The applicability of the agricultural production systems simulator (APSIM) model to decision-making in small-scale, resource-constrained farming systems: a case study in the Lower Gweru Communal area, Zimbabwe

By

Tirivashe Phillip Masere

Submitted in fulfilment for the academic requirement for the degree of

Master of Agriculture

Agricultural Extension and Rural Resource Management in the

School of Agricultural Sciences and Agribusiness,

University of Kwazulu Natal

Pietermaritzburg

December 2011

ABSTRACT

Small-scale farmers rarely get enough yields to sustain themselves to the next harvest. Most of these farmers are located in marginal areas with poor soils and in semi-arid areas which receive little rainfall yet the farmers practice rainfed agriculture. A number of reasons can be attributed to the low yields characterizing these farms. Lack of relevant knowledge for decision-making and climate change are among the major reasons for poor yields. Whilst there is not much the small-scale farmers can do to influence climate, they can at least make informed decisions to improve their yields. The information necessary for agricultural decision-making include the climate forecast information and information about performance of new technologies be it fertilisers, varieties or other practices.

The study aimed to answer the primary research question: What is the applicability of the APSIM model in decision-making by small-scale resource constrained farmers? This question was supported by secondary research questions namely:

- How useful is the APSIM model in small-scale farmers' adaptation to future climate change?
- What are the current farming systems of Lower Gweru farmers with regards to maize production?
- What are farmers' perceptions of climate change and what changes have they noticed in the last 10 years?
- How do small-scale farmers make crop management decisions?

Data was gathered through five methods namely, Focus Group Discussions, resource allocation mapping technique, APSIM simulations, on-farm experimentation, and semi-structured interviews. Data was collected from a group of 30 small-scale farmers of Lower Gweru Communal area. The study concentrated on maize production due to the fact that it is the staple food and was grown by all farmers.

All the farmers perceived climate to be changing. The changes noted included late start of the rain season, early cessation of rain season and temperature extremes. The majority of farmers highlighted that they were using local indicators to make decisions about climate or to forecast the nature of the coming season before they were exposed to SCF and APSIM.

The data gathered from three selected resource allocation maps were used to run the APSIM model. For which farmers were convinced that the model was credible in yield prediction based

on the simulated results which reasonably compared to observed yields. The what if questions raised by farmers during the discussions were also assessed and this further increased the farmers' confidence with the model, as they viewed it as a planning and guiding tool before one can actually commit resources. The semi-structured interviews showed that most farmers will continue to use the model outputs in their decision-making. The reasons being that it was a good planning and budgeting tool, it is cheaper and faster since one can assess a lot of options in a short time and would then decide on which options are viable in a given season. The few farmers who said they would not use the model or its outputs in decision-making cited reasons including lack of a computer to install the model and that it was complex for them. Semi-structured interviews confirmed the data collected in resource allocation mapping, focused group discussions and APSIM sessions.

DECLARATION

I, Tirivashe Phillip Masere, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other person's data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This thesis does not contain other person's writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

    (a) Their words have been re-written but the general information attributed to them has been referenced.

    (b) Where their exact words have been used, then their writing has been placed inside quotation marks, and referenced.

5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged and the source being detailed in the thesis and in the Reference section.

____________________________ ____________________

Signature Date

As the candidate's supervisor I have approved this thesis/dissertation for submission.

Dr. Steven Worth

Name	Signature	Date
Dr. Steven Worth		

ACKNOWLEDGEMENTS

Firstly I would want to thank the Almighty God for the wisdom in enabling me to carry out this research. I would also want to thank my supervisor Dr Steve Worth for the guidance, instructions and finding time to help me. Special mention goes to Dr John Dimes for helping me on APSIM issues and in conducting simulations with the Lower Gweru farmers. I would also want to thank the project leader Prof F.T Mugabe for giving me the opportunity to carry out my research. To Dr Munodawafa, Veronica Makuvaro, Cyril Murewi Ignatius Chagonda and the Agricultural Technical and Extension Services (AGRITEX) staff, thank you for all your efforts, I would not have managed to carry out this research without you. Many thanks go to the Nyama and Mdubiwa farmers for their time and commitment to this research. To Mr Tshuma and Mrs Bhebhe (deceased) thank you for allowing me to use your fields for on-farm experiments. Last but not least I would want to thank my wife Victoria and son Phillip (Jnr) for their unwavering support throughout the duration of the research and thesis writing.

LIST OF ACRONYMS

APSRU	Agricultural Production System Research Unit
APSIM	Agricultural Production Systems Simulator
AN	Ammonium Nitrate
AGRITEX	Agricultural Technical and Extension Services
CFAR	Climate Forecasting for Agricultural Resources
FGD	Focus Group Discussion
FGDs	Focus Group Discussions
GCMs	Global Climate Models
GEF	Global Environment Facility
IDRC	International Development Research Centre
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
JFM	January-February-March
NACA	Network of Aquaculture Centres in Asia-Pacific
OND	October-November-December
PAWC	Plant Available Water Content
RAM	Resource Allocation Mapping
RAMs	Resource Allocation Maps
SCF	Seasonal Climate Forecast
SSIs	Semi-Structured Interviews

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1. Problem statement

Most communal farmers are getting low crop yields due to a number of reasons. Among them lack of relevant and adequate information necessary for making informed crop management decisions. These farmers are resource-constrained and rely on agriculture for the sustenance of their livelihoods, yet they rarely plan properly for the next season. Added to the current situation is climate change that is taking place leading to reduced yields of many crops including maize, the staple food of Zimbabwe. Due to lack of or inaccessibility of official climate information and agricultural information, farmers rely on indigenous indicators to forecast the nature of the coming season and plan their farm management. The indigenous knowledge systems which evolved over many generations ago are considered by the farmer to be safer and less risky than new technologies. Most resource-constrained farmers are risk averse and will not take undue risks (Prasad *et al.* 1996). As such, the continued reliance on these indigenous systems, which, in most cases, have not been updated, is now failing to cope with climate changes which they were not designed to handle (Hurni 1996) is resulting in poor yields.

Risk aversion in dry areas tends to slow down adoption and diffusion of improved technologies (Prasad *et al.* 1996). Resource-constrained farmers prefer crop varieties and production strategies that require low monetary budgets, while at the same time providing insurances against climate variability. Most communal farmers rely on rainfed agriculture and display risk aversion characteristics as their primary goal is self-sufficiency in family food requirements (Prasad *et al.* 1996). Despite the availability of improved technologies to meet rainfed farming needs, which have shown to be several times more productive than traditional farmer practices, the adoption of these technologies is low. The risk faced by farmers practicing rainfed agriculture is not only nature induced but also as a result of lack of knowledge in the management of production strategies (Prasad *et al.* 1996).

As a result of poor crop yields characterizing communal areas, most farmers in the Lower Gweru Communal area (study site) have long ceased to plough their major fields and are concentrating on the smaller ones inside their yards. This research introduced to the small-scale, resource-constrained farmers the official season climate forecast, crop simulation modelling and how to apply such information in making decisions. The crop simulation model used in this research was the Agricultural Production Systems Simulator (APSIM). The main purpose of the study was to assess the applicability of APSIM and its outputs in crop management decision-making amongst smaller-scale resource-constrained farmers. The APSIM model is capable of exploring many alternative farming options under different climates and also of giving outputs that famers can use in making decisions (Dimes *et al.* 2003).

Most risk averse farmers will only change from their usual practice upon having firsthand evidence of the actual performance of new technology and information in terms of crop yields (Prasad *et al* 1996). It is submitted that a fast and inexpensive way of testing different strategies is through use of crop simulation models like APSIM.

In this research farmers were given a chance to make decisions upon introduction of SCF and running APSIM using their crop management data for previous seasons. This also served to test whether farmers where going to utilize the model information outputs in planning and making decisions about the on-farm experiments which formed a later part of the research programme which required them to select treatments (management practices) that were to be included in two simultaneous experiments to be held in two wards of Lower Gweru Communal area.

Generally, farmers prefer information which tells them the effect of changing to different practices with regards to yield gained or lost. Most of the new technologies, for example, new varieties or fertilisers or even the use of SCFs, do not really tell farmers the actual yield response and hence risk averse farmers will not easily change their way of doing things or risking their livelihood with something in which they do not have trust (JP Dimes 2008, pers. Comm.[1]).

Before this research was conducted, the Lower Gweru communal farmers were not aware of crop models and most were also not aware of the official SCFs – both of which are useful and relevant sources of information that can be used to make informed farm management decisions. This lack of information implies that small-scale, resource-constrained farmers will not have sufficient

[1] Dr. JP Dimes, ICRISAT, P.O. Box 776, Bulawayo, Zimbabwe

information pertaining to the type of the coming season (good or poor rainfall season) for them to plan and invest accordingly. Although most of these small-scale farmers use indigenous knowledge to forecast climate, sometimes it may not be clear as to the type of season and sometimes predictions are not accurate. In these years, where even the small-scale farmers themselves are acknowledging that the climate is changing, farmers will need relevant, accurate and timely information to make good decisions. It is suggested that APSIM can be useful in addressing some of the farmers' problems. From the researcher's experience with APSIM, the simulator has demonstrated that the model is excellent in quantifying risks of different practices; something which even SCFs cannot do.

1.2. Description of the study site

The study was conducted in two wards of Lower Gweru communal area of Zimbabwe, namely Nyama and Mdubiwa. The two were selected based on their easy accessibility, because they were representative of the whole Lower Gweru Communal area, and also because of their contrasting nature with regards to wetness/water availability. Nyama ward is wetter than Mdubiwa as it has a higher water table than Mdubiwa which is located at a relatively higher altitude than Nyama. From each of these wards the farmers were selected randomly from three villages. From Nyama the randomly selected villages were Matonsi, Guduza and Siyabalandela, and, in Mdubiwa, Mxotshwa, Nsukunenji and Madinga villages were selected.

Lower Gweru is a developed communal settlement in the Midlands province of Zimbabwe. It is located about 40 km North West of City of Gweru, and stretches a further 50 km to the West. Lower Gweru is situated at 19° 14' 0" South and 29° 15' 0" East. Nyama ward stretches from 19^{o} $10^{'}$ 05'' to 19^{o} $18^{'}$ $24^{''}$ South and 29^{o} $17^{'}$ $12^{''}$ to 29^{o} $26^{'}$ 34'' East. Mdubiwa ward stretches from 19^{o} $12^{'}$ $45^{''}$ to 19^{o} $21^{'}$ 15'' South and 29^{o} $26^{'}$ 0'' to 29^{o} $32^{'}$ $48^{''}$ East (1: 50 000 map of Gweru) (Matsa and Mutekwa 2009)

Soils are mainly sand loams which are moderately shallow derived from granite. The topography is generally flat with moderate slopes. The altitude for both wards range from 1200 - 1346 metres above sea level. Most of the areas, including Nyama ward, are well watered and marshy.

Mdubiwa ward is found in the dry parts of the communal area. The major river is Vungu which is a tributary of the greater Shangani River (Mubaya 2010).

Market gardening is the main economic activity in Nyama ward since the soils are fertile and well watered all year round. Mdubiwa ward is characterized by the gold panning activities as a major coping strategy to low agricultural yields since it is dry thereby not supporting crop productivity (Mubaya 2010).

Zimbabwe is subdivided into five agro-ecological regions usually numbered in roman numerals I to V based on effective rainfall, vegetation and other agro-ecological factors, in a continuum with region I having the highest rainfall and V the least as shown in Table 1. Agricultural potential is highest in Region I and decreases gradually to region V. Region IV and V are also characterized by high temperatures especially in the summer season and low temperatures in winter (May to September). Lower Gweru communal area falls in natural region (agro-ecological zone) IV (Vincent and Thomas 1960 in Zimfarmer 2010).

Table 1: Agro-ecological zones of Zimbabwe and the recommended farming systems in each zone

Natural Region	Area (Km^2)	Rainfall (mm/year)	Farming System
I	7 000	>1000	Specialized and diversified farming
II	58 600	750 – 1 000	Intensive farming
III	72 900	650 - 800	Semi-intensive farming
IV	147 800	450 -650	Semi-extensive farming
V	104 400	<450	Extensive farming

(*Source: Vincent and Thomas 1960 in Zimfarmer 2010)*

Natural region IV is semi-arid to arid and receives rainfall in summer from October to April ranging from 450mm to 600mm annually, with frequent droughts. Rainfall season is characterized by periodic seasonal droughts and severe dry spells. As shown in Table 1 natural region IV is a semi-extensive farming region covering about 38% of Zimbabwe. Crop production is therefore risky except in certain very favourable localities, where limited drought resistant crops are grown (Reynolds 2004) including millet, sorghum, legumes, cotton and maize. The farming is based on livestock and drought resistant fodder crops.

1.3. Research questions

The research in this study addressed two primary and four sub-research questions.

1.3.1. Primary research questions

This study explores two main questions:

- What is the applicability of the APSIM model in decision-making by small-scale, resource-constrained farmers?
- How useful is the APSIM model in small-scale farmers' adaptation to future climate change?

Conclusions about these questions are discussed in Chapter 6.

1.3.2. Sub-research questions

To answer the main research questions, the following additional questions were explored:

- What are the current farming systems of Lower Gweru farmers with regards to maize production?
- What are farmers' perceptions of climate change and what changes have they noticed in the last 10years?
- How do small-scale farmers make crop management decisions?

Answers to these questions are addressed in the presentation of the research findings in Chapter4.

1.4. Research objectives

This study had the following five research objectives:

- To assess the applicability of the APSIM model in decision-making by the small-scale, resource-constrained farmers.
- To evaluate the usefulness of APSIM in adapting to future climate change.

- To characterize farming systems of Lower Gweru farmers regarding maize production.
- To determine perceptions of Lower Gweru farmers on climate variability and change.
- To identify current farmer decision-making processes.

1.5. Scope of study

This study was conducted in two wards of Lower Gweru Communal area, namely, Nyama and Mdubiwa wards. From these wards three villages were selected and five farmers from each of the six villages were chosen to participate in the study. The total number of farmers was thus 30 which experience with APSIM has shown was the maximum number that can be effectively engaged when introducing this particular simulation modelling (APSIM) and SCF. The sample size afforded the researcher adequate contact time with the farmers when explaining and working with the model. The study was also limited to maize farming systems, as it is the staple food and the crop most commonly grown in Zimbabwe.

1.6. Assumptions of the study

It was assumed the participating farmers would provide accurate information that gives a true reflection of their farming systems and decision-making processes of the Lower Gweru Communal area. It was also assumed that the participating farmers would be willing, and able to understand and work with the APSIM model.

1.7. Structure of thesis

Chapter 1 is an introductory chapter outlining the research questions, objectives of study, site description and structure of the thesis.

Chapter 2 is a review of literature. It covers pertinent issues regarding the APSIM model, small-scale, resource-constrained farmers, farmer decision-making processes, seasonal climate forecasting, as well as adaptation to climate variability and change.

Chapter 3 describes the research methods used to tackle the research questions. These included Focus Group Discussions (FGDs), on-farm experimentation, Resource Allocation Mapping (RAM), APSIM simulations and Semi-Structured Interviews (SSIs).

Chapter 4 presents the research findings. Results from each of the methods used are presented with initial analysis.

Chapter 5 engages in deeper discussion of the findings presented in Chapter 4. In Chapter 5, the findings are analyzed and made sense of by comparing findings from each method against each other. Secondly, the findings are compared to findings from the literature presented in Chapter 2.

Chapter 6 presents the conclusions, recommendations and policy implications emanating from the study and addresses each of the research questions. In addition, it presents weaknesses in the study and recommendations for further study.

CHAPTER 2
REVIEW OF LITERATURE

2.1. Introduction

The purpose of this chapter is to outline the general facts concerning the Agricultural Production System Simulator (APSIM), small-scale, resource-constrained farming systems, as well as their decision-making processes. The main thesis of this review centres on the applicability of the APSIM model to decision-making in small-scale, resource-constrained farming systems subject to climate variability and change. The review will include an outline of how small-scale communal farming has been affected by changes in climate as well as how these farmers are adapting to this climatic variability and change. The review then addresses the decision-making processes regarding crop management, climate and factors affecting the decision-making process. The main sections of this chapter are the APSIM model, climate change forecasting (SCFs), small-scale, resource-constrained farming systems and decision-making, and adaptation to climate variability and change.

2.2. The Agricultural Production Systems Simulator (APSIM)

APSIM is a crop simulation model developed as a result of the need for accurate predictions of crop yields in line with climatic, environmental and management factors and also to move away from stand-alone crop models which were unable to simulate essential aspects of cropping systems (Keating *et al.* 2003). Predictions from a model that incorporates simultaneously all factors at play in a crop production system are more credible than those from stand-alone models. APSIM was designed to simulate various processes taking place in the soil during crop production under a range of management options in different climates (Agricultural Production system Research Unit (APSRU) no date; Probert and Dimes 2004). According to Climate Kelpie (2010), APSIM simulates effects of environmental variables and farm management decisions on crop yield and profits. The fact that APSIM is made up of different soil modules, a range of crop modules and crop management options under different climates makes it an accurate tool for predicting crop yields, if all the data input is done correctly. This also implies that it can be used everywhere in the world, including in small-scale farming systems of Africa, as long as it is validated for local conditions and crops. APSIM is also concerned about the long term repercussions of the actions of farmers, for example, on yield levels and soil nutrient status. Keating *et al.* (2003) noted that the main thrust of APSIM is a combination of crop yield estimation, as a result of how farmers manage their farming systems, and effects of these management decisions in the long run.

2.2.1. Overview of APSIM

APSIM operates using input data namely, soil data, crop management data and long term daily climate data. Climate data required are daily rainfall (in mm), daily temperatures (both minimum and maximum in ^{0}C units), minimum temperature (^{0}C) and radiation (MJ/m^2). The important soil parameters are the initial nitrogen and organic carbon. For the model to predict correctly there is need to input accurate data. Crop management data include crop type and variety, sowing dates, weeding dates and fertiliser management (type, amount, dates of application) (Keating *et al.* 2003; Climate Kelpie 2010).

2.2.2. Applications of APSIM in small-scale, resource-constrained agriculture

APSIM has been used by various users in different climatic and soil conditions across the world for a wide range of applications including aiding farm management decision-making, appraising the value of climate forecast information, risk evaluation, predicting crop yield and other aspects of farming systems under different management options, soils and climatic conditions (Climate Kelpie 2010). The applications of the APSIM model can be “classified into several classes including: water balance, climate impacts, cropping systems, crop management, land use studies and soil processes” (Keating *et al.* 2003:280), to name but a few. The model applications range from research-minded uses involving testing of current against possible alternative management options to actual practical use through aiding field decision-making (APSRU no date).

Synergies between APSIM and participatory research have been identified and areas of potential model applications have been suggested. Dimes *et al.* (2003) suggested the uses of APSIM range from interpreting on-farm experimentation results, exploration of investment options and risk analysis, evaluation of new technologies and creation of virtual learning opportunities, which is difficult and risky practically, to direct farmer engagement with the model. Small-scale, resource-constrained farming is very risky due to overdependence on rainfall. The risk will be even greater as a result of the likely changes in rainfall patterns associated with climate change. However, small-scale farmers often overestimate this risk. Crop simulation models, like APSIM, offer the opportunity to change this circumstance by exploring options that farmers can „try out' and by helping them evaluate the "risk associated with various operational decisions under climate variations" (Struif-Bontkes and Wopereis 2003:19). APSIM facilitates the evaluation of these alternative crop management options and actually, offers the prospect of developing a wider range of fertility level for different classes of farmers in terms of both resource endowment and risk preferences. APSIM does not, however, pursue a single best solution, but rather aids the assessment of an array of technologies suited to different seasons and priorities of the farmer (Rohrbach and Okwach 1997).

The APSIM model can also be applied to help in the design of on-farm experiments and the timing of certain farm operations by simply setting the threshold dates for the operation; for example, one can input data into the model to perform a "weeding operation" 35 days after sowing. This is possible because APSIM simulations include the effect of weed competition on crop growth and yield (Struif-Bontkes and Wopereis 2003). The resulting simulation output (of weeding after 35 days) can thus be used to guide decisions on when it is best to weed or whether there is need for a second or third weeding.

The APSIM model outputs for a given area can also be reliably extrapolated and used in another area by making the necessary adjustments to suit the new area conditions. This is because the model provides an excellent framework for extrapolating research outputs to other areas through enhancing the understanding of system processes, management situations as well as the long term effects of farmers' actions (Dimes *et al.* 2003).

2.2.3. Limitations of APSIM model

Although the APSIM model is an excellent tool for quantifying risks due to climate variability and simulation of various processes that take place in the cropping systems, its use in small-scale systems is restricted due to a shortage of capable modellers as well as a lack of reliable input data, especially in semi-arid Africa (Struif-Bontkes and Wopereis 2003). The model does not include the effects of pests and diseases in its framework; hence, the simulation results are most likely to be higher than the actual observed yields (Holzworth *et al.* 2006). APSIM is also very complex and needs expert support and skills to aid simulation building, for example, soil scientists and agronomists. Whilst this support is usually available to modellers, the same cannot be said about small-scale farmers (Holzworth *et al.* 2006).

2.2.4. Conclusion

APSIM adds value to SCF information and aids farm decision-making as it allows for the assessment of a range of management options or alternatives to the current farmer practice. The resultant simulation outputs, after comparisons, will be useful in helping farmers with management alternatives they can employ for that particular season. The management options may include differing the planting dates, comparing two weeding times against just weeding once, effects of different varieties on yield, comparing different levels of fertiliser, comparing fertiliser and manure, benefits of split application of fertiliser, benefits of adding a legume crop in a crop rotation and the effects of in-field conservation techniques on yield. The capability of APSIM to simulate the long-term effects of farmers' actions on the soil nutrient status and yields, can also give insights as to how they can solve anticipated problems and hence enable them to plan ahead, for instance, introducing crop rotations with leguminous plants to improve the nutrient status of soils. The model output for one site can also be extrapolated and used for other sites as long as the necessary adjustments are done to suit the conditions of the sites. However, for APSIM to give accurate outputs, the model inputs (daily climatic data, soil data and crop management data) should be as accurate as possible. The limitations of APSIM include that it requires skilled or trained personnel to run it and most small-scale, resource-constrained farmers would not be able to use it on their own. Unavailability of the input data required for running the model, especially in sub-Saharan Africa where the long-term daily climate data normally have missing data and also long term yield data needed for model validation, is usually not documented (Struif-Bontkes and Wopereis 2003).

2.3. Climate change forecasting

This section covers how climate is forecast, how SCFs can be used by small-scale farmers to make decisions, and the advantages and limitations of seasonal forecasts. The sequence of this section is: climate change, seasonal climate forecasting, applications of SCFs and limitations of SCFs and, finally, a conclusion.

2.3.1. Climate change

Climate change is the longer term variations in average weather parameters such as temperature or rainfall often resulting wholly or in part from anthropogenic factors, most notably, global warming (Hellmuth *et al.* 2007). Climate change forecasting involves the use of scientific technology to foresee the state of the atmosphere for a particular period in the future for a specific location, including a SCF.

2.3.2. Seasonal climate forecasting

SCFs give an indication of the nature of the season in terms of rainfall and temperature. SCFs refer to the likely estimates of the amount of rain anticipated in a season based on the behaviour of seas and oceans (Washington and Downing 1999, in Ziervogel 2004). In Zimbabwe, the forecast is issued by the Meteorological Department in two phases namely, October-November-December (OND) and January-February-March (JFM), just before the onset of the rainy season. The chances of total seasonal rainfall are classified as: below normal, normal or above-normal, although the figures will only be available to climate experts (Chikoore and Unganai 2001).

The methods of dissemination of the forecast include use of radio, television, newspapers or through extension staff. According to Chikoore and Unganai (2001), the most efficient method of disseminating seasonal forecast information to small-scale, resource-constrained rural communities in Southern Africa is by radio broadcast. However, in a study by Ziervogel (2001) in Basotho village in Lesotho, most farmers preferred to get the forecast from the extension agents, citing that they do not have radios and also that the agents will even help them understand through demonstrations.

The aim of the forecasts is to equip users (mainly farmers) with climate information, which they can incorporate into their existing agricultural management strategies so as to make informed decisions on their farms to increase food security (Chikoore and Unganai 2001). The information from SCFs helps farmers to plan; for example, if it is going to be a good rainfall season, farmers may invest in more inputs (like fertilisers, hybrid seeds and labour) and in a poor rainfall season, farmers may opt for early maturing varieties. Farmers will modify some of their management techniques or decisions as a response to the seasonal forecast, if they perceive it to be accurate.

If a forecast predicts a poor season (issued in advance), the start date of the season, as well as information on adequacy of rains, are the most valuable pieces of information to farmers (Phillips *et al.* 2001). Early warning of a poor season will give farmers ample time to decide on the type of crops to grow, for example, to change from maize to sorghum which requires less water. Farmers may also develop other coping strategies when the forecast predicts a drought, for example, income generating projects to ensure their livelihood. Farmers located in areas which normally receive low rainfall will try to maximize or make the most of a forecast predicting a wetter season (Phillips 1998).

2.3.2.1. Use of SCFs

Applying forecast information can result in a number of benefits to small-scale farmers. Most of these small-scale farmers are risk-averse, yet they are the most vulnerable to climate variability and change because they live in areas with marginal and infertile soils, depend on rainfall for their farming systems and do not have the resources to cope or recover from the effects of climate change (Ziervogel 2001). These farmers often adopt conservative risk management strategies that usually result in poor utilization of the few resources they have and reduced productivity (Hansen 2002b; Hansen and Sivakumar 2006). SCF information can be used to change this conservative way of thinking and foster better risk management through better-informed decision-making (Hammer *et al.* 2000; Hansen 2002b; Hansen and Sivakumar 2006).

Farmers can also apply forecast information to assess possible market trends. For example, a good season implies excess grain available for purchasing; hence farmers may decide to grow scarcer crops which will be in higher demand in the market (Ziervogel 2001). Small-scale farmers who depend solely on agriculture for survival and livelihoods may need additional income to meet some of their needs; growing crops that are in high demand can provide the needed income. The farmers' livelihood and food security can be increased if they can adjust to climate variability by utilizing forecast information to reduce adverse impacts and also capture advantages of these uncertain conditions (Selvaraju *et al.* 2004; Ziervogel 2004).

According to Meinke *et al.* (2009), application of climate forecast information by farmers is said to be effective if it leads to a change in a decision and results in either an economic improvement or reduction in risk (Carberry *et al.* 1996). Further, SCFs will have value only if adaptive options that can deliver genuine benefits are available (Fraisse *et al.* 2006). Farmers, however, need to have confidence in SCFs for them to fully embrace them in their decision-making. Farmers often demonstrate remarkable resourcefulness once they are convinced of the benefit of an innovation (Hansen 2004).

2.3.2.2. Limitations of SCFs

Although seasonal forecasts are very useful in crop management and aiding decision-making, there are still some barriers that hinder their effective use by small-scale farmers. In the Climate Forecasting for Agricultural Resources (CFAR) project in Burkina Faso, for example, barriers included labour shortages at critical periods, timing of the seasonal forecast dissemination and lack of detailed content on the nature of the season (Ingram *et al.* 2002). Farmers also need the forecasts in time for them to use the information to plan for the coming season. Forecasts lose value if received after the commencement of the season or after planting, because the farmers will have already made decisions on planting date, choice and variety of crop, and water retention techniques Hansen (2002a).

The format of the seasonal forecast is another problem. In Zimbabwe, for example, the rainfall forecasts are issued as total predicted rainfall per rainy season, whereas farmers are interested in knowing the start and stop dates of rains and the likelihood, severity and timing of dry spells

(Chikoore and Unganai 2001; Hansen 2002a). The rainfall amount does not tell the farmers about how the rains will be distributed or the intensity of the rainfall. Hence, decisions based on it will not be very accurate – all of which are important to farmers for effective decision-making (Chikoore and Unganai 2001).

Another potential barrier to the application of forecasts is that farmers normally agree to incorporate the information only when the official forecast is in agreement with their own traditional forecast. Farmers often have their own indicators which include position of the moon, wind direction, plants flowering at certain times, colour of the gathering clouds and diminishing wells and springs (Ziervogel 2001; Mapfumo 2010). It was also noted that in a study by Ziervogel (2001), farmers in the Basotho village of Lesotho were not adjusting their management practices if a below-normal season was forecast but were rather continuing as they do for a normal season (Ziervogel 2001).

The lack of or limited understanding of the science behind the seasonal forecasts on the part of organizations such as extension services and seed companies, who are supposed to explain the forecasts to small-scale farmers, is another drawback to the beneficial use of forecasts (Chikoore and Unganai 2001). If these organizations are unable to understand and interpret the SCFs in terms of how the information can be used effectively for farm management decision-making, it renders the forecast essentially ineffective and may lead to the farmers not having confidence in the SCFs altogether.

Although SCFs provide information about almost everything farmers require to know before going into a season, Hansen and Indeje (2004) noted that it would be more useful had the forecasts informed farmers of the likely yields and returns of different management options. Integrating the SCFs and crop simulation modelling could be a solution to this, as simulation adds value to climate information.

2.3.2.3. Conclusion

SCFs are valuable tools that can be used in managing climate variability risks, planning and aiding farmers' decision-making provided they are accurate and address issues and are presented in formats that are relevant to the farmers who should benefit from them. Further limitations and obstacles inhibit the use of SCFs, including the nature, format and timing of the forecast, and farmers and service providers who may not understand the science behind the seasonal forecasts, which is why farmers prefer „indigenous' forecasting systems which they can study earlier thus giving them ample time to prepare for the season. Small-scale farmers being very risk-averse will not want to take unnecessary risks and will make use of seasonal forecasting only if they can readily see the benefits of it.

2.4. Usefulness of APSIM in adding value to SCFs

The use of crop simulation models (such as APSIM) in conjunction with climate forecast information enhances the opportunity to improve the value and usefulness of seasonal forecasts for agricultural decision-making (Hansen 2004). The APSIM model is capable of quantifying the effects of possible management alternatives in response to a seasonal forecast (Meinke and Stone 2005). While seasonal forecasts predict rainfall, APSIM can generate probable crop yields for different production strategies relevant to the forecast. Such projections can be made over a long period of time thereby helping farmers to select better options in different seasons. The integration of the two information sets improves the possibility of matching farmer needs to likely changes in weather. Coupling SCFs and APSIM modelling shifts the focus from climate anomalies to predictions of quantifiable yield (Hansen 2005). Integrating forecasts and APSIM also facilitates relevant discussions between farmers and experts. Such discussions generate information that can be utilized by small-scale farmers (Selvaraju *et al.* 2004).

2.5. Small-scale resource constrained farming systems

This section of the thesis is centred on small-scale farmers, how they make crop management decisions, factors affecting their decision-making processes and how they are affected by climate variability. The section begins by a general overview of small-scale farming systems in Zimbabwe, outlining the major characteristics of small-scale farming. This is followed by the effects of climate variability on the small-scale, resource-constrained farmers and their farming systems. The section discusses decision-making by small-scale farmers, particularly the key factors affecting these. This section concludes by outlining the value of local knowledge to small-scale farmers' decision-making.

2.5.1. Overview of small-scale farming systems of Zimbabwe

Semi-arid small-scale farming systems account for more than 75% of Zimbabwe's total farming area, encompassing approximately 60% of the total population of small-scale farmers in the country (Rohrbach and Okwach 1997). These farming systems are located in regions with "low and erratic rainfall and a short growing season" (Vincent and Thomas 1960 in Shumba 1993:69). The primary aim of production is for household consumption, if there is any surplus, it will be sold (Ziervogel 2004). This type of farming system is characterized by low productivity and widespread persistent poverty (Rohrbach and Okwach 1997; Selvaraju *et al.* 2004). Shumba (1993) noted that these systems are also characterized by small farm sizes, poor investment in farming inputs, and are labour-intensive with mixed cropping. Most of these farmers even fail to produce enough food to meet their own household needs (Rohrbach and Okwach 1997). The farmers are faced with a number of challenges that threaten their livelihoods; chief among them is climate variability, and infertile, marginal soils.

Climate variability effects on dryland small-scale, resource-constrained farming systems, with regards to yields of main crops, are most probably very marked (Cline 2007). This is because these farmers are poor and reside in locations with low fertility levels, thereby making them more susceptible to changes in climate whilst at the same time possessing the least ability to cope with these changes (Altieri and Koohafkan 2008).

Small-scale farmers, worldwide, are usually located in areas with poor soils which give poor returns under current climate conditions due to extensive cropping with little or no addition of fertilisers (Mushiringwani 1983). It becomes very difficult to obtain good yields from these soils without regular and large amounts of inorganic fertiliser, manure or lime (Grant 1981). These soils are also characterized by low water holding capacities which in turn limit the crop's response to the added nutrients in the form of inorganic fertilisers (MacKenzie 1987).

Added to the climate and soil constraints are the poor resource levels, low technology and small farm sizes which restrict the farmers to their traditional risk-aversion practices which barely support their household needs (Prasad *et al.* 1996). This tends to increase their vulnerability to future climate changes, although the resilience factor of small-scale farmers, including existing non-agricultural coping strategies and indigenous knowledge, should not be underestimated (Morton 2007). These farmers are more concerned with securing their household food requirements than with higher outputs from improved technology which involves increased risk (Prasad *et al.* 1996).

2.5.2. Climate variability effects on small-scale farming

Small-scale farming systems in developing countries are affected the most by climate uncertainties as they lack the scientific knowledge and resources to counter the effects of climate change (Cline 2007). Small-scale farmers lack finance to purchase inputs as well as to hire labour for field observation. Although farmers have always used "tried and tested" traditional and indigenous strategies to manage environmental challenges, some of these strategies are inadequate in the face of changing climate (Hurni 1996). However, the issue is not really that current strategies are inadequate; it is that farmers have stopped learning. They are using the old methods of their ancestors to address their challenges; they have become stuck, blindly applying what their forefathers developed (Thinh 1995). So the real issue is lack of innovative spirit.

Some of the effects of climate change to small-scale farmers are:

1. An increased likelihood of crop failures and declining production; changes in rainfall patterns are likely to have both short and long-term effects on food production with increased probabilities of crop failures in the short run leading to reduced production in the long run (Nelson *et al.* 2009). Simulated maize yields, from a study by Matarira *et al.* (2004), showed considerable variations under climate change scenarios thereby making maize farming an unattractive option under long term climatic changes.

2. A high incidence of livestock deaths and diseases leading to disposing of livestock with very little compensation (Morton *et al.* 2006).

3. Disruptions of families in attempts to cope with climate changes like selling household assets, family members moving to other areas to seek livelihood options and high numbers of farmers relying solely on food handouts (Food and Agricultural Organisation (FAO) 2007).

4. Price increases of most important agricultural crops including maize, wheat, soya beans and rice as a result of low agricultural production (Nelson *et al.* 2009).

2.5.3. Decision-making by small-scale farmers

Decision-making is an important issue in farming enterprises of any magnitude, including small-scale, resource-constrained farming systems. The ability to make decisions involves correct analysis of the relevant information (Hansen 2002). At various times in the year, small-scale farmers have to make climate related and crop management decisions, including crop and variety choices, planting dates, fertiliser or manure use, and weeding times and dates among others. Whatever decisions farmers make before and during the season will affect the growth and yield of crops and hence their livelihood. It should be noted that “without decisions nothing happens, even allowing things to drift along as they are implies a decision, perhaps not a good one but a decision nonetheless” (Kay *et al.* 2004:23).

2.5.3.1. Factors affecting small-scale farmers’ decision-making

There are a number of key factors that affect decision-making by small-scale farmers. These are:

- availability of information
- climate
- farmer risk typology
- economic and social pressures
- level of education and agricultural training
- time frame and bio-physical laws of nature

Availability of information: Decision-making strategies used by individuals vary with the amount of information to which they have access and with the sequence in which they obtain it. The process is also affected by the amount of pressure that they are under to reach a decision, for example, time or importance of outcome (Stephens 2002). Most small-scale farmers in poor regions of Africa exclusively use indigenous information, which they inherited from their forefathers, for making crop management decisions. Some small-scale farmers also use modern climatic and market information obtained through the radio, extension agents or other farmers in addition to indigenous knowledge (Prasad *et al.* 1996). Farmers can reconsider their usual decisions or practices if new information vital for decision-making is availed to them. Kay *et al.* (2004) highlighted several sources of new information that farmers must take into account when making decisions, including climate, technology and environmental changes. Farmers make decisions based on available information. Indigenous knowledge is easily accessible to them so farmers tend to use it exclusively, except in cases where they are exposed to scientific or market information.

Climate: All agricultural activities are influenced by the climate, particularly rainfall and temperature. Rainfall is the "most decisive parameter of climate to affect rainfed agriculture in the tropics" (Prasad *et al.* 1996:20); it influences basic decisions such as crop selection and planting times. Climate information can be obtained from scientific SCFs or from studying indigenous indicators like direction of wind, fruiting of certain local tree species and birds. However, these two information sources (scientific and indigenous forecasts) may fail to agree and most small-scale farmers will stick to the traditional indicators when such a situation arises (Ziervogel 2001, Ziervogel 2004).

Farmer risk aversion: Some farmers are risk averse while others are risk adopters. A risk averse farmer does not want to take risks even with the prospect of high returns. Sub-Saharan farmers are mostly risk averse and are generally reluctant to take undue risks. Although there have been some technologies proven to increase productivity and to reduce risks, risk averse farmers are not willing to adopt these strategies; for example, less than five percent of smallholder farmers in southern Zimbabwe use fertiliser (Rohrbach and Okwach 1997). This is despite the possible yield increases that may result after using fertilisers. Risk aversion behaviour of small-scale farmers thus affects choices and decisions that farmers make. These farmers place relatively more importance on maintaining their current crop yields (even when they are low) than on innovative methods with better yields but with a possibility of some risk (Prasad *et al.* 1996; Hansen 2002; Hansen and Sivakumar 2006).

Economic and social pressures: Decision-making is affected by a wide range of economic factors, from more farm specific factors such as seasonal labour shortages and the lack of capital to finance the preferred management options, to more pervasive factors such as poverty. Most people (even farmers) feel socially obligated to go with the general norms or „way of doing things' in their communities, and are therefore not comfortable with doing things differently to the whole group (Beckford and Barker 2007).

Level of education or agricultural training: The education level reached, most importantly in agriculture, by farmers also plays an important role in decision-making. Educated farmers seem to make better decisions in farming than their less educated or illiterate counterparts.

Time frame: Farmers make immediate, medium-term and long-term management decisions (Whisler *et al.* 1986; Penning de Vries 1990; Struif Bontkes and Wopereis 2003); each is treated differently by the farmer. Immediate operational decisions (such as weeding and irrigation dates) tend to be based on opinion or custom. Medium and longer term decisions, for example, crop and variety choice and field improvements respectively, are based on detailed analysis of climate and soil information whether scientific or indigenous (Penning de Vries 1990).

Bio-physical laws of nature: Notwithstanding the foregoing factors, even the „best' decisions may result in poor yields due to uncertainties especially in farm business management. The distinguishing quality of farm business management is the constraint placed on decision-making by the bio-physical laws of nature (Kay *et al.* 2004).

2.5.3.1.1. Local knowledge and its value to small-scale farmer decision-making

Local knowledge refers to the information amassed from trying and testing solutions in addressing challenges facing people of a given culture (Wang 1988 in Prasad *et al.* 1996:99). It is characterized by skills and strategies that have evolved over time and shared by a given group or community with the same experiences, shaped by socio-economic realities and problems, low risk technology and low external inputs (Hurni 1996; Beckford and Barker 2007).

Local knowledge is relevant to rainfed agriculture practiced by small-scale resource-poor farmers in developing countries (Wang 1988 in Prasad *et al.* 1996:99). It provides a platform for decision-making by small-scale farmers, related to both known and unknown problems affecting their farming systems and livelihoods (Hurni 1996; Beckford and Barker 2007). Small-scale farmers consider it less risky than options provided from scientific information. Local knowledge has been developed informally and is entrenched in local culture and traditions. This makes it accessible and understood by all members of the community regardless of the level of education of farmers.

It should be noted however, that the local indigenous knowledge has numerous drawbacks including failing to cope with climate change. Most small-scale farmers in the world still practice the same farming strategies used by their forefathers and as a result these practices are failing due to external pressures like climate change with which they are not able to cope (Roncoli *et al.* 2000). In other words indigenous knowledge has not been updated and tested under the current climate variability and change and there have not been any significant improvements to the strategies used by the small-scale farmers' forefathers. New local knowledge can only be developed over a long period of time of trying and testing under current climatic conditions.

There is a need to encourage a combination of exogenous (modern scientific knowledge) and local knowledge through use of the practical achievements of modern knowledge and technology to shed light on, elucidate and update the practical value of traditional knowledge (Thinh 1995). This will create an environment for small-scale farmers to inherit the created new information and subsequently continue to develop it. Hurni (1996) noted that indigenous knowledge systems are still important in identifying practices suitable for adoption or adaptation with a view to improve or reinforce accepted methods and processes.

2.5.4. Crop management decision-making by small-scale farmers

Crop management decisions that farmers are expected to make include dates of field operations, amounts of inputs to invest in, machinery to be used, crop choice and varieties to grow and area in which to grow certain crops, among others. What is important though is the basis on which these decisions will be made. Whilst it is clear that farmers base their crop management decisions on climate, particularly on rainfall, it is not very clear whether farmers will continue to use indigenous knowledge or scientific climate forecasts or both.

The decision on which type of forecast to base crop management decisions is affected by the factors already outlined in the above sections, including lack of knowledge of alternatives. Whilst most small-scale farmers have been exclusively using indigenous knowledge, there is need for more flexibility on the part of these farmers to deal with the ever dynamic climate environment (Davis-Morrison and Barker 1997).

Lack of farm experimentation with other alternative practices can also influence small-scale, resource-constrained farmers' crop management decisions. Choices made by these farmers generally reflect their farming experience in terms of expected yields and livelihood priorities. The experience is however, often limited by the capacity of the farmers to try out other management options (Delve *et al.* 2004) due to a number of reasons ranging from risk aversion to lack of crop modelling experience. Crop simulation modelling can create this experience quickly without the risk of actually implementing the various alternative strategies practically (Dimes *et al.* 2003).

2.5.5. Conclusion

Small-scale farming systems are the most affected by climate change as they rely entirely on rainfed dryland farming for a livelihood. Most of them already reside in semi-arid areas with poor soils and are failing to meet their household food requirements. With climate change expected to reduce rainfall as well as reducing season length and other new challenges to their livelihood, small-scale farmers will be hardest hit. The risk aversion nature of small-scale, resource-constrained farmers means that farmers will continue to use local indigenous knowledge for climate related and crop management decisions. Although the indigenous knowledge systems have been tried and tested, they have not been tested under current climate variability and future change. This presents a need to improve or update the knowledge through integrating it with modern technologies like crop simulation modelling, for example, APSIM. However, the process of integration will require farmers to participate in the testing of modern technology both on and off the field to develop new information or farming systems. This will be important as farmers prefer information which they can claim ownership of and will apply the generated information in decision-making. Modern technology, like APSIM modelling, helps farmers to explore and test the performance of a number of options quickly and cheaply without committing resources. The preferred options can also be tested on the ground through on-farm experimentation.

2.6. Adaptation to climate variability and change by small-scale farmers

This subsection of review of literature covers the ways by which farmers adapt to climate variability and changes, the challenges they face and a discussion on whether the APSIM model can be applied in coming up with possible adaptation strategies to forecast climate change. The following subheadings apply: overview of adaptation, challenges to adaptation and applicability of APSIM in small-scale adaptation to current climate variability and future climate change.

2.6.1. Overview of adaptation to climate change

Adaptation can either be autonomous or planned adaptation, with the autonomous being more suited to small-scale, resource-constrained farmers. Autonomous adaptation is progressive in nature and makes use of farmers' tried and tested methods and modern knowledge they come across to counter variations in climate of their areas (FAO 2003). This form of adaptation is highly relevant for the small-scale, resource-constrained farmers as it does not require a lot of funding or a high level of scientific knowledge to implement. The International Fund for Agricultural Development (IFAD) (2008) identified the following examples of autonomous adaptation options:

- Changing crop varieties and or species to drought tolerant ones;
- Use of water conservation techniques like mulching;
- In areas where climate change results in increased rainfall, use of diversion furrows to avoid water logging and leaching of nutrients by proper timing of split fertiliser application;
- Varying sowing times to minimize the risk;
- Spreading risk by investing other farming enterprises like rearing livestock (Global Environment Facility (GEF), 2007); and
- Basing crop management decisions on seasonal forecasts to increase chances of getting yields.

Whilst the above examples of autonomous adaptation can offset climate change impacts, most of them are not sustainable. As such, small-scale farmers must make plans which ensure that their livelihood is safeguarded (that is, planned adaptations). This process, therefore, calls for integration of all relevant information outputs and technologies (for example, crop simulation modelling like APSIM) and investments with the decision-making environment (IFAD 2008). Small-scale farmers, as would all individuals, are more likely to change their perceptions of new or modern technology and fully apply the information in adaptation "after researching and evaluating the results of their actions" (Stroeken and Knol 1998:39). This implies that farmers' perceptions can be changed through having tangible evidence of the performance of new or modern technology like APSIM. Testing the performance of the various options in the form of field experimentation should change the perceptions of the farmers. Thus, it can be argued the introduction of modern technology or farming systems should be done through participatory research, as it will help farmers to co-learn with the researchers and give them a sense of ownership of the technology developed.

2.6.2. Challenges faced by small-scale farmers in adaptation

Small-scale farmers in all regions of the world face numerous challenges in addressing the impact of changes in climate, yet they are already poor and most of them are failing to meet their own family food needs before the forecasted climate changes. In other words, the farmers are very vulnerable and have a low adaptive capacity (Smit *et al.* 1999). Farmers' adaptive capacity is the potential of farmers to moderate the negative impacts of variability and change in climate so as to reduce potential damages while at the same time to maximize possible opportunities (IPCC 2001). The challenges include:

- Shortage of land
- Lack of site specific climate information
- Nature and scale of agricultural research aimed at helping farmers in dryland farming
- Lack of income

Shortage of land: Without adequate land for spreading risk through various farm enterprises, small-scale farmers can hardly make meaningful adaptations which can support their livelihood. Since most of these farmers have small fields which are currently insufficient to produce enough for their households, any adaptation plans they might have are likely to go to waste due to a lack of space to implement them.

Lack of site specific climate information: Small-scale farmers require context-specific climate change information to enable improved decision-making, for example, what crop types and varieties to grow and when and how to allocate resources in the medium and long-term (Mapfumo 2010). The official SCF information is often only accessible to elite members of the community with no intentions to facilitate distribution to small-scale farmers (Mapfumo 2010). Prasad *et al.* (1996) highlighted lack of exposure to new achievements and discoveries on the part of rural resource-poor farmers and as a result they are not even able to imagine what research can accomplish for them.

Nature and scale of agricultural research aimed at helping farmers in dryland farming: Most research makes recommendations that are not suitable to or within the reach of small-scale farmers; farmers are often unable to meet the requirements of technologies recommended by research. This can be solved by engaging farmers in participatory research which can lead to the generation and transfer of technologies with least risk and that take the resource constraints into consideration (Prasad *et al.* 1996). These can be in the form of high yielding varieties, timely sowing, moderate amounts of fertilisers, for example, 20kg N/ha, and periodic weeding which was shown to double crop yields of pearl millet and cluster beans in India (Prasad *et al.* 1996).

Lack of income: Income is one of the main prerequisites to enable farmers to adapt to change. Without strong financial backing it will be difficult for small-scale farmers to face up to climate variability and change.

2.6.3. Applicability of the APSIM model in adapting to climate change impacts

APSIM can be used to help farmers in managing future climate change impacts through modifying current climate data to create climate change scenarios, depicting the likely climate conditions to prevail in the future. This can be achieved through use of the Global Climate Models (GCMs) (Matarira *et al.* 2004). Simulating the growth of specific crops grown by small-scale farmers should be run under the created climate change scenarios to verify the changes in yields due to climate change (Sala no date). This will aid small-scale farmers to find viable options (management systems) they could pursue under each of those climate change scenarios. The APSIM input data comprises the modified climatic data, crop management data and soil data.

The management options that will be tested will thus be compared to what current (baseline) management options are in place to assess the effects of climate change under a „business as usual approach', that is without modifying the base management practices. The simulation outputs of these management options can be followed up by discussions amongst farmers and researchers to come up with „what if' scenarios. These „what if' scenarios will be coined from what the farmers can try out in order to maximize their yields under the projected climate scenarios. The identified scenarios can thus be tested and their effect on yields quantified by APSIM.

The performance of these proposed management options will be noted and the farmers can use that information to come up with ways they can possibly use to address future impacts of climate change. The options may include selecting the best sowing dates, early maturing varieties which are also resistant to heat waves and water harvesting techniques or improving the soil nutrient status and water holding capacity or conservation agriculture.

Whilst APSIM and other models can be useful in aiding future adaptation for farmers, the task is not complete without a dedicated communication strategy to convey the message to farmers. Mohammed *et al.* (2005) highlighted that even though there are a lot of useful advances (including testing future adaptation options) in the agricultural sector, that information is hardly reaching the intended users (small-scale farmers) due to an absence of dissemination structures. It is against this background that more efforts are needed in the small-scale farming sector to convey reliable, clear and relevant information timeously to farmers (Sala no date).

2.6.4. Conclusion

Small-scale, resource-constrained farmers rely mostly on traditional indigenous knowledge as a basis for decision-making. The continued reliance on these systems, however, does not signify that the indigenous knowledge is very successful, but an indication of the lack of exposure to adequate relevant modern technology which can help farmers in environmental challenges like climate change. Modern technology, like seasonal climate forecasting and crop simulation modelling, could be useful in aiding small-scale farmers' decision-making under variable climatic conditions. Literature suggests that farmers will only use or adopt new technology once they are convinced that it will involve less risk and can sustain their livelihoods at the very least. Crop simulation models like APSIM can help farmers to assess a number of options quickly and cheaply and help in planning farming activities through discussions amongst farmers and researchers. Whilst APSIM does not guarantee solutions to farmers' problems, it can only help to evaluate options which could be risky for the farmers to pursue in their crop management. Seasonal climate forecasting can guide farmers as to the options they can choose for a particular season, but APSIM can quantify the possible yields from each of the options. This will make it easier for farmers to make decisions as they will be based on quantified simulated yields. APSIM has been applied in many parts of world, but it is at the small-scale level of resource-poor farmers of sub-Saharan Africa, where direct engagement with farmers has been minimal. This study thus sought to assess the applicability of APSIM in decision-making by small-scale, resource-constrained farmers.

CHAPTER 3
RESEARCH METHODOLOGY

3.1. Overview of data collection methods

This research was conducted in order to determine the applicability of the APSIM model by small-scale resource constrained farmers in decision-making, to evaluate the usefulness of APSIM in adapting to future climate change, characterize farming systems of Lower Gweru farmers regarding maize production, perceptions of Lower Gweru farmers on climate variability and change, and to determine current farmer decision-making processes.

In order to answer these research objectives, a study was conducted amongst 30 farmers in the Lower Gweru Communal areas of Zimbabwe. These participants were selected by means of stratified random sampling. They were chosen because they were representative of the Lower Gweru small-scale resource constrained farming systems. Five instruments were used to collect the data required: FGDs, RAM, APSIM simulations, on-farm experimentation and SSIs. Figure 2 shows the data collection methods used and how they relate to one another.

The first focus group discussion was used to gather information about climate change using RAM, seasonal climate forecasting and crop simulation modelling. Following the forecasting and modelling exercises, a second FGD was held during which the farmers identified their agricultural problems and how they would develop strategies to manage these problems.

The on-farm experiments were set in Nyama and Mdubiwa wards of Lower Gweru Communal area based on treatments nominated by the farmers which had been identified during the FGDs. A third FGD was held to present and discuss the results of the on-farm experiments according to the outputs of the simulation modelling. Finally, the SSIs were conducted amongst the farmers who had participated in the previous activities. The purpose of the interviews was to collect data on an individual basis and to evaluate the applicability of the APSIM model and its information outputs in decision-making by small-scale, resource-constrained farmers. In addition to gathering data directly from the selected farmers, data were also gathered from secondary sources including related research, literature, climate files and extension services documents. This data was used to run the APSIM model to focus on the research questions of this study.

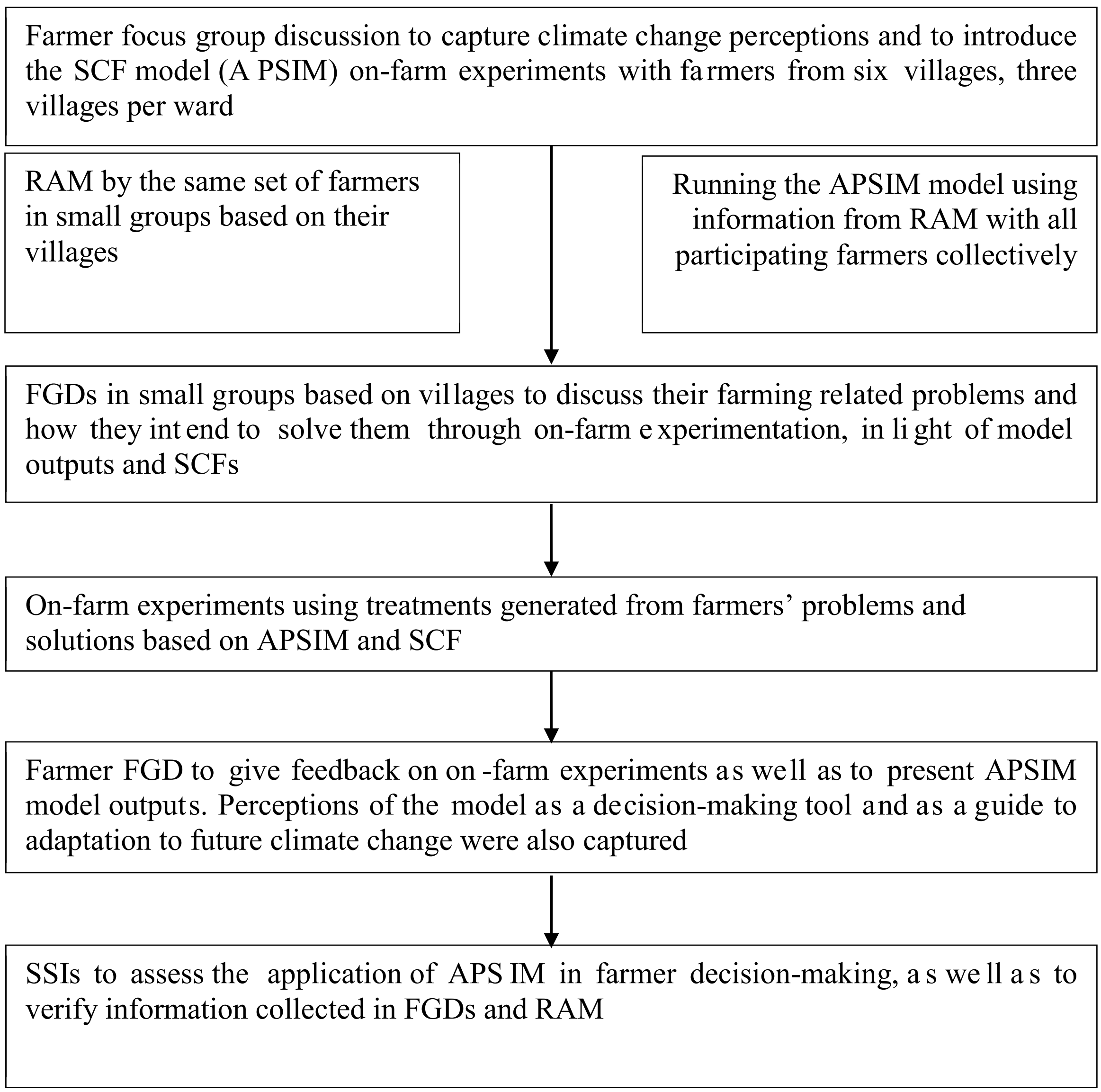


Figure 1: Flow diagram showing the data collection methods and the sequence of data collection

3.2. Farmer FGDs

The study began with a series of meetings with a group of farmers. The meetings held were in the form of FGDs, a form of qualitative research in which a group of people are asked to discuss their perceptions, opinions, beliefs and attitudes towards a certain subject, product, service, or concept (Henderson 2009). Questions are asked in an interactive group setting where participants are free to talk with other group members. Focus groups allow interviewers to study people in a more natural setting than a one-to-one interview. This data collection technique is cost effective as one can get results relatively quickly from several people at once (Debus 1988; Marshall and Gretchen 1999). Farmer FGDs offer a platform for discussions between farmers and facilitators. Throughout the research project, these discussions were more generally referred to as Farmer Group Meetings; for the purposes of this study, the terms FGD and Farmer Group Meeting are interchangeable.

The major purpose of this technique is to acquire in-depth information on concepts, perceptions and ideas from a group of farmers concerning a certain subject. The farmer meeting is set up in such a way that group members discuss the topic among themselves, with guidance from the facilitator. International Development Research Centre (IDRC) (2004) suggested multiple uses of FGDs including focusing research, formulation of research questions, and introducing new concepts or technology to communities where they have never been used before.

Ideas and concepts are more readily remembered by farmers when they are learned through farmer group meetings than they are through individual meetings (Merton *et al.* 1990). This is because other farmers may help or may say something to prompt memory of other things. A major advantage of conducting farmer group meetings is the depth and richness of information that can be learned. Apart from the members reminding each other, the moderator can ask probing questions and explore unanticipated issues (IDRC 2004).

A major drawback of this data collection tool is that the researcher has less control over a group than in a one-on-one interview. Thus time can be lost on issues irrelevant to the topic. Also, the collected data can be difficult to analyze because the talking is partly in reaction to the comments of other group members. Another problem is with the setting itself as the participants may either hold back on their responses (due to lack of anonymity) or try to answer the moderator's questions in a manner they feel the facilitators want to hear (IDRC 2004). Participants in FGDs may also hesitate to air their actual ideas and experiences freely preferring to centre their views on the general agreed social norms. Notwithstanding its limitations, the farmer group meeting method has been used in numerous studies on coping with climate change. The method was used by Carberry *et al.* (2004) in studies on simulation modelling and to solicit data on the adaptation and coping strategies employed in the face of climate variability and change by rural farmers in Zimbabwe. It was also used to capture perceptions and strategies to manage impacts of climate changes in the Philippines (Network of Aquaculture Centres in Asia-Pacific (NACA) 2009).

In this study, four farmer focus group meetings were held at Maboleni High School in the study area. The purpose of the first meeting was to capture perceptions of small-scale farmers on climate change, to introduce SCFs as a tool that aids decision-making, to introduce the concept of crop simulation modelling, and to investigate current farmer decision-making processes. (See Appendix 3 for the lead questions at the meeting). During this meeting, farmers were asked to describe their climate and if they had noticed any changes over the last several years. Figure 2 shows one group of the participating farmers discussing the climate they have been experiencing. During the same session farmers were asked to describe the indicators they use to predict the nature of the coming season in relation to rainfall before they were introduced to scientific forecasts.

The second farmer focus group meeting with the same farmers who had participated in the first meeting was conducted to map out how farmers allocate and distribute their resources (inputs and fields). The farmers were grouped according to their villages resulting in a total of six groups. In this session RAM was used to gather data. (See Appendix 6 for the information captured). The farmers mapped what they had done in the 2007/2008 season in terms of the varieties planted, field size, fertilisers used, weeding times and dates, as well as yields of each field. This information was used later in APSIM simulations to test the accuracy of the model by comparing observed yields from the farmers against simulated yields.

Figure 2: Group discussing their perceptions of climate and the changes they have been noticing in their village over the last several years

The third farmer focus group meeting was held after the APSIM simulations were run to outline the magnitude of household constraints. The aim of this meeting was to decide on on-farm experiments based on the APSIM simulation results and the then current official SCF (2009/2010). The farmers were grouped according to their villages in order to isolate the problems faced by each village. The findings from each of the six groups (villages) were used in selecting the final treatments to include in the on-farm experiments. Figure 3 shows one of the groups deciding on the treatments they wanted to explore in the on-farm experiments. This exercise of deciding on experiments served as the first step in assessing the use of the APSIM model and its output in decision-making by small-scale farmers.

The fourth and final farmer focus group meeting was conducted to deliver feedback on the two on-farm experiments at Nyama and Mdubiwa, to run the model with farmers, and to capture farmer perceptions on APSIM as a decision-making tool (see Appendix 4). Each group spokesperson gave feedback on their adaptation strategies as shown in Figure 4. The process was intended to expose farmers to adaptation strategies that they can employ to reduce the effects of climate change. Farmers began by nominating possible adaptation strategies that they would use under forecasted climate change. The strategies were later explored using the APSIM model to check the benefits that they will bring in terms of maize yield.

Figure 3: Small group discussion on farmers' current problems and the treatments they wanted to test in on-farm experiments

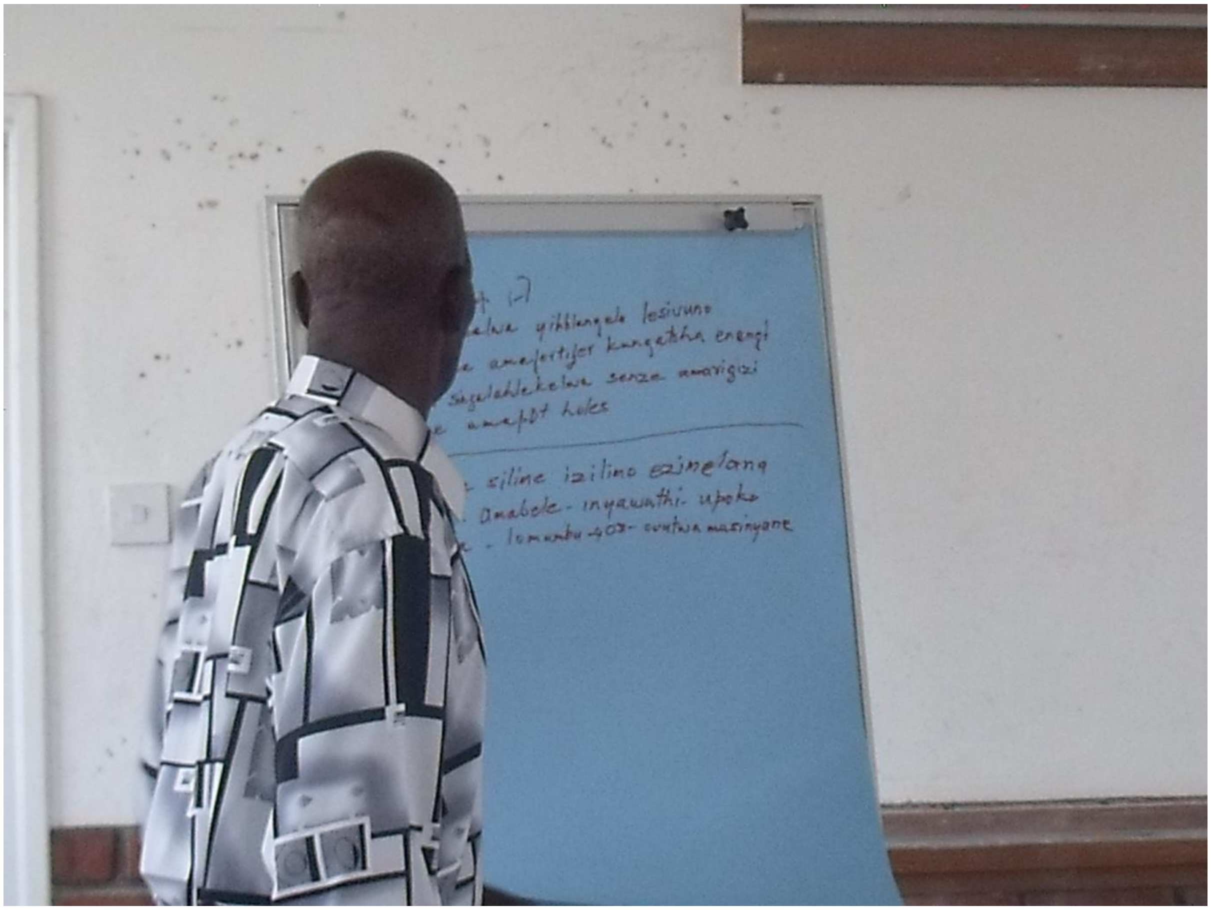


Figure 4: Group spokesman giving feedback after small group discussions

Still as a part of the fourth meeting, farmers were next introduced to the concept of crop simulation culminating in an explanation of the APSIM model. As a part of this exercise, an object lesson was presented using a toy car through which the farmers were helped to understand that a model is a representation of the real thing. In this case the toy car represented a real car – but was itself not actually a real car. Introducing a new technology is often supported using approaches involving visual aids. Carberry *et al.* (2004) used hand drawn images on a flipchart to show all the agricultural processes involved during the rainy season as a part of introducing computer simulated crop production. In that study images were used to show the link between the growth process and rainfall. Figures 5 and 6 below show flipcharts drawn to help explain how APSIM simulates all the growth processes. Visual imagery as a representation of reality helped the participants understand the use of simulated production using the same information that would be used in a real-world setting (Carberry *et al.* 2004).

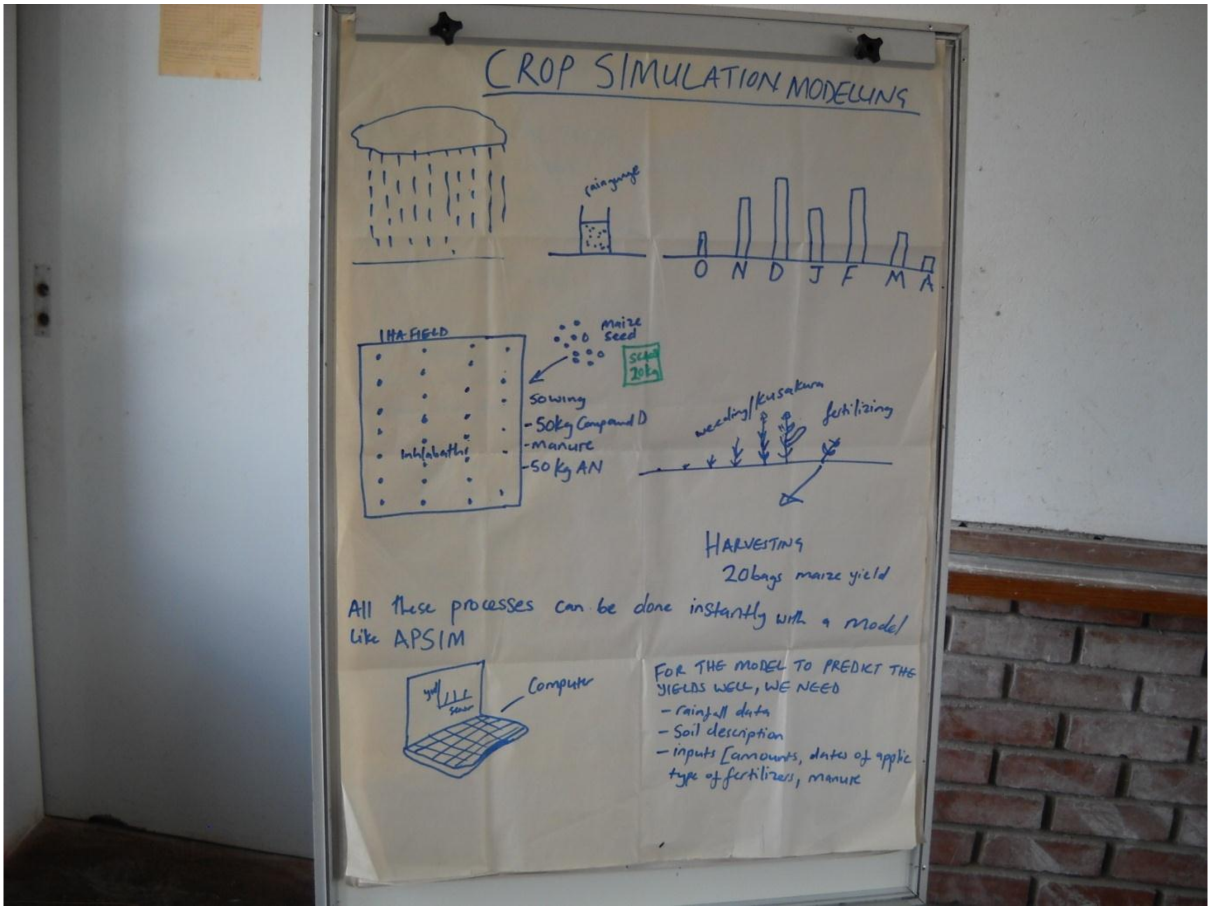


Figure 5: Hand drawn flipchart used to explain how APSIM can simulate all the processes involved in growing crops

The car example laid the foundation for explaining how APSIM represents a real farm. It was explained that APSIM can, for example, "produce" say 4 tonnes of maize yield after "applying" a certain amount of fertiliser. It was explained further to the farmers that APSIM can also simulate what they practice in the field from sowing to harvesting, but the difference being that it "performs" these operations faster and without committing any actual resources such as inputs or time. Through this exercise, the farmers understood that APSIM could show instantaneously the effect of actions or decisions and hence can be a useful tool to explore various strategies and alternatives before actually implementing them. To consolidate their learning, farmers took turns to work through a demonstration of how the model works on a laptop.

Figure 6: Researcher explaining the crop simulation modelling concept to farmers at a farmer focus group meeting

Finally, in the final session of the fourth focus discussion group, the requirements for the model to run and the need for accurate input data to get accurate yield were outlined. The requirements for the model to run, what the model does, its advantages and disadvantages as well its outputs and how it can be of use to the farmers were also explained. It was further explained that in order for the model to deliver accurate results it required the input of accurate data including climate data (for example, daily rainfall, maximum and minimum temperatures and radiation), soil description in terms of total organic carbon, nitrogen and plant available water content (based on soil chemical analysis or roughly from soil experts in partnership with farmers and extension service), and crop management data (dates of all farm operations, fertiliser type and amount). With this background the farmers were told that the APSIM model was going to be run using their own input data for the previous season which they were to supply during the resource mapping exercise.

3.3. RAM

Resource Allocation Maps (RAMs) are maps drawn by farmers to represent their homesteads, their fields and how they allocate resources. RAMs are a useful tool for soliciting information from farmers about their farming systems (Kamanga *et al.* 2001). The collected information can also be used as input into the APSIM model to establish a baseline. This technique has been used successfully by Kamanga *et al.* (2001) in a study investigating fertiliser application practices in Zimbabwe, by Esilaba *et al.* (2005) in their research on resource flows and nutrient balances in the smallholder farming systems in Uganda, and by Dimes *et al.* (2003) in their research on application of new tools in Zimbabwe. In each case, a wide range of data was recorded about the participants' farms and homesteads. Data recorded was varied to suit the particular needs of each study.

The RAM technique offers a platform for farmer interaction in group discussions on several farming aspects in the field, including planning by farmers, farmer's information exchange and the basis used for allocating resources in different fields (Kamanga *et al.* 2001; Dimes *et al.* 2003; Esilaba *et al.* 2005). RAM also helped in gaining an insight into farming systems and resources of different farmers, but more importantly, assisted in the formulation of „what if" questions to be explored using the APSIM model (Dimes *et al.* 2003). However, while farmers appear to enjoy the RAM process (Dimes *et al.* 2003), in some cases farmers (especially less literate farmers) may experience difficulties in constructing the RAMs and recording information (Kamanga *et al.* 2001).

RAM was used in this study to capture baseline information on farming systems, farmers' fields, soil types, crops grown, allocation of resources (for example, fertiliser and seed), timing of farm operations and yields (see Appendix 6 for the information included on the map). The same farmers from the first focus group meeting were grouped according to their villages and met in those groups. All the farmers in a group were asked to draw a map of their homesteads and fields showing how they had allocated their resources for the 2007/2008 season. The research leader outlined to the farmers the range and type of information to include in the map, for example, soil type, size of fields, varieties grown, dates of field activities and the actual yields obtained from each field. The other team members (including the extension workers) moved around the groups helping the farmers and offering clarification as needed. All the farmers drew their RAMs on sheets of papers so that they would learn and appreciate how they had allocated their resources, but one representative from each group then drew their RAM on a flip chart and then explained it to everyone during a report back. The representative farmers were chosen on the basis of the quality of RAM they produced, with all the required information as determined by the research leader. The presentations were used as a basis for discussions, during which the farmers identified what could have been done differently through a series of „what if' questions. The plan for this activity was to have only one member of the group to draw their resource allocation map with the other farmers helping out. However, every farmer was asked to draw their own maps as a means of keeping them actively involved in the process and to encourage a culture of keeping their records which would be needed later in the study.

3.4. Agricultural Productions Systems Simulator (APSIM)

APSIM is a farming systems model designed to simulate various processes taking place in the soils and during crop production under a range of management options in different climates (APSRU no date; Probert and Dimes 2004). The model requires long-term daily climatic data in the form of rainfall, radiation, and minimum and maximum temperatures (Climate Kelpie 2010).

The model is set up in such a way that it has numerous templates where one can input all the data starting from the start and end date of simulation, climatic and soil description data and crop management data. There are 14 simulation templates including Blank Simulation, Continuous Maize Simulation, Continuous Sorghum Simulation, Continuous Maize and Weeds Simulation, among others. The relevant template for this study was the Continuous Maize and Weeds Simulation as weeding was a factor in the on-farm experiments and the resource-poor farmers in this study do not use herbicides to eliminate weeds. If they were using herbicides to eradicate weeds then the Continuous Maize Simulation template would have been relevant as weeds would not have been a factor affecting maize yield (see Appendix 1) (JP Dimes 2008, pers. Comm.[2]).

The start date of the simulation is the first day of the simulation period with the end date being the last day of the simulation. For example, when simulating for one season, one say like

[2] Dr. JP Dimes, ICRISAT, P.O. Box 776, Bulawayo, Zimbabwe

2009/10, the start date of simulation can be 1 October 2009 and the end date 31 May 2010. In other words it should cover the growing season. The met files are historical daily climatic (rainfall, maximum and minimum temperatures and radiation) records for different sites in the world (Climate Kelpie 2010).

For crop management data like sowing dates, varieties, fertiliser management (rates, amount and type), weeding times and dates the data input will be on the paddock (field folder) under the management folder. The model makes provision for setting up different farming operations, for example, weeding can be set to de done after weeds have reached a threshold biomass of say, 5000kg/ha. This means that weeds will be removed after its biomass reaches 5000kg. Alternatively one can use *days after sowing* to guide weed removal for weeds will be removed after 30 days from the sowing date (JP Dimes 2008, pers. Comm.[3]).

The soil type can be selected from the numerous soil types found in the model toolbox or can be described based on actual soil samples of the field. The most important parameters required by APSIM are the Plant Available Water Content (PAWC), the initial soil moisture condition and initial soil nitrogen level. The PAWC is the difference between the moisture available to plants at field capacity and permanent wilting point. It is calculated for each of the four soil depths in the model, 0-10cm, 10-30cm, 30-60cm and 60-90cm. The initial soil content is the amount of moisture in the soil on the day of simulation expressed in three forms namely: as fraction of maximum available water, as depth of wet soil and as layered depth. In all the three forms soil water can be characterized as filled from the top or evenly distributed (APSIM no date)

APSIM has been used in different parts of the world for applications ranging from interpretation of on-farm experiments to risk assessment of a range of alternative management options. It aids farmers in decision-making. Dimes *et al.* (2003) found APSIM simulations to be highly accurate in estimating yield and risk for the different application rates of nitrogen fertiliser. Carberry *et al.* (2004) found the model to be credible as the simulated outputs match the actual yields reasonably well and due to the fact that the farmers' own data were used in running the simulations. Initially the farmers resisted the process, but resistance decreased as the session progressed. Ultimately the process led to the farmers formulating the questions they wanted to be

[3] Dr. JP Dimes, ICRISAT, P.O. Box 776, Bulawayo, Zimbabwe

explored to observe the effects on yield and paved the way for farmers to participate in on-farm experimentation based on their particular management interests.

In addition to its accuracy for prediction, Dimes *et al.* (2003) also noted a number of synergies between simulation models and participatory research. Simulations compliment on-farm experimentation by explaining the result and the processes contributing to why yields are as they are. Simulation can also help to explain experiments by giving output that can be achieved in experiments after certain conditions are met. Selection of experiment treatments can also be done after exploring all the options with the simulation model to assess the performance and the output of each option. The experiments serve to practically assess the simulated options and also the data from the experiments is useful in validating the simulation models.

Despite its strengths, APSIM does, however, have limitations. Its use is hampered by an absence of capable users as well as lack of reliable input data, especially in poor regions of Africa (Struif-Bontkes and Wopereis 2003). Further, APSIM is not calibrated for other crop varieties commonly used by farmers especially the open pollinated varieties such as *bogwe*. Finally, it also does not take into account the effect of pest and diseases on yield. This implies that during seasons where there is pest pressure the APSIM outputs need to be reviewed down based on the actually effect pests had on yield. In this study, there has not been a problem of pests and as such there was no need to review yields downwards.

APSIM was run with all 30 participating farmers collectively, that is, as one group with the researcher explaining all the steps while simultaneously entering data into the model on a laptop. The outputs were drawn on a flip chart for farmers to visualize the results clearly. The crop management information used came from the RAMs presented by the six representatives of the groups discussed earlier. The accuracy of the information was verified by the local extension agents who reside in the same villages with the participating farmers. The climatic data used was from Thornhill Met station in Gweru, which was the nearest station to the study site. In the absence of actual soil description data, the soil descriptions used were modified from the soils already in the model, based on the experience of the extension agents and the lead researcher. In cases where simulations are done without actual testing, the effectiveness of the simulation will be dependent on the partnership between the farmers and the extension service. The modified parameters were the Plant Available Water Content (PAWC), initial soil nitrogen content and initial soil water. Initial soil nitrogen content was set at 6kg/ha in the form of nitrates and 3kg/ha as urea. The initial water content was set at 10% filled from the top layer. The simulation template used was the Continuous Maize and Weeds Simulation (see Appendix 1). The date range for the simulation was set at 1 October 2000 to 31 May 2008, although the 2007/2008 season was the only season used for the RAM session. The other simulated years had been included in the event that farmers might remember the yield they got during those years and how they compare to the simulated ones.

Six farmers drew their maps and all their farms were supposed to be simulated. However, the simulation was conducted for only three farmers as they adequately represented the yields and crop management typical of the participating farmers. One used manure (10t/ha) without any inorganic fertiliser (Farmer A practice), the second farmer (Farmer B practice) used manure (4 t/ha) applied at sowing and 50kg/ha top dress fertiliser and the third farmer (Farmer C practice) used a higher rate of fertiliser (150kg/ha starter fertiliser + 50kg/ha top dress fertiliser). The variety used in all these cases was SC403, is a short season maize variety.

The results were used to show farmers what the model is capable of doing and what information it can therefore supply to farmers to guide their decisions. The „what if' scenarios formulated during the RAM session were also quickly assessed by APSIM to note the margin of increases in yield over the baseline (original farmer practice). Figure 7 shows an example of a „what if' scenario by a Mr Ndlovu changing from manure to chemical fertiliser and an extra weeding. The results of these simulations were drawn on a flip chart for all farmers to see.

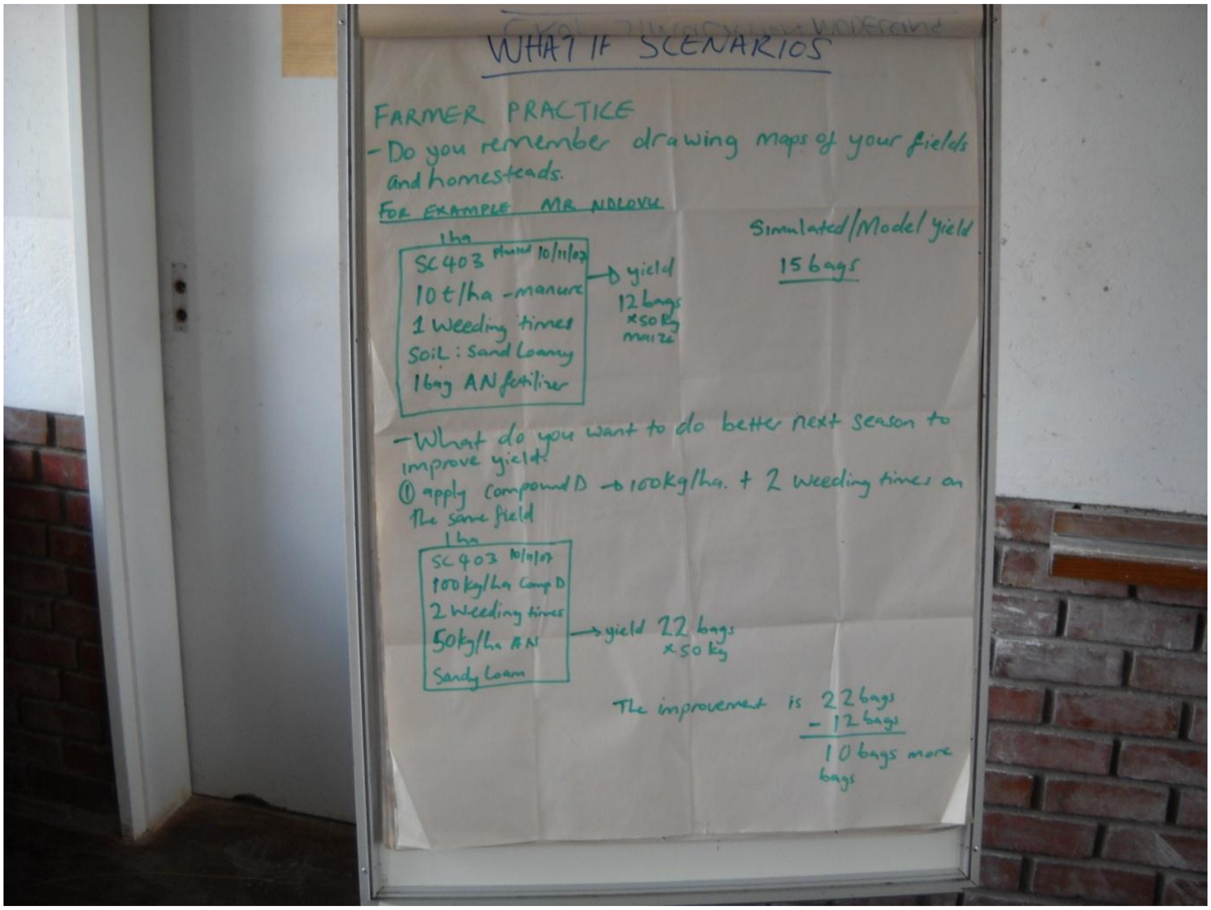


Figure 7: Hand drawn flipchart used to explain the „what if' scenarios that can be explored using the APSIM model

After showing each of the simulation outputs, namely 10t/ha manure, 4t/ha manure +17kgN/ha and 150kg/ha compound D + 17kgN/ha and the one combining all the three farmers' practices, farmers discussed, asked questions as well as registering their comments. Farmers were responding to lead questions asked by the researcher (see Appendix 4 for lead questions). The purpose of the discussion was to expose farmers to model outputs and to get their perceptions of APSIM as a decision-making tool as well as its applications in small-scale, resource-constrained farming systems.

3.5. On-farm experimentation

On-farm experimentation permits farmers and the researcher to work as partners in the technology development process. The major objective for conducting on-farm experiments is to incorporate and empower farmers, as the more they are co-opted in the testing process, the greater the chances that they will adopt the new technology or information (Rudebjer 2001). On-farm experiments are important for assessing effects of various options on yield as well as obtaining realistic input-output data for various analyses to identify viable options through financial analyses. They also provide important diagnostic information about farmers' problems. On-farm experimentation enables farmers to nominate treatments based on their risk-taking behaviours and resource endowment with regards to inputs (seed, fertiliser, weeding) while the researchers can concentrate on biophysical objectives within the same experiment (Rudebjer 2001). The results can help farmers and the researcher learn a great deal about the farmers' problems, preferences and livelihood strategies from interacting with them in on-farm experiments. Furthermore, on-farm experimentation results are an important source of information required for testing and establishing the credibility of APSIM (Delve *et al.* 2004).

On-farm experiments have an important advantage in that they are based on what the farmers practice in the field rather than what they say. They are established in farmers' fields; hence the results are generally more representative of the farmers' biophysical conditions than on station experiments (Shepherd *et al.* 1994; Rudebjer 2001). There is a higher chance that the farmers will utilize the results of on-farm experiments in decision-making for the next season than they would from on-station trial results, where they are far less involved in the decision-making process (Rudebjer 2001).

The on-farm experiments were set up based on what the farmers wanted to explore. In making decisions on what options and treatment to pursue, farmers were being assessed on whether they would use the APSIM model and the simulation outputs based on the three farmer practices (A, B and C) from the RAM and „what if" sessions. Four factors were selected based on the most common across all the six villages/groups: fertility, variety, tillage and weeding. There were two levels for each factor, as shown in Table 2.

Table 2: On-farm experimental treatments selected by small-scale farmers

Factor	**Level 1**	**Level 2**
Tillage	Flat	Ridge
Fertility	Zero fertiliser	Low fertiliser (24kgN/ha)
Weeding	One weeding time	Two weeding times
Variety	SC403 (very early maturing variety)	SC513 (medium maturing variety)

As shown in Table 2, the treatment structure of the experiments is a four-by-two structure, implying a total of 16 treatments. These treatments were replicated three times to give a total of 48 plots. The gross plot size was five metres long by four metres wide to give a plot size of $20m^2$. The net plot size was $12m^2$ and was used for observations and calculations to eliminate the guard row effect. Table 3 shows the treatment combinations in the experiments.

Table 3: Treatment combinations for the on-farm experiments

Tillage	Maize Variety	Fertiliser	Weeding times
Flat	SC403	Zero	1
Flat	SC403	Zero	2
Flat	SC403	Low	1
Flat	SC403	Low	2
Flat	SC513	Zero	1
Flat	SC513	Zero	2
Flat	SC513	Low	1
Flat	SC513	Low	2
Ridges	SC403	Zero	1
Ridges	SC403	Zero	2
Ridges	SC403	Low	1
Ridges	SC403	Low	2
Ridges	SC513	Zero	1
Ridges	SC513	Zero	2
Ridges	SC513	Low	1
Ridges	SC513	Low	2

The experiments were set up in the two wards of Nyama and Mdubiwa, with farmers volunteering to host the experiments. There was no criterion used to select the farmer to host the experiments, except that each ward should host one experiment. It was explained clearly to the farmers that they were not supposed to perform any operation in the experiments unless instructed to do so by the researcher. The on-farm experiments were managed by the researcher with all farmers free to participate in all field activities. Table 4 summarizes the dates of all operations in each of the on-farm experiments.

Table 4: Crop management data and total rainfall for the two on-farm experiments

Nyama Mother Trial		**Mdubiwa Mother Trial**	
Operation	**Date**	**Operation**	**Date**
Sowing	25/11/09	Sowing	26/11/09
First weeding	16/12/09	First weeding	17/12/09
Weeding for treatment with one weeding time	05/01/10	Weeding for treatment with one weeding time	05/01/10
Second weeding	02/02/10	Second weeding	03/02/10
Top dressing	18/01/10	Top dressing	18/01/10
Harvesting	07/04/10	Harvesting	07/04/10
Total seasonal rainfall: 501mm		**Total seasonal rainfall: 432mm**	

The main purpose of the on-farm experimentation was to investigate some agricultural problems faced by farmers in their highly variable climates, and to explore management options to respond to SCFs before implementing them on a larger scale. The results of the experiments were aimed at supporting farmer adaptation to climate variability and change. Thus, prior to setting up the experiments, as explained at the third section of the first FGD, the farmers were asked to come up with problems confronting their farming systems. Each of the six groups was tasked to compile their farming problems and challenges and how they thought they could manage them. They were also asked to decide what they wanted to be included in the experiments in light of the outputs of the SCF using APSIM and the „what if" scenarios generated from the RAM session (see Appendix 7).

Again, group representatives were asked to present their group plans and to respond to questions and comments from other farmers. The identified problems and possible treatments from all the groups were summarized and the researcher, together with the farmers, chose the treatments to include in the experiments based on the most common problems. Figure 8 shows one group representative presenting her group's planned adaptation strategies.

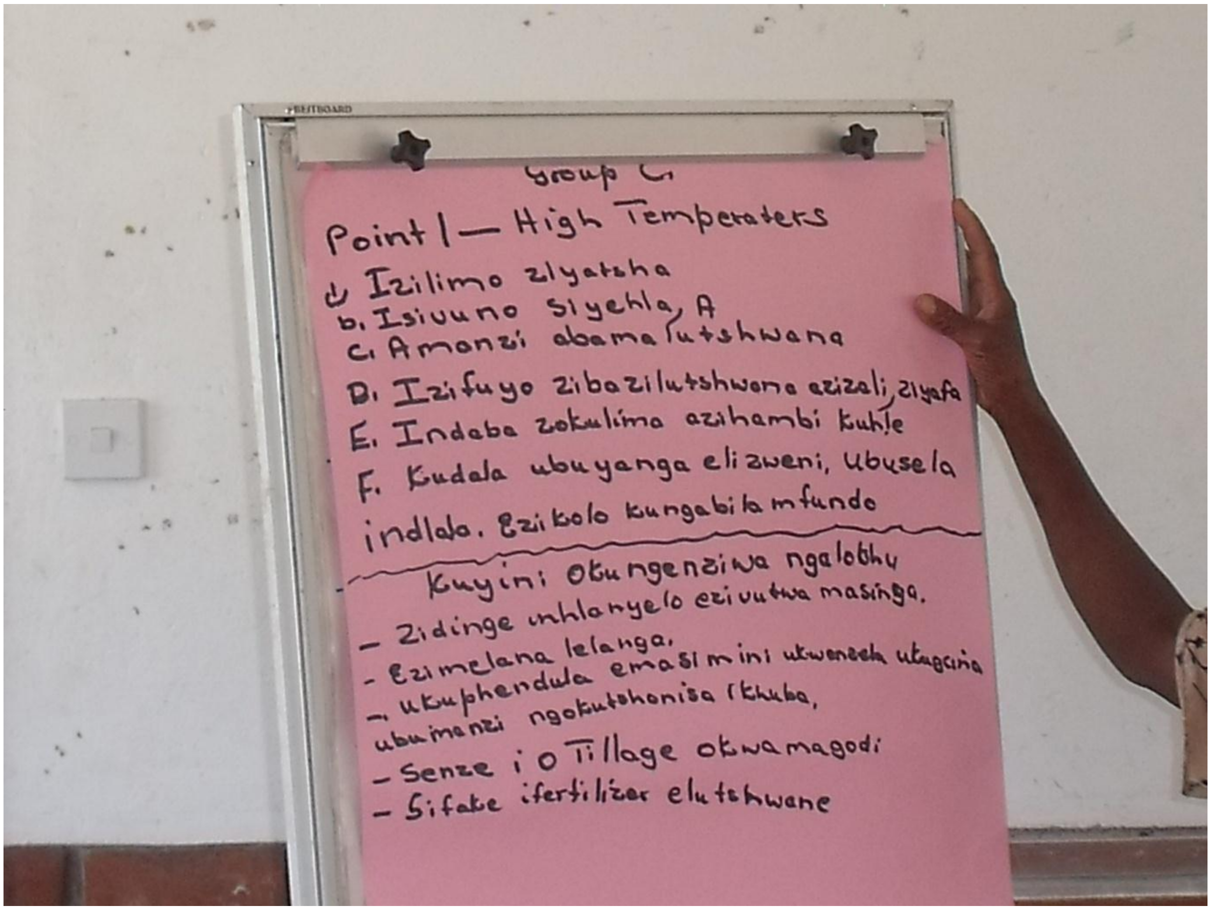


Figure 8: Group spokeswoman presenting her group's proposed adaptation strategies to climate change based on APSIM simulations

3.6. SSIs

SSIs are a simple yet rigorous method for gathering data. They also allow for some statistical analysis and permit comparable surveys elsewhere (Ladio *et al.* 2007:700). This means that the findings from SSIs in a certain location can be compared with findings from a different location. When carrying out the interviews, the interviewer needs to have a list of questions or a guide of the subject to be covered. This technique also allows for flexibility in the sense that some prepared questions on the guide may fall by the wayside depending on the ensuing discussions (Campion *et al.* 1988; Alexiades 1996).

SSIs can be used to collect data on a variety of issues. They can be used to collect more profound information from key informants, concerning the farmer associations as well as to corroborate some issues that had arisen in the questionnaires (Felimone 2009). They can be used to capture the socio-economic issues of farmers and to investigate reasons for other details surrounding adapting specific technologies (Quedraogo *et al.* 2001). Nakamanee *et al.* (2008) used SSIs to understand in great detail forage-for-sale production and to evaluate its profitability and sustainability for smallholder farmers in Thailand. Further, SSIs are more flexible than is a questionnaire when collecting individual information because they allow both the interviewer and the interviewee to ask each other questions (FAO 1990).

The SSIs used in this study were targeted at the 24 farmers from the 30 participating farmers. The farmers selected consisted of two classes, namely poor farmers and better-off farmers, with each class having twelve farmers. The stratified sampling was used to select the 24 farmers for the interviews (see Appendix 5 for the criteria used in classifying farmers). Figure 9 shows the researcher interviewing one of the participant farmers in her field.

The purpose of the SSIs was to solicit information from individual farmers (taking into consideration the socio-economic factors affecting them) about their application of the APSIM model to decision-making as well as their perceptions of climate forecasting and how they cope and adapt to climate variability and future change. The SSIs covered questions about current decision-making processes on crop management and climate, effects of climate variability and change, adaptation strategies, farmer perceptions of SCFs and APSIM as well as applicability of the model to decision-making (see Appendix 2).

Figure 9: Researcher conducting an interview with one of the participating farmers

3.7. Integration of methods

While the data collection methods used in this study have been described and explained individually and were applied sequentially, they were approached in an integrated fashion. The integration occurred largely through the way in which the FGDs and SSIs were organized and the nature of the questions used when conducting them.

The farmer group meeting was useful as a starting point where farmers were introduced to SCFs, RAM, crop simulation modelling (demonstrating how models work through running the APSIM model) and field experimentation. Farmers' perceptions of climate change were also covered. The collected data from resources allocation maps, current agricultural problems, the issued seasonal forecast, experience of running APSIM from RAMs and „what if' questions were instrumental in deciding the field trials. The performance of the APSIM model was also tested with experimental data, for farmers to gauge its accuracy and credibility as well as to check whether they can utilize it as a decision-making tool. Follow-up SSIs with participating farmers and key informants were conducted to corroborate field experiments and data gathered during the farmer meetings.

CHAPTER 4
RESEARCH FINDINGS

4.1. Introduction

This chapter presents results from each of the methodology used in the study to answer the research questions. It will present and briefly discuss findings from each of the data collection exercises in the order that they occurred during the research. A more detailed and integrated discussion of these finding is presented in Chapter 5.

4.2. FGD: Session 1

The first farmer group meeting was held to capture farmer perceptions of climate change, to explore the farmers' farm management decision-making processes, and to introduce crop simulation modelling (APSIM) and seasonal climate forecasting. All 30 farmers present at the meeting perceived climate to be changing. However, various reasons were given as to why it is changing, from religious/cultural to scientific. Farmers highlighted a number of indications that the climate is changing and Table 5 presents the indicators used by the participating farmers to signal climate change; these can be called „indigenous indicators' as they arose simply through the farmers' own experience and learned informally. The farmers use these indicators to forecast the nature of the coming season which is exclusively measured in terms of amount of rainfall to be received and/or when rain occurs; other factors (such as temperature) were not raised. A small percentage of farmers, who said they knew of seasonal climate forecasting before they were introduced to it by the researcher, said they got the information from the radio. However, they admitted that they did not fully understand how to interpret and use the information to plan their farming activities.

Table 5: Climate change indicators as perceived by Lower Gweru farmers

• Increased number of seasons without enough rains
• Increased rainfall extremes in the last 10 years
• Long dry spells during the season
• Rains ending early
• Rains starting late
• Temperature extremes

Although farmers said they had not heard of on-farm experiments before, it was clear in their discussions that they at least knew about demonstrations. However, they understood the concept well after it was explained to them and were able to identify uses of on-farm experiments including being used to test options on a small-scale before implementing them on a large-scale. They expressed keen interest to participate in the proposed experiments.

Regarding crop simulation modelling, none of the farmers had previously heard of or understood what a crop model was, its uses in farming and how it operates. The object lesson used to introduce a model was well received and helped in explaining what a model is. Farmers indicated that they understood that APSIM can simulate the growth process from sowing to harvesting just in the same way as growing the crop in a field. The advantages realized from using APSIM during the session were that it is a cost-efficient and time-efficient way of testing alternatives before committing resources. Farmers highlighted that they would be in a better position to make farm management decisions when using the APSIM model and its outputs.

4.3. RAM

The key findings from the RAM exercise included land size, maize varieties grown, land preparation (including traction power), weeding times and fertiliser management and maize yields. All this crop management data was particularly for the 2007/2008 season.

It was found that the farmers from Lower Gweru were using similar farming practices, the only difference being in the amount of resources and timing of operations like land preparation. The range of maize varieties grown by the farmers included SC403 and SC513 hybrids, pannar, pioneer and open pollinated varieties, both the improved ones and the ones from the granary from the previous year's crop.

Most farmers (88%) indicated that they do their first land preparation in winter (around June); the purpose being to conserve moisture. The second ploughing is done from mid-October in anticipation of the onset of the rainfall. However, some of the farmers said they do not own cattle for ploughing and must wait to hire oxen until after the owners have finished their own land preparations. As a result, these farmers often get lower yields compared to the better-resourced farmers.

Nearly all of the farmers (91%) weed their fields twice per season with the remainder weeding only once per season. The farmers indicated that they use cultivators and hoes for weeding. Farmers without draft power have to wait until their counterparts with draft power finish weeding their fields. The poorer farmers, who sometimes use a hoe alone for weeding, are generally the ones who weed only once.

The RAM exercise established that the average size of farms was 2.4ha; the smallest was 1.6ha and the largest was 3.2ha. The exercise also found that all of the farmers were ploughing only a portion of their farms; they concentrate on the fields within their homestead yards. On average, the farmers ploughed about 0.75ha. The farmers identified four factors influencing the decision to limit the amount of land they ploughed: low yields, lack of inputs, lack of labour and climate variation (in particular the increasing number of below-normal rainfall seasons).

Regarding fertiliser use, most farmers (73%) were not prepared to use fertilisers. They cited two main reasons. Firstly, fertiliser is expensive and unavailable on the open market. Secondly, it is risky to use fertiliser because it can burn their crop (that is. increase water stress to their crop) given the low amount of rainfall received in the area. Less than half of the farmers (46%) use cattle kraal manure which is broadcast before ploughing to incorporate it into the soil. The amount of cattle manure used by the farmers ranged from 2.5 - 10 t/ha. The amount applied depended on the number of cattle the farmer had. Those without cattle did not use manure; some of them used anthill material, which they said strengthens the soil.

The farmers identified four soil types found in the area: sandy loams (*inhlabathi*), red clay soil (*isikobvu*), sodic soils (*isikwakwa*) and dark clays (*isidaka*). The dark clays were recorded only in Mdubiwa.

Yields obtained by the farmers for the season mapped using RAM ranged from 0.3 - 2.1 t/ha. The variation correlated with the inputs used during that season; it was observed that the low yields were obtained by farmers who used manure or nothing at all. This was attributed to the poor quality manure which was not well treated. However, some farmers attributed their low yields to poor soils as well as the heavy downpours that fell in December 2007 (498mm), which in turn caused water-logging and leaching of nutrients.

4.4. APSIM simulations

Simulations were initially based on the three selected RAMs and, later on, based on the „what if" scenarios generated from the discussions that followed the initial three RAM simulations. The three simulated cases were: Manure (10t/ha), Manure (4t/ha) + 50kg/ha top dressing fertiliser in the form of Ammonium Nitrate (AN) and Starter fertiliser Compound D (150kg/ha) and 50kg AN. In each case the SC403 maize hybrid was used. The farmer who used manure (10t/ha) was named Farmer A, with Farmer B being the farmers who used 4t/ha manure + 50kg/ha top dressing fertiliser (AN) and lastly Farmer C who used 150kg/ha Compound D + 50kg/ha top dressing fertiliser. The following graphs (Figures 10-16) show the simulated maize yield from 2000/2001 season to 2007/2008 season. The graphs were drawn on flip charts for all farmers to see clearly and to avoid conflict of interest as the farmers were also developing interest with the laptop. This became the first direct engagement with the APSIM model and its outputs for the small-scale farmers. Firstly, farmers supplied information about their farming systems and soils which are important inputs for the model. Secondly, farmers actually participated in the building up of the simulations through the actual data input into the model with guidance from the researcher. Finally, farmers discussed each of the three RAM based simulations and suggested and explored a couple of „what if" scenarios as ways to improve yields.

4.4.1. Farmer A practice (10t/ha of manure)

This simulation was done using information supplied by Farmer A (who used 10t/ha manure) on his resources allocation map. Figure 10 shows the results of the simulation. Comparisons were made for the farmer observed yields and APSIM simulated yields for the 2007/2008 season only. This was because farmers only had crop management data for the previous season (2007/2008) at the time they drew their resource allocation maps. The crop management data for 2007/2008 was used for all the other seven seasons as the farmers said that they did not deviate from their normal practices. The other simulated seasons were included just in case the farmers might remember whether they were getting yields close to the simulated yields for a particular season.

Farmer A's yield for 2007/2008 was just 50kg/ha; this was due to water-logging caused by heavy rainfall received during the season. The model simulated zero yields, although it showed stover weight of 1216kg. This implied that the crop was affected by water-logging before the grain filling stage. Farmer A noted that for most (five out of eight) of the seasons APSIM matched his actual observed yield and most importantly the trend of actual yields was similar to that of simulated yields although in some seasons the difference was significant. The farmer also indicated that he remembered having better yields in the 2002/2003 season (490kg/ha). He reported that his average yield over the last ten years was six 50kg bags/ha per season (300kg/ha).

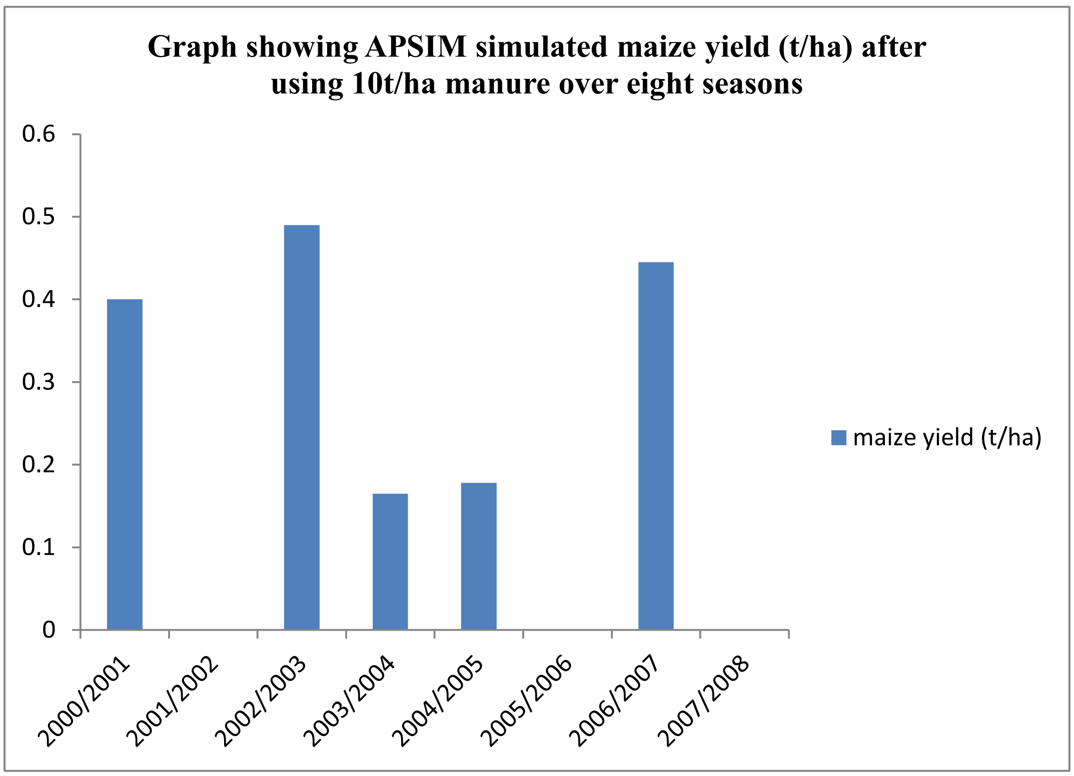


Figure 10: Simulated maize yield with 10t/ha manure used as the only fertiliser from 2000/2001 to 2007/2008 season

4.4.2. Farmer B practice (4t/ha manure and 17kgN/ha)

Figure 11 shows the simulation results based on Farmer B who used 4t/ha of manure and 50kg/ha (17kgN) of AN fertiliser. Farmer B confirmed that the simulation results were a true representation of actual yields he received over the eight simulated seasons. A comparison of yields observed for the 2006/2007 season and the simulated results for the same period indicated a negligible difference; the actual was 1050 kg and the APSIM result was 1147.4kg. This confirmed again that APSIM was indeed a good yield predictor. The participating farmers found the model to be credible regarding yield prediction.

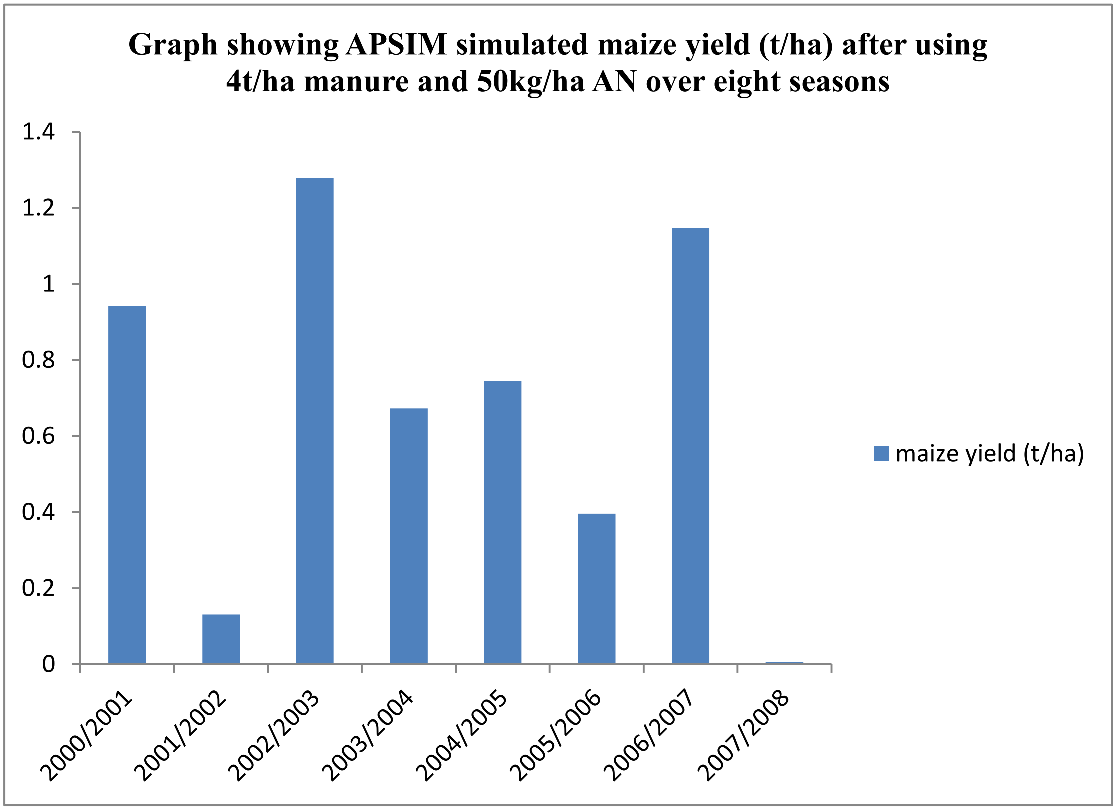


Figure 11: Simulated maize yield obtained from using 4t/ha manure and 17kgN/ha over eight seasons

The issues arising from the farmer discussion that followed the presentation of Figure 11 was that APSIM simulated the yield in most of the seasons very well and it is also sensitive to increase in fertiliser levels. The average actual maize yield for the Lower Gweru area is 0.3t/ha. Farmer B gets an average of 0.8t/ha, which is 0.5t/ha and nearly three times more than the Lower Gweru Communal area average. The farmers quickly noted that the returns of using fertiliser based on APSIM simulations are that one bag of topdressing fertiliser, which cost US$35, led to an increase of about 0.5t/ha, which, when expressed in monetary terms, translates to US$150 (US$15/50kg maize multiplied by ten bags).

4.4.3. Farmer C practice (150kg/ha Compound D + 17kgN/ha)

Figure 12 shows the results of the simulation based on the farming practice and allocation of resources mapped on the resources allocation map of Farmer C. This farmer did not use manure but inorganic fertilisers (compound D as starter fertiliser and AN as top dress fertiliser). Using the 2006/2007 observed results against the simulated ones, in this case there was a larger variation between the results of the APSIM and the farmer's actual results; the APSIM result was 18.4% higher. The high simulated yields might have been as a result of the lack of pests and diseases in the APSIM framework, among other limitations of the model. Despite this variation, the farmers still considered this an acceptable prediction; other participating farmers who used similar farming systems indicated that the simulated yield matched their actual yields during the same period. For the other years the farmer did not have yield records to compare to the simulated yields.

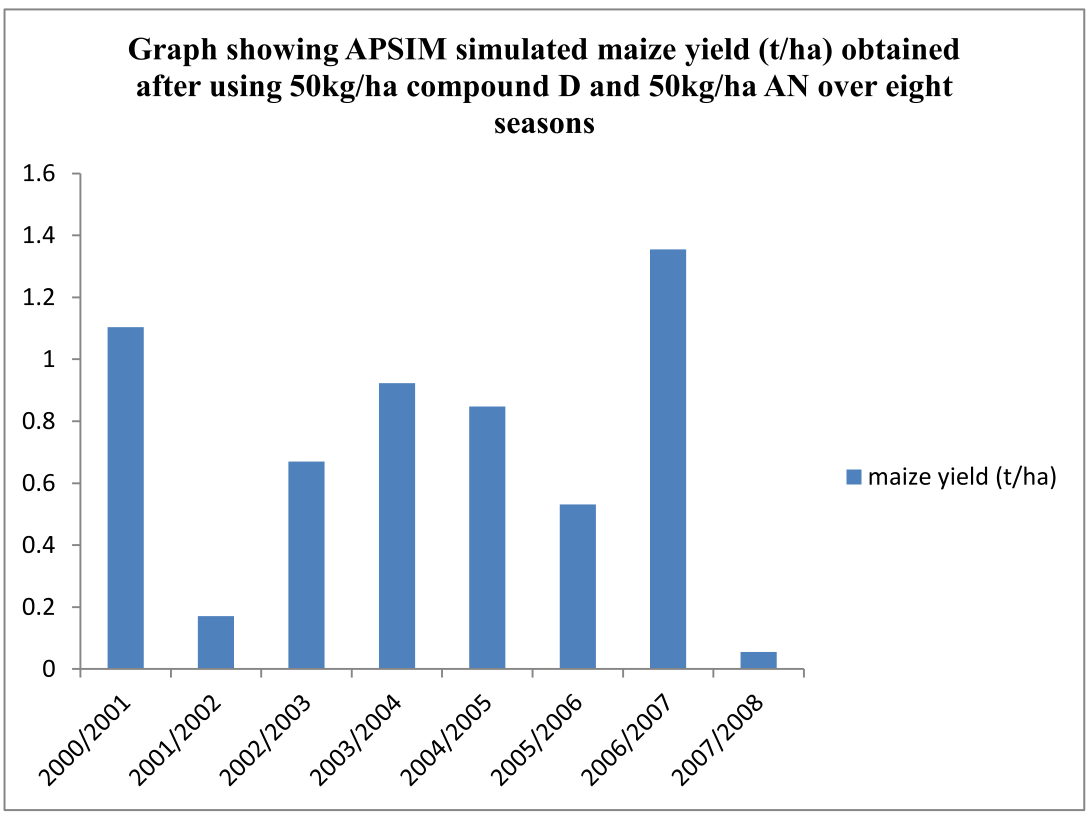


Figure 12: Simulated maize yield with 150kg/ha Compound D and 17kgN/ha used as fertiliser from 2000/2001 to 2007/2008 season

4.4.4. Comparison of the three farmer practices (A, B and C)

During the discussions of the consolidated simulated yield shown in Figure 13, farmers expressed amazement at how the model can compare different strategies at the same time. Farmers noted clearly the distinction of yield differences as a result of using three different fertilisers through APSIM. This resulted in the farmers rating the model high as a decision-making tool.

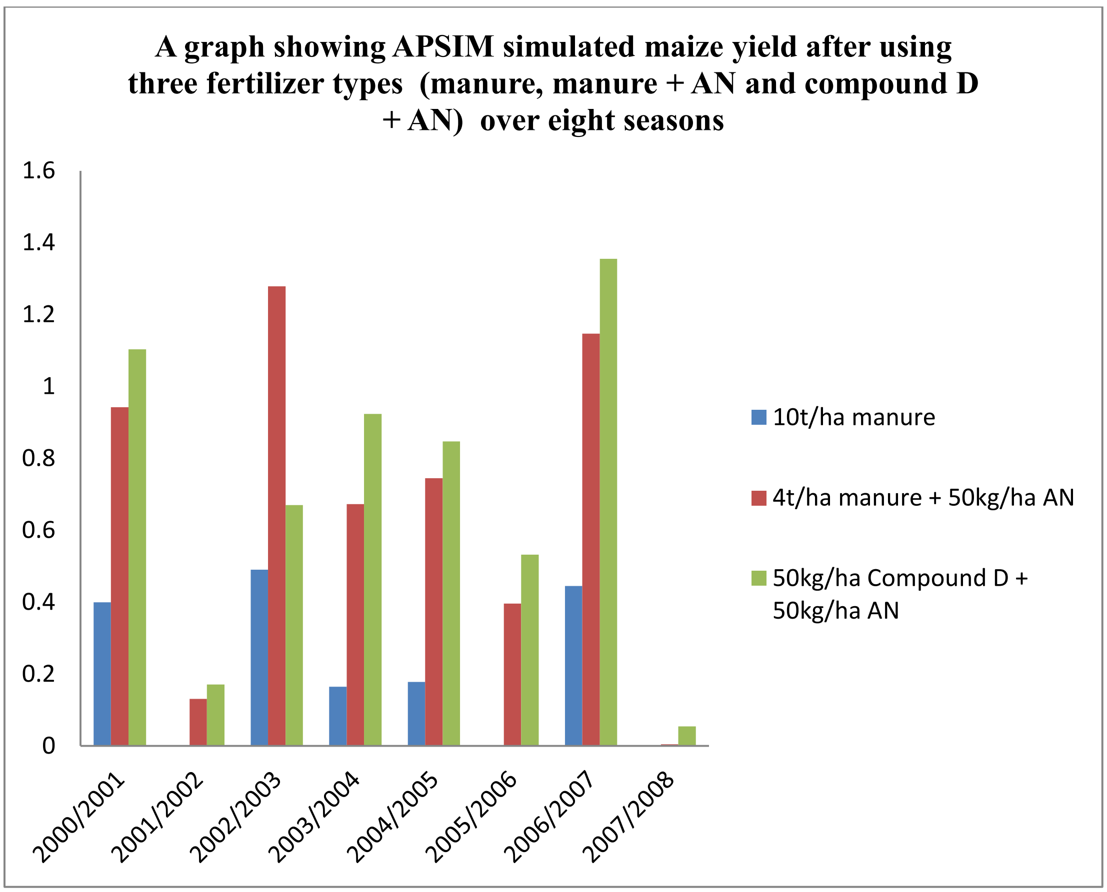


Figure 13: The consolidated simulated maize yield from three different fertiliser types and levels from 2000/2001 to 2007/2008 season

When asked what they thought was the best practice based on the results outlined in Figure 13, they highlighted that Farmer C's practice was the best, followed by Farmer B and lastly Farmer A. They argued that in all seasons except in 2002/2003, the management practices of Farmer C had the highest yield despite the low rainfall seasons. They noted that during the 2001/2002 season, very low rains were recorded, especially in the second half of the season. This resulted in low yields for all the three practices with Farmer A failing to get any yield at all. The farmers learned a great deal from these outputs, particularly regarding management approaches to pursue in below-normal seasons, in normal and above-normal seasons. Whereas during the FGDs, most of the farmers had indicated that they would not/did not use fertilisers when they forecast a poor rainfall season, following the simulation exercise, some indicated that they were changing their perceptions as they were seeing the probable benefits of using fertiliser. The yields obtained from the use of fertiliser justified the cost and proved to be more profitable based on the average yields for the farmers using it against those not using it. On average, Farmer A had 0.21t/ha, Farmer B 0.66t/ha and Farmer C 0.71t/ha. Farmer B and Farmer C's yields are not significantly different at 5% significant level, but are significantly different to Farmer A's yield. The major finding from this session was that farmers noted that APSIM was validated for the most common practices of Lower Gweru and all the farmers noted that it was a good and credible yield predictor. After this session farmers highlighted that they understood how the model works and that it gives accurate results.

4.4.5. 'What if' scenarios

Having validated the model using data collected from farmers' RAMs and with farmers giving the model credibility as a yield predictor and a decision-making tool, farmers nominated questions they wanted to be explored by APSIM. Two „what if" scenarios were explored by the participating farmers. The first scenario was the effects of weeding on maize yield. The second scenario was the effect of fertiliser on maize yields. This exercise was conducted based on how one would improve the yields. The „what if" scenarios were based on Farmer C's practices, which was use of organic fertilisers (150kg/ha Compound D + 50kg/ha topdressing fertiliser). Farmer C's practice was chosen as a baseline because the other two farmers had used manure and it was not easy to determine the quality of manure, which is an important input parameter in the APSIM model. Without accurate input data on the quality of manure, the APSIM model may give inaccurate results.

4.4.5.1. Scenario 1: Weeding effects on maize yield

The first „what if' scenario explored the effect of weeding on maize yield over the eight year period (2000/2001 to 2007/2008 season). The management approach of Farmer C was used with the number of weeding times being varied from one to two times for each season. Figure 14 shows the impact on yield of the two weeding options.

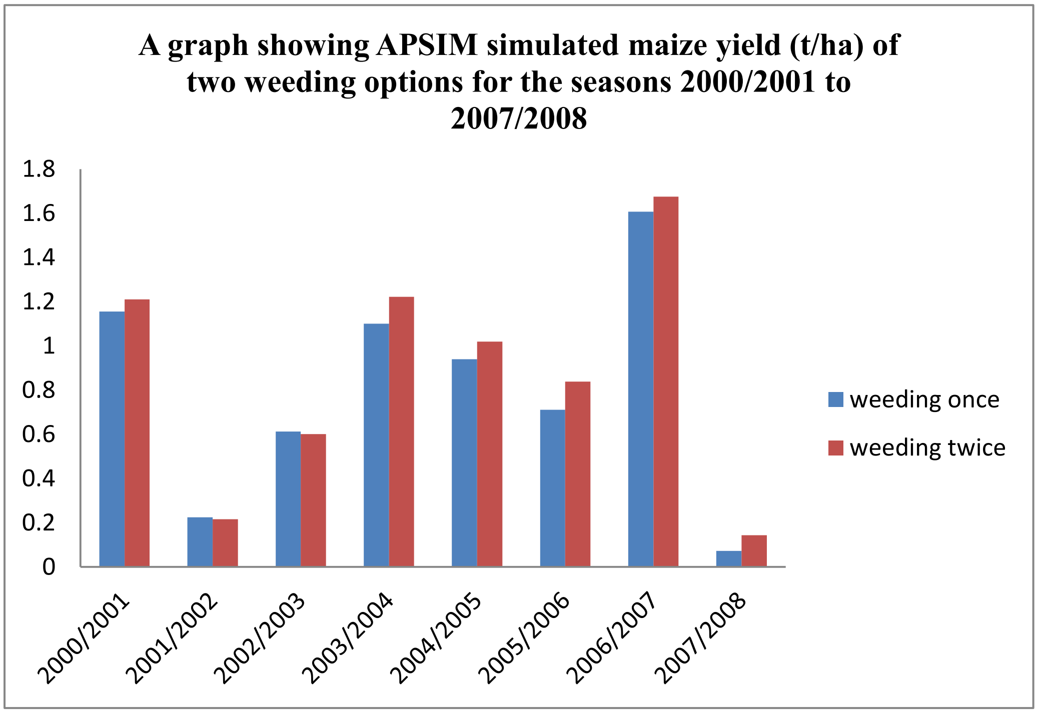


Figure 14: Effect of weeding times on maize yield over eight seasons (2000/2001 to 2007/2008)

The „what if' scenario exercise sought to compare the effect on yield of one and two weeding times per season across the eight seasons which „experienced' below-normal, normal and below-normal rainfall. Farmers noted that in six of the eight seasons an extra weeding increased maize yield and only one season (2002/2003) showed a slight decrease in yield; one weeding yielded 0.81t/ha and two weedings yielded 0.87t/ha. Table 6 shows the simulated changes in terms of 50kg bags as a result of changing from one weeding time to two. The average net gain of two weeding times over one weeding was 2 bags per ha which translates into a 12.5% yield increase over the one weeding option. The yield increases in most seasons was, according to the farmers, as a result of reduced competition for nutrients, water and sunshine (radiation).

Table 6: The net effect of increasing weeding times from one to two over eight seasons in number of bags/ha

	Yield (50kg bags/ha)							
Season	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08
One weeding	23	5	12	22	19	14	32	1
Two weedings	25	5	12	25	20	17	34	3
Net change (No. 50kg bags/ha)	+2	0	0	+3	+1	+3	+2	+2
Percent change	9%	0%	0%	14%	5%	21%	6%	200%

The cost of weeding a hectare in Lower Gweru is US$20, yet the 2 extra 50kg/ha bags derived from an extra weeding equal US$30. The return per dollar invested in an extra weeding is US$1.50. Farmers noted that the increase was only marginal when expressed in monetary terms but to them an extra 2 bags would be the equivalent of two and a half months of *sadza* (staple food) for an average family of six. They explained that in most cases they do not hire labour for weeding but will do it as a family; hence they do place a monetary value on weeding and their fields are generally small. However, a number of farmers questioned the viability of the extra weeding, especially if one was to use hired cultivators for the weeding operation, as it would cost more than the US$30/ha realised after selling the extra yield gained from the weeding.

4.4.5.2. Scenario 2: Fertiliser effect on maize yield

The use of fertiliser was also assessed after it emerged that most farmers do not use fertilisers in below-normal rainfall, while other farmers use fertiliser in low quantities. Figure 15 shows the simulated results for these two fertiliser levels. The results showed that lower fertiliser rates, such as 50kg/ha compound D and 50kg/ha, can increase yield considerably when compared to no fertiliser at all.

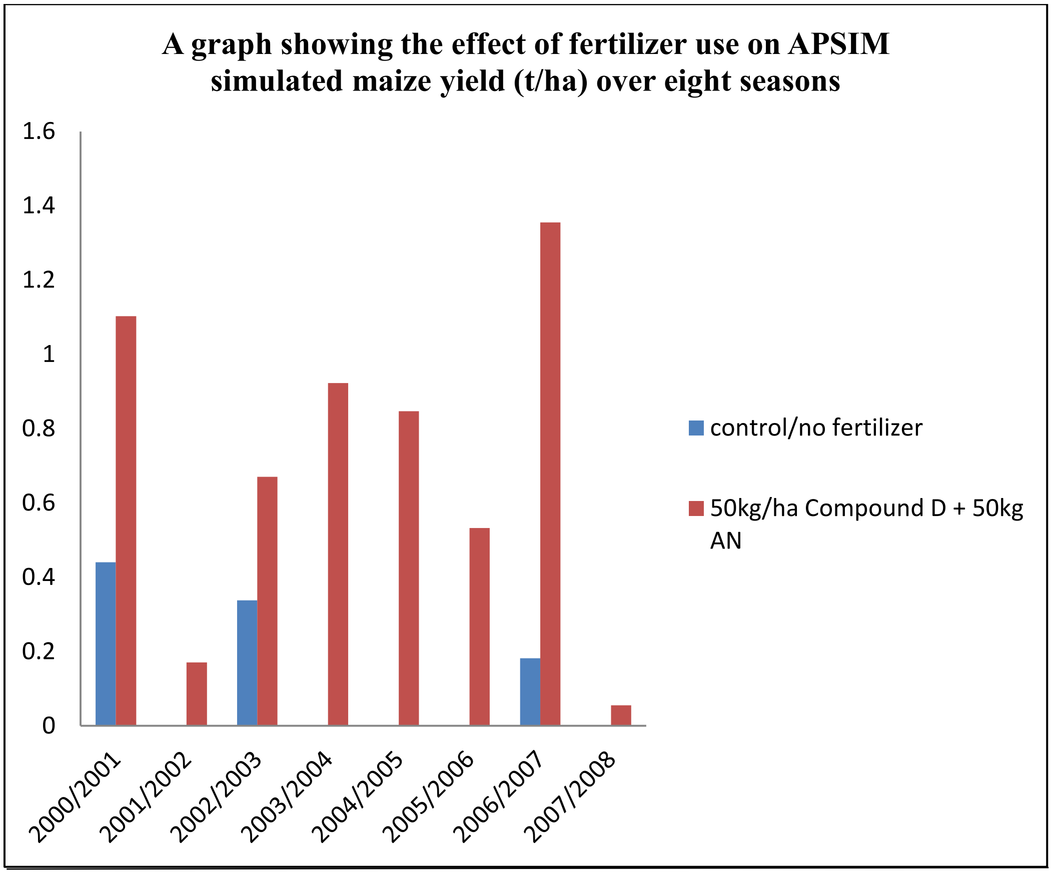


Figure 15: Effect of fertiliser on maize yield over eight seasons

The net gain on maize yield after using 50kg compound D and 50kg AN was presented to farmers to visualize in terms of number of bags gained per hectare. The farmers realized that without using fertilisers yields will be low or nothing at all as shown in five of the eight simulated seasons. Farmers noted that even in the low rainfall seasons like 2001/2002, low fertiliser rate application resulted in an increase in yields compared to nothing under the control (no fertiliser) to about four 50kg bags (200kg). The average yield for the control and 50kg/ha compound D and 50kg/ha AN were 0.12t/ha and 0.71t/ha, respectively. Table 7 shows the net gain in yield over the eight seasons.

Table 7: Simulated yield gain in number of bags/ha in eight seasons after adding 50kg starter fertiliser and 50kg/ha top dress fertiliser (AN)

	Yield (50kg bags/ha)							
Season	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08
No fertiliser	9	0	7	0	0	0	4	0
50kg compound D + 50kg top dressing fertiliser	22	4	14	19	17	11	27	1
Net change (No. 50kg bags/ha)	+13	+4	+7	+19	+17	+11	+23	+1
Percent change	144%	n/a	100%	n/a	n/a	n/a	575%	n/a

APSIM highlighted that the soils of Lower Gweru are infertile as shown by the majority (five) of the eight seasons failing to get any yield and poor yields in the three seasons with yields. The yield response to low fertiliser use (50kg/ha Compound D and 50kg/ha AN) was significant at 5% significant level using the Analysis of Variance. Under the five seasons with no yield under the control option, the fertiliser option resulted in a total of 52 bags at any average of 10 bags/season. The overall net increase average of adding fertiliser for the eight seasons was 12 bags/season. The cost of both a 50kg bag of Compound D and AN is US$35, implying a total cost of US$70. The income that can be realized from selling the extra 12 bags of maize yield is US$180 (rate is US$15/per bag). The return per dollar invested in fertiliser is thus US$2.60. This makes fertiliser use a more viable enterprise for the farmers in all seasons (below-normal, normal and above-normal seasons). APSIM confirmed for the farmers that the gains of fertiliser use are even greater in normal and above-normal rainfall seasons like the 2006/2007 season. It was an insight which farmers confessed never to have visualized before and as a result highly valued this capability of APSIM to explore „what if‟ questions and its subsequent use in decision-making.

All the farmers who participated at this meeting stated that they would use APSIM in their decision-making as it proved to be a planning tool that is a cheap and fast way of assessing options. The main concern raised by the farmers at this meeting was that they did not have computers needed to use APSIM. The question was however answered by the lead researcher who explained that they can still use the model outputs from simulations which they had done for a given SCF. For example, if the use of a certain amount of fertiliser in combination with two weeding times performed well in a below-normal season, it means the farmers can use this information in other below-normal rainfall seasons.

All the farmers understood the crop modelling concept. This was evidenced by their ability to narrate/ describe what a model is, how it works and how it can help them improve crop yields. In an exercise carried out to find out what farmers thought about the usefulness of the model, most of the farmers (82%) agreed that in normal years (without floods), simulated yields matched the yields they expected on their farms.

4.5. On-farm experimentation

Two on-farm experiments were established in each of Mdubiwa and Nyama wards based on eight treatments/options chosen by the participating farmers. Farmers highlighted that they had used APSIM model outputs and SCF to suggest treatments and they wanted to investigate their performance in the field. The experiments were tested the effect of fertiliser applications and weeding on maize yield. The experiments also served to test whether simulation results of the „what if' scenarios, which had been done earlier, can actually be achieved in the field. In other words, the experiments also assessed the credibility of the model.

The collected data was analyzed using the Genstat statistical package which recorded yields for all eight treatments. Figure 16 shows actual maize yield for each of the treatments at both Nyama and Mdubiwa experiments.

The analysis of variance for the Nyama experiment indicated that fertility (P value = 0.002) and variety (P value = 0.005) were significant at 5% significant level. Weeding did not have significant effects on grain yield. At the Mdubiwa experiment the analysis of variance indicated that fertiliser (P value = 0.002) and weeding (P value = 0.035) were significant at 5% significant level. Fertiliser increased yield by 53% and 103% in Nyama and Mdubiwa respectively, at an average of 78% from the average yield in control plots of 0.45t/ha. The average return per dollar invested in fertiliser was US$2.10 based on the costs of fertiliser and the market price of a bag of maize grain. A second weeding gave a marginal and an insignificant yield increase in the Nyama on-farm experiment, whereas a significant increase was noted in Mdubiwa of 60% where the return per dollar invested for an extra weeding was US$1.50. It was however noted that there were no significant interaction effects in variety, weeding times and fertiliser on maize yields for both Mdubiwa and Nyama sites.

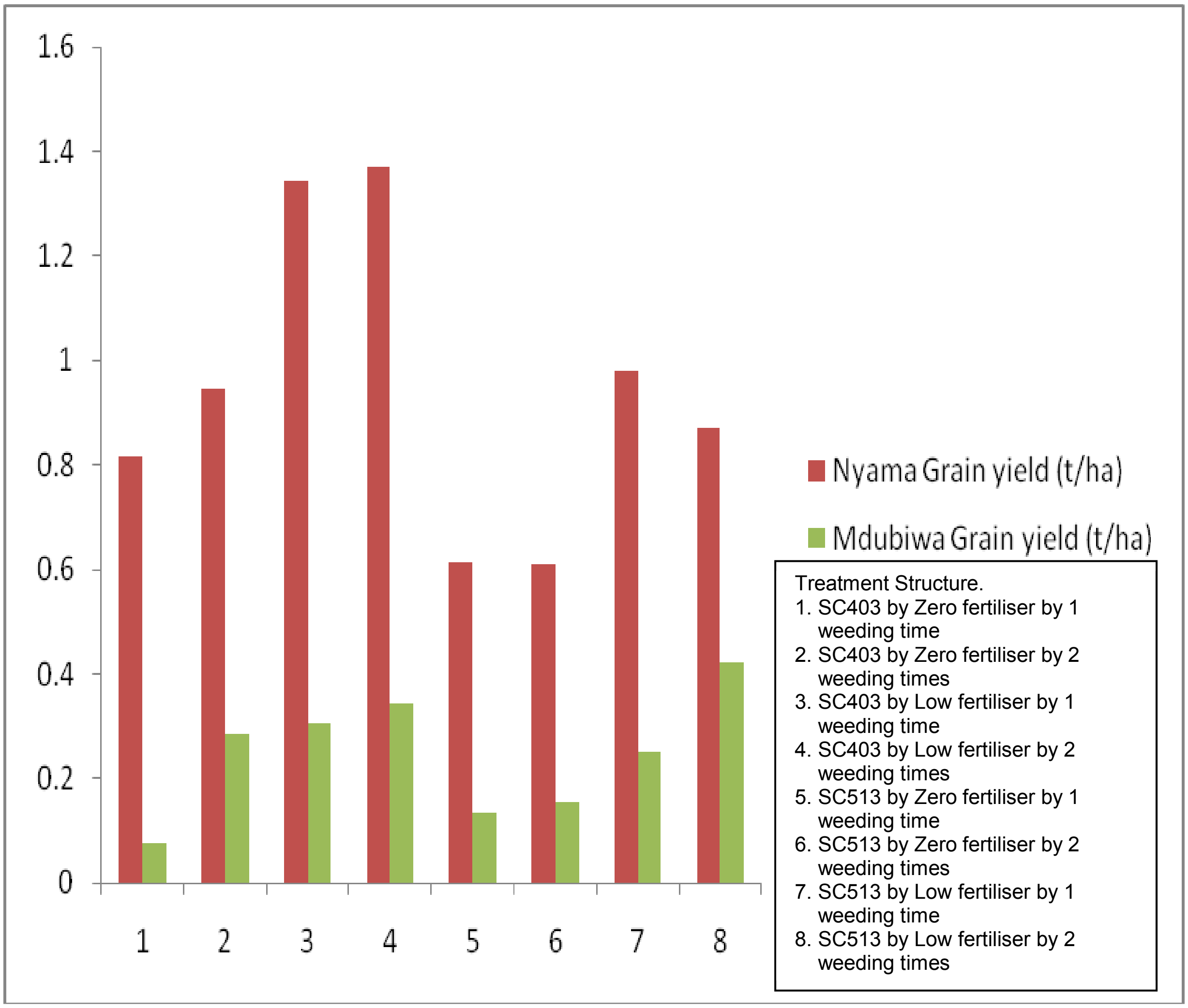


Figure 16: Nyama and Mdubiwa on-farm experiments results showing maize grain yield for different treatments

Overall, there were significant differences between Nyama and Mdubiwa maize yields in all the eight treatments. The yields for the experiment in Mdubiwa were much lower than those in Nyama. The average was 0.94t/ha and 0.25t/ha for Nyama and Mdubiwa, respectively. The possible reasons for this include that the Mdubiwa field was on higher land and the depth of soil was shallow and generally the ward is dry compared to Nyama which has a high water table.

The yields from the on-farm experiments confirmed what was predicted by the simulation at the focus group meetings: yields can increase greatly even when using low rates of fertiliser compared to when no fertiliser is applied. Further, the combination of weeding twice and a low rate of fertiliser gave the highest yield across the two varieties used.

4.6. FGD: Session 2: Feedback on on-farm experimentation

The farmers discussed the results of each treatment and made comparisons of the yield from the different treatment. All the farmers highlighted that had they not utilized the model and its outputs to come up with the treatment in the experiments, they would have just "prepared for the worst". By this they meant that they would have done their usual practice of not applying any fertiliser in a below-normal season as they would not risk burning their crop. However, their experience with the APSIM simulation changed that notion as the benefits of low fertiliser and two weeding times greatly improved yields; this was confirmed in the Mdubiwa on-farm experiment, while at the Nyama on-farm experiment fertiliser was the only significant factor that resulted in yield increase.

The purpose of this last meeting was to obtain the perceptions of farmers of the APSIM model as a decision-making tool and a guide to climate change adaptation. After explanations, the farmers understood the model outputs and they again showed confidence in utilizing the model as a decision-making tool. Their application of APSIM and its outputs were later assessed individually through SSIs.

4.7. SSIs

The interview guide was divided into four sections, namely demographics, farming systems, use of APSIM model and climate change and SCFs. Most of the information covered by these SSIs had been collected through farmer focus group meetings and resource allocation maps. The only difference was that the SSIs collected information from individuals without the influence of the group. The interviews proved useful in verifying the data collected using group discussions and resources allocation maps.

4.7.1. Demographics of participating farmers

Most of the interviewed farmers (63%) were female. The respondents ranged in age from 27 to 83 years. All the participant farmers were household heads and were responsible for making all farming decisions. Eighty percent (80%) of the farmers educated their children up to secondary school level as well as tertiary education; farmers still make all the decisions as the educated children migrate to urban areas where they are engaged in non-farming activities. The young children and grandchildren who stay with the farmers are the ones who often help with some labour, including in farming activities like ploughing, planting and weeding. Only a handful of farmers (13%) were educated up to secondary school, all of who were less than 45 years old. The remainder of the farmers either reached grade 7 at primary school level or less. There was no farmer with formal agricultural qualifications or training. The only training farmers had had was the Master Farmer training for a few farmers (25%), with the majority (75%) having general training which they receive from agricultural extension staff and lead (Master) farmers. The objective of master farmer training is to spread modern, scientific farming techniques in communal areas. The trained master farmers receive farming information from the extension services and are expected to pass on the information and skills to other farmers through farmer-to-farmer dissemination and demonstration.

4.7.2. Current farmer practice on maize production

All farmers with cattle draft power (63%) first plough their fields in winter to conserve moisture, with a second ploughing being done in mid-October to mid-November. Only 33% of the farmers without cattle practice winter ploughing. Farmers without cattle hire cattle from those who have; this means they can only plough after the cattle owners have finished ploughing their fields. One farmer owns a plough and enters into a cooperative arrangement with farmers with cattle to plough their fields. 22% of farmers without cattle are forced to resort to zero tillage (no till) due to a lack of money to hire draft power.

Lack of draft power, according to farmers without cattle (37%), affects maize production mainly in three ways: failure to prepare land on time, failure to plough in winter to conserve moisture and leads to zero tillage meaning reduced capacity of the soil to hold more water. Hiring draft power also means that money which could have been used for acquiring inputs (hybrid seed and fertiliser) is diverted to hiring draft power leading to low yields. Lack of cattle also means farmers cannot use manure. Based on the on-farm experiments, farmers without cattle noted that hiring draft power to till one and a half hectares is equivalent to the cost of a 50kg bag of fertiliser and as such were of the opinion that it is better to use hand hoes or to practice zero tillage and apply fertiliser. Farmers noted that even those who use draft power and fail to apply fertiliser are not getting yields better than those from the on-farm experiments. Since this information was collected in individual SSIs it was not possible to get input from other farmers.

In terms of climate, crop management decisions were found to be mostly affected by rainfall followed by temperature. These two aspects guide sowing dates, crop choice and varieties, and fertiliser investment decisions. Most of the interviewed farmers (79%) indicated that they sow at the beginning and up to mid-November based on the first rains. The remaining (21%) said that they were now practicing dry planting due to the late commencement of the season; this is done towards the end of October and the beginning of November.

Weeding times ranged from one to two. Most of the interviewed farmers (71%) said weeding was based on weed pressure, with the remaining farmers weeding when the crop reaches fifth leaf and knee height stages. All the no-till farmers were among those who based their weeding operations on weed pressure and even highlighted that in some seasons they may even go for a third weeding. All the farmers with cattle use cultivators in conjunction with hoes, while the no-till farmers use hoes for weeding purposes.

All farmers without cattle stated that they normally use inorganic fertilisers although in small amounts (average of 30kg compound D and 50kg/ha AN) in normal and above-normal seasons and compost manure or mulch from crop residues and tree leaves in below-normal seasons where fertiliser is considered risky. The average rate of mulch application is 2t/ha. The average rate of application of cattle manure by those farmers with cattle is 6.5t/ha. Farmers also indicated that they sometimes mix the two with manure being applied at or before sowing and fertiliser applied as a top dress. The reason for this, according to farmers, is that manure is easy to broadcast and incorporates into the soil during ploughing, and fertiliser is also easy to apply at planting stations and is readily available to crops, whereas manure needs time to decompose into forms that can be utilized by crops.

4.7.3. APSIM model

Key findings include that most farmers remembered the APSIM model, with only a few who did not, as shown in Table 8. Those who failed to remember were among the same group of participating farmers and had engaged with the model and its outputs at the FGDs.

Table 8: Farmer categories based on whether they remembered using APSIM or not

Farmer category	Number of farmers in category	Percentage of farmers in category
Farmers who remembered APSIM model	22	92%
Farmers who did not remember APSIM model	2	8%
Total number of interviewed farmers	24	100%

The major reason pointed out by farmers who could not remember the APSIM model, was that they only attended the first simulation exercise out of a series of follow-up simulation sessions. The second reason was that the session they attended was done more than two years ago and as such they had forgotten about it. It was noted that the two farmers who failed to remember are advanced in age, both of them over 70 years old. They however, later confirmed that they were beginning to remember some aspects of the model as the interview continued.

Of the 92% of farmers who managed to remember the APSIM model, two classes emerged, namely those who will continue to use APSIM and those who will not continue with the model. Table 9 shows the number of farmers who will continue and will not continue to use APSIM in decision-making and the reasons for their choice.

Table 9: Farmer categories for continued APSIM use and reasons for their choice

Farmer category	No. of farmers	Percentage	Reasons for choice
Remembered and will continue to use the APSIM model	19	86%	• it helps to plan and make crop management decisions and it offers testing opportunities for various management options without wasting money and time • it helps in budgeting and allocating resources • the model enlightened or educated them to take risks by investing in fertilisers
Remembered but will not continue to use the APSIM model	3	14%	• they do not have computers, they do not understand how it works • most of these farmers missed out the other meetings where farmers engaged with the model and its outputs
Total	22	100%	

Most of the farmers who said they remembered using the APSIM model and its outputs, nominated the three RAM simulations and the „what if" scenarios. Simulated basins output, mulching output and switching varieties were some of the model outputs they still remembered. The reason for this could have been that the last APSIM simulation session the researcher had with farmers was about possible adaptation strategies to climate change where the use of basins, mulch and long season varieties were tested. The farmers noted that APSIM use helped them in coming up with coping strategies to climate change. Due to small-scale farmers' experience with the model they pointed out that they would continue using model outputs in decision-making.

Farmers who said they remembered using the APSIM, but will not continue using it pointed out that they do not have the model and do not have laptops to run the model, do not really understand the science behind it as well as the complexity of the model, and do not have the confidence to use the model on their own without experts. The other reason given by these farmers was that they needed more time to learn more about the model as some of them said they missed some APSIM simulation sessions. One of the three farmers who will not continue with APSIM highlighted that he would continue to use indigenous knowledge as he had managed to survive well without modern technologies like APSIM. The remaining two farmers who will not continue to use APSIM however, pointed out that if given another opportunity to interact with the model and its outputs they would want to use it. These farmers (who will not continue using APSIM) also noted the advantages of using the model; this was despite their failure to really understand it enough to continue its use. These three farmers pointed out that their counterparts who really understood and will continue using the model in decision-making will be better off due to the usefulness and advantages associated with the model and its outputs. This was the reason why they wanted to be given another chance to learn more about APSIM and to run simulations.

Farmers indicated that APSIM adds value to SCFs since it predicts crop yields for any given forecast unlike indigenous indicators which only give an indication of the amount of rainfall received. They also noted that indigenous indicators can also misinform them or will not be clear, hence their choice of using APSIM in decision-making.

4.7.4. Climate variability and SCF

All the farmers interviewed agreed that the climate was changing and identified late start of rains, early ending of the rainy season, low rainfall amount, drying up of wetlands, high temperatures among others as indicators/evidence of this. Farmers also pointed out that they used to have their first maize crop at flowering stage towards late December, but now it only reaches fifth leaf stage by this time. They said they also used to plant early on their wetland crops but now most wetlands have dried up. Farmers noted that the early rains that used to come in August to rot the stover in the fields are no longer arriving. The highlighted changes were said to be affecting their maize production negatively as evidenced by the fact that they are recording poor germination leading to low yields, by the long dry spells resulting in increasing water stress leading to wilting, and by the reduced area under maize production as farmers are growing small grains like sorghum and millet which require less water that maize. All the farmers from Nyama ward (which has a high water table) indicated that they will resort to gardening in the event of droughts and prolonged dry spells. Nyama farmers grow vegetables, horticultural crops and to a lesser extent maize. They get the water from shallow wells.

Farmer climate-related decision-making was noted to be based on indigenous indicators and official SCFs. All the farmers were found to be using indigenous indicators and 11% used both indigenous indicators and official seasonal forecasts. Table 10 outlines the indigenous indicators used by the Lower Gweru farmers to forecast a good season and a poor season.

Table 10: Indigenous indicators for good and poor rainfall season

Indicators for a good season	**Indicators for a poor season**
• Plenty of raindrops from *Thithamuzi* (raining tree)	• No raindrops from the tree
• High temperatures	• Low temperatures
• Early ripening of indigenous fruit trees like *mugan'atsha*, *muchakata*, wild grapes (*tsambatsi*)	• No or less fruiting
• Presence of dew on trees	• Less dew or no dew at all
• Birds (*dendera*) arriving early in the season	• Late arriving or absence of the birds
• Prevalence of north-easterly winds in October-November	• Absence of north-easterly winds in October-November

A small percentage (11%) of the farmers said they use the official SCF which they said they got from the radio. All the farmers acknowledged that they were now able to use the official SCF only after the introduction of this study.

The information obtained from climate forecasting, whether in the form of official or indigenous seasonal forecasting, is used for aiding crop management decision-making and planning coping or adaptation strategies for their farming. For example, indications of a poor rainfall season prompt farmers to look for early maturing varieties, avoid use of fertiliser or use fertiliser in low amounts, use ridges to keep the little moisture and weed regularly. With forecasts for a good season farmers prepare land early, invest in fertilisers and high yielding varieties while a few farmers (17%) highlighted that they will dry plant (usually in October) in anticipation of good rains.

Sources of farming information are identified mainly as extension agents, other farmers through their farmers' clubs and, to a small extent, radios. The extension services are highly valued as farmers said they offer demonstrations and are much better trained than other farmers in their clubs, who sometimes do not have accurate information. All the farmers (100%) preferred the extension services (AGRITEX) as a source of information over radios and other farmers. While the farmers acknowledged that they receive information about plant spacing, compost making, among others, they all indicated, however, that the extension agents have not been supplying them with any climatic information, with the exception of the last two years. This was because the extension agents were themselves not familiar with the official scientific forecast until they were trained in how to use them during this study. Extension agents are now trained and are getting the scientific seasonal forecast from the local Meteorological department to disseminate to the farmers. The extension department highlighted that they would continue to supply farmers with forecasts every season as they would be supplied with the information locally and are able to interpret it for small-scale farmers. Ninety percent (90%) of farmers stated that they preferred or valued climatic information over soil treatment and agronomic information. They argued that without climatic information one cannot adequately plan or make decisions on crop choice and varieties, which fertilisers to invest in, and when to sow or carry out other farming operations.

CHAPTER 5

DISCUSSION OF FINDINGS

5.1. Introduction

This chapter discusses findings presented in Chapter 4. As explained in that chapter, data had been collected using 5 different methods: FGDs, RAM, APSIM Simulations, On-farm experiments and SSIs. The first aspect of the discussion focuses on a comparison of data gathered from the different collection methods as well as how these findings relate to the findings cited in the reviewed literature in Chapter 2. The chapter continues with the conclusions reached based on the research findings and literature.

5.2. Comparison of findings from research methods and how it relates to literature

There are three major themes for which the findings from the different methods were discussed. These are weather indicators, farming practices and circumstances of the farmers. Each of these themes was further divided into several sub-themes.

5.2.1. Weather indicators

Weather indicators were divided into the two sub-themes: type of climate forecast used; and climate change perceptions. These are discussed separately.

5.2.1.1.Type of climate forecast used

The data gathered from the SSIs, RAM and the FGDs were mostly consistent. Most of the participant farmers were advanced in years and have lived and farmed for very long periods of time in their area. They have not been formally trained in agriculture. Over this long period of farming in their area, they have studied the climate of their area using local indicators and have relied on their findings to make decisions. The SSI findings were however, more specific than the findings of FGDs and RAM by dividing the local indicators into those which signal a good rainfall season and a poor one. The cause for this could be that in the SSIs farmers were free to give their views without fear of other farmers in the group. This echoed findings by Beckford and Barker (2007) which indicate that social pressures also affect farmers' actions as most people are reluctant to stand out against the general norms and ethos of the community, particularly in traditional society.

The major difference in the findings of the SSIs and those of FGDs and RAMs was that the farmers were also using the official SCF to prepare for the next season. The main reason for this was that the FGDs were held earlier in the study, when farmers highlighted that they exclusively used local indicators since they did not know how to apply the official forecast information. They only started to consider official forecasts after they learnt about them and this was confirmed in the SSIs which were conducted after the two-year study. This was summed up by following quote from one respondent farmer from the SSIs:

> "*Taingoshandisa ruzivo rwedu rokucherechedza kubereka kwemiti nedova kuti tizive kuti mwaka unenge wakamira sei. Asi izvozvi tavakunzwa kunanamazvikokokota wemamiriro ekunze kuti vanenge vachitiwo zvakamira sei*" (We used to rely on studying the fruiting of certain tree species and presence of dew to determine what the season will be like. However, we are also waiting to hear the official seasonal forecast from experts). Semi-structured interviewee, Lower Gweru Communal area.

The other reason why these farmers started to consider the official forecast could have been that it is divided into two halves: OND and JFM. This ensures flexibility in making other mid-season decisions, for example, when to weed and when to apply fertiliser based on the forecast for the last half (JFM) of the season. This is unlike an indigenous forecast which is less specific in that it just tells the farmers whether the rainfall amount will be adequate or inadequate.

5.2.1.2. Climate change perceptions

The participant farmers noted that the climate has been changing over the last decade and the highlighted changes in both the SSIs and the FGDs were similar. They have noted: an increase in the number of seasons without enough rainfall; rains starting late and ending early; increased temperature extremes and reduced length of the rain season. However, the SSI findings had more changes (which did not come up in the FGDs) noted by the farmers, including the drying up of wetlands and absence of August rains which used to rot the crop stover. They were basing their perceived changes on indigenous indicators. These findings were consistent with the findings by Ziervogel (2001) and Mapfumo (2010) that farmers often have their own indicators to monitor weather conditions, including position of the moon, wind direction, plants flowering at certain times and diminishing wells and springs.

As noted in the first FGD, the participant farmers perceived climate to be changing; it also emerged in the SSIs that the majority of respondent farmers valued climatic information more than any other agricultural information for making decisions. This was summarized by the following quote:

> *"Ini ndinokoshesa nhau dzemamiriro ekunze kupfuura zvimwe zvese zvakaita sekudzidza marimiro kana zveivhu nekuti mwaka irikushanduka uye ivhu redu tinoriziva, zvakare tinoronga zvatinoda kuzoita mumwaka mushure mokunge taona kana kunzwa kuti mwaka uchange wakamira sei"* (I value climate information over other agricultural information like agronomic practices or soil management because we know our soils and they do not change like what climate is doing these days, besides it is this climatic information that determines how we will go about farming that season). Semi-structured interviewee, Lower Gweru Communal area.

The difference between the findings of the FGD and SSIs was only in the source from which to acquire this information, particularly the official climate forecast. They highlighted their preferred source of the official climate information to be extension agents, as they can manage to study local indicators on their own.

The participating farmers preferred the extension agents as the source of the climate information as they (extension agents) are always with them on the farms and they explain better than radios and newspapers, and they are able to probe if they do not understand. This was also noted by Ziervogel (2001) in a study in Lesotho where most farmers preferred to get the forecasts from extension agents. This was despite the fact that extension agents in the area had not been giving them this information save for the two-year period they were involved in this study. The reason for that was that they too were also not very familiar with the official forecasts and APSIM before this study.

5.2.2. Farming practices

Farming practices were divided into five sub-themes: land preparation; ploughing; fertiliser use; weeding; and harvesting/yield. Each is discussed separately.

5.2.2.1. Land preparation

Land preparation was also noted to be a function of the nature of the oncoming season. If a below-normal season is predicted either by local indicators or otherwise, the farmers would opt to clear their fields of the previous crop residues, make use of conservation strategies like tied ridges, as well as to begin spreading manure early and then plough it into the soil. The purpose for this is to reduce competition of nutrients and the little water by weeds. Farmers prepare land early; invest in fertiliser and high yielding varieties as well as dry planting in anticipation of good rains or an above-normal season. These strategies were also suggested by IFAD (2008) as forms of autonomous adaptation to climate variability and change.

According to RAM findings, the average farm size for the farmers was noted to be 2.4ha. However, the farmers were only farming a certain portion of their land due to low yields, lack of inputs, increased number of below-normal seasons and labour constraints. The average farmed land under maize is 0.75ha per household. Depending on the forecast nature of the season, farmers can then decide how much area should be under a crop as well as the timing of this operation. This means that if a good rainfall season is predicted, farmers are willing to maximize their yields by increasing the cropping area and preparing their land well.

5.2.2.2. Ploughing

All five data gathering methods used in the study produced similar findings regarding the ploughing operation. The land was ploughed twice; firstly in winter (around June) to conserve moisture and, secondly, towards the onset of the rain season around (mid October to November). The findings of the SSIs tended to differ slightly from the other methods in that quite a considerable proportion of the respondent farmers were actually not winter ploughing and some were not ploughing at all due to lack of cattle and money to hire. Eighty-eight percent (88%) of the farmers at the RAM sessions claimed to practise ploughing, while only 63% was noted in the SSIs. It was noted in the SSIs that up to 22% of the farmers practiced zero tillage (no-tilling of land) due to the lack of draft power.

The reason for this difference was that the information collected by the FGDs, RAM, APSIM simulations and on-farm experimentation had farmers working in a group setting and hence many issues were generalized. The SSIs were the only method where information was collected from individuals and was specific, and highlighted issues that had not been collected from the group settings. This shows that farmers are likely to make different decisions regardless of living in the same area and experiencing similar conditions (for example, climate and soils). This also demonstrates that some farmers do not practice what they say they do when in groups.

5.2.2.3. Fertiliser use

Fertiliser use in Lower Gweru has been limited over the years due to the risks that local farmers attribute to its use. This was noted in the first data collection tools (FGDs and RAMs) used to get a baseline regarding its use in the Lower Gweru (semi-arid) region. The earlier findings of the FGDs and RAM showed that fertiliser was not being used by the majority of farmers (73%), especially in a below-normal season, arguing that it was too risky in their area which receives very low rainfall. This finding agrees with findings by Rohrbach and Okwach (1997) that despite proven increases in productivity due to fertiliser use, only 5% of small-scale farmers in southern Zimbabwe were using fertiliser. However, Rohrbach and Okwach (1997) noted that the other reason for the reduced number of farmers using inorganic fertilisers was that they are expensive and not readily available on the open market. However, the SSI findings showed an increase in the number of respondent farmers using and investing in fertiliser.

The reason for the difference in the findings of FGDs and RAM with those of the SSIs was the experience gained from the APSIM simulations (over the two-year study period) and on-farm experiments. The APSIM simulations and on-farm experiments which explored the fertiliser options proved to be the reason for the increased investment in fertiliser use. The simulations showed increased maize yield following use of as little as 24kg/ha of nitrogen fertiliser. The resulting yield increase from fertiliser use justified the costs based on current fertiliser costs. The on-farm experiments, whose findings were consistent with those of APSIM simulations, gave what the farmers called „tangible evidence' of the amount of maize yield gained, whereas APSIM simulations were only theoretical. Most farmers (including the no-till farmers who were opting to invest in fertiliser rather than hiring draft power for tilling operations) were now using fertiliser even in below-normal seasons. This fact confirms Hansen's (2004) theory that farmers often demonstrate resourcefulness once they are convinced of the benefit of an innovation. This was actually highlighted in the quote below by one of the no-till farmers:

> *"Zvirinani kutenga saga refotiriza pane kuhaya mombe dzekurima iwe uchizoshaya fotiriza nekuti hapana musiyano muhombe pagonho raunowana usina kurimirwa nemombe asi fotiriza inowedzera goho zvakanyanya kunyangwe mumwaka inemvura irishoma"* (It is better to buy a bag of fertiliser than to hire draft power for the same amount and then fail to buy fertiliser because the yield difference between tilling and not tilling the land is negligible but with fertiliser (50kg/ha) the yield increase will be greater even in below-normal seasons). Semi-structured interviewee (no-till farmer), Lower Gweru Communal area.

The farmers who had not been using fertiliser highlighted that they would not have used or invested in fertiliser had they not heard and learnt of APSIM. They said they were encouraged by APSIM's capability to explore the performance of fertiliser in all types of seasons (normal, above-normal and below-season) to give probable maize yields. What the farmers were highlighting was actually the ability of APSIM to quantify the risk of applying fertilisers in terms of yield gain or loss. They would have just continued with their usual practices of exclusively using local knowledge to guide decisions including their risk perceptions of fertiliser. Climate Kelpie (2010) suggested that APSIM can aid farm decision-making by evaluating the value of climate forecast information and other aspects of farming systems under different management options. Farmers were satisfied with APSIM as a decision-making tool and guide to climate change and adaptation. This means that these farmers are flexible and adaptive in their decision-making and thus can cope with the changing economic and physical conditions.

5.2.2.4. Weeding

Although it was reported in the RAM and SSIs that weeding is done either once or twice (majority), the SSIs went further to identify that weeding was generally based on weed pressure, with only a few farmers (8%) stating that they weed at particular stages, namely at fifth leaf stage and at knee height. Those who based their weeding on weed pressure reported that they sometimes can do a third weeding, especially the no-till farmers (those who do not plough but just sow). This shows that there is no clear cut standard as to the number of times a farmer can weed his/her field and the decision is impulsive.

The highlighted benefits of weeding by the Lower Gweru farmers were consistent with APSIM simulations and actual yields from the on-farm experiments. This means that weeding in most, if not all, seasons will result in higher yield. For weeding to be beneficial it should be done on time so that weeds are removed before utilizing nutrients and moisture meant for the crop. In other words, the number of weeding times is not really important but its timing is probably more important.

The weeding scenario explored by APSIM showed that in six of the eight simulated seasons (2000/2001 to 2007/2008), a second weeding increased yield by an average of two 50kg bags (100kg) which is 12.5% more than the yield from one weeding. Based on the costs of weeding and price of maize grain, the return per dollar invested for an extra weeding in Lower Gweru was US$1.50 per hectare. However, farmers did not place monetary value on labour and thus indicated that they would go for the second weeding as long as there is an increase in yield. In this regard these farmers seem not to be conscious of the opportunity costs for increasing weeding. Farmers valued the capability of APSIM to test and explore the „what if' scenario and hence aid planning and making decisions. Meinke and Stone (2005) also noted the capability to quantify the effects of possible management alternatives in response to a seasonal forecast. Small-scale farmers thus should decide the strategies that work for them based on the simulation outputs by doing a cost benefit analysis. The "model offers the opportunity to change the overestimation of risk by exploring options that farmers can try out and help them evaluate the risk due to climate variability" (Struif-Bontkes and Wopereis 2003:19).

5.2.2.5. Harvesting/yield

Maize yield for the lower Gweru farmers was generally very low, averaging 0.3t/ha as noted in the RAM findings. The RAM maize yields were lower than the on-farm experiments and the APSIM simulated yields. This was because the yield reported in the RAM findings occurred when the farmers were still not comfortable with fertiliser use, unlike when they utilized fertiliser in the on-farm experiments and APSIM simulations. The on-farm experiments, which served to test the same management strategies used in APSIM simulations (fertiliser and weeding), confirmed what was found in the „what if' simulations of the fertiliser and weeding scenarios explored before setting up of the on-farm experiments.

The combination of the low rate of fertiliser (24kgN/ha) and two weeding times gave the highest yield across the two maize varieties (SC 403 and SC 513) in both the on-farm experiment and APSIM simulations. The average yield was found to be 0.71t/ha compared to 0.12t/ha on the control. The average number of 50kg bags gained by use of 24kgN/ha was 12 (600kg). The return per dollar invested in fertiliser was US$2.60 per hectare. The returns could be better in normal and above-normal rainfall seasons. This agrees with findings by Prasad *et al.* (1996) where timely sowing, moderate amounts of fertiliser like 20kgN/ha and periodic weeding were shown to double cereal crop yields in India. This shows that yield is a function of the amount of inputs (for example, fertilisers, seeds, and weeding) during the farming process as well as the climate conditions. This means that without fertilisers and weeding, the yields will be low, thus also implying that the soils are mostly likely to be infertile and unable to supply adequate nutrients to meet the crop's needs, notwithstanding the competing weeds.

5.2.3. Circumstances of the farmers

This section is divided into four sub-themes: demographics; quality of farms; draft power; and modern technology. Each of these is addressed separately.

5.2.3.1.Demographics

The demographics of the farmers interviewed indicated that most of the farmers (63%) were women. The majority of the farmers were advanced in years, over 50 years old and only 13% were educated up to secondary level. These farmers are the household heads and make all farming decisions. None of them had any formal agricultural training with only 25% of them having informally trained as Master farmers. All these factors influence the way they make crop management decisions, and how they view outside help or changes from their normal farming methods.

5.2.3.2. Quality of farms

The Lower Gweru farmers reside in an area where the soils are generally infertile and manure used was generally of poor quality. This agrees with Shumba *et al*. (1993) that these farming systems are characterized by low productivity, widespread and persistent poverty, low resource base and are labour intensive. Findings of a study by Mushiringwani (1983) noted that small-scale farmers are usually located in areas with poor soils which give poor returns due to extensive cropping with little or no addition of fertilisers. This could be the reason why participant farmers who had not been using inorganic fertilisers were getting low maize yields. This tallies with Grant (1981) who states that it becomes very difficult to obtain good yields from these soils without regular and large amounts of inorganic fertiliser, manure or lime. These poor soils are one of the reasons why small-scale, resource-constrained farmers in developing countries are the most vulnerable to impacts of climate variability and change (Altieri and Koohafkan 2008).

5.2.3.3. Draft power

Two farmer groups emerged regarding draft power; those with draft power and those without. Those without draft power usually hire power from those who do, usually after the owners had finished their own land preparations. Some farmers without draft power often fail to hire due to financial constraints and end up sowing without tilling the land (zero tillage). This means that these farmers were likely to get lower yields compared to those who till their fields. The SSI findings went further than the RAM findings by naming three ways lack of draft power was affecting maize production, namely: failure to prepare land on time, failure to effect winter ploughing to conserve moisture and sowing without tilling the land. This implies that despite good decisions that the no-till farmers can make, they are limited as they may not be able to implement the decisions due to a lack of finance. This also highlights the fact that making a decision does not mean sticking to that decision.

5.2.3.4. Modern technology

The findings of the SSIs highlighted that 92% of the farmers remembered the model and of these 86% (which means 86% of the 92%) chose to continue using the APSIM model. Their reasons were that it helps in planning, offers quick testing opportunities without committing resources, guide farm resource allocation and helps in quantifying the risks of management strategies. APSIM does not pursue a single best management strategy, but rather aids the assessment of an array of alternative options suited to different seasons and priorities of the farmer (Rohrbach and Okwach 1997). This means that a lot of experience is created quickly without the actual risk of implementing the various alternative strategies practically (Dimes *et al*. 2003). This shows that most of the small-scale farmers are really concerned about their livelihoods (farming) and can utilize help, including modern technologies, once convinced that they are useful and beneficial to their farming. Furthermore, the farmers aim to make informed decisions provided they have relevant information, tangible evidence or experience, in this case, simulation outputs.

5.2.4. Crop management decisions

SSIs revealed that the farmers made their crop management decisions, like sowing dates, crop choice and varieties and fertiliser investment decisions based on both forms of forecasts (indigenous and official/scientific) and APSIM outputs. This differs from what farmers reported in the RAM and the FGDs where indigenous knowledge was used exclusively. The reason for this disparity was lack of relevant and credible alternatives to farmers as they had not yet been exposed to other alternatives like APSIM outputs and official forecasts. This means that all the possible management strategies identified through use of either indigenous and or scientific forecast can be explored and quantified by APSIM to help farmers decide the best strategy to pursue in that season.

The initial simulations run using RAM data established the credibility that farmers needed to verify the performance of the APSIM model. The next simulation runs, which explored the „what if‟ scenarios, offered the farmers a platform to make informed decisions on the management strategies to employ in the on-farm experiments. The actual performance of the chosen strategies tested in on-farm experiments in terms of yield gain or loss was instrumental in the establishment of APSIM outputs as an aid to decision-making.

The coupling of SCFs and APSIM modelling shifts focus from climate anomalies to prediction of quantifiable yield (Hansen 2005). Thinh (1995) suggested the need for encouraging the combination of exogenous and local knowledge through use of practical achievements of modern knowledge and technology to shed light on, elucidate and update the practical value of local knowledge. This is also in agreement with Prasad *et al*. (1996) that some small-scale farmers are also using modern climatic and market information obtained from radios and extension agents, in addition to indigenous knowledge.

5.3. Conclusions

Based on the findings of the study and cited literature, a number of key conclusions were drawn. They outline an interplay between local knowledge and so-called modern technologies, in this case the APSIM model.

The over reliance on local knowledge and indicators by small-scale farmers is due to a lack of clear proven alternatives. For example, the official forecasts were never made available or explained to the farmers and, hence, the farmers did not know how to use the information.

The APSIM model cannot replace or displace the use of local indicators or official SCFs, but it can add value by quantifying risks associated with strategies identified to manage climate change.

The APSIM model is a complex model that can only be run by trained personnel and modellers. However, the farmers can use the information outputs to aid decision-making, for example, information outputs from fertiliser use under certain climatic conditions.

After gaining an understanding of the APSIM model and the official SCFs, the majority of the farmers started and confirmed that they would continue to use the official forecasts as well as the APSIM outputs to plan their agricultural activities. Farmers also used the APSIM outputs to make decisions on options to pursue in the on-farm experiments during the 2009/10 season.

Working firsthand with the APSIM model changed perceptions of the risk that small-scale farmers attribute to fertiliser use in semi-arid environments by showing that fertiliser can guarantee yields, unlike where farmers do not apply any fertilisers and in some seasons yields cannot be guaranteed. This confirms the view noted by Stoeken and Knol (1998) that people are inclined to learn once they have seen the outcome of a practical experience in which they were personally involved or engaged.

On-farm experimentation is useful in testing simulated farming strategies as a sure way of ensuring the importance or the performance of APSIM. This is especially important in small-scale risk-averse communities who want tangible evidence of how APSIM can aid decision-making before using it. The on-farm experiment results were instrumental in the applicability of APSIM as an aid to decision-making. It was through the combination of the two methods that the farmers found confidence in accepting the potential of a new technology. They had to see it for themselves on their own farms.

The small-scale farmers are willing to learn new technologies like APSIM that can help them in making informed decisions. These farmers admitted that their over reliance on local indigenous indicators in the face of climate change would threaten their yields and threaten their livelihood. As such, they welcome, consider and even act once they are exposed to relevant technology that alleviates their reducing yields of main crops. Relevant agricultural information or technology outputs should thus be made available to farmers in time to make informed decisions, but it must be done in a way that meets the experiential learning requirements of the farmers.

Most of the small-scale farmers do not keep farming records. This limits their decision-making ability as they do not have accurate information telling them what worked/did not work for them before or to assess important farm management such as changes in yield. In this study yields were declining, but farmers could not quantify it and therefore could not take informed decisions to correct this.

The APSIM model on its own does not guarantee good decision-making, but it gives insights to the potential results of a number of alternatives in quantifiable terms which are easy for farmers to understand. It should be supported by other tools, such as cost benefit analysis, to allow farmers to select their best option from a number of alternatives. This calls for farmers to be aware of the costs involved in pursuing different management options, for example, an additional weeding time or additional 50kg/ha of fertiliser.

Beyond these conclusions, the study also highlighted the farmers' keen interest and the willingness to learn when their livelihoods are at stake. However, being risk averse and perceiving themselves as highly vulnerable to the many influences on their farming activities, including climate change, the farmers proceed with caution and wisdom. They will not rush to adopt any significant change unless they have hard facts that they themselves have participated in generating. Whether introducing a model like APSIM or any other technology, unless the farmers are directly involved with its testing in the field – preferably their own farms – they are unlikely to adopt what is offered.

CHAPTER 6
SUMMARY OF MAJOR FINDINGS, CONCLUSION AND POLICY RECOMMENDATIONS

6.1. Introduction

This chapter is comprised of three main parts. First is a summary of key findings from the study aimed at drawing conclusions based on evidence and conceptual framework. Second is a presentation of answers to the two primary research questions. Third is an outline of policy implications and recommendations relevant to supporting informed decision-making in the context of small-scale, resource-constrained farming systems.

This chapter also provide a reflection on how the research could be improved. It concludes with recommendations for further research.

6.2. Summary

Farmers have been making decisions on crop management based on the local indigenous knowledge through studying indigenous tree species and certain birds' behaviour. They have been using these indicators to forecast the nature (good or poor rainfall) of the coming season. This has been working for them for generations and they would use this knowledge to make seasonal plans, including which crops and varieties to grow. The question is whether these indigenous forecasts can still be relied on for aiding decision-making given the changing climate.

Lower Gweru farmers agreed that climate was changing and specifically picked out some of the changes, including late start and early cessation of the rain season, temperature extremes as well as long mid-season dry spells. However, with this change, farmers highlighted that there are two major reasons that they are still using the same local knowledge used by their ancestors. Firstly, they do not have any reliable alternatives and secondly, because it (indigenous knowledge) has been tried and tested. Whilst they acknowledged that this indigenous local knowledge has not been updated to cater for current climate changes, they highlighted that it would take some time for them to establish what works for them, given the fact that climate is becoming very variable.

A number of new alternatives to indigenous knowledge have been available to small-scale farmers for quite some time now, for example, scientific SCFs and crop simulation models like APSIM. But as noted by Prassad *et al.* (1996), small-scale farmers will only make use of such new information or technology once they are sure of the benefits of the technology at little or no risk. As noted in discussions in Chapter 5, despite being risk averse, small-scale farmers are very eager to learn anything that could help them in safeguarding their livelihoods. The farmers enjoyed learning about the APSIM model, how it works, its requirements, what it could do for them as well as the scientific seasonal forecasts. However, it was imperative to them that they see the model's predictions work in practice before giving credibility.

As reported in the research findings in Chapter 4, a small percentage (11%) of Lower Gweru farmers knew of SCFs before this study, but did not understand or use them having only heard them on the radio and hence had many questions that needed to be answered. The only people who could answer these questions were the extension agents and, as the Lower Gweru farmers themselves highlighted, they prefer extension agents to give them the forecasts and explain them as well as to address their concerns or questions. The extension agents are preferred because there are always there and reside in their villages and some of them actually farm in the areas. The farmers thus trust the extension agents as they offer demonstrations in their own fields and have the interest of farmers at heart.

At the commencement of this research, the Lower Gweru farmers based all their crop management decisions exclusively on local indigenous knowledge. However, they reported in the SSIs held at the end of this two-year research, that they were now using indigenous knowledge in conjunction with official forecasts and APSIM. The two forecasts (indigenous and scientific) were used for identifying the possible management systems that could be pursued in that particular season. APSIM was then used to quantify the risk associated with each management system in that particular season in terms of crop yield, thereby making it easier for farmers to make decisions like crop type and variety, fertiliser application (dates, type and rates) number and timing of weeding as well as sowing dates, among others.

According to the SSI findings presented in Chapter 4, farmers were now comfortable with using scientific forecasts and appreciated them even more than indigenous forecasts. One of the reasons found was that local indicators were sometimes giving conflicting signals. For example, fruiting of local indigenous tree species (which indicate a good rainfall season) and absence of dew (which signals a low rainfall season) may be noticed or occur before the commencement of a season, yet these two indicators signal different types of season. A second reason was that some of the local indigenous tree species that were traditionally used by the farmers' forefathers for studying have been cut down or have become extinct. Finally, the scientific forecast, which comes in two parts (OND and JFM), was noted to be helpful when making mid-season decisions, especially the timing of certain farm operations like fertiliser application (whether farmers will split-apply or apply the whole amount at once), or making furrows to retain moisture if the second part of the forecast predicts less rainfall. This was seen as an advantage over the local indigenous forecast which gives a rather blanket/broad form of forecast for the whole season, with no indications of the actual amount of rains to be received.

While farmers were using all the information and technology (both indigenous and scientific forecasts and APSIM) to make decisions, it should be noted that decision-making does not equate to the actual implementation of those decisions. For instance, if a farmer decides to use fertiliser in an above-normal season, he/she may fail to acquire the fertiliser due to financial constraints. Decision-making should thus be supported by funding and availability of resources.

6.3. Research questions

The summary discussed above and the conclusions presented in Chapter 5 provide the insight needed to answer the research questions originally posed.

6.3.1. What is the applicability of the APSIM model in decision-making by small-scale resource- constrained farmers?

The majority of farmers applied the APSIM model in decision-making and indicated that they would continue to use the information outputs to guide decision-making. However, these small-scale farmers are using the model in conjunction with local knowledge and official climate forecasts. The indigenous forecasts and official forecasts were used to identify management options that the farmers can pursue in a particular season and APSIM tested the various alternative management options so as to help farmers make informed decisions. This is in agreement with Meinke and Stone (2005) and Climate Kelpie (2010) that APSIM can be used to aid farm management, decision-making, evaluating the value of climate forecast information and various aspects of farming systems under different management options.

The only major concern raised by the farmers was that they do not have computers and the APSIM software to continue running the model and cannot run the model without expert help. Dimes *et al.* (2003) highlights that the model outputs can be extrapolated and even applied to other areas and other seasons; hence it is possible to continue using APSIM outputs to aid decision-making without running the simulations again with the model.

The small-scale farmers can only use what they have or what they know or their experience to make decisions. Unless the small-scale farmers have been exposed to new information, for example, the performance of APSIM against the actual yields in the fields, they can only rely on their indigenous knowledge for decision-making regardless of its effectiveness.

The first time that these farmers were tested on whether they could apply the model in deciding management practices they would implement was in coming up with management options (treatments) they wanted to test practically in the on-farm experiments. The close match of the simulation results and the actual yields from the on-farm experiments increased the model's credibility as a yield predictor and hence as an appropriate and effective aid to decision-making. On-farm experimentation results are a source of information necessary for the testing and validation of the APSIM model (Delve *et al*. 2004). The major factor that led to the applicability of the model was that it managed to change perceptions of some farmers through the exploration of the risk of fertiliser in a below-normal season in a semi-arid environment (Lower Gweru Communal area), which was also confirmed later in the on-farm experiments. This is consistent with findings of Struif-Bontkes and Wopereis (2003).

6.3.2. How useful is the APSIM model in small-scale farmers' adaptation to future climate change?

Farmers gave the model credibility as a decision-making and planning tool after the model simulated outputs which satisfactorily matched most of the actual observed yields in the farmers' fields. The „what if" scenarios explored after simulation of three selected farmer practices helped farmers to learn the testing capabilities of the model. The farmers went on further to make use of the model to decide the practices they wanted to test in on-farm experiments and in adapting to future climate change. The adaptation strategies nominated by the farmers included mulching, use of basins and switching maize varieties (from early maturing to late maturing varieties). The testing capabilities of the APSIM model were noted as the tool to test all the identified management options in the predicted future climate change. This was confirmed by the farmers as the help they require to make informed crop management decisions.

6.4. Policy implications and recommendations

Whilst the APSIM model can help farmers in making sound decisions, farmers also need to be trained to do a cost benefit analysis that allows them to calculate the opportunity cost they incur by choosing one option over the other. This will enable them to screen management options and thus decide on their best management option at the right cost in the right season.

Based on the importance of the extension services to small-scale farmer's learning and training as shown in the research findings and discussion chapters as well as in this chapter, there is a need to increase the mobility of the extension agents. This is necessary to ensure that they reach all parts of the communities and impart technical knowledge to farmers. Such information includes the SCFs and APSIM outputs, and how to apply them to their decision-making, as well as answering other questions that farmers might have.

The increased mobility of extension agents must be matched with capacity building within the extension service itself to improve their help to farmers, particularly if it requires introducing and applying complex technologies. As noted in the research findings in Chapter 4, local extension officers were not familiar with how a SCF works and the information that can be gleaned from it in order to benefit farmers. They are even less familiar with crop simulation modelling; as the extension agents mentioned, they had not heard of such a thing and were exposed to APSIM for the first time through this research.

Although the extension agents benefited from the training in the use of seasonal climate forecasting and application of APSIM and its information outputs in decision-making together with the farmers, they noted that they need more training and instruction about other new and relevant agricultural technologies. Therefore, the government, through its relevant structures, should come up with a programme of equipping the extension services with innovative technologies and knowledge which they should pass on to the farmers in their communities.

As noted by Kay *et al.* (2004), farmer decision-making depends on information availed to them. However, availing information alone is not enough. As shown in the research findings and discussions in Chapters 4 and 5, the farmers' confidence in using APSIM (a new technology to them) increased once its credibility was illustrated through testing the same management strategies from the simulations to actual on-farm experiments. The matching maize yields of APSIM simulations and the actual maize yields in on-farm experiments was instrumental in increased farmers' application of the APSIM in decision-making.

The introduction of new technology and information to small-scale farmers should thus be accompanied by adequate testing on the ground with full participation of the farmers every step of the way. This was successful in this research where APSIM capabilities were tested by replicating simulations in the farmers' fields. Without this confirmation of new technology in on-farm experiments and farmers' participation, farmers are less likely to use new technology.

Further, there is a need for support from various organizations and government for successful implementation of farmers' decisions. The meteorological department should engage the extension services in order to avail forecast information early for dissemination to farmers. The extension agents should also be trained in how to deliver clear and well-understood information to farmers. The government should provide inputs at subsidized prices to small-scale farmers, should they require them, so that they can implement their decisions rather than be limited by lack of finances and unavailability of resources. And beyond this, the farmers should be actively engaged in learning about and testing technologies and accompanied through the process of measuring the fit into their farming enterprises and through the decision-making related to these new technologies.

6.5. Weaknesses and limitations of this study

Given that the sample size, for practical reasons, was limited to 30 farmers, the findings of this study cannot be generalized. Additional research with more farmers in other areas experiencing similar or different climate issues would enhance the learning about how farmers can use complex technologies alongside their indigenous practices when forecasting the nature of the coming season.

More experience in using the participatory research tools would have enabled the researcher to draw out more and richer findings from the participating farmers. This applies to both the researcher and the extension agents who assisted with the research.

As was discussed in the findings, the research was limited by the lack of crop management records on the part of the farmers. For future research it may be useful to assess the availability of farm records before commencing the field research.

6.6. Recommendations for further research

The indigenous indicators used by farmers to predict the nature of the coming season appear to still have value among current farmers. However, they were not designed to cope with the scale of climate change that is now being experienced. It is recommended that research be conducted first to codify the indigenous criteria, then to assess their veracity in today’s climate situation and finally to partner with farmers in adapting these indicators and/or developing new ones.

This research was conducted around maize production. However, there are many other crops and farming systems which could benefit from similar research. Exploring the application of APSIM to other staples as well as speciality or even cash crops is recommended.

REFERENCES

Alexiades MN 1996. Collecting ethnobotanical data: An introduction to basic concepts and techniques. In Alexiades MN ed. 1996. Selected Guidelines for Ethonobotanical Research: Afield manual. The New York Botanical Gardens, Bronx, New York, pp 53-94.

Altieri MA and Koohafkan P 2008. Enduring Farms: Climate change: Smallholders and traditional farming communities. Third World Network, Malaysia. http://www.fao.org/ nr/water/docs/Enduring_Farms.pdf. Accessed 2 February 2011

APSIM no date. Agricultural Productions Systems Simulator. News website. http://www. apsim.info/Wiki/News.ashx. Accessed on 2 April 2010.

APSRU (Agricultural Production Systems Research Unit) no date. Agricultural Production Systems Simulator Fact Sheet. www.apsim.info/apsim Accessed on 2 April 2010.

Beckford C and Barker D 2007. The role and value of local knowledge in Jamaican agriculture: adaptation and change in small-scale farming. Geographical Journal, Volume 173, Issue 2, pp 118-128.

Campion MA, Pursell ED and Brown BK 1988. Structured interviewing: Raising psychometric properties of the employment interview. Person Psychol. Volume 41, pp 25-42.

Carberry PS, Adiku SGK, McCown RL and Keating BA 1996. In "Dynamics of roots and nitrogen in cropping systems of the semi-arid tropics". Japan Int. Res. Center for Agric. Sci., pp 637-648.

Carberry P, Gladwin C and Twomlow S 2004. Linking Simulation Modelling to Participatory Research in Smallholder Farming Systems. In: Delve RJ and Probert ME. Eds. 2004. Modelling Nutrient Management in Tropical Cropping Systems. ACIAR Proceedings No. 114. Canberra, pp 32-46.

Chikoore H and Unganai L 2001. Integrating Climate Forecast Information in Agricultural Management. A perspective from southern Africa. Prepared for presentation at the Open Meeting of the Global Environmental Change Research Community. Rio de Janeiro, 6 – 8 October 2001. Rio de Janeiro. http://sedac.ciesin.org/openmeeting/downloads/1005837863_presentation_ hchikoore_riopaper1.doc. Accessed on 8 April 2010.

Climate Kelpie 2010. Decision support tools for managing climate: APSIM. http://www.climatekelpie.com.au/manage-climate/decision-support-tools-for-managing-climate/ apsim. Accessed on 15 May 2010.

Cline W R 2007. Global warming and agriculture. Impact estimates by country. Washington DC, Centre for Global Development and the Peterson Institute for International Economics.

Davis-Morrison V and Barker D 1997 Resource management, environmental knowledge and decision-making in the Rio Grande valley, Jamaica Caribbean Geography Volume 8, pp 96–106.
Debus M 1988. A handbook for excellence in focus group research. HEALTHCOM Project special Report Series. Washington, D.C. Porter/Novelli.

Delve RJ, Probert ME and Dimes JP 2004. Improved Capabilities in Modelling and Recommendations: Summary. In Delve RJ and Probert ME Eds. 2004. Modelling Nutrient Management in Tropical Cropping Systems. ACIAR Proceedings No. 114. Canberra. pp 135-138.

Dimes J, Twomlow S and Carberry P 2003. Applications of APSIM in Smallholder Farming Systems in the Semi-Arid Tropics. In: Struif-Bontkes TE and Wopereis MCS Eds. 2003. Decision Support Tools for Smallholder Agriculture in Sub-Saharan Africa. A Pratical Guide. International Center for Soil Fertility and Agricultural Development, USA. pp 85-99.

Esilaba AO, Nyende P, Nalukenge G, Byalebeka JB, Delve RJ and Sali H 2005. Resource flows and nutrient balances in smallholder farming systems in Mayuge District, Eastern Uganda.

FAO (Food and Agricultural Organisation) 1990. The community's toolbox: The ideas, methods and tools for participatory assessment, monitoring and evaluation in community forestry. http://www.fao.org/docrep/ x5307e/x5307e08.htm. Accessed on 24 December 2010.

FAO (Food and Agricultural Organisation) 2003. "Strengthening coherence in FAO's initiatives to fight hunger", Conference at thirty-second Session, 29 November to 10 December, Rome, Italy.

FAO (Food and Agricultural Organisation) 2007. Adaptation to climate change in agriculture, forestry and fisheries: Perspectives, Framework and priorities.
Felimone CFX 2009. Involving farmers in Agricultural research through Farmer Associations. The case from Maputo Province, Mozambique. MSc Thesis, Agriculture Department, University of Denmark, Copenhagen.

Fraisse CW, Breuer NE, Zierden D, Bellow JD, Paz J, Cabrera JE, Garcia A, Ingram KT, Hatch U, Hoogenboom G, Jones JW and O'Brien JJ 2006. AgClimate: A climate forecast information system for agricultural risk management in the southeastern USA Computers and Electronics in Agriculture, Volume 53, Issue 1, pp 13-27.

Grant PM 1981. The fertilization of sandy soils in peasant agriculture. Zimbabwe Agricultural Journal Vol. 78, pp 169-175.

Global Environment Facility (GEF) 2007. Status Report on the Climate Change Funds as of April 30, 2007.

Hammer GL, Nicholls N and Mitchell C 2000. Applications of Seasonal climate forecasting in Agricultural and Natural ecosystems. The Australian Experience. Kluwer Academic Publications. 469 pp.

Hansen J 2002a. An International Sampling of Agricultural Applications of SCFs. In: Proceedings of the SCFs in Agriculture Conference, Coimbatore, India 26 September 2002. Tamil Nadu Agricultural University.

Hansen JW 2002b. Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agricultural Systems 74, pp 309-330.

Hansen JW 2004. Can smallholder farmers benefit from SCFs? In: Fischer T, Turner N, Angus J, McIntyre L, Robertson M, Borrell A and Lloyd D Eds. New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September-1 October 2004. The Regional Institute Ltd; Gosford, Australia: 2004. (Published online at http://www.cropscience.org.au/icsc2004/. Accessed on 14 June 2010.

Hansen JW 2005. Integrating seasonal climate prediction and agricultural models for insights into the agricultural practice. Philos. Trans. R Soc. London B Biological Sciences. 360:1463, pp 2037-2047.

Hansen JW and Sivakumar MVK 2006. Advances in applying climate prediction to agriculture. Climate Research 33, pp 1-2.

Hansen JW and Indeje M (2004) Linking dynamic SCFs with crop simulation for maize yield prediction in semi-arid Kenya. Agric For Meteorol 125:143–157

Hellmuth ME, Moorhead A, Thomson MC and Williams J eds. 2007. Climate Risk Management in Africa: Learning from Practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, USA.

Henderson NR 2009. Managing Moderator Stress: Take a Deep Breath. You Can Do This!. Marketing Research, Vol. 21, pp 28-29.

Holzworth D, Meinke H, DeVoil P, Wegener M, Huth N, Graeme H, Howden M, Robertson M, Carberry P, Freebairn D and Murphy C 2006. The development of a farming systems model (APSIM) – a disciplined approach. www.iemss.org/iemss2006/papers/w4/Holzworth.pdf Accessed 17 January 2011.

Hurni H ed. 1996. Precious Earth: From Soil and Water Conservation to Sustainable Land Management. Generating and Disseminating Knowledge: The role of science, local knowledge and education. International Soil Conservation Organisation and Centre for Development and Environment, Berne, pp 63-75.

IDRC (International Development Research Centre) 2004. Designing and conducting Health systems research projects. Module 10 C: Focus Group Discussion. http://www.idrc.ca/en/ev-56615-201-1-DO_TOPIC.html. Accessed on 29 October 2010

IFAD (International Fund for Agricultural Development) 2008. Climate Change and the future of smallholder agriculture. How can rural poor farmers be part of the solution to climate change? Rome, Italy.

Ingram KT, Roncoli MC, and Kirshen PH 2002. Opportunities and constraints for farmers of West Africa to use seasonal precipitation forecasts, with Burkina Faso as a case study. Agric. Syst., 74, pp 331–339.

IPCC (Intergovernmental Panel on Climate Change) 2001. Special Report and Emission Scenarios. Retrieved June 2007.
Kamanga BCG, Shamudzararira Z and Waddington SR 2001. On-farmcomparison of fertiliser application practices to assess nitrogen use efficiency with maize in Zimuto Communal area, Zimbabwe. Seventh Eastern and Southern Regional Maize conference.

Kay RD, Edwards WM and Duffy PA 2004. Management and decision-making. In: Kay RD, Edwards WM and Duffy PA 2004. Farm Management. McGraw-Hill 5th Edition, pp17-30.

Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow V, Dimes JP, Silburn M, Wang E, Brown S, Bristow KL, Asseng S, Chapman S, McCown RL, Freebairn DM and Smith CJ 2003. An overview of APSIM, a model designed for farming systems simulation. European J. Agron. 18, pp 267-288.
Ladio A, Lozada M and Weigandt M 2007. Comparison of traditional wild plant knowledge between Aboriginal communities inhabiting arid and forest environments in Patagonia, Argentina. Journal of Arid Environment. Volume 69, pp 695-725.

MacKenzie S 1987. The practical application of economics to small-scale dryland farming in communal lands in the semi-arid areas of Zimbabwe. Paper presented at the AGRITEX/DR&SS workshop on "Cropping in the semi-arid areas of Zimbabwe" Harare, 24-28 August 1987.

Mapfumo P 2010. Lack of resilience in Africa Smallholder farming: Exploring measures to enhance the adaptive capacity of local communities to pressures of climate change. Proceedings from Climate Change and Adaptation in Africa learning forum, Nairobi, Kenya, 8-12 March 2010.
Marshall C and Gretchen BR 1999. Designing Qualitative Research. 3rd Ed. London: Sage Publications, pp 115.

Mashiringwani NA 1983. The present nutrient status of the soil in communal areas of Zimbabwe. Zimbabwe Agricultural Journal Vol. 80, pp 73-75.

Matarira CH, Makadho JC and Mukahanana-Sangarwe M 2004. Vulnerability and Adaptation of Maize Production to Climate Change in Zimbabwe. Government of Zimbabwe.

Matsa M and Mutekwa T 2009. From cradle to grave...and then what? The role of environmental factors in the distribution of pollutants around the city of Gweru's dumpsite. Journal of Sustainable Development in Africa. Vol. 11,No.1, pp174-185.
Meinke H and Stone RC 2005. Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. Climatic Change Vol. 70, pp 221-253.

Meinke H, Howden SM, Struik PC, Nelson R, Rodriguez D and Chapman SC 2009. Adaptation science for agricultural and natural resource management – Urgency and theoretical basis. Current Opinion in Environmental Sustainability. In press. http://www.wcc3.org/wcc3docs/pdf/PS2_abstract_meinke.doc Accessed on 23 June 2010.

Merton RK, Fiske M and Kendall PA 1990. The focused Interview: A manual of problems and procedures. The Free press, NY.

Mohammed B, Cerda MS, Pratt M and Sponberg K. 2005. Climate, Communications, and Innovative Technologies: Potential Impacts and Sustainability of New Radio and Internet Linkages in Rural African Communities. Climatic Change, Vol. 70, pp 299–310.

Morton J 2007. The impact of climate change on smallholder and subsistence agriculture. Natural Resources Institute, University of Greenwich, Kent ME4 4TB, United Kingdom.

Morton J, McPeak JG and Little PD 2006. Pastoral Livestock Marketing in Eastern Africa: Research and Policy Challenges, (Intermediate Technology, Rugby, UK), pp 227–246.

Mubaya CP 2010. Farmer strategies towards climate variability and change in Zimbabwe and Zambia. Unpublished PhD Thesis. Bloemfontein: University of Free State, Faculty of Economic and Management Sciences.

NACA (Network of Aquaculture Centres in Asia-Pacific) 2009. Meetings address climate change impacts on small-scale milkfish farmers in the Philippines.

Nakamanee G, Srisomporn W, Phengsavanh P, Samson J and Stur W 2008. Sale of fresh forage – a new cash crop for smallholder farmers in Yasothon, Thailand. Tropical Grassland Volume 42, pp 65-74.

Nelson GC, Rosegrant MW, Koo J, Robertson R, Sulser T, Zhu T, Ringler C, Msangi S, Palazzo A, Batka M, Magalhaes M, Valmonte-Santos R, Ewing M and Lee D 2009. Climate change: Impact on Agriculture and costs of adaptation. International Food Policy Research Institute.

Penning de Vries FWT 1990. Can crop models contain economic factors? In: Rabbinge R, Gouudriaan J, van Keulen H, Penning de Vries FWT and van Laar HH eds. Theoretical Production Ecology: Reflections and Prospects. Simulation Monographs. Pudoc, Wageningen, pp 89-103.

Phillips JG 1998. Comparing Optimal Use of ENSO Forecast Information in two socioeconomic contexts. Invited Talk at the American Association of Geographers Annual Meeting, Boston, MA, March 1998.

Phillips JG, Makandze E and Unganai L (2001). Current and potential use of climate forecast for resource-poor farmers in Zimbabwe. American society of Agronomy special publication „Impacts of El Nino and climate variability on Agriculture, pp 87-100.

Prasad C Kesseba AM and Singh SP 1996. Extension Strategy for resource poor farmers in rainfed agriculture. Macmillian India limited. pp 352.
Probert ME and Dimes JP 2004. Modeling Release of Nutrients from Organic Resources using APSIM. In: Delve RJ and Probert ME. Eds. 2004. Modelling Nutrient Management in Tropical Cropping Systems. ACIAR Proceedings No. 114. Canberra, pp 25-31.

Quedraogo E, Mando A and Zombre NP 2001. Use of compost to improve soil properties and crop production under low input agricultural systems in West Africa. Agriculture, Ecosystems and Environment. Volume 84, pp 259-266.

Reynolds C 2004. Agro-climatic Zones in Zimbabwe. http://www.fas.usda.gov/pecad2/ highlights/2004/06/zimbabwe/images/AEZ_zimababwe.htm Accessed 16 December 2010.

Rohrbach DD and Okwach GE 1997. Setting Targets: Model Crop Performance or Cropping decisions . Proceedings of the CARMASAK Risk Management Workshop in Machakos, Kenya. 22 – 29 May 1997. apps.cimmyt.org/english/docs/proceedings/rm/SettingRisk.pdf. Accessed 10 March 2010.

Roncoli C, Kirshen P, Ingram K and Flitcroft I 2000. „Opportunities and constraints to using seasonal precipitation forecasting to improve agricultural production systems and livelihood security in the Sahel-Sudan region: a case study of Burkina Faso, CFAR – Phase 1' Paper presented at IRI Forum on Climate Predictions, Agriculture and Development, New York.
Rudebjer PG 2001. Training Course on Participatory On-farm Experimentation and Integrated Approaches to Land Management. Proceedings Bandur Lampung and Kutabumi, Indonesia, 17-23 November 2000. International Centre for Research in Agroforestry. Southern Asian Network for Agroforestry Education.

Sala S no date. Information and Communication Technologies for climate change adaptation, with a focus on the agricultural sector. Università degli Studi di Milano, Crop Production Department.

Selvaraju R, Meinke H and Hansen JW 2004. Approaches allowing smallholder farmers in India to benefit from Seasonal climate forecasting. In: Fischer T, Turner N, Angus J, McIntyre L, Robertson M, Borell A and Lloyd D eds. 2004. New Directions of a Diverse Planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia. 26 September – 1 October 2004. Gorford, Australia Regional Institute Ltd (published online at http://www. cropscience.org.au/icsc2004/ .Accessed on 14 June 2010
Shepherd K, Swindles R and Jama J 1994. A question of management: The pros and cons of farmer and researcher-managed trials. Agroforestry.

Shumba EM 1993. Constraints in the Smallholder Farming Systems of Zimbabwe. In: Cranswell ET and Simpson J eds. 1993. Soil Fertility and Climate Constraints in Dryland Agriculture. Proceedings of ACIAR/SACCAR workshop held at Harare, Zimbabwe, 30 August – 1 September 1993. ACIAR Proceedings No. 54, pp 69-73.
Smit B, Burton I, Klein RJT and Street R 1999. The science of adaptation. A framework for assessment. Mitigation and adaptation strategies for global change 4, pp 199-213.

Stephens W 2002. Decision Theory and Decision Support Systems. In: Matthews R and Stephens W eds. Crop-Soil Simulation Models. CAB International, pp 95-115.

Stroeken, JHM and Knol, WHC 1998. The stimulation of the diffusion and adoption of information technology in small and medium-sized enterprises through IT scenarios. research report of Eindhoven Centre for Innovation Studies. pp 117.

Struif-Bontkes TE and Wopereis MCS 2003. Opportunities for the Use of Decision Support Tools for Smallholder Agriculture in Sub-Saharan Africa. In: Struif-Bontkes TE and Wopereis MCS Eds. 2003. Decision Support Tools for Smallholder Agriculture in Sub-Saharan Africa. A Practical Guide. International Center for Soil Fertility and Agricultural Development, USA. pp 1-23.

Thinh ND 1995. Local knowledge and development In: Saraswati B Ed. 1997. Intergration of endogenous cultural dimensions into development. http://www.ignca.nic.in/cd_05014.htm Accesed 10 February 2011.

Whisler FD, Acock B, Baker DN, Fye RE, Hodges HF, Lambert JR, Lemon HE, McKinion JM and Reddy VR 1986. Crop simulation models in agronomic systems. Advances in Agronomy Volume 40, pp 141-208.

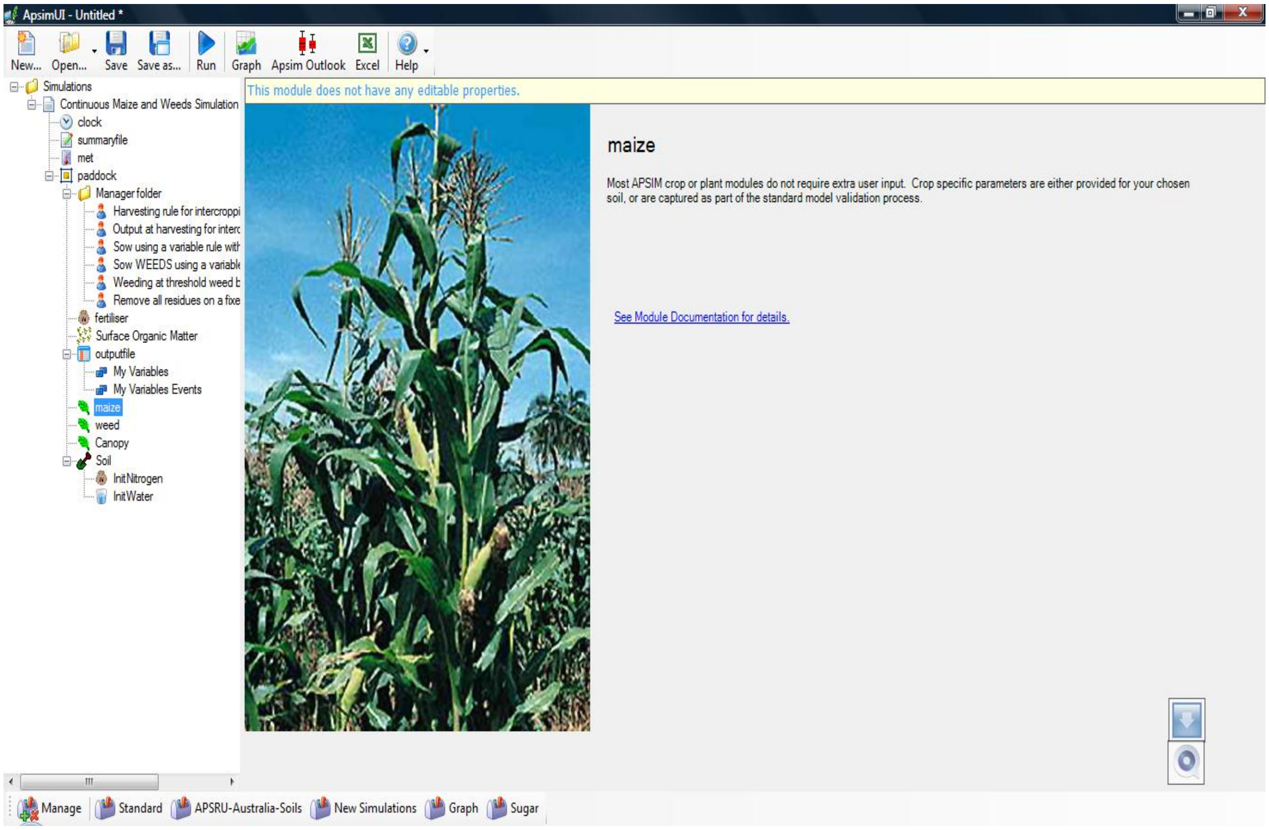
Ziervogel G 2001. Global science, local problems: SCF use in a Basotho village, southern Africa. Prepared for presentation at the Open Meeting of the Global Environmental Change Research Community, 6-8 October 2001. Rio de Janeiro. http://sedac.ciesin.org/openmeeting/downloads/1002573617_presentation_riopaper.doc. Accessed on 10 June 2010.

Ziervogel G 2004. Targeting SCFs for integration into household level decisions: the case of small farmers in Lesotho. Geographical Journal Volume 170, pp 6-21.

Zimfarmer 2010. Agro-ecological regions. http://zimfarmer.org/environment/agriculture/agro-ecological-regions?format=pdf Accessed on 16 December 2010.

APPENDICES

Appendix 1: Continuous Maize and Weeds Simulation template


ApsimUI - Untitled *
New...
Open...
Save
Save as...
Run
Graph
Apsim Outlook
Excel
Help
Simulations
Continuous Maize and Weeds Simulation
clock
summaryfile
met
paddock
Manager folder
Harvesting rule for intercroppi
Output at harvesting for interc
Sow using a variable rule with
Sow WEEDS using a variable
Weeding at threshold weed b
Remove all residues on a fixe
fertiliser
Surface Organic Matter
outputfile
My Variables
My Variables Events
maize
weed
Canopy
Soil
InitNitrogen
InitWater
This module does not have any editable properties.
maize
Most APSIM crop or plant modules do not require extra user input. Crop specific parameters are either provided for your chosen soil, or are captured as part of the standard model validation process.
See Module Documentation for details.
Manage
Standard
APSRU-Australia-Soils
New Simulations
Graph
Sugar

Appendix 2: Semi Structured interview guide

Purpose: to solicit information from individual farmers (taking into consideration the socio-economic factors affecting them) on their application of the APSIM model to decision-making as well as their perceptions of climate forecasting and how they cope and adapt to climate variability and future change.

Name of Farmer...

Village...Ward..

Enumerator...

1. Household information

Household head...Sex.........................Age..............

Level of education for the household head...

Spouse...

Number of children..

Level of education of children...

Number of other people dependent on/living with the farmer (relationships)..........................

....

Any agriculture training...

Farmer typology...

2. Current farmer practice

What is your usual farming practice for maize production?

Varieties...

Date of land preparation...

What do you use for land preparation?..

Do you own cattle that you can use as draft power for tillage operations?.............................

....

If no, what do you use for land tillage operations? Eg hire ox-drawn implements.................

....

What are the effects of this on your farm production?..

What guides your decision-making about climate?..

....

What guide your decision-making about crop management?...

....

When do you sow?..

When do you apply fertiliser (or manure and how much)?...

....

When to weed, and how many times?...

....

3. **APSIM model**.

Are you familiar with the APSIM model?...

Have you used it at any one time?...

From whom have you heard about APSIM model?..

Where/How did you learn about it?..

....

....

....

How credible is the model in yield prediction?..

....

Do you apply the APSIM model in your decision-making?...

If no,

- give reasons
- What advantages does it have?
- What are some of its weaknesses?
- What are your perceptions on whether APSIM adds value to SCFs?

If yes:

- give reasons
- Specify the actual decisions that you use the APSIM model?
- How useful is it to your decision-making processes about crop management?
- From your own opinion, what are some of the advantages of using APSIM in crop management over traditional indigenous systems and scientific SCFs?
- What are your perceptions on whether APSIM adds value to SCFs?
- How do APSIM outputs help you to adapt to future climate variability and change? If yes, specify how

4. Climate variability and SCF

What have you noticed about changes or variations in the climate over the last several years?

Explain the nature of changes and specify the timeframe for the changes?

How does/has climate variability affect your farming system particularly, maize production?

How do you forecast climate? What tools or other processes to do this? Do you use scientific seasonal forecasts or indigenous indicators? If you use local indicators specify them and what each would indicate? If you use scientific forecasts, explain these.

How do you apply the information from your climate forecasting to your decision-making and farm management?

How are you coping and adapting to climate variability?

Where do you get farming advice? Extension service, other farmers, internet, radio, etc.

What kind of advice have you been getting from extension service, other farmers, meteorology department, internet, radios and TVs?

Which source of advice do you value the most and why?

Is the advice of any use to your farm management or decision-making?

Which type of advice do you value most? Climatic, soil treatments, agronomic etc

Do you have any general questions or comments about farming or climate or APSIM?

Appendix 3: Lead questions in farmer group meeting to capture climate change perceptions and to introduce SCFs, crop simulation modelling (APSIM) and on-farm experimentation

1. What are you perceptions of climate change?
2. Describe the climate you have been experiencing over the last 10 or so years?
3. What guide your climatic and crop management decisions?
4. Are you familiar with SCFs?
5. What do you understand by SCF?
6. What are experiments and how can they assist you in farming?
7. What is crop simulation model?
8. Uses of crop simulation models in small-scale farming?

Appendix 4: Lead question at group discussion to give feedback on experimentation results to present APSIM model

1. What are your comments on the on-farm experimentation results presented by the researcher?
2. What role did APSIM play in setting up on-farm experiments?
3. What are your perceptions of APSIM as a decision-making tool?
4. What are some of the possible applications of the model in small-scale resource constrained farming systems?
5. What adaptation strategies do you wish to explore using APSIM to counter future climate change?

Appendices 5: Criterion used for classifying farmers for the semi structured interviews

1. Level of agricultural resources
2. Draught power
3. Technology adoption rates
4. Position in farmer group
5. Commitment to farming (demonstration and meeting attendance)
6. Agricultural qualifications/training

Appendix 6: Information to include on a Resource Allocation Map

1. Size of field (in acres or hectares)
2. Soil type of each field
3. Maize varieties grown in 2007/2008 season
4. Seeding rate
5. Harvest (in tonnes/ha or number of 50kg bags)
6. Land preparation (date, implements used)
7. Sowing date
8. Weeding times and dates
9. Fertiliser type used, amount and dates of application
10. Livestock owned (cattle, donkeys, goats etc)

Appendix 7: Lead questions for the APSIM simulation session

1. What are your comments on model outputs derived from practices by farmers A, B, C?
2. What would you have done differently to increase yield basing on farmer C practice (what if scenarios)?
3. Comment on the simulated outputs from the two scenarios explored by the APSIM model?
4. What can you comment on the capabilities of the APSIM model?
5. What are some of your farming and household constraints?
6. After running the APSIM model using the three farmers' practices and "what if scenarios and given the SCF, nominate the treatments that you want included in on-farm experiments?