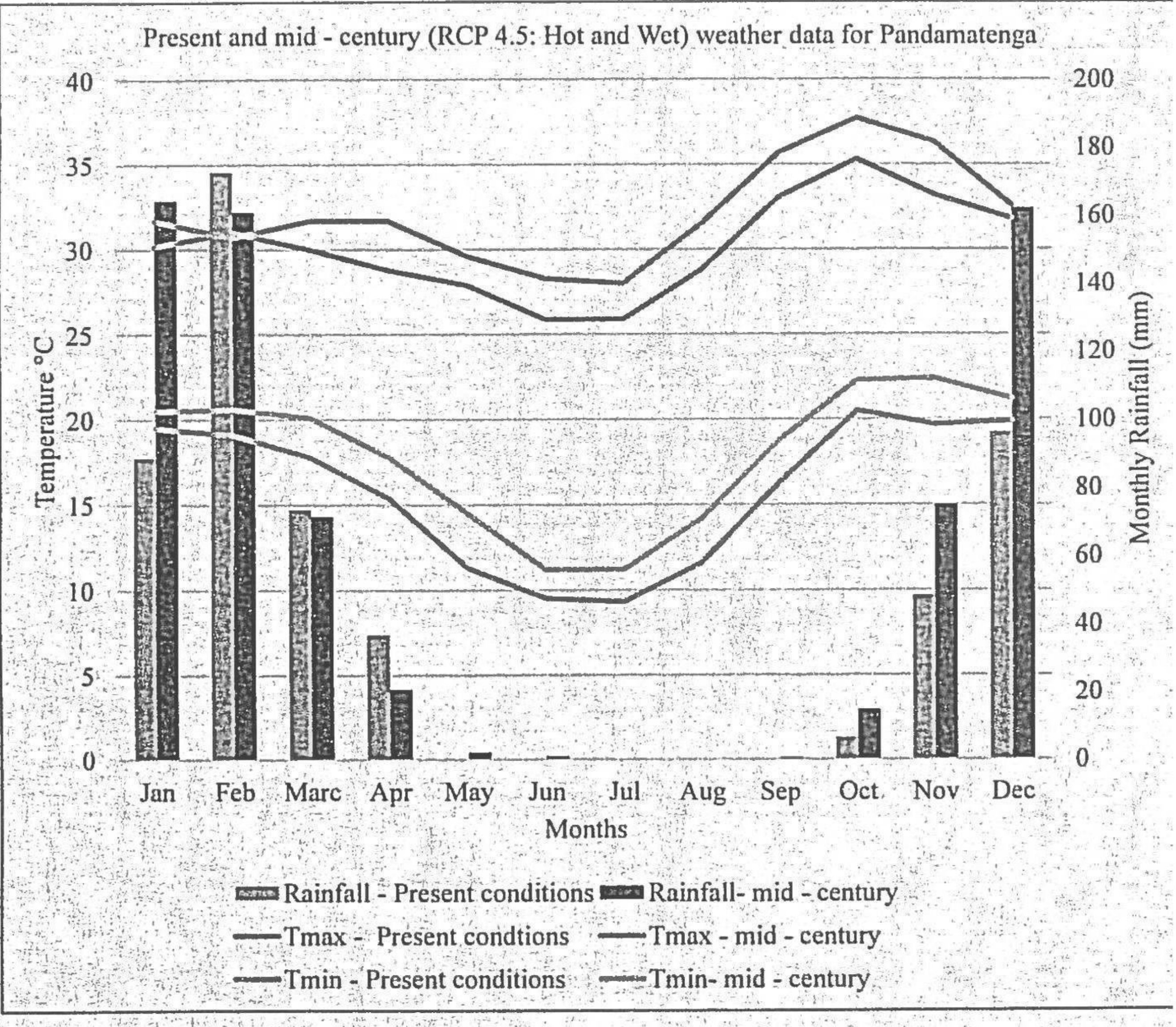

Figure 4. 5 Present and mid – century (RCP 4.5 Hot and Wet) weather data for Pandamatenga Department of Agricultural Research Station

Climate conditions under RCP 8.5 hot and dry and hot and wet, both the maximum and minimum temperatures will be increased by 3°C and 2°C (Figure 4.6 and 4.7). A decreased amount of rainfall will be experienced in the RCP 8.5, hot and dry climate conditions in all the months except in months of January and October (Figure 4.6).

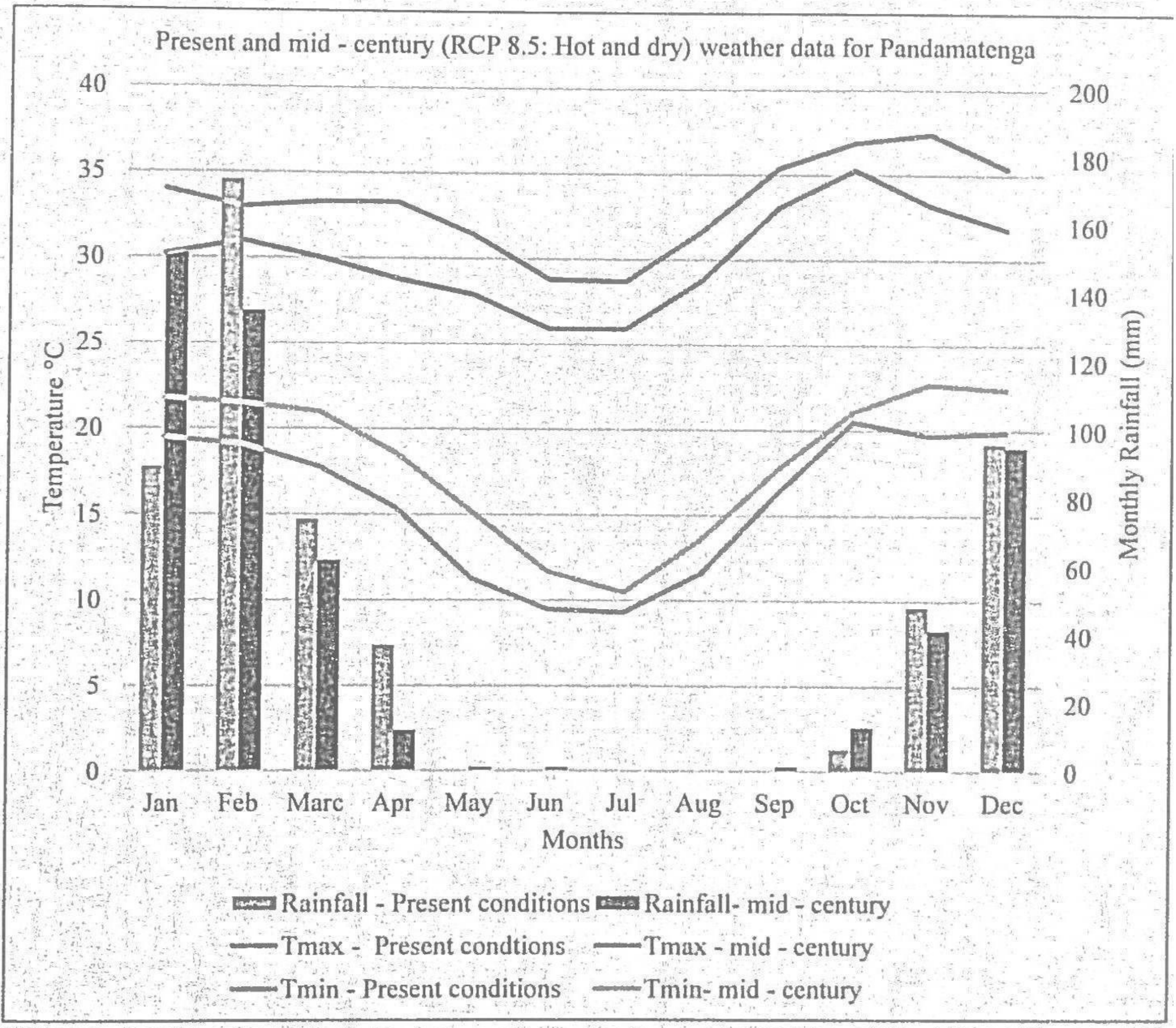

Figure 4. 6: Present and mid – century (RCP 8.5 Hot and Dry) weather data for Pandamatenga Department of Agricultural Research Station

The amount of mean monthly rainfall will be increased under RCP 8.5, hot and wet climate conditions in the months of January, March, October, November and December. The total amount of rainfall will also be higher than present conditions by 23.4%.

Temperature and rainfall are the main critical factors that affect the growth and yield of sorghum. Therefore, these changes will be attributed to the mid - century yields of sorghum in Pandamatenga area.

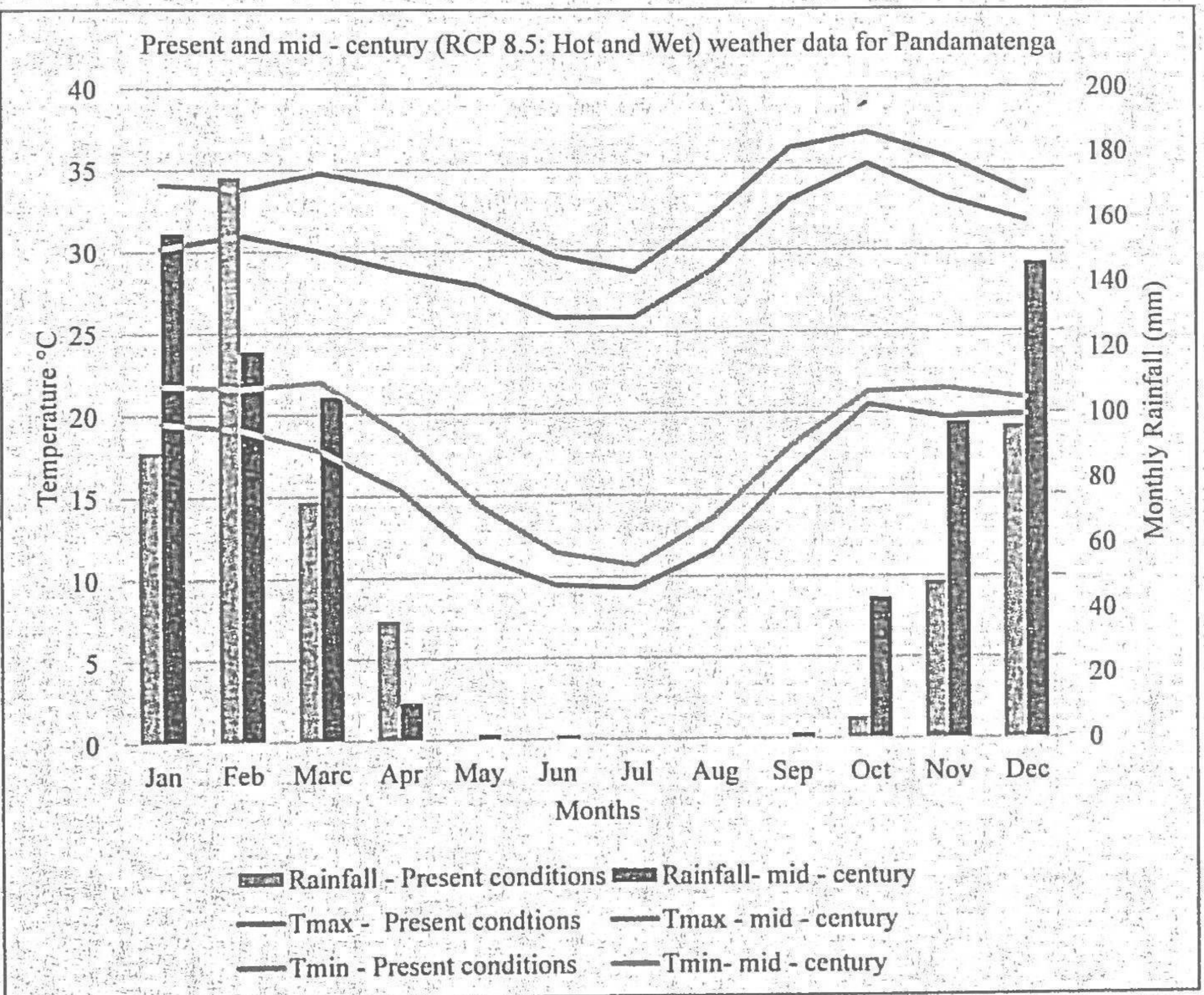

Figure 4. 7: Present and mid – century (RCP 8.5 Hot and Wet) weather data for Pandamatenga Department of Agricultural Research Station

4.5.3.2 Predicted sorghum grain yield from CA technologies in the mid- century

Simulation results of sorghum growth and yield under future climate conditions in DSSAT model are presented in (Table 4.10). According to these results, under climate change scenario (RCP 4.5 and 8.5) sorghum yield will be decreased in the mid-century as compared to the present conditions (2016) which was considered as an above average baseline season. Sorghum grain yield will be reduced by 20%. In the mid- century, the growth periods will be reduced as compared to the present conditions (Table 4.10). Even though the predicted future sorghum grain yield showed a decrease in all the CA technologies, however NT + M will have the highest sorghum yield in the mid – century under the RCP 4.5 and RCP 8.5 climate scenario in both hot and dry and hot and wet conditions as compared to other CA technologies (Table 4.10). Broad bed and furrow will have the second highest sorghum grain yield whilst MT will record the lowest (Table 4.10). If the mid – century will be hot and wet, sorghum yield will be higher as compared to hot and dry in both RCPs.

Table 4. 10: Predicted sorghum grain yield (kg/ha) using the mid – century weather data (2040 -2070)

Present condition		Mid – century			
	2016	RCP 4.5		RCP 8.5	
		Hot and dry	Hot and wet	Hot and dry	Hot and wet
NT	1228	869	896	858	1090
MT	1221	866	886	856	1084
NT+M	1267	878	912	868	1146
BBF	1249	874	904	862	1098
DAP	56	54	56	51	50
MDAP	132	96	99	92	89

Anthesis: (DAP=days to flowering after planting) and (MDAP =days to maturity after planting

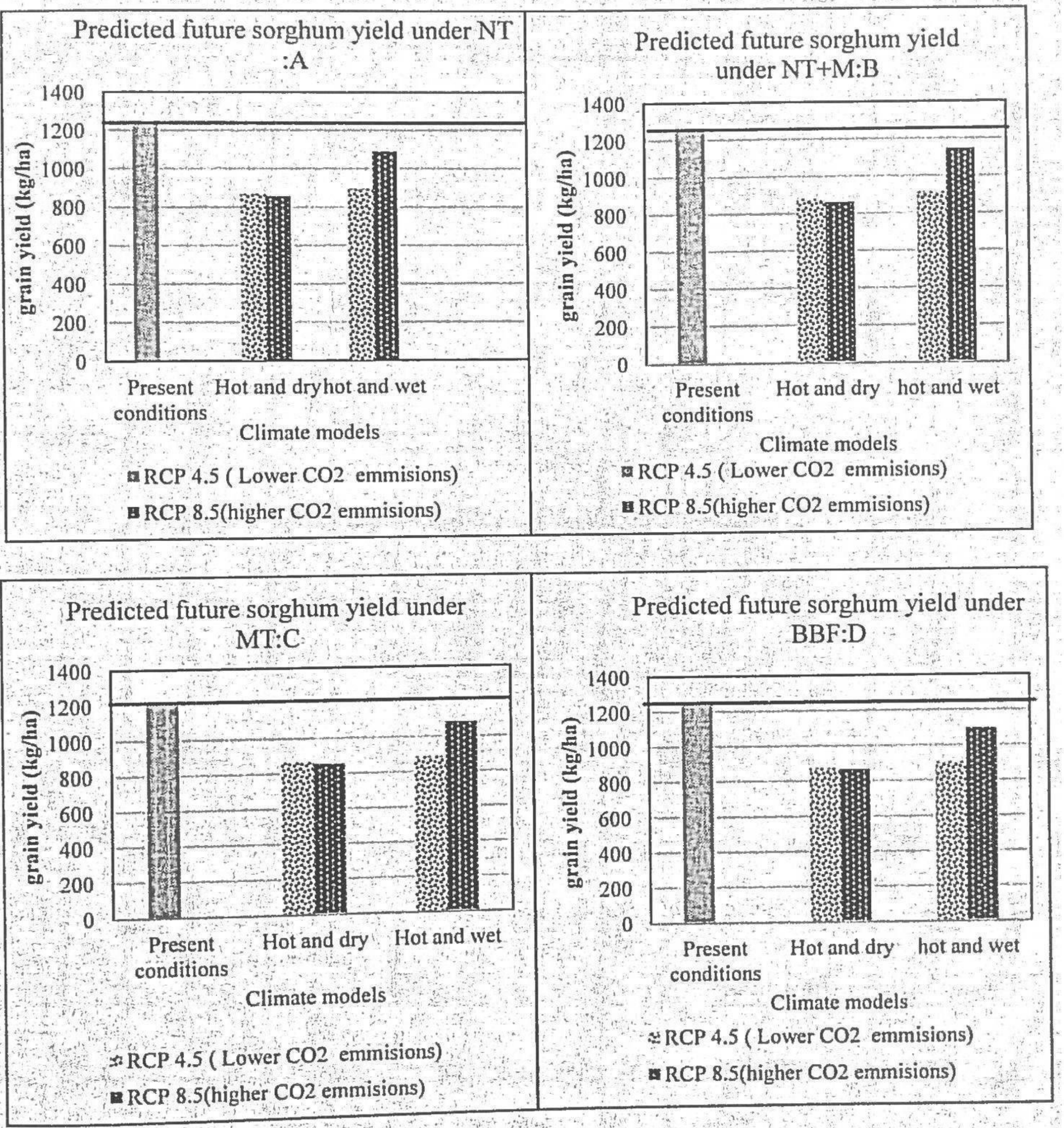

Figure 4. 8: Predicted future sorghum grain yield (kg/ha) under Conservation Agriculture technologies

CHAPTER FIVE

5. DISCUSSIONS

5.1 Socio-economic and demographic characteristics of smallholder rainfed farmers in Pandamatenga region

Farmers' socio-economic and demographic characteristics are expected to have a great influence on agricultural development.

In Table 4.2, adopters were older than non-adopters though not statistically significant. Jumbe & Nyambose (2016) also found out that age of household head was not significantly different for adopters and non-adopters of conservation agriculture in Malawi.

In contrast, Ngombe *et al.* (2014) and Mwangi & Kariuki (2015) found out that age of household head was statistically significant and it implied that older household heads are often associated with long years of experience in farming.

Average number of family members in the household was not statistically significant (Table 4.2). This might imply that not all the household members participate equally and are productive in the fields so that the big household size translates to availability of labour and hence adoption. Also, in the study area family labour was scarce due to migration to urban areas for jobs and schooling. In contrast Fanuel (2013) found out that adopters had a large household size compared to non-adopters and it was statistically significant in Zimbabwe.

Table 4.2 also indicated that labour potential in terms of average number of adults working in the field was not statistically significant. On average, the number of active adults was 1.2 for adopters and 1.83 for non –adopters which is not enough to be assumed as economically active. Some farmers indicated that the activity that demanded most labour was weeding and they tackled it by the use of herbicides that was supplied by the government for free. Jumbe & Nyambose (2016) found similar results that labour potential between adopters and non-adopters was statistical insignificant. In contrast, Ngombe *et al.* (2014) and Mlenga & Maseko (2015) reported that an increase in economically active family members contributed to agricultural labour and it was found to be a significant variable. The average number of years in farming (that is, farming experience) is another important variable that has a relationship to adoption. Table 4.2 has shown that the difference in percentage of farming experience in years was not statistically significant between adopters and non-adopters. From the study area, most of the respondents were old people (especially the non-adopters) who had more than 10 years of farming and it is not easy for them to convert to modern agriculture practices. The findings of this study are contrary with the results of Tigist (2010) and Fanuel (2013) who reported that the mean difference in years of experience between adopters and non-adopters was statistically significant and it was further indicated that longer farming experience implied accumulated farming knowledge and skill which has contribution to adoption.

The study also indicated that gender of smallholder rainfed farmers in terms of number of male farmers who participated in the survey between adopters and non-adopters in the study area was statistically significant with a higher percentage difference. This might be due to males having better chances of access to information as compared to their female counterparts in the study area. Female especially in rural areas tend to have less time for community meetings due to household chores. The findings of this study are in contrast with those of Jumbe & Nyambose (2016) who reported none statistical significance in the gender of the household between adopters and non-adopters (Table 4.2).

There was also a significant statistical difference in the marital status of the smallholder rainfed farmers (Table 4.2). This implies that married couple are in a better position to consult with each other to make good decisions. Ngombe *et al.* (2014) reported similar significant results between adopters and non-adopters of CA. They reasoned that married farmers had higher social connections and interactions with other farm households which gave them better access to information about agricultural technologies.

According to Jumbe & Nyambose (2016), human capital endowment factors enable potential adopters to understand and evaluate new information, thus affecting both adoption and diffusion of new technologies. They further stated that exposure to education increases the ability of farmers to obtain, process, and use information relevant to the adoption of new technology. From the results of this study, education level of smallholder rainfed farmers, who were able to read and write was statistically significant. This shows that education is an important household characteristic as it can increase the transfer of relevant information to the farmers. Fadare *et al.* (2014) and Bazezew (2015) reported that education was one of the significant variables to enhance the adoption of CA.

Furthermore, this study revealed that the average number of livestock (TLU) was one of the variables that was statistically significant with a higher percentage difference. This implies that ownership of livestock is an important household economic characteristic as it was regarded as a source of income in the study area. Similar results were reported by Kassie *et al.* (2012) and Bazezew (2015). Finally, this study revealed that mean land size difference between adopters and non-adopters was statistically significant (Table 4.2). This means that ownership of large areas of land was very vital in the study area. Similar results were reported by Fadare *et al.* (2014). In contrast, Ngombe *et al.* (2014), found out that land size difference between adopters and non-adopters was not statistically significant.

5.2 Smallholder rainfed farmers' perceptions and level of acceptance of CA technologies in the Pandamatenga region

The relative superiority of the technology in terms of its advantage enables farmers to have favourable perception about it. Having a favourable perception about a given technology enhances decision in favour of adoption of that technology. Farmers' perception about technology is one of the factors, which can facilitate or undermine adoption of CA practices.

Table 4.3 showed that most farmers did not have a full knowledge of CA. Only few responded with "agree". This might be due to farmers' understanding of CA in different ways. Some of them reported that they only saw the practices on television, and had never practiced it in their farms to appreciate its benefit.

Most farmers responded with "agree" to CA as it is labour intensive. Lack of farming implements was perceived a limiting factor to adopt CA as farmers did not have enough funds to purchase farm implements. Finally, over 77% of smallholder rainfed farmers showed interest towards acceptance and adoption of conservation agriculture practices (Table 4.3).

5.3 Social and economic factors influencing smallholder rainfed farmers' decisions to adopt different CA technologies in the Pandamatenga region

Section 5.1 dealt mainly with descriptive statistics of the sample population. This study also tested whether or not there was association between farmers' decisions to adopt CA technology and selected socio-economic and demographic variables. There was need to identify factors that influenced CA adoption decisions and quantify their relative influence for purposes of priority-based intervention. In this section, results from the binary logistic regression model were used to measure the relative influence of different socio-economic variables on smallholder rainfed farmers' adoption decisions regarding CA technologies in the study area. Age was positively related to farmers' decision to adopt CA practices. The coefficient on this variable was statistically significant (Table 4.4). Older farmers are more likely to adopt CA practices than younger farmers. This might be because older people normally have more land ownership rights than their younger counterparts (Jumbe & Nyambose 2016).

Adoption of CA technologies was expected to be higher among males compared to females. The results however, showed that males were less likely to adopt than females in the study area (Table 4.4). This might be because, in the study area, land preparations for CA technologies is mainly done by females during dry season. During this period, men would be busy with off-farm activities which would hinder them from participating in the dry land preparation hence reducing their probability of the adoption of CA technologies in the study area. The results are consistent with those of Phiri (2013) who established that the higher adoption rate was more likely among female farmers than their counterpart male farmers. In contrast, Jumbe & Nyambose (2016) reported that males were more likely to adopt CA technologies than females.

The results from this study show that farm size was positively related to farmers' decision to adopt CA practices. The coefficient on this variable was statistically significant (Table 4.4). Farmers with large hectarage under crop production have a greater incentive to invest in CA. This is also confirmed by Fadare *et al.* (2014), Bazezew (2015) and Jumbe & Nyambose (2016). From the descriptive statistics shown in Table 4.2, the adopters had more land owned on average than non-adopters and the difference was statistically significant. Farming experience and total livestock owned were found to positively influence farmer's decision to adopt CA technologies but their influence on farmers' CA adoption decisions was not statistically significant. Education level, labour potential and herbicides price were found to negatively influence farmer's decision to adopt conservation agriculture technologies but their influence on farmers' CA adoption decisions was also not statistically significant (Table 4.4).

5.4 Effects of CA technologies on the yield of sorghum in the Pandamatenga region

5.4.1 Soil sampling and analysis from the trials

Bulk density showed a decrease in its values across the growing seasons for NT, MT and BBF (Table 4.5). The decrease is attributed to the increase of volumetric moisture content due to the continuous expansion of vertisols on wetting as it was stated by Pardo *et al.* (2012).There was an increase in volumetric water content from all the treatments from 2016 to 2017. This is attributed to the fact that collection of soil samples was done during wet periods.

5.4.2 Effects of conservation agriculture technologies on sorghum grain yield

5.4.2.1 Continuous Sorghum yield

Conservation agriculture has a potential for increasing yields regardless of the bad environmental conditions (Owenya *et al.*, 2011). The effects of these practices on sorghum grain yields has not been fully appraised in Botswana conditions especially in the Pandamatenga vertisols despite their influence on offering sustainability of crop production through more effective management of soil and water.

The study showed that the highest sorghum grain yield was experienced in 2016 growing season as compared to the other two growing seasons (Table 4.6). The highest sorghum grain yield was within the potential yield range of the *segaolane* variety (1-3 tons/ha) at optimum conditions in Botswana. This highest amount of grain yield was attributed to the highest amount of rainfall which was received in 2016 growing season (Figure 4.2). The lowest sorghum grain yield in 2015 and 2017 growing seasons was attributed to the lowest amount of rainfall which was experienced (Figure 4.2). The lowest yields can also be attributed to the distribution of rainfall during the growing season especially in 2017. Additionally, the effect of late planting for 2017 contributed to decline in sorghum grain yield.

In this study, NT and NT+M treatments had the highest sorghum grain yield in all the growing seasons (Table 4.6). The highest yield from these treatments might be attributed to the fact that NT or minimum disturbance of the soil allowed the retention of soil organic matter, which provided

5.4 Effects of CA technologies on the yield of sorghum in the Pandamatenga region

5.4.1 Soil sampling and analysis from the trials

Bulk density showed a decrease in its values across the growing seasons for NT, MT and BBF (Table 4.5). The decrease is attributed to the increase of volumetric moisture content due to the continuous expansion of vertisols on wetting as it was stated by Pardo *et al.* (2012).There was an increase in volumetric water content from all the treatments from 2016 to 2017. This is attributed to the fact that collection of soil samples was done during wet periods.

5.4.2 Effects of conservation agriculture technologies on sorghum grain yield

5.4.2.1 Continuous Sorghum yield

Conservation agriculture has a potential for increasing yields regardless of the bad environmental conditions (Owenya *et al.*, 2011). The effects of these practices on sorghum grain yields has not been fully appraised in Botswana conditions especially in the Pandamatenga vertisols despite their influence on offering sustainability of crop production through more effective management of soil and water.

The study showed that the highest sorghum grain yield was experienced in 2016 growing season as compared to the other two growing seasons (Table 4.6). The highest sorghum grain yield was within the potential yield range of the *segaolane* variety (1-3 tons/ha) at optimum conditions in Botswana. This highest amount of grain yield was attributed to the highest amount of rainfall which was received in 2016 growing season (Figure 4.2). The lowest sorghum grain yield in 2015 and 2017 growing seasons was attributed to the lowest amount of rainfall which was experienced (Figure 4.2). The lowest yields can also be attributed to the distribution of rainfall during the growing season especially in 2017. Additionally, the effect of late planting for 2017 contributed to decline in sorghum grain yield.

In this study, NT and NT+M treatments had the highest sorghum grain yield in all the growing seasons (Table 4.6). The highest yield from these treatments might be attributed to the fact that NT or minimum disturbance of the soil allowed the retention of soil organic matter, which provided more nutrients for the growing crop and also stabilized the structure of the soil and made it less vulnerable to crusting and erosion thus benefiting crop growth under dry condition (FAO, 2010). No tillage is an optimal management practice which minimises sub – soil compaction and induces natural structure formation through shrink and swelling cycles (Hati *et al.*, 2015). The maintenance of a permanent soil cover with mulch also increased the stability of vertisols. Furthermore, soil surface was protected from raindrops resulting in high infiltration rates and reduced runoff leading to moisture availability to crops (Wall & Thierfelder 2013). Mulch also reduces cracking in vertisols as residues form a physical barrier that reduces speed of wind over the surface and this leads to the reduction of soil moisture evaporation thus enhancing soil availability for plants uptake (Bandyopadhyay *et al.*, 2003; Federica, 2015). Similarly, Zheng *et al.* (2014) stated that no tillage had the highest grain yield as compared to other CA practices. Similar results were reported by Araya *et al.* (2011), in which yield of crops were significantly affected by CA practice treatments.

5.4.2.2 Cowpea Rotated Sorghum

Positive and negative effects of crop rotation and monoculture are more marked in CA farming than in conventional systems. Crop rotation in the field is very important in the fertilization of the soil through nitrogen fixation process in legumes (Wall & Thierfelder, 2013).

In this study NT+M had the highest mean grain yield for cowpea rotated sorghum for two cropping seasons (Table 4.7). The higher yield from this practice might be attributed to the fact that no tillage mixed with mulch improved soil fertility as there was less soil disturbance and this allowed soil organic matter retention as living organisms in this environment broke down the mulch and incorporated it into the soil. Mulch also improved soil moisture conditions by improving soil structure and reduced soil water evaporation, thus benefiting crop growth under dry conditions. Similarly Zheng *et al.* (2014) stated that no tillage with straw retention had the highest grain yield as compared to other CA practices.

On the other hand, BBF had the lowest amount of cowpea rotated sorghum grain yield on average (Table 4.7). However, Wubie (2015) reported an increase of 59% as compared to the control and it was attributed to the fact that in BBF the surface drainage was enhanced which resulted in early establishment of the crop so that it relatively tolerated the rainstorm and escaped the terminal moisture stress. Finally, sorghum grain yield between continous sorghum and cowpea rotated sorghum was not significant in all the treatments except in 2016 growing season for MT.

5.5 The DSSAT Crop Model

5.5.1 Evaluation of the DSSAT Model

The DSSAT crop simulation model can be a valuable tool in evaluating the effects of climate change on yield under different CA practices. Before accurate results can be obtained from the model, however, evaluation of the model is necessary. In this study, the DSSAT model was used to simulate sorghum grain yield under CA technologies. The evaluation of the model was performed using the field experiment for 2016 growing season from Pandamatenga Department of Agricultural Research station. The variables that were used for evaluation were anthesis date, maturity date and sorghum grain yield.

The evaluation process revealed that the model predicted sorghum anthesis date, maturity date and sorghum yield very well as the RMSE for all variables were very low (Table 4.9). This implies that the model performed well for the field experiment in question. This is supported by Ngwira *et al.,* (2014) who found out that the DSSAT study evaluation was well for maize grain yield as their mean difference between simulated and observed was low.

The coefficient of determination R^2 explained more than 90% of the total variation for all the variables. This shows that the model provided excellent correlation between simulated and observed data. In addition, values of the modelling efficiency in all the variables indicated that the model predictions were as accurate as the mean of the observed data. Similarly, Liu *et al.* (2013), evaluated the model on maize yield and reported a good agreement between simulated and measured grain yield as it had a lower RMSE.

From this study the d- statistics, which was primarily used to determine the relative degree of agreement, showed a poor model agreement in anthesis date and maturity date. In sorghum grain yield the d- statistics confirmed a good agreement between simulated sorghum grain yield and observed yield. In contrast , Ngwira *et al.* (2014), found out that there was a good agreement between simulated and observed anthesis and maturity dates as the error was low for all the treatments. Carboni (2010) also found out that the evaluation of CERES –Wheat crop simulation was done successfully giving excellent values of RMSE, d- statistics and R^2 in anthesis, maturity days and yield. These results are also in agreement with Harb *et al.* (2016), who found that CERES- Maize model evaluation showed excellent and good simulation accuracy for seed yield.

5.5.2 Simulated sorghum grain yield versus observed sorghum grain yield

There was a good agreement between simulated and observed yield for all the treatments in sorghum grain yield as it had a coefficient of determination of 0.99 (Table 4.9). This implies that 99% of the total variation was explained by the model. The model simulated the grain yield well for all treatments (Figure 4.3) These comparisons show that the model has the potential to simulate sorghum yield.

5.5.3. Prediction of sorghum grain yield under CA technologies using mid-century weather data (2040 -2070)

Smallholder rainfed farmers in Botswana are experiencing lower yields yet more erratic rainfall which challenge their ability to grow crops are based on predictions on the effects of climate change. New drought-resistant varieties can go some way to help them adapt, but only by combining them with new cropping systems to overcome crop production challenges. Simulation models can identify the best farming practices to counter the effects of climate change.

In this study, the simulated sorghum grain yield under the mid – century weather data, showed that the yield for sorghum will be reduced in the mid -century as compared to the present conditions (Table 4.10). This can be attributed to the high temperatures which will be experienced in the mid-century (37°C under RCP 4.5 hot and dry and 38°C hot and wet). Also, under RCP 8.5 the temperatures will be higher, (37°C hot and dry and 36°C hot and wet). Since sorghum is sensitive to high temperature conditions which affect both vegetative and reproductive growth and it requires temperatures of 27-30°C for optimum growth. High temperatures increase the development rate of sorghum hence shortening the time to flowering which lead to yield reduction. In the mid- century again, it was projected that the rainfall amount will be decreased especially in the planting months. Water is one of the factors which influences the physiological processes affecting crop productivity. Water provide turgidity to the cell, while water stress causes dehydration reducing the enlargement of the cell resulting in yield reduction. Also, Fu *et al.* (2016) reported that the model demonstrated that sorghum grain yield would decrease with increasing temperatures. Fu *et al.* (2016) further stated that the CERES-Sorghum model provided a valuable preview of sorghum response to climate change factors such as temperature and precipitation, and it proved its capability to simulate the impacts of climate change on sorghum production.

In contrast, Msongaleli *et al.* (2014) reported that simulation crop models from eight General Circulation Models (GCMs) under RCP 4.5 by mid – century showed a mixture of increase and decrease in sorghum yields. Four GCMs projected yields to increase by 5% - 23% and one GCMs showed a decrease by 2% - 9%.

Identifying the most effective technologies is the first step towards preparing smallholder rainfed farmers to face changing climates. Not all conservation agriculture technologies are best for all farming situations. Selecting the most appropriate system for a particular soil and cropping situation requires matching the operations to the crop sequence, topography, soil type and weather conditions. In this study NT +M showed that it will have the highest sorghum grain yield in the vertisols of Pandamatenga during the mid – century both under RCP 4.5 and RCP 8.5 as compared to other CA technologies (Table 4.10).

The highest yield under this practice is attributed to the fact that no tillage improves soil fertility as there is less soil disturbance and this allows soil organic matter retention. Mulch also improves soil moisture conditions by reducing evaporation and runoff, thus benefiting crop growth under dry conditions which will be experienced in the mid – century. Similarly, Mehmood *et al.* (2014) found out that tillage and mulching had a significant effect on grain yield of sorghum when compared to zero tillage and minimum tillage. Broad -bed and furrow had the second highest sorghum yield in the Pandamatenga Department of Agricultural Research treatments. This BBF system is an efficient soil and water conservation strategy by reducing runoff and draining excess water from the beds as vertisols are prone to waterlogging.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Socio - economic and demographic characteristics of smallholder rainfed farmers had a significant influence on farmers' decision to adopt different CA technologies in Pandamatenga region. Understanding the specific socio-economic and demographics that influence adoption of agricultural technologies is essential in planning and implementing technology related programs for meeting the challenges of food production.

From this study, no tillage (NT) and no tillage plus mulch (NT+M) had the highest sorghum grain yield in different growing seasons in both continuous and cowpea- rotated -sorghum trials. No tillage mixed with mulch is the most suitable cropping system for adoption by smallholder rainfed farmers in Pandamatenga.

The DSSAT crop model performed well in simulating sorghum grain yield under NT, MT, NT+M and BBF on vertisols of Pandamatenga. Crop simulation model (DSSAT) can identify the best farming practices to counter the effects of climate change since traditional experiments are expensive and time consuming given the limited resources available to researchers and can aid as decision making tool.

REFERENCES

African Development Bank (ADB). (2008). *Pandamatenga Agricultural Infrastructure Development Project Appraisal Report Operations , Sector Vice-Presidency Agriculture and Agro-Industry Department Botswana.*

Alliance for a green Revolution in Africa (AGRA). (2014). *Agriculture Status Report: Climate Change and Smallholder Agriculture in sub - Saharan Africa.* Nairobi, Kenya.

Araya, T., Cornelis, W., Nyssen, J., Govaerts, B., Bauer, H., Gebreegziabher, T., Oicha, T., Raes, D. (2011). Effects of conservation agriculture on runoff , soil loss and crop yield under rainfed conditions in Tigray , Northern Ethiopia. *Soil Use and Management, 27*(May), 404–414.

Araya, T., Cornelis, W. M., Nyssen, J., Govaerts, B., Getnet, F., Bauer, H., Amare, K., Raes, D., Haile, M., & Deckers, J. (2012). Medium-term effects of conservation agriculture based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands. *Field Crops Research, 132*, 53–62.

Araya, T., Nyssen, J., Govaerts, B., Deckers, J., Sommer, R., Bauer, H., Gebrehiwot., K., Cornelis, W. M. (2016). Seven years resource-conserving agriculture effect on soil quality and crop productivity in the Ethiopian drylands. *Soil and Tillage Research, 163*(2016), 99–109.

Arup - Atkins. (1990). *Pandamatenga Development Study. Final Report. Main Report.* Ministry of Agriculture Gaborone Botswana.

Bandyopadhyay, K. K., Mohanty, M., Painuli, D. K., Misra, A. K., Hati, K. M., Mandal, K. G., Ghoshi., P.K., Chaudhary., R.S Acharya, C. L. (2003). Influence of tillage practices and nutrient management on crack parameters in a Vertisol of central India. *Soil and Tillage Research, 71*(2), 133–142.

Bazezew, H. A. (2015). Adoption of conservation agricultural practices : The case of Dangila

District , Amhara Region , Ethiopia. *Global Science Research*, *3*(9), 295–307.

Bidogeza, J. C., Hoogenboom, G., Berensten, P. B. M., Graaff, J. D., & Lansink, A. G. J. M. de. (2012). Application of DSSAT Crop Models to Generate Alternative Production Activities Under Combined Use of Organic-Inorganic Nutrients in Rwanda. *Journal of Crop Improvement*, *26*(July), 37–41.

Boitshepo, K. (2012, July). The secret behind the Pandamatenga Success. *Agrinews, Ministry of Agriculture Farmers's Monthly Magazine*, 4–5.

Botswana Tourism Organization. (2013). Botswana Tourism Organisation. Retrieved September 2, 2016, from www.botswanatourism.co.bw/climate.

Buol, S., Southhard, R., Graham, R., & McDaniel, P. (2003). *Soil Genesis and Classification*. Blackwell Publishing, Iowa State University.

Carboni, G. (2010). *Evaluation of conservation tillage and rotation with legumes as adaptation and mitigation strategies of climate change on durum wheat in Sardinia*.

Centre for applied Research (CAR). (2009). *Environmental and Social Impact Assessment of the Zambezi Integrated Agro-Commercial Development Project Phase 1*. Gaborone.

Chisenga, C. M. (2015). *Socio-economic factors associated with the adoption of conservation agriculture among women farmers in Balaka District*. United States – Indiana.

Corbeels, M., Sakyi, R. K., Kühne, R. F., & Whitbread, A. (2014). *Meta-analysis of crop responses to conservation agriculture in sub-Saharan Africa . CCAFS Report No. 12. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).*

Crespo. O. (2015). Methodology of developing the future weather climate from Agricultural Model Intercomparison and Improvement Project (AgMIP). Research Project Paper. University of Cape Town.

Dagar, J. C., Sharma, P. C., Sharma, D. K., & Singh, A. K. (2016). Use of Saline

Water/Industrial Effluents in Diverse Crop Intervertions in Vertisols. In G. G. Rao, S. Arora, & A. R. Chinchmalatpure (Eds.), *Innovative Saline Agriculture*. Retrieved from http://books.google.co.bw

Deckers, J., Spaargaren, O., & Nachtergaele, F. (2001). Vertisols: Genesis, Properties and Soilscape Management for Sustainable Development. In J. K. Syers, F. W. T. Penning de Vries, & P. Nyamudeza (Eds.), *The Sustainable Management of Vertisols* (Vol. 169, pp. 815–817). CAB international.

Derpsch, R., & Friedrich, T. (2009). *Global Overview of Conservation Agriculture no till Adoption. In 4th World Congress on Conservation Agriculture*. New Deli, India.

Derpsch, R., Friedrich, T., Kassam, A., & Hongwen, L. (2010). Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural & Biological Engineering*, *3*(1), 1–25.

Dias, M. P. N. M., Navaratne, C. M., Weerasinghe, K. D. N., & Hettiarachchi, R. H. A. N. (2016). Application of DSSAT crop simulation model to identify the changes of rice growth and yield in Nilwala river basin for mid- centuries under changing climatic conditions. *Procedia Food Science*, *6*(Icsusl 2015), 159–163.

Dile, T. Y., Karlberg, L., Temesgen, M., & Rockström, J. (2013). The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in sub-Saharan Africa. *Agriculture, Ecosystems and Environment*, *181*(2013), 69–79.

Edwards, M. (2016). Community Guide to Development Impact Analysis. Retrieved September 3, 2016, from http://gis.lic.wisc.edu/licgf/about-us/projects.

Fadare, O. A., Akerele, D., & Toritseju, B. (2014). Factors Influencing Adoption Decisions of Maize Farmers in Nigeria. *International Journal of Food and Agricultural Economics*, *2*(3), 45–54.

Fanuel, M. (2013). *Determinants of Adoption of Conservation Agriculture by Communal Farmers in Masvingo District, Zimbabwe*. UNIVERSITY OF ZIMBABWE.

Food and Agriculture Organization (FAO). (2008). *An international technical workshop Investing in sustainable crop intensification. The case for improving soil health. Integrated Crop Management* (Vol. 6). Rome.

FAO. (2010a). *Cultivating Sustainable Livelihoods : Socioeconomic Impacts of Conservation Agriculture in Southern Africa. (FAO Regional Emergence Office for Southern Africa) REOSA Technical Brief No. 2.*

FAO. (2010b). *Farming for the Future in Southern Africa : An Introduction to Conservation Agriculture. (FAO Regional Emergence Office For Southern Africa) REOSA Technical Brief NO 1.*

Federica, D. (2015). Conservation Agriculture and Soil Fauna: Only Benefits or also Potential Threats? A review. *EC Agriculture, 5*, 473–482.

Food and Agriculture Organization of the United Nations (FAO). (2016). What is conservation Agriculture? Retrieved August 25, 2016, from http://www.fao.org/ag/ca/la.html.

Fu, T., Ko, J., Wall, G. W., Pinter, P. J., Kimball, B. A., Ottman, M. J., & Kim, H. (2016). Simulation of climate change impacts on grain sorghum production grown under free air CO 2 enrichment. *International Agrophysics, 30*, 311–322.

Government of Botswana Ministry of Agriculture. (2005). *NEPAD – Comprehensive Africa Agriculture Development Programme Botswana: Investment Project Profile. Pandamatenga Commercial Arable Farms Infrastructure Development* (Vol. 2). Gaborone.

Harb, O. M., Abd El-hay, G. H., Hager, M. A., & Abou El-enin, M. M. (2016). Calibration and Validation of DSSAT V.4.6.1, CERES and CROPGRO-Models for Simulating No-Tillage in Central Delta, Egyp. *Agrotechnology, 5*(2).

Harford, N., & Le Breton, J. (2009). *Farming for the future: A Guide to Conservation Agriculture in Zimbabwe*. Zimbabwe.

Hati, K. M., Chaudhary, R. S., Maudal, K. G., Bandyopadhyay, K. K., Singh, R. K., Sinha, N. K., Mohanty., M., Somasundaram, J., Saha, R. (2015). Effects of Tillage , Residue and

Fertilizer Nitrogen on Crop Yields , and Soil Physical Properties Under Soybean – Wheat Rotation in Vertisols of Central India. *Agricultural Research, 4*(1), 48–56.

Hoogenboom, G., Jones, J., Wilken, P., Porter, C., Boote, K. J., Hunt, L. A., Singh, U., Lizaso, J.L.,White, J.W., Uryasev, O., Ogoshi, J.K., Shelia, V., Tsuji, G. (2015). The Decision Support System Agrotechnology Transfer (DSSAT). Washington: DSSAT Foundation.

IBM, Corp. (2013). *SPSS Statistics for windows version 22.* New York.

International Fund for Agricultural Development (IFAD). (2011). *Smallholder conservation agriculture Rationale for IFAD involvement and relevance to the East and Southern Africa region.* Rome, Italy.

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A.,Wilken, P.W., Singh, U., Gijsman, A.J., Ritchie, J. T. (2003). The DSSAT cropping system model. *European Journal of Agronomy, 18*(2003), 235–265.

Joshua, D. (1991). *Physical properties of the soils of Botswana.* Gaborone.

Jumbe, C. B. L., & Nyambose, W. H. (2016). Does Conservation Agriculture Enhance Household Food Security ? Evidence from Smallholder Farmers in Nkhotakota in Malawi. *Sustainable Agriculture Research, 5*(1), 118–128.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Muricho, G. (2012). Plot and household-level determinants of sustainable agricultural practices in rural Tanzania. *Environment for Development,* (12-02), 41 pp.

Kethobile, E. (2006). *An Investigation of Tillage Systems and Implement Design for Water Conservation in Semi Arid Conditions in Botswana.* Cranfield University, National Soil Resources Institute.

Liu, S., Yang, J. Y., Zhang, X. Y., Drury, C. F., Reynolds, W. D., & Hoogenboom, G. (2013). Modelling crop yield, soil water content and soil temperature for a soybean-maize rotation under conventional and conservation tillage systems in Northeast China. *Agricultural Water Management.*

Mehmood, S., Zamir, S., Rasool, T., & Akbar, W. (2014). Effect of Tillage and Mulching on Soil Fertility and Grain Yield of Sorghum. *Scientia Agriculturae*, *4*(1), 31–36.

Milder, J. C., Scherr, S. J., & Majanen, T. (2011). *Performance and Potential of Conservation Agriculture for Climate Change Adaptation and Mitigation in Sub-Saharan Africa.*

Mlenga, D. H., & Maseko, S. (2015). Factors Influencing Adoption of Conservation Agriculture : A Case for Increasing Resilience to Climate Change and Variability in Swaziland. *Journal of Environment and Earth Science*, *5*(22), 16–25.

Moganane, B., Waveren, E. Van. & Remmelzwaal, A. (1990). *The Solis of the Pandamatenga Plains.* Gaborone.

Mohanty, M., Sinha, N. K., Hati, K. M., Painuli, D. K., & Chaudhary, R. S. (2012). Stability of Soil Aggregates under Different Vegetation Covers in a Vertisol of Central India. *Journal of Agricultural Physics*, *12*(2), 133–142.

Msongaleli, B., Rwehumbiza, F., Tumbo, S.D. and Kihupi, N. (2014) Sorghum Yield Response to Changing Climatic Conditions in Semi-Arid Central Tanzania: Evaluating Crop Simulation Model Applicability. *Agricultural Sciences*, 5, 822-833

Mwangi, M., & Kariuki, S. (2015). Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries. *Journal of Economics and Sustainable Development*, *6*(5), 2222–1700. Retrieved from www.iiste.org.

Ngombe, J., Kalinda, T., Tembo, G., & Kuntashula, E. (2014). Econometric Analysis of the Factors that Affect Adoption of Conservation Farming Practices by Smallholder Farmers in Zambia. *Journal of Sustainable Development*, *7*(4), 124–138.

Ngwira, A. R., Aune, J. B., & Thierfelder, C. (2014). Soil & Tillage Research DSSAT modelling of conservation agriculture maize response to climate change in Malawi. *Soil & Tillage Research*, *143*, 85–94.

Oicha, T., Cornelis, W., Verplancke, H., Nyssen, J., Deckers, J., Behailu, M., Haile., M., Govaerts, B. (2010). Short-term effects of conservation agriculture on Vertisols under tef

(Eragrostis tef (Zucc.) Trotter) in the nothern Ethopian highlands. *Soil and Tillage Research, 106*(2), 294–302.

Owenya, M. Z., Mariki, W. L., Kienzle, J., Friedrich, T., & Kassam, A. (2011). Conservation agriculture (CA) in Tanzania : the case of the Mwangaza BCA farmer field school (FFS), Rhotia Village , Karatu District , Arusha. *International.*

Pal, D. K., Wani, S. P., & Sahrawat, K. L. (2012). Vertisols of tropical Indian environments : Pedology and edaphology. *Geoderma, 189–190*(2012), 28–49.

Pardo, M. T., Ristori, G., D'Acqui, L. P., & Almendros, G. (2012). An Assessment of Soil Fertility and Agronomic Constraints in Southern African Savannas: a Case Study of the Pandamatenga Area, Botswana. *South African Geographical Journal, 85*(1), 35–41.

Patil, M. D., Wani, S. P., & Garg, K. K. (2016). Conservation agriculture for improving water productivity in Vertisols of semi-arid tropics. *Soil and Water Management, 110*(9).

Patil, N. G., Pal, D. K., Mandal, C., & Mandal, D. K. (2012). Soil Water Retention Characteristics of Vertisols and Pedotransfer Functions Based on Nearest Neighbor and Neural Networks Approaches to Estimate AWC. *Journal of Irrigation and Drainage Engineering, 138*(2), 177–184.

Phiri, C. (2013). *Factors Affecting the adoption of conservation Agriculture among small scale farmers in Zambia's Mumbwa District.* University of Zambia.

Rusinamhodzi, L., Corbeels, M., Nyamangara, J., & Giller, K. E. (2012). Maize – grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crops Research, 136*, 12–22.

SAS Institute. (n.d.). *SAS User Guide Statistics Version 9.2.* New York, USA: SAS Institute Incl., Cary.

Seleka, T. B., & Khaufelo, R. L. (2016). Public Transfers and Participation Decisions in Botswana ' s Subsistence Economy. *Review of Development Economics*, 1–21.

Soldevilla-Martinez, M., Martin- Lammerding, D., Tenorio, J. L., Walter, I., Quemada, M., & Lizaso, J. I. (2013). Simulating improved combinations tillage-rotation under dryland conditions. *Spanish Journal of Agricultural Research, 11*(3), 820–832.

Statistics Botswana. (2012). *Annual agricultural survey Report*. Gaborone.

Statistics Botswana. (2013). *Annual Agricultural Survey Report*. Gaborone.

Statistics Botswana. (2014). *Annual Agricultural Survey Report*. Gaborone.

Statistics Botswana. (2015). *Gross Domestic Product, Third Quarter*. Gaborone.

Stocker, T. (Ed.). (2014). *Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Tapela, M., Kayombo, B., & Pule - Meulenberg, F. (2007). Potential for No-Tillage Agriculture in the Pandamatenga Vertisols of Botswana. *Agricultural Mechanization in Asia, Africa and Latin America, 38*(2).

Thierfelder, C., & Wall, P. C. (2010). Investigating Conservation Agriculture (CA) Systems in Zambia and Zimbabwe to Mitigate Future Effects of Climate Change. *Journal of Crop Improvement, 24*(2), 113–121.

Thomas, R. L. (1996). *Modern Econometrics: an introduction. China*. Prentice Hall.

Tigist, P. (2010). *Adoption of conservation tillage technologies in Metema woreda , North Nondar Zone , Ethiopia. Haromaya University*. Haramaya University.

United Nations Development Programme. (2012). *Agriculture and Food Security Policy Brief. Reflecting on the Challenges of Attaining a Green Economy for Botswana*. Seanama Conservation Consultancy.

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A Mezzalama, M., Wall, P., Deckers, J., Sayre., K.D., Fran, I. (2010). Conservation agriculture, improving soil quality for sustainable production systems? In R. Lal & B. . Stewart (Eds.), *Advances in Soil*

Science: Food Security and Soil Quality (pp. 137–208). USA: CRC Press, Boca Raton.

Verhulst, N., Le, Nelissen, V., Jespers, N., Haven, H., Sayre, K. D., Deckers., J., Govaerts, B. (2011). Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semi-arid highlands. *Plant and Soil, 344*(1), 73–85.

Waffa, R., & Benoit, G. (2015). Simulation of climate change impact on Wheat Production in the Tiaret Region of Algeria Using The DSSAT Model. *European Scientific Journal, 9*(36), 249–259.

Wall, P. C., & Thierfelder, C. (2013). *The Role and Importance of Residues: BMZ and IFAD - funded projects on Facilitating the Adoption of Conservation Agriculture in Eastern and Southern Africa.*

Wilkens, P. W., Hoogenboom, G., Porter, C. H., Jones, J. W., & Oxana, U. (2004). DSSAT v4 (Vol. 4).

Willmott, C. J., Ackleson, S. G., Davis, R. E., Feddema, J. J., Klink, K. M., Legates, D. R., O' donnel ., J., Rowe, C. M. (1985). Statistics for the Evaluation and Comparison of Models. *Journal of Geophysical Research, 90*(20), 8995–9005.

Wubie, A. A. (2015). Review on Vertisol Management for the Improvement of Crop Productivity in Ethiopia. *Journal of Biology, Agriculture and Healthcare, 5*(12), 92–103.

Yang, J. M., Yang, J. Y., Liu, S., & Hoogenboom, G. (2014). An evaluation of the statistical methods for testing the performance of crop models with observed data. *Agricultural Systems, 127*, 81–89.

Zheng, C., Jiang, Y., Chen, C., Sun, Y., Feng, J., Deng, A., Song., Z., Zhang, W. (2014). The impacts of conservation agriculture on crop yield in China depend on specific practices, crops and cropping regions. *The Crop Journal, 2*(5), 289–296.

APPENDICES

Appendix 1

Appendix Table 1: Mean air temperatures, mean solar radiation and mean monthly precipitation for Pandamatenga Agricultural Research station (2015-2017)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Seasonal Average
Temperature (°C)											
2015	24.3	25.2	24.7	21.7	19.6	17	17.7	20.7	24.7	28.2	22.38
2016	26.8	25.8	24.5	23	19.1	17.5	17.2	20.1	24.6	28.6	22.72
2017	23.4	24.2	22.9	17.7	19.9	18.1	17.9	20	21.6	26.9	21.26
Solar Radiation (Mj/m2											
2015	28.8	29.9	27.6	21.5	23.2	21.5	21.8	24.7	26.3	29.3	25.46
2016	27	28.7	23.6	24.5	23.1	21.2	21.9	25.3	26.6	29.3	25.12
2017	22.2	25.6	25.2	22.6	21.9	20.3	21.3	23.5	26.4	25.6	23.46
Precipitation (mm)											
2015	62.9	176.1	47.2	77.8	0	0.7	0	0.2	0	4.2	369.1
2016	61.7	182.8	82.9	23	0	0	0	0	0.6	0.6	351.6
2017	86.7	128	67.1	27.6	0	0	0	0	0	10.6	320

Appendix Table 2: Physical and Chemical Properties of Pandamatenga Vertisol

Depth (cm)	Bulk density (g/cm^3)	UL (cm^3 cm^{-3})	LL (cm^3 cm^{-3})	Sat. water content (cm^3 cm^{-3})	Organic carbon (%)	Clay (%)	Silt (%)	pH
0-5	1.32	0.388	0.236	0.515	0.90	61	10	7.04
5-15	1.33	0.388	0.236	0.518	0.90	64	11	7.10
15-25	1.32	0.377	0.236	0.518	0.80	68	10	7.10
25-40	1.34	0.380	0.235	0.514	0.80	71	9	6.50
40-55	1.33	0.379	0.236	0.523	0.70	73	8	6.50
55-70	1.33	0.388	2.236	0.515	0.70	73	9	6.50
70-100	1.32	0.377	0.236	0.514	0.80	74	8	7.50

UL – volumetric water content at field capacity, LL- volumetric water content at wilting point

Appendix Table 3: Summary of management crop data

Management crop data	Description
Crop Name	Grain sorghum, cowpeas
Cultivar	M38
Planting dates	14 February 2015, 2016 and 16th March 2017
Planting methods	Dry seed
Plant population per m^2	5
Row spacing	75cm
Planting depth	4cm
Tillage	Tillage implements used and their depths

Appendix Table 4: Colour of the upper horizon that is used to approximate the Albedo

Colour	Albedo
Brown	0.13
Red	0.14
Black	0.09
Grey	0.13
Yellow	0.17

Appendix Table 5: Drainage classifications

Drainage	Drainage coefficient
Excessive	0.85
Somewhat excessive	0.75
Well	0.60
Moderately well	0.40
Somewhat poorly	0.25
Poorly	0.50
Very Poorly	0.01

Appendix Table 6: The soil hydrologic groups needed for selection of a runoff curve number for croplands

Hydrological group	Description
A – Lowest Runoff potential	Includes deep sands with very little silt and clay, also deep rapidly permeable loses
B – Moderately Low Runoff Potential	Mostly sandy soils less deep then A, and less deep or less aggregated then A, but the group as a whole has above – average infiltration after thorough wetting.
C – Moderately High Runoff Potential	Comprises shallow soils and soils containing considerable clay and colloids, though less than that of group D. The group has below – average infiltration after thorough wetting.
D – Highest Runoff Potential	Included mostly clays of high swelling percent, but the group also includes some shallow soils with nearly impermeable sub horizons near the surface.

Appendix Table 7: Runoff curve numbers for various hydrologic conditions, slopes and conservation practices

	Hydrological Conditions			
% Slope	A	B	C	D
0-2	61	73	81	84
2-5	64	76	84	87
5-10	68	80	88	91
>10	71	83	91	94

Appendix Table 8: Mean monthly rainfall (mm), temperature max and min (°C), solar radiation (Mj.m-2) for present period (2015-2017) and for mid – century (2040-2070) RCP 4.5 HOT AND DRY

2015 - 2017					2040 - 2070			
	SRad	TMax	TMin	Rain	SRad	TMax	TMin	Rain
JAN	25.9	30.2	19.5	88.9	23.3	33.0	20.8	147.4
FEB	27.8	31.0	19.1	172.9	22.2	32.5	20.6	124.9
MAR	25.6	30.0	17.8	73.6	20.8	32.5	20.7	63.7
APR	22.9	28.8	15.4	36.9	20.0	32.4	18.0	10.0
MAY	22.7	27.9	11.3	0.0	18.3	30.8	13.8	2.3
JUN	21.0	25.9	9.5	0.3	17.1	28.3	10.4	1.1
JUL	21.5	25.9	9.3	0.2	18.2	28.4	10.2	0.1
AUG	24.5	28.8	11.6	0.1	21.1	32.4	14.0	0.1
SEP	26.4	33.1	16.3	0.0	24.3	35.7	17.9	0.4
OCT	28.0	35.3	20.5	6.5	25.5	37.1	21.0	10.4
NOV	27.1	33.2	19.7	48.3	25.3	36.3	21.9	60.7
DEC	26.8	31.8	19.9	96.1	24.0	34.2	20.9	110.6

Appendix Table 9: Mean monthly rainfall (mm), temperature max and min (°C), solar radiation (Mj.m-2) for present period (2015-2017) and for mid – century (2040-2070) RCP 4.5 HOT AND WET

2016-2017					2040 - 2070			
	SRad	TMax	TMin	Rain	SRad	TMax	TMin	Rain
JAN	25.9	30.2	19.5	88.9	23.3	31.7	20.5	164.5
FEB	27.8	31.0	19.1	172.9	22.1	30.7	20.6	161.1
MAR	25.6	30.0	17.8	73.6	21.0	31.7	20.1	71.7
APR	22.9	28.8	15.4	36.9	19.9	31.7	17.8	20.8
MAY	22.7	27.9	11.3	0.0	18.3	29.6	14.5	2.2
JUN	21.0	25.9	9.5	0.3	17.1	28.3	11.2	1.0
JUL	21.5	25.9	9.3	0.2	18.2	28.0	11.2	0.1
AUG	24.5	28.8	11.6	0.1	21.1	31.5	14.2	0.1
SEP	26.4	33.1	16.3	0.0	24.3	35.7	18.8	0.5
OCT	28.0	35.3	20.5	6.5	25.4	37.7	22.3	14.8
NOV	27.1	33.2	19.7	48.3	25.2	36.3	22.4	74.9
DEC	26.8	31.8	19.9	96.1	24.0	32.6	21.2	162.2

Appendix Table 10: Mean monthly rainfall (mm), temperature max and min (°C), solar radiation (Mj.m-2) for present period (2015-2017) and for mid – century (2040-2070) RCP 8.5 HOT AND DRY

	2015-2017				2040 - 2070			
	SRad	TMax	TMin	Rain	SRad	TMax	TMin	Rain
JAN	25.9	30.2	19.5	88.9	23.4	34.0	21.8	151.9
FEB	27.8	31.0	19.1	172.9	22.2	33.0	21.5	134.5
MAR	25.6	30.0	17.8	73.6	21.0	33.3	21.0	61.7
APR	22.9	28.8	15.4	36.9	20.0	33.3	18.6	12.0
MAY	22.7	27.9	11.3	0.0	18.3	31.4	15.2	1.1
JUN	21.0	25.9	9.5	0.3	17.1	28.8	11.7	1.0
JUL	21.5	25.9	9.3	0.2	18.2	28.7	10.5	0.1
AUG	24.5	28.8	11.6	0.1	21.1	31.7	13.6	0.1
SEP	26.4	33.1	16.3	0.0	24.3	35.4	17.7	1.4
OCT	28.0	35.3	20.5	6.5	25.4	36.9	21.1	12.9
NOV	27.1	33.2	19.7	48.3	25.5	37.4	22.7	41.5
DEC	26.8	31.8	19.9	96.1	24.4	35.4	22.4	95.0

Appendix Table 11: Mean monthly rainfall (mm), temperature max and min (°C), solar radiation (Mj.m-2) for present period (2015-2017) and for mid – century (2040-2070) RCP 8.5 HOT AND WET

	2015 - 2017				2040 - 20170			
	SRad	TMax	TMin	Rain	SRad	TMax	TMin	Rain
JAN	25.9	30.2	19.5	88.9	23.3	34.1	21.8	155.7
FEB	27.8	31.0	19.1	172.9	22.1	33.8	21.6	119.6
MAR	25.6	30.0	17.8	73.6	20.5	34.8	22.0	105.4
APR	22.9	28.8	15.4	36.9	19.9	33.9	18.9	11.6
MAY	22.7	27.9	11.3	0.0	18.3	31.9	14.5	1.8
JUN	21.0	25.9	9.5	0.3	17.1	29.7	11.5	1.3
JUL	21.5	25.9	9.3	0.2	18.2	28.7	10.7	0.2
AUG	24.5	28.8	11.6	0.1	21.1	32.1	13.6	0.2
SEP	26.4	33.1	16.3	0.0	24.2	36.3	18.0	1.7
OCT	28.0	35.3	20.5	6.5	25.1	37.2	21.3	43.3
NOV	27.1	33.2	19.7	48.3	25.1	35.7	21.5	97.2
DEC	26.8	31.8	19.9	96.1	23.7	33.5	20.9	146.2

Appendix 2

Appendix 2.1 Questionnaire

Questionnaire sample for smallholder rainfed farmers in Pandamatenga region

BOTSWANA UNIVERSITY OF AGRICULTURE AND NATURAL RESOURCES
DEPARTMENT OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING

Title: **AN ASSESSMENT OF SOCIO-ECONOMIC POTENTIAL OF CONSERVATION AGRICULTURE AND PREDICTION OF ITS FUTURE PERFORMANCE USING THE DSSAT MODEL FOR THE PANDAMATENGA VERTISOLS IN NORTHERN BOTSWANA**

Questionnaire for smallholder rainfed farmers

Farmer No ……………………… ………

Date of interview ………………………

Country ……………………………………

Village ……………………………………

Adopter ……… Non-adopter ……….

PART 1: HOUSE HOLD CHARACTERSTICS

Name of family member	Gender of (SRF) Male -1 Female - 0	Age of SRF	Education level of SRF	Major occupation of SRF	Marital status of SRF	Total family size

SRF – Smallholder rainfed farmer (respondent), Education level of SRF: 1- Read & Write (Literate), Illiterate - 0

Major occupation of SRF: 1-Government employment, 2- Private employment, 3-Self-employed, 4- others specify…………………………………………………

Marital status: 1- Married, 2- Single, 3- Divorced

1.2 Farming experience of the Smallholder rainfed farmer ……………. (In years).

1.3 Land holdings:

Area (hectares)	Tenure status

Tenure status: 1- Own plot, 2- Gift, 3- Rented

2. Crops grown and Cultural practices used;

Area (h)	Crops grown	Production (kg/ha)	Variety used 1-improved 2-local	Method of land preparation	Used Herbicides 1- Yes 2- No	Hand weeding 1- Yes 2- No

Method of land preparation: 1- Pair of own oxen/ donkeys, 2- own tractor, 3-Rented tractor 4- Rented oxen/ donkeys 5- others ....

2.1. If accomplished through hire of oxen, what is the cost of a pair of oxen per day_______?
2.2. If accomplished through hire of tractor, what is the cost of tractor per hour _________?

3. Livestock possession

Livestock Category	Number	Corrected Number
Cows		
Oxen		
Goats		
Sheep		
Donkeys		
Horse		
Poultry		

4. Family labour

4.1 Do you have enough labour for accomplishing farming activities on time? 1- YES 0- NO

4.2 If the answer is no, which activities are most affected by labour shortage?

1- land preparation (Ploughing), 2- Planting (sowing), 3- Weeding, 4- Harvesting,

5- in all times, 6- in planting and harvesting, 7-others (specify) ....

4.3 How do you overcome the labour shortage constraint?

1- hire labour, 2- hire tractor, 4- use herbicides, 5-hire combiner, 6- both 1 and 2,
7- other (specify) ....

4.4 Is labour available for hire easily if you want to do so? 1-Yes 0- No

4.5 In which of the farming activities female family members participate?
1- land preparation (Ploughing), 2- Planting (sowing), 3- Weeding,
4- Harvesting, 5- others (specify)......................................

4. 6 How many active family members participate in farming activities? ....

5. Herbicides price

5.1 Is herbicide available in time and the right quantity? 1-Yes 0-No

5.2 In your view how do you see the price of herbicide in relation to hired labour for weeding and ploughing?
1-Very expensive, 2- expensive, 3- moderately expensive, 4- less expensive, 5-not expensive

6. Access to credit

6.1 Did you apply for credit in the last 12 months? 1-Yes 0- No

6.2 Did you take any credit for purchasing herbicides during the last 12months?

1-Yes 0-No

7. Participation of non – farm activities

7.1 Household's participation in non-farm activities in last one year. 1-Yes 0 - No

7.2 Household's participation in non-farm activities in last one year.

Type of activity (A)	Participation time (B)	Participation in a year(C)	Income per day or year (P)

Kind of activities (A): 1- Trading, 2- Handicraft, 3-Daily labourer, 4-others (specify).............

Participation time (B): 1-out of the time of farming activities, 2-at any time,
3- throughout the year, 4- others (specify). ------------------
Approximate Participation in a year (C) 1- for a month 2-for two months 3-for three months 4-others (specify). ....

8. Famers' perception towards CA technologies;

8.1 How did you first hear about CA and when? ....

technologies	No till	No till + Mulch	Minimum tillage	Broad bed and furrows	Crop rot
technology practiced					
ation in years					

ement/ Question	1	2	3
1. Have full knowledge of CA technologies			
2. I have experience of CA technologies			
3. CA technologies can be of beneficial to me as a farmer			
4. CA technologies can be advantageous as it can help in increase yield			
5. CA technologies can be advantageous as it can help in increase income			
6. CA technologies can be used to prevent soil erosion			
7. CA technologies can be disadvantageous as it is labour intensive			
8. Lack of farm implements are the limiting factors for me to employ CA technologies			
9. Having tried CA technologies in my farm, I will adopt using the technologies			

1- Strongly agree, 2- agree, 3- neutral, 4- disagree, 5- strongly disagree

8.2 How do you see CA technology when compared with conventional agriculture? 1-Good, 2- Bad

8.2.1 If good, why you prefer CA over the conventional one?
1- It is cheaper, 2- Easy to apply, 3- saving labour, 4- others (specify) ....
8.2.2 If bad, what is the reasons?______________________________
8.2. What is the main weakness you observed from CT technology? ____________

1- High cost of the chemical, 2- Danger in handling poisonous, 3- Danger for grazing animals

4- Pollution to environment, 5- any other (specify)............................

continued, he only kept them locked up in the *kraal* when Laura's grandson Bertie, who managed the farm, needed to work with them. The work could be, for example, when the extension officers from the Department of Veterinary Services (DVS) came to inspect or vaccinate the cattle in accordance with BMC regulations, or when they needed to be branded.

Thamae watched as his oldest son and daughter ran around the *kraal* playing, and explained to me that one of the bulls did not like children. Although the cattle under his care were kept for meat, his family were allowed to milk them for their daily consumption. He knew the milking cows quite well, he said, but not the other ones individually, although he knew how each and every one of them was related. When the mothers of the calves had drunk their fill of water, he sorted them out from the herd one by one by walking strategically behind them, and guided them towards the sectioned-off calves. One at a time, the cows were let in to the calves, and the two children went in with them. When the calf recognised its mother and started suckling milk, the boy bound the cow's hind legs with a rawhide rope. He squatted beside the cow's teats with a bucket between his knees. Pushing the calf away, he squeezed some milk out and washed his hands and the teats with it, and then started milking. With skilled movements, he squeezed one teat at a time with both hands so that a steady stream of milk spurted down into the bucket, making a frothy foam. Meanwhile, his younger sister was busy with a stick on the other side of the cow, keeping the calf from suckling. The calf needed to be close enough for the mother to smell it, as it encouraged her to let the milk go, but having the calf suckling at the same time as milking made the task difficult.

The young girl ran around the cattle unafraid, and was eager to help with them, although the older brother seemed to want to run the show and do it himself. Once the milking was done, the girl untied the cow, which then walked away with her calf close behind her. Only two teats were milked on each cow, so that the milk from the other two were left for the calf. Some of the milk was drunk straight away or added to tea, while some was poured into a plastic container and left overnight to make 'sour milk'. Milk, in its different forms, was a staple food for the children and an important source of energy for the whole family.

When all the cattle had been watered, the milk cows were let back out to the water trough to drink some more, so that they would be able to produce a lot of milk. Meanwhile, we walked back to the compound and sat in the shade. Around two o'clock, Thamae went to let the milk cows out to graze again, and let the calves in to drink water instead. Once they had drunk, they went back into the closed-off section, and at around four o'clock some cattle came in to drink again. Which cows were milked changed during the year, and with the calving season spread out there were almost always a few cows to milk. However, in the event of a drought, they did not milk since the cow then would not be able to produce enough milk for both the calf and humans. Then the family would become entirely dependent on the rations from the farm owners that were included in Thamae's salary, and whatever else they could afford to buy at the farm's tuck shop.

The minimum salary of cattle-hands was 500 pula per month, and Thamae was paid slightly more than that. A five kilogram package of maize meal costs approximately fifteen pula and a five kilogram package of sugar around thirty pula. Agricultural workers were not expected to pay rent, but neither could they expect comfortable housing. The prices in the tuck shop were the same as in the Ghanzi grocery store, but the selection of items was much smaller.

For Laura and for Christine, cattle farming involved taking decisions on breeding and grazing management, selling, as well as organising vaccinations, branding and all of the other practicalities necessary for selling cattle on the market. They thus had *de facto* control over their cattle, although Laura left managing decisions to her son and Christine consulted with her husband on issues of beef cattle management. However, the stud breeding operation was entirely under Christine's control. Laura thought that she was too old to be participating in most of the farm work, and left it to her grandson to manage the hired labour. Christine, in contrast to Laura, was often out on her farm supervising her employees, giving a hand here and there, as well as checking on her cattle. Twice a week, Christine drove the two hours to Ghanzi town to leave and fetch her daughter at boarding school, do errands, get supplies and groceries and to check on the hardware store her family owned together with relatives. She ran a stud-breeding programme on her farm and preparations for the yearly Ghanzi Agricultural Show in late June, where she showed her breeding bulls, took up a lot of her time.

Christine's grandparents farmed cattle in Ghanzi, but her mother moved to South Africa, where Christine grew up. She often visited her grandparents, and always liked the cattle farming there better than the potato and maize farming that her parents were engaged in. When she got older and married, she moved with her first husband to Ghanzi and they started a cattle operation together. Christine mainly did the housework and took care of the children, but she also learned more and more about farming. When her first husband died she operated the farm by herself, but after she married Stuart, she went back to doing more administrative tasks.

Xgaiga, an older Nharo man, was employed by Christine and her husband and lived with his wife and grandchildren at one of the watering holes on the farm. They had built three mud huts with thatched roofs; typical for Nharo cattle-hands on fenced farms. His wife, Xaga, was not employed, but took care of the children and the family. Xgaiga and Xaga grew up in the area and had worked on the farm for a long time. Conditions varied between farms, but it was common that it was contractually specified that farm owners would deliver supplies to their employees once a week, as part of their salary. These usually included sugar, tea, tobacco, meat and mealie meal. Should they have wished anything else, they could have bought it from a tuck store if there was one close by or through the owners of the farm with credit from the upcoming salary.

Xgaiga's salary was however often finished before pay day, and milk from the cattle was crucial for the families' diet. The days at Xgaiga's and Xaga's compound are similar to those of Thamae and Koaba's above, and we spent long hours sitting in the shade on the sand, watching the cattle drink. Only in the evening did the family collect again, coming together around the fire for a cup of freshly brewed tea with several spoons of sugar before bed time. A small herd of goats lay down in the sand and we could hear them shuffling in the dark. The donkey that was used for riding to check on the borehole pump also slept close by. Xgaiga told me that this donkey had only been with them for a couple of years, since the old one was eaten by a lion.

The account above shows how Christine took on the role of the house wife when first moving to Ghanzi took charge of the cattle operation when becoming a widow, only to step back into administration again when she remarried. Whereas she at times had been in charge of the cattle management, the daily tasks of watering, and monitoring the cattle was always left to the employees. Cattle management and work was seen as male, but hands-on cattle chores even more specifically identified as tasks for male Nharo employees. Even among the children, as described above, it was the boy who milked the cows, although the girl was enthusiastically helped. Class, race and gender thus intersected to shape what is seen as appropriate engagements for various people, creating opportunities for some and challenges for others. Christine and Laura, 'rich, white' women, are in a position to easily access fences, cattle and grazing land as well as cattle-hands – or in Ribot and Peluso's (2003) terms, technology, capital and labour. However, in chapter 6, I will show how control over cattle varies also within this group of cattle owners. Further, Christine, and others as we shall see in later chapters, engaged in 'new' tasks associated with commercial production – administration and stud breeding – hinting at a gendering of the commercialisation of cattle production.

Non-fenced, communal grazing land in Charleshill sub-district

Charleshill sub-district was characterised by non-fenced communal grazing land on which many farmers kept their cattle according to grazing rights obtained and issued by the local Land Board. The population in the sub-district is predominantly made up of Batswana, Bakgalagadi, Herero and San. When it came to selling cattle, most of the villages in the sub-district had a village *kraal* and loading facilities so that buyers could set up a cattle market and then load the cattle they had bought on to trucks that would take them to feedlots or butcheries. As shown in the narrative introducing this chapter, cattle owners took their cattle to the village *kraal* when buyers announced that they are coming. However, the more remote a village was, and the poorer the condition of the road, the fewer were the available market possibilities. Further, as the introductory story also showed, such sales were not always a straightforward matter.

Twenty-three of the women cattle farmers I interviewed with different sized herdskept their cattle on non-fenced communal grazing land in Charleshill sub-district, and four of these women had cattle on non-fenced village grazing areas. Kabomo, an older widowed Motswana woman, and Gendrede, an older Herero woman, both had their cattle herds on non-fenced communal grazing land outside the village areas.

Kabomo lived in Ncojane village, a couple of hours' drive on a badly corrugated gravel road south of Charleshill village towards the west of Ghanzi District. Her house was made out of cement blocks and although it had electricity, she cooked in her outdoor kitchen on an open fire shielded from the wind by a stick wall. While we cooked together, sitting on plastic chairs by the fire, combining her dried beans and spices with my vegetables and rice into an evening meal, she told me about her cattle. She spoke in Setswana and Thato, who is with me to translate, helped us to communicate.

Her herd of cattle, Kabomo explained, grazed at a cattle post a few kilometres outside of Ncojane village. She had hired a cattle-hand to stay there and see to the animals. He opened the gate to the *kraal* where the water was in the late morning and late afternoon, she told me, and made sure that all the cattle got to drink. He kept track of how they were doing and would notice if one had gone astray. As there were no fences around her cattle's grazing land, they could walk away at any time, but usually came back home when they got thirsty. Sometimes a younger male relative

would help out, if her hired cattle-hand needed to go away. When he
former employed cattle-hand quit, it took some time to find a new one.

Kabomo herself went to visit the cattle post every week, to make sur
that everything was all right, to bring supplies to the hired hand, and simpl
to spend some time at the *kraal*. She used to go with her husband to th
cattle post when he was alive, and so she knew a good deal about cattl
farming, Kabomo told me. The cattle were under her control and sh
decided herself what animals to sell and when. The hired cattle-han
however, had the right to milk the cows for his own consumption. Kabom
also went to the cattle post when it was time to vaccinate the cattle, or t
oversee other procedures such as selecting cattle to sell. She did not sel
enough cattle at any single time to get the BMC truck to come and fetc
them from her *kraal*, but paid someone with a small truck to come and tak
them to the market place whenever a buyer advertised a market.

Another day, north from Kabomo's house, Thato and I sat dow
outside a small house built of cement blocks and circled by a low fenc
made of sticks to talk to Gendred, an old Herero widow. We travelled
good two hours on a wide sand road to the north of Charleshill village t
reach Gendrede's house that lay not far from her *kraal*. Typically, th
Herero women in this area live close to the *kraal*, I was told, unless the
were wealthy and could afford to have a house in the village and emplo
cattle hands.

Although it was not yet noon that winter morning, the sun was warm an
we sought out the shade. Her house was a small cement square withou
electricity or running water, and sparsely furnished. Gendrede, in he
horned hat, characteristic of married Herero women, wore a long dress th
reached her feet and had long arms and a high neck. The dress was said t
be inspired by those worn by missionary wives from around the turn of th
twentieth century.

She told us that her herd of around twenty individuals were out grazin
on the *veld*, out of sight. Later they would come in to drink at th
watering hole close to Gendrede's house. Gendrede told us that he
children used to help her take care of the cattle, and water them, but no
they were in school. She had hired a man to help her, as she was now to
old to walk far, or to catch the cows and tie up their hind legs when it wa
time to milk them. It was not always easy to find a reliable cattle-han
and young boys went to school nowadays. The milking she did herself, a
is customary for Herero women, she added, and she turned some of it int
sour milk by letting it stand in the shade for a few days. Her husban
who used to take all the decisions concerning the cattle, died some t

years ago and since then Gendrede herself had managed the herd. She saw them twice a day when they come to drink. When she needed to vaccinate them or take them to the market, her children would come to help, but the cattle were under her control and it was Gendrede herself who decided what cattle to sell and when.

However, contrary to the general understanding of widows' cattle ownership discussed earlier in this chapter, Gendrede explained that cattle would not traditionally be left to the widow, but instead would be inherited by one of the sons. As the family usually lived together, everyone would still benefit from the cattle, she explained, and the sons would of course support their mother. These days, Gendrede explained, families no longer lived together and sons would quarrel over who should get the cattle. Therefore, she decided to keep the cattle herself.

Cattle production at Kabomo's and Gendrede's *kraals* were gendered in that they both claimed control over the herds only when their husbands had died. However, they were gendered differently in that Gendrede used to engage in the hands-on cattle tasks when she was younger, whereas Kabomo's herd was always tended by a male cattle-hand. Today their engagements are similar, save for the milking that Gendrede does herself for her own consumption. In the following chapters I show how the way that widows benefit from their cattle varies, as does their motivation to keep cattle. I also show how Herero women's property relations to cattle vary.

On the fenced and non-fenced grazing land across Ghanzi District, the daily life of the cattle and the daily tending of the cattle was, as we have seen, similar. However, farmers on non-fenced land faced greater challenges to access the market, as the story at the beginning of the chapter showed, and the level of material welfare as well as the way that women are involved differ. Further, it is not only widows, Hereros and 'rich, white' women who are involved in cattle production in Botswana today, as I will show, and in the next section I discuss how women have different starting points in terms of access to technology, capital, labour and the market, providing them with different starting points from which to face the opportunities and challenges in cattle farming. Thus access to labour, technology, capital and markets differs greatly among women cattle owners in Ghanzi District, and access was to a large extent mediated by social identity linked to historical property relations based on gender, ethnicity, race and class and often accessed through other social relations such as through marriage or kinship (Ribot and Peluso 2003).

Different starting points for women cattle owners in Ghanzi

The forty women cattle owners interviewed are all self-identified cattle owners. However, their property relations and access to their cattle differ. Twenty-six had independent ownership with their own registered brand recognised by the state, and eleven were in co-ownership with their husband. One woman used her mother's brand, one used that of her boyfriend, and one used that of her husband, while they all differentiated ownership with earmarks. Although this allowed them to recognise claims to different animals, it was the brand owner who controlled the sales, as we saw in the story at the beginning of the chapter.

Land tenure, herd sizes and labour relations varied among the women I met in Ghanzi. So did the ways in which they acquired their cattle, as I show throughout the following chapters. Inequalities in terms of ethnicity, race and class discussed on a national level in chapter 4 are to some extent also present among the women cattle owners that I interviewed. All of the women cattle owners I interviewed with cattle on freehold Ghanzi Farms had acquired their land as gifts from their parents or as inheritance from husbands. This group was made up of all the English and Afrikaner women in my sample as well as one Mokgalagadi woman. These women have different herd sizes, but all Afrikaner and English women belonged to a higher class of wealthy families, so even those with smaller herds had a comfortable material living standard. Five of the women with cattle on tribal land in Charleshill sub-district had their cattle on leasehold fenced farms (or had access to leasehold farms in times of drought). They were Batswana, Bakgalagadi and Herero women with different sized herds and their access to grazing land was mostly mediated through other social relations. Two of these women used grazing land where the leases were registered by husbands, one by a boyfriend and two by parents, and one woman was allocated land herself by the Land Board. In this way, even the women with smaller herds had gained access to fenced grazing lands, albeit sharing it with others.

Nineteen of the Batswana, Bakgalagadi and Herero women I interviewed grazed their cattle on non-fenced, communal tribal land and one on the village grazing area. Six of these women had gained access to water and grazing land by registering a borehole syndicate together with their husbands and relatives. Five had access to grazing land through their husbands, five kept their grazing land rights when their husbands died, and two shared grazing land with relatives. Thus, the more attractive forms of property relations to non-fenced grazing land were accessed through husbands or male relatives, showing how such property relations are not only mediated through class but also gender.

Property relations to land are shaped by Botswana's colonial heritage, where descendants of the European elite still have private property rights to freehold land and access to leasehold grazing land, with private usufruct rights for non-European cattle farmers being limited to those with larger herds, as we saw in chapter 4. Access to grazing land for the forty women cattle owners that I interviewed followed these patterns to a certain extent, as the table below shows.

Table 2. Land tenure of the women cattle owners.

	Fenced Freehold land	Fenced Rented Freehold land	Fenced Leasehold tribal land	Communal Tribal land	Communal Village grazing area	Total
'White'	9	3	0	0	0	12
'Black'	1	0	4	19	1	25
'San'	0	0	0	0	3	3
Total	10	3	4	19	4	40

The kind of property relations farmers have to land has an impact on cattle management practices. The fact that Elisabeth, from the narrative at the beginning of the chapter, had a fenced property increased her chances of ensuring that all of her cattle have boluses inserted in their stomachs at the time of sale, as she knows where they are at all times and can collect them easily when the DVS officers come. The fences also increased the chances that they will obtain sufficient access to grass and water to put on enough weight to wield a decent price at the weigh-in. Further, it is easier to control calving seasons as she can separate the bull from the cows and heifers at will. With most of the calves born around the same time, it is easier to administer a larger sale that in turn reduces the proportionate cost for transport, as well as the time and effort it takes to go through the sale procedure.

Unequal access to capital, in this case in the form of cattle and grazing land, technology, here in terms of fences, and labour as Ribot and Peluso (2003) suggest, shape the conditions under which the women cattle farmers operate.

For all Tswana and Kgalagadi women interviewed, except one who sold fish and one who had newly started her herd, the cattle were their main livelihood and source of monetary income, although for some, piece jobs, crops, small stock production or a butcher's shop supplemented their livelihoods. For the three Nharo women, cattle were the only alternative potential income besides drought relief programmes or dependence on their relatives. For all the Herero women, except for two who were also wage labourers doing administration or cleaning at the Rural Administration Centre (RAC) in Charleshill village, one of whom also had goats, cattle production was their main livelihood and only source of monetary income.

Except for three of the Afrikaner and English women on the Ghanzi farms – one of whom was a wage labourer, one ran a butcher's shop, and one was a student supported by her mother – live cattle sales represented their main livelihood and source of income. Some of these women also had businesses on the side, such as stud breeding, a hardware store or vegetable plantation, and some also kept goats on the farm. The Afrikaner and English farmers were thus all part of the wealthiest group in Ghanzi, and belonged to the highest class of cattle owners. The Batswana, Bakgalagadi and Herero, with larger herds and fenced grazing land, could be counted as being members of the higher wealth classes (Bolt and Hillbom 2013a), although while Batswana and Bakgalagadi women that I met lived and socialised together, the Herero women made up a more distinct community.

Although Afrikaner and English women were to some extent part of the same 'white' high class community, they mingled more amongst themselves than between ethnicities. Sometimes, race became important in relation to others, while at other times, it was ethnicity that was highlighted. This was also done through hierarchies of class, as class was racialised, as discussed above. Again, gender is brought to the forefront in combination with ethnicity, race and class, shaping what is seen as appropriate and reasonable for men and women to do, as I discuss further in chapter 6. Thus multiple dimensions of social relations interact (McCall 2005) so that relations to others emerge out of different social processes in an ongoing and interactional manner (West and Fenstermaker 1995). Along which axis that boundary work (Kent 2002) is done thus varies.

The majority of the Batswana, Bakgalagadi and Herero women I interviewed lived under poorer material living standards with small cement houses and less material goods, and belonged to lower social classes than the English and Afrikaner women. Some, however, with larger herds were part of a wealthier strata and a higher class. The Nharo women I interviewed were all part of the lower wealth and social class with poor material living conditions. In addition, having the money, from cattle sales or otherwise, to buy feed for the cattle in times of drought or to send them to the feedlot to reach the ideal weight for sales also makes a difference to the ability to benefit from the cattle.

The women farming on communal land in Ghanzi District who said that they sold cattle told me that they sold either to the BMC, Marie's feedlot or to other 'whites', referring to other cattle agents functioning as middle men to the BMC. Farmers on large freehold farms, predominantly white, contracted the feedlot to fatten their cattle from time to time, and also bought feed for the cattle in their own *kraals*. Although the weaner production system, focusing on selling calves at weaning age, does not intentionally set out to favour some groups over others, it does play into the hands of those with opportunities to secure enough feed or grazing to produce heavy weaners, as well as the feedlot owners making a profit out of being middle men to the BMC (GoB 2013). It is in a sense a situation where those with a more privileged starting point in terms of capital can benefit from the feedlot system that encourages export beef production, while those farming under poorer conditions find it harder to compete.

As Ribot and Peluso (2003) suggest, access to capital is crucial in order to be able to benefit from a natural resource, in this case cattle. In a sense, cattle can be thought of as both resource and capital, but as we shall see later in this chapter, a large herd size represents something different than simply more resources, as size in itself affects both herd growth and how the herd is affected by removing individuals from the herd, when selling them for example. As we have seen, access to land and cattle and grazing land, and thus class, is influenced by gender, ethnicity and racialisation. In this way, interlinked processes of power articulate historically situated property relations to land and cattle (McCall 2005). Further, they also shape farm labour relations in Ghanzi.

Labour relations linked to gender, ethnicity, race and class

Access to farm labour in Ghanzi is also defined by historically situated social relations shaped through cattle production. Christine declared to me that she would not know what to do without Xgaiga, and that she would always take good care of him and his family. She tells me the story of how she went with one of her Nharo-speaking employees to the healthcare centre when she fell sick, in order to make sure that she got proper care and was not discriminated against because of her ethnicity. Through stories of the initial encounter between Afrikaner settlers and Nharo inhabitants with an emphasis on a shared love of the land, Christine described the unequal property relations and labour relations of Afrikaner, or 'Boer' and San, who were often referred to as 'Bushmen' in Ghanzi as being natural and unproblematic:

C: When the settlers came in to Ghanzi they encountered the Bushman. I think it's a symbiotic relationship between the Afrikaner and the Bushmen; they were drawn to each other. I think it's more something about the way they live. That's why they.. it's like magnets. You can't take away the Bushman, what are we going to do? You can't take us [the Afrikaner] out of the equation, what about the Bushman? We are dependent on each other and I don't think that it would end in the near future – I'm sorry. [Laughs]

A: Would you want it to end?

C: I don't think so. You know [...] It goes back to that kind of nature's child. We as Afrikaner farmers, we are also connected to the land as are the Bushmen. (interview 5 August 2013, Ghanzi town)

Through such stories, claims to land and labour become reasonable (Fortmann 1995). They were cooperating in Christine's view, and now live in a mutually beneficial relationship. However, while she emphasised both her dependence on the San employees and their similarities in that they were both connected to the land, there was also an unspoken rule concerning the hierarchical nature of their relationship. Both ethnicity and race become important here, as Christine draws on perceived differences between both 'whites' and 'Bushmen' (Bhavnani 2001, Ballard 2002) and at the same time appealed to the connectedness of the land that was associated with both the San and the Afrikaner, or Boer. Class hierarchies tied to property relations are in this way painted as 'natural' differences between groups of people by alluding to race (Sundberg 2008). Both 'race' and 'nature' were here made important in terms of how they have been related to each other throughout history (Moore et al. 2003).

The relationship between Xgaiga and his family and Christine and her family was characterised by both closeness and distance. While Christine praised Xgaiga for his cattle skills, reliability and his attitude to life, an unspoken rule made sure that he never went inside her house. "They don't like us sitting on their furniture" (field notes 7 May 2013, Ghanzi Farms), explained Ditiro, the San man who was my translator, when he refused to come with me into an Afrikaner woman's house for tea.

Christine's take on a mutual, historic dependency is in some ways reflected in Russell's (1976) as well as in Russell and Russell's (1979) reflections over early relations between 'Bushmen' and 'Boer' in Ghanzi, as discussed in chapter 4, where emphasis lies on the similarities between the Afrikaner and the African lifestyles rather than their roles as colonisers. It also reflects Guenther's (2015) understanding of the San-Afrikaner relationship as one of 'racial paternalism' and an initial symbiosis.

When Thamae told his story, emphasis was on the abundance of food and the freedom of the life before the fences in Ghanzi, in sharp contrast with the scarce resources available as a cattle-hand today. When he was a young boy, he and his family lived in the area, he told me, hunting wild game and collecting roots, nuts and plants for food. When they were no longer allowed to hunt on the land and water sources outside of the farms became scarce, they came to live on the farms. However, he did not like it, he says, because he had nothing of his own and was unable to build something for himself.

His story, then, starts before Christine's story in time, and naturalises different property relations (Fortmann 1995) than Christine's story does, emphasising instead how they had been denied their longstanding access to the land. His and his family's property claims to the land were thus not sanctioned by the socially legitimate institutions of the new colonial elite who had the power to enforce or deny them (Sikor and Lund 2009) and without their claims being legally and socially recognised and enforced by an external legitimised authority (Agarwal 1994b), they lost their rights to the land. Race was here constructed together with the environment and bound up with ideas about 'nature' and what were seen to be appropriate relations to it for different people, defining resource allocation (Sundberg 2008). Further, class relations were simultaneously constructed as the denial of Thamae and his family's claims to access to the land made them dependent on Christine's family and their neighbours, creating readily available labour for them. Moreover, the relations were gendered as only men were employed as cattle-hands at the *kraals*, with their wives expected to take care of their household and live off their husband's salary and rations.

The hierarchy between the Afrikaner and Nharo people I met in Ghanzi was upheld even outside of formal working relations, so that Nharo people as a group were constructed and perceived as being on unequal terms with Afrikaners as a group. While Christine praised the qualities of the 'Bushmen' (San), it was clear that it was all right for her to engage with Nharo people differently than with Afrikaner or English people.

Further, when I tagged along with Magriet, Peter and other white farmers, I was always invited by white farmers to ride inside their trucks while the 'Bushmen' always rode on the back. When driving with an Afrikaner farmer and stopping somewhere for a visit, there seemed to be no need for 'us' to inform 'them' about the plan, and when 'we' came back after, for example, a forty minute coffee visit at a relative's house, the employees and other 'Bushmen' passengers rushed from the shade and jumped up on to the back of the truck. Without a word, the farmer and I got in the air-conditioned front seat and drove off. This situation left me with an embodied experience of racial hierarchies and left me uncomfortable.

It is a mutual understanding of a hierarchical relationship expressed clearly by Ditiro's comment above, revealing that although he was not even an employee at the farm, he assumed that the Afrikaner farm owners did not want him – a 'Bushman' – inside their house. The apparent acceptance of the social hierarchy between Afrikaner and Nharo, between white and San, is also apparent in young Afrikaner Yolanda's comment on their relationship on the farm where she was raised: "They used to be our friends, but when we grew up they became our employees" (interview 4 December 2013, Ghanzi town). Yolanda's statement captured neatly the naturalised labour relations between Afrikaner cattle owners and San cattle-hands. It provided her and other 'white' women cattle owners on the fenced Ghanzi Farms with easy access to labour, facilitating their ability to benefit from land and cattle (Ribot and Peluso 2003).

Christine's and Yolanda's statements were grounded in historical socioeconomic relations that construct a world of inequalities, and identify identified Nharo-speaking people as being inherently different from Afrikaans or English speakers. The way that cultural distinctiveness coupled to race was used to differentiate between the two groups of people in a way that placed them at opposite ends of political and economic continuum (Hylland-Eriksen 1991, Ballard 2002) gave Xgaiga and Christine very different starting points and possibilities. Additionally, the essentialist nature of certain characteristics attributed to the constructed ethnic category of Nharo made it possible for Christine to avoid a problematisation of this relationship, while also helping to normalise a situation of extreme inequalities. Other Afrikaner men were also hired as managers on Afrikaner-owned farms, and Batswana or Herero men and women were hired for manual labour around the homestead, though rarely living at the *kraals* like the Nharo employees.

Labour relations between women cattle owners I met in Charleshill sub-district and the cattle-hands taking care of their cattle varied. Among the Batswana, Bakgalagadi and Nharo women cattle owners, male family members and relatives would often take care of their cattle in exchange for monetary or other compensation, but unrelated men were also employed. Similarly, among the Herero women I met that did not live full time at the *kraal*, it was common that family members or hired Nharo or Herero cattle-hands would take care of the daily tasks, while the women living at the farms would do most of the daily work of watering and milking the cattle themselves. The racial or ethnic divides between owner and worker were