# Modelling the Socio-Economic Benefits of the Adoption of Climate Information: An Innovative Approach to Subsistence Farmer Adaptation to Climate Change in Garu-Tempane District, Ghana.

By

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**ABSTRACT**

Decreasing average crop yield resulting mainly from variability and changes in climatic conditions continues to worsen food insecurity and the already low incomes of subsistence farmers in the Garu-Tempane District, Ghana. These devastating impacts on the livelihoods of subsistence farmers persist in part due to the continuous reliance on indigenous climate information and cultivation of indigenous seed with a share of land of about 81%.

Garu-Tempane is located within the savannah sahel vegetation zone — a region very vulnerable to climate variability and changes. With about 70% of the district's population engaged actively in crop farming, changes in climatic conditions has been an undesirable phenomenon to deal with among farmers.

Climate-smart seed and scientific climate information has the potential to reduce the impacts of climate change. However, adoption rates in the district are low — about 19% farm land coverage. It is thus exigent to investigate the reasons for the low adoption rate. Even though much is reported in literature on the low adoption rate of climate information and climate-smart seed among farmers, little is known about the hindrances to adoption.

With a system dynamics simulation model, this research explains the reference behaviour and identifies policy options for effective adaptation to climate change by subsistence farmers in the district. Anchored on adoption and diffusion of agriculture technology modelling, the research brings to light, the impact of climate information on crop yield and incomes of subsistence farmers in the district, the factors that affect adoption and how these can be addressed to enable farmers to turn the challenges of climate change into opportunities.

A rigorous approach of data collection and triangulation from participatory learning with communities, focus groups, interviews with climate information service providers and secondary data are the basis upon which conclusions are drawn.

Identified in this study, main factors that affect the adoption of both climate information and climate smart-seed include: trust in climate-smart seed and scientific climate information, knowledge in the cultivation of climate-smart seed and input cost.

Trust in the climate-smart seed is necessary to speed up further adoption towards the transition from the indigenous seed trajectory to climate-smart seed.

Equally important is knowledge, comprising most importantly climate information (onset and cessation of rainfall and extreme weather events) and existing farm management practise as well as learning from extension services to meet the variability and changes in climatic conditions. According to the study, what farmers need is reliable farmer specific weather/climate forecast. It is indispensable in the knowledge upgrading process to make available climate information/seasonal forecast with in-season updates and climate resilient seed to enable farmers to make informed decisions to increase harvest.

Most important is the affordability of input costs especially of fertilizer cost because maize does well when fertilizer is applied to it. Farmer household income levels determines the affordability of climate information and seed. And adoption of scientific climate information and appropriate advisories (climate-smart seed) is a necessary condition for a transition from subsistence agriculture to commercial farming and to make these affordable.

Proposed policy options from the simulation model include subsidising fertilizer prices further for example by 50% to increase adoption of climate-smart seed and information in the short run. This will help increase and stabilise incomes to enable farmers to pay the actual cost of fertilizer. Constructing climate information centres (designed with loud speakers) will help disseminate climate information/seasonal forecast to a number of communities at a time to reduce cost of individual subscription to climate information service providers. These centres could also serve as platforms for marketing farm produce. Instituting radio programmes would create a platform for farmers to share best practises to increase knowledge of other farmers as well as farmer field schools and demonstration farms. These would shorten trust adjustment in climate-smart seed and information and increase knowledge significantly within a short period of time for increased adoption.

*Key Words: Adoption, Diffusion, Climate-Smart Seed, Climate Information, Subsistence Farmers, Household Income, Garu-Tempane District, Ghana*

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# CHAPTER ONE

# GENERAL INTRODUCTION

## 1.1 BACKGROUND

Climate variability and change is bringing new opportunities albeit increasing risks and uncertainty about the future. The impacts of climate change on agriculture, which include crop failure, translated to hunger and loss of incomes, are already being felt, especially in Sub-Saharan Africa. Such impacts add another layer of difficulty in achieving productive and secure livelihoods among the most vulnerable people on the continent. Climate change is better expressed one of the main challenges to development in general (Ambani and Percy 2014) and livelihoods and food security in the Sub-Saharan African region in particular, given that about 70% of the population is engaged in small-scale rainfed agriculture (Alemaw and Simalenga, 2015).

Rain-fed agriculture is severely exposed to the vagaries of climate change (Alemaw and Simalenga, 2015) in this region. Widespread hunger and rural poverty confirm the severity of climate change in Sub Saharan Africa. This is an indication of the urgent need to increase food production and poverty alleviation efforts. The combined effects of extreme weather events including droughts and floods presented by climate change continue to reduce crop yield thus affecting the resilience of rain-fed agriculture (ibid). The Alliance for a Green Revolution in Africa, 2014) reports that, an estimated 223 million people currently in this part of the world are undernourished and it is envisaged that climate change could worsen this, increasing this figure by an additional 132 million by 2050.

In Ghana, the situation is no different. It can be described as worse in the savannah sahel vegetation zone where the study district-Garu-Tempane is located. This region experiences a single continually shorten rainfall season. Changing climate — late start of the rains, reduced amount and erratic distribution of rainfall and temperature extremes has resulted in continuous shift in the crop planting period from early April in the 1960s to late April or early May in recent years (Tonah, 1993: Mensah-Bonsu, 2003). With about 70% of the district's population engaged actively in crop farming, changes in climatic conditions has been an undesirable phenomenon to most especially to these farmers. Observations over decades in this part of the country indicate that such a change and variability in the climate has brought about unpredictable floods or dry spells induced by excessive rains and/or long periods of droughts.

It is thus glaring how agriculture production systems largely dependent on rain fall in Sub-Saharan Africa, particularly the study district is vulnerable to changes in climatic conditions bringing devastating impacts on household livelihoods.

To minimise the devastating impacts of climate change, forecast that predict the weather to enhance understanding well ahead of the season is very beneficial to those involved in agricultural production if communicated in user specific and relevant format (Coe and Stern, 2011). Well documented evaluations of the resulting benefits from the applications of forecast affirm a potential to improve rural livelihood and agriculture production with such forecast. However, constraint of access and understanding the information available has been a hindrance to adoption of climate information especially among small holder farmers (Hansen *et al.* (2011). Reporting on a study on Zimbabwean farmers, Hansen *et al.* (2011) discovered that they achieved a 19% yield benefit in 2003/04 unlike their colleagues who did not apply the forecast to their decisions. Ambami and Percy (2014) allude to this fact adding that climate information plays a major role in understanding climate as a major influence on livelihoods, resources and development efforts. The Alliance for a Green Revolution in Africa, (2014) discusses further these opportunities including adoption of 'climate-smart' agricultural technologies to build resilience to these changes. On the state of food and agriculture in the midst of climate change, the Food and Agriculture Organisation (2016) also emphasises the urgent need to support small holder famers and all whose livelihoods are intimately and inextricably linked to the climate with greater access to technologies and information to enable them to adjust their production systems and practices accordingly. This is necessary because continuous reliance on indigenous knowledge of predicting climatic conditions is no longer adequate. It can then be deduced that skilfully communicating seasonal forecasts tailored to the needs of the farmer helps to better understand the planting season and to make informed decisions to reduce their vulnerability.

However, it is the case in Africa and Ghana is no exception that there exists a considerable evidence of a gap between existing seasonal forecast and the information needed to support the decision- making processes of famers. It is often difficult for farmers to understand the current hard core scientific language and format in which such relevant forecast is communicated (Hansen *et al.* (2011). Farmers are not in need of general forecast but downscaled and locally interpreted information about the growing season beyond seasonal averages, transparently accurate in probabilistic terms and most importantly interpreted in a form that brings out clearly the implications of such forecast to agriculture (ibid). It is not enough to generate climate information because scientific understanding is only the beginning of the process of developing socio-economic benefits from satellite data. Such data must be turned into information to be disseminated at the right time in useable forms to individuals and organisations that put the information to practical use (Williamson et al, 2002). In view of this, the Community Based Adaptation 9 Conference highlights: "Communicating climate information to local communities needs to be revisited to ensure that available climate information is effectively adopted for decision making towards resilient livelihood (Nyasimi & Mungai, 2015). It has also been observed that where such farmer specific and detail information exists, it is usually provided by private climate information services requiring that farmers bare the subscription cost, one major hindrance to adoption of such invaluable resource.

It is thus imperative that Agricultural Units and Agricultural Extension Personal collaborate with climate information service providers to provide user specific climate information (Coe and Stern, 2011). This collaboration would help to augment existing indigenous information and knowledge since indigenous climate information and knowledge is no longer adequate to support decision-making. Scientifically generated climate information is detailed enough to provide the amount, distribution, onset and cessation dates of rainfall and other relevant climatic factors, capable of enabling vulnerable groups to effectively adapt to irregular and inadequate rainfall distribution patterns.

Regardless of the existing literature that emphasises the relevant role climate information plays in effective climate change adaptation and especially safe-guarding livelihood, none gives an integrated, process-oriented policy perspective that helps study the dynamics of adoption of climate information. Specifically, the relationship between these factors that hinder or facilitate the adoption of climate information by farmers and how these can be addressed. In most cases where these factors are presented, an integrated policy leverage is absent.

This study focuses on adoption and diffusion of available scientific climate information and services/advisories, identifying the endogenously generated hindrance to adoption of agriculture technology and leverage points to facilitate the adoption process. The research emphasises how the causal-effect relationship among adoption of climate information and services, agriculture production and livelihoods could be well managed with sustainable policy options through the community-based system dynamics modelling approach. The system dynamics model developed, provides a concrete framework for the researcher to study the dynamics of adoption of climate information and climate- smart seed among rural subsistence farmers over time. The scenarios generated from the model then forms the basis for informed policies options presented in this research for alleviating and improving food security and incomes of the population under study.

## 1.2 REFERENCE MODE

Literature reviewed and data from the field revealed that there is a wide gap between the generation of climate information and the adoption of such information by the target end-users.

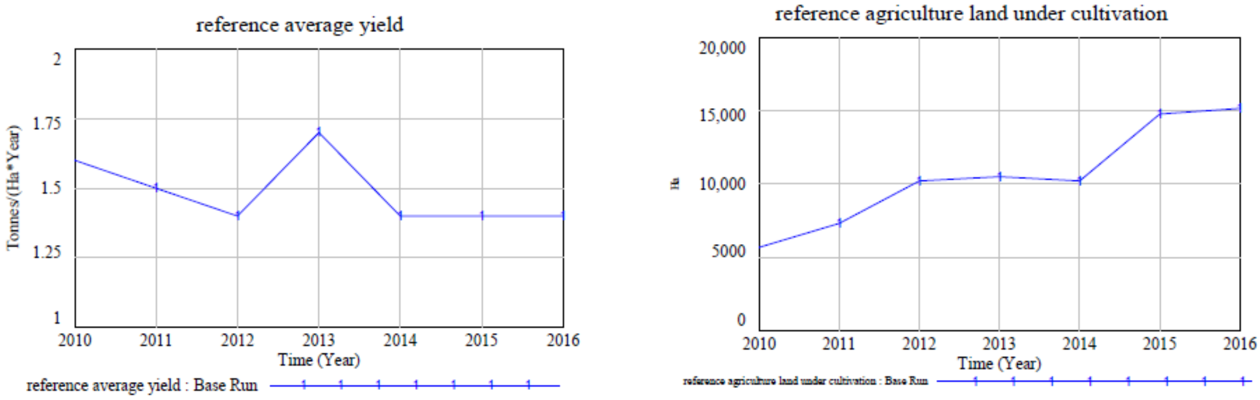
For instance, Patt & Gwata (2002) report limited utilisation of climate information among Zimbabwean farmers. In Ghana, a study in Akasti (in the Volta region) in 2006 observed a similar situation. Of 26 farmers who were provided with weather forecast and information on the onset of the planting season and rainfall pattern, 9 farmers of the sample, that is 34.6% of the farmers agreed to heed the forecast and the advisory. The rest chose to follow their indigenous knowledge. Of the 34.6% who agreed to plant early based on the climate information relayed to them, only 15% actually did (Adiku, 2012). Everyone else planted based on indigenous knowledge.

A common finding in the above is that though scientifically generated climate information may be available there is still a gap between the generation and the actual adoption of this information in farmer decision-making. This gives rise to the need to study the dynamics of diffusion and adoption of the information and climate-smart seeds for effective adaptation to climate change.

Historical data on the adoption and coverage of climate information in the Garu-Tempane district is not available. As such, since the use of climate-smart seeds by farmers is accompanied by the dissemination of scientific climate information, coverage of the use of climate-smart maize seeds by farmers is used to as a proxy to determine the adoption of climate information in the study district. Available data suggests that improved seeds in general were introduced in the district in the 1990s (Ibrahim, Personal Communication). However, judging from the aforementioned cases on the usage of scientific climate information, it is not surprising to observe that as at 2010, only about 19% of cultivated land was with improved maize seed. It is thus the proxy for the estimated coverage of land under scientific climate information in this study.

Deductively, about 81% of maize cultivated area is under indigenous seed. Farmers continue to rely on indigenous seed and ways of forecast. Indigenous forecast is however no longer adequate to predict changes and variability in climate. The indigenous seed is also less resilient to these changes that occur. The resultant low yields per farm is attributable to the effect of the low coverage of climate-smart seed with relatively higher yield potential, accompanied by scientifically generated climate information. To cope with the decreasing yield per unit of land, farmers who have the capacity are shifting to cultivating more land in order to meet their domestic food needs as well as for sale. However, with population growth, this is not a sustainable approach. Table 1.1 depicts the reference mode of behaviour motivating this study.

Figure 1.1: Reference Mode of System Behaviour




Source: Garu-Tempane District Crop Unit, 2016

## 1.3 RESEARCH METHODOLOGY

The system dynamic approach to problem identification and problem solving is the main approach applied in this study. The approach is used because it allows the development of a framework that integrates the many factors presented in different studies thus laying the foundation for integrated feasible policy options to the problem identified. With a simulation model, it is possible to understand the dynamic implications of processes of accumulation in trust and knowledge building process which is necessary in the adoption of technology (Kopainsky *et al* 2012). Such a framework enables an in-depth analysis of the adoption of climate information and its impact on agricultural production, livelihood sustenance and effective adaptation to climate change given its emphasis on cause-effect relationship and accumulation characteristics. The approach helps to develop sustainable solutions guided by the feedback perspective of system dynamics given that the structure dictates the behaviour (Hovmand, 2014). It provides a scientific basis for investing in climate information illustrated through scenarios generated with the simulation model. In this study, it was essential to involve communities in this approach particularly because it facilitates learning among participants about the system, creates an opportunity for social learning among stakeholders whilst building social capital to support implementation of policies (Stave, 2010).

### 1.3.1 Research Objectives

- To develop a concrete simulation model that explains the reference behaviour and feasible policy options for effective adaption to climate change among subsistence farmers in the Garu -Tempane District.
- To determine the impact of the adoption of climate information and climate-smart seed on crop yield and incomes of subsistence farmer in Garu-Tempane, Ghana
- To examine the factors that influence farmers' adoption of climate information and climate-smart seed.

### 1.3.2 Research Questions

- What is the impact of the adoption of climate information and climate-smart seed on crop yield and farmers income?
- What factors determine adoption of climate information among subsistence farmers in Garu-Tempane District?
- What challenges and opportunities could hinder or support effective adoption of weather and climate information and services in the study district?

### 1.3.3 Techniques and Tools for Data Collection and Analysis

Given the qualitative and quantitative nature of the research questions and the sample size of the study, the research strategy follows a mixed approach and is carried out as a mixed-method case study. Specifically, the following techniques were used:

- Secondary data collection/reviews
- Semi-structured interviews
- Focused group discussions
- Community-based system dynamics modelling
- Pair-wise ranking

Literature reviews complemented with expert interviews with purposively sampled stakeholders (subsistence farmers, agricultural units and climate information services providers) were conducted to seek expert views and to confirm the researcher's observation of the actual system represented in this study.

These expert interviews provided information relevant to identifying variables in the adoption of climate information.

Focus group discussion were conducted with communities to develop the causal structure, generating the problem under study. This formed the basis for the simulation model.

After this extensive multi-method data collection; model building, testing, validation and analyses that studied the leverage points influencing adoption was then done.

Results of these analysis from the model are the basis for the conclusions on how adoption can be strengthened, that is, which factors need to be focused on, in terms of policies to support the effective adoption of climate information and advisories.

### 1.3.4 Data Analysis

Validation was conducted subjecting the model to various test to determine its robustness and usefulness in for its purpose. Focus was primarily on the interaction between crucial elements of climate information and seed adoption processes. Of much interest is the behavioural outcomes of the feedback mechanisms and causal relationships and not necessarily the exact numerical outputs.

With a valid model. Scenario runs were generated from the simulation model based on which behaviour analysis was done. Such structural- behaviour oriented analysis informed the conclusions on the feasible policy options suggested thereof.

## 1.4 ORGANIZATION OF THE STUDY

This study is organised into six chapters. Chapter one is an introduction to the study. It encapsulates the background, problem statement; research questions, scope of study and research methodology. Chapter two covers literature reviewed on climate change and agriculture production, climate-smart seed variety adoption, climate information and service adoption, indigenous seed variety, indigenous climate information and adoption and household incomes. In chapter three, a description/documentation of the model is presented. Chapter four discusses the model validity and confidence in its usefulness. With a valid model structure in chapter four, model behaviour analysis and policies developed as leverage points to attain desired system behaviour is presented in chapter five. Chapter six discusses the researcher's conclusion and recommendations for further studies.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter covers a review of relevant literature that specifies the boundaries for the study. It sets out the basis for assumptions regarding the model developed to represent the real system. Literature was reviewed on the adoption of climate information and its relevance in this context, the adoption of climate-smart seed, indigenous seed variety, and the characteristics of these seed varieties and how well these have been performing amidst changing climatic conditions.

## 2.2 CLIMATE-SMART AGRICULTURE

The Food and Agricultural Organisation of the United Nations defines Climate-Smart-Agriculture as “agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes Green House Gases (mitigation) where possible, and enhances achievement of national food security and development goals”. In this definition, the principal goal and basic concept of Climate-Smart Agriculture is seen as food security and development (Food and Agriculture Organisation 2013a; Lipper *et al*. 2014). This suggests that for a practice or input to be classified climate-smart, it should exhibit the above qualities. These tenets of climate-smart agriculture are illustrated in the figure below, the guiding principle for the definition of climate-smart seed in this study:

Figure 2: Climate-Smart Agriculture (CSA)


Source: Papuso, and Faraby, (2013) Climate Smart Agriculture. Seminar on Climate Change and Risk Management.

## 2.3 DETERMINANTS OF ADOPTION AND DIFFUSION OF AGRICULTURE TECHNOLOGY

Adoption is defined differently by many authors. A common yet significant theme in the definitions is becoming knowledgeable of a technology, making the decision to attempt using it for the first time and continuous use over time. Loevinsohn *et al*., (2013) defines it as the process of integrating a new technology into existing practice which is often preceded by a period of experimenting and some degree of adaptation. For Bonabana-Wabbi, (2002) it is a mental process that an individual goes through from first hearing about an innovation to finally utilising it. Mwangi and Kariuki, (2015) agree with the other mentioned authors and goes further to make mention of a distinction of relative speed with which farmers make use of an innovation as the rate of adoption which encompasses the element of time and the level of use of that technology which also gives an idea of the intensity of the use of it within a given period of time.

Literature on the determinants of adoption of technology clearly show that many authors come out with categorisations of the determinants of technology adoption that fits best the context of their study. Relevant to this study is the categorisation by Loevinsohn *et al*. (2013). Farmers' decision to adopt new technology is determined by the dynamic interaction between characteristics of the technology itself and their conditions and circumstances (ibid). Implementing the adoption decision is as a result of a series of individual decisions and these decisions are usually the result of making a comparison between the uncertain benefits of the new technology with the uncertain costs to be incurred (Hall and Khan, 2002).

Traditionally, economic analysis explains the adoption dynamics relative to personal characteristics and resources, imperfect information, risk, uncertainty, institutional constraints, infrastructure and availability of inputs (Uaiene, 2009). Recent literature on adoption includes social networks and learning as determinants of technology (ibid). Some others group these factors into different categories including those of Akudugu *et al*. (2012)'s grouping of the determinants of agricultural technology adoption into three categories namely; economic, social and institutional factors. McNamara *et al*, (1991) classify them into, farmer characteristics, the structure of the farm, institutional characteristics and managerial structure, while Wu and Babcock (1998)'s categorisation is into human capital, production, policy and natural resource characteristics.

The determinants of adoption and diffusion of new technology can be largely grouped into four main categories including varietal characteristics, farm-level characteristics, farmer characteristics and institutional characteristics as presented in the table 0.1.

Table 0:1Determinants of Adoption and Diffusion of New Agricultural Technologies

| Category | Determinant |
|---|---|
| Varietal Characteristics | yield (expected gross margin, respectively), input prices uncertainty associated with the variety riskiness of the variety |
| Farm-Level Characteristics | climatic and agro-ecological suitability of the location for the variety<br>E.g. quality of the land |
| Farmer Characteristics | agronomic expertise & skills, knowledge about variety, risk aversion, capital availability, access to credit |
| Institutional Characteristics | consumer and market demand for improved varieties |

Source: Kopainsky & Derwisch, (2009).

For the purposes of the study and development of the system dynamics model, only the endogenous determinants (those that can be altered depending on the farmers' level of knowledge and resources and can be changed over time) were considered as described in this section. The only exception in this case was the consideration of input cost because the study identified that income for that matter mater *affordability* of both climate-smart seed and information has a greater influence on the implementation of the adoption decision. *Affordability* is relative to the income levels of farmers.

## 2.4 METHODS OF DETERMINING AGRICULTURE TECHNOLOGY COVERAGE

Two approaches can be used in measuring the rate of adoption of any agricultural innovation: in terms of the number of farmers who adopt the innovation and in terms of the total area on which the innovation is implemented or applied. These two measures will yield equivalent results when farm sizes are roughly the same and/or the rate of adoption is constant across farm sizes. There is no rule of thumb indicating which of these two measures is inherently better; one's choice of either of them is dependent on the issue being addressed (Morris, *et al*, 1999). If one seeks to determine the number of people who have been affected by an innovation, it is appropriate to find out the proportion of farmers who have adopted the innovation. However, if the aim is to determine the economic benefits resulting from adoption, it is appropriate to find out the percentage of the area affected by adoption (Morris *et al* 1999). The penetration and utilisation of an innovation is conditioned by adoption and diffusion processes where adoption focuses on what makes a farmer begin to use an innovation and diffusion focuses on the speed of penetration into the potential market. This could be measured in terms of the percentage of total agriculture land area that is cultivated with improved seed or the percentage of farmers that adopt improved seeds (Kopainsky & Derwisch, 2009).

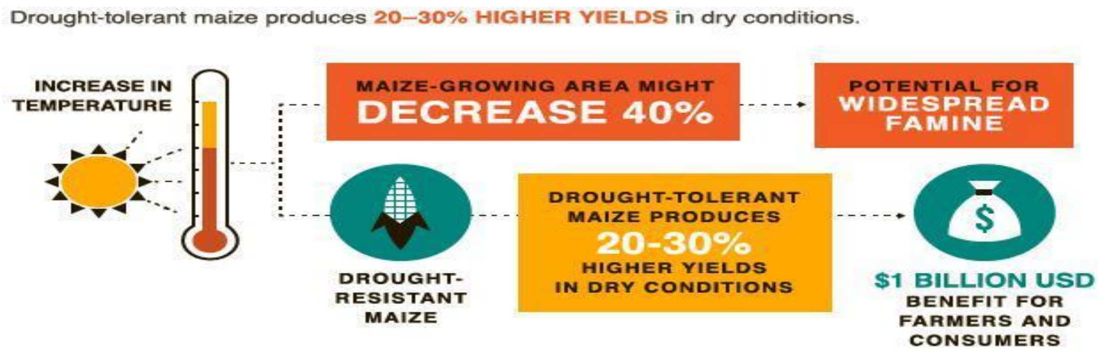
Taking into consideration the objectives of this research, it is not sufficient to only consider the number of farmers who have adopted climate information and climate-smart seed but more importantly how this adoption process affects the livelihoods of these farmers. Thus, the coverage of both climate information and climate-smart seeds are measured in terms of the percentage of land on which these technologies have been implemented.

## 2.5 CLIMATE-SMART SEED VARIETIES

As discussed in chapter one, the severe and incessant climatic stress with its negative impact on food security and livelihood of the African continent has propelled research into climate-smart technologies to save the continent from the dire consequences. In the quest to reduce vulnerability and improve food security, the Drought-Tolerant Maize for Africa (DTMA) project released 160 drought-tolerant maize varieties between 2007 and 2013 which were tried on demonstration grounds to validate their potency and adaptability to environmental conditions (La Rovere *et al.* 2010). In this guide, Drought-Tolerant Seed Variety (DTSV) designed by DTMA in its pursuit to reduce vulnerability to climate change and variability as climate smart seeds given the following features of this seed variety:

To begin with, the maize seed varieties developed by the project are drought-tolerant and have increasing yield potential even under moderate drought conditions, thus ensuring food security whilst raising income for farmers. The varieties are also adaptive such that they enable farmers to cope with more persistent droughts resulting from climate change. Added to that climate-smart seed possess a mitigative potential which helps farmers reduce greenhouse gas emissions by combining the use of drought-tolerant maize with farm management practises such as no-till agriculture. The characteristics of improved seeds that make them climate-smart are illustrated in figure 3. The figure depicts that rising temperature including other changes that come along with climate change could lead to a decrease in the maize growing area by 40% with a looming danger of widespread famine on the African continent and Ghana or the district as vulnerable to these changes such Garu-Tempane is equally highly likely to experience eve worse. However, if there is a paradigm shift from the cultivation of current maize varieties to high yielding climate-smart varieties, food insecurity will be minimised significantly with sustained significant adoption rates.

Figure 3: Climate-Smart Seed




Source: La Rovere *et al.* (2010).

Added to that La Rovere *et al.* (2010) in an assessment of the potential impacts of Drought Tolerant Maize for Africa project reports makes it known, the income generating characteristic that qualifies the drought tolerant maize seed as climate-smart. With sustained optimistic adoption rates and yield increases of 10-34% over non-drought-tolerant varieties by 2016 the project could lead to a cumulative economic benefit of nearly USD 0.9 billion to farmers and consumers alike. Drought-tolerant maize variety could assist more than four million people to escape poverty while improving the livelihoods of several millions of people. Moreover, farmers are reporting a percentage increase in yields of 20–30% above what they would attain with traditional varieties, even under moderate drought conditions (ibid).

This vision is being implemented in many African countries and in the case of Ghana, Quality Protein Maize was released in Ghana in the early 1990s by the Crops Research Institute, Kumasi (Osei *et al.* 1999). However, widespread usage followed much later in most parts of the country.

## 2.6 SEED DELIVERY SYSTEM IN GARU-TEMPANE, GHANA

Traditionally farmers would usually reserve seeds at harvest for sowing the next season. In the event that a farmer has no seed from the previous season, seeds are obtained from colleague farmers or from local markets. Over time, formal seed systems have emerged but traditional seed system still prevails in most parts of the country (Etwire1 *et al*, 2016). The informal or traditional seed system refers to the exchange of seeds or obtaining them as gifts or through purchase from local markets (ibid). This system of acquiring seed comprises about 80% of the total seed system for a considerable number of staple crops in Ghana (Louwaars & Boef, 2012). The formal seed system on the other hand is a framework of institutions connected through processes of production, multiplication, storage and marketing of specified quality improved seed varieties along with the interactions and support to provide seed to a particular end user (Etwire1 *et a*, 2016). Therefore, the formal seed system as described by (Cromwell, *et al* 1992) is a chain of longitudinal integration of activities from germplasm manipulation and selection to purchasing of seed by final customers through successive generations. The production of improved seed in Ghana is spear headed by the Crop and Scientific Research Institute (CSRI) supported by other producers.

## 2.7 CROP PRODUCTION IN GARU-TEMPANE DISTRICT

Agriculture plays an important role in economic growth, food security, poverty reduction, livelihoods and rural development in Ghana (Ghana Statistical Service, 2008).

Agriculture in Ghana contributes to 40% of Gross Domestic Product (GDP), 3/4 of export earnings, and provides employment to 60 percent of the labour force (Breisinger, *et al* 2009). The sector grows at an average annual rate of 5.5%, a growth rate that has been more rapid than growth in the non-agricultural sectors in recent years (ibid). The main driving factor behind the rapid agricultural growth is the crop subsector dominated by staple crops such as maize, sorghum and rice. This subsector is the largest, contributing to more than two-thirds of the agricultural economy. Breisinger *et al* (2010) observed that the crop subsector contributed to 75 – 85 percent of agricultural growth between 1991 and 2006.

In Garu-Tempane District, smallholder farmers produce staple crops and livestock as their main livelihood activity. Their purpose of production is to address their immediate food consumption needs before other interests such as selling to raise income (Ibrahim, 2014). Statistics indicate that about 85.2% of the district's population is engaged in unskilled agricultural forestry and fishery (Garu-Tempane District Assembly, 2014). From the 2014 Medium Term Development Plan of the district, the space economy of the district can be described as principally characterised by mainly the production of subsistence food crops, a few cash crops and livestock/poultry. About 70% of the district's population is engaged in this subsector producing major crops including millet, maize sorghum, rice, sweet potatoes and groundnuts.

Food crop cultivation in Garu-Tempane is largely possible during the single period of rainfall that occurs between May and August. For the rest of the year, there is less activity since agriculture is rain-fed (Garu-Tempane District Assembly, 2014). Engaged mainly in small-holder rain-fed agriculture, households find it difficult to meet their basic needs due to unfavourable environmental conditions to support agriculture production even during the main cropping season. This is not surprising because one very crucial factor in agriculture activities; availability of water for agriculture is estimated to have decreased. It is estimated that about 1.55 to 1.65 cubic metres per square area of the rainfall is lost per annum as a result of evapotranspiration from open surfaces partly due to the low vegetative cover and dry nature of the land (Garu-Tempane District Assembly, 2014). Morover, farmers are faced with late start of the rains, reduced amount and erratic distribution of rainfall and temperature extremes has resulted in continuous shift in the crop planting period from early April in the 1960s to late April or early May in recent years (Tonah, 1993: Mensah-Bonsu, 2003)

**2.8 MAIZE AS A CASE STUDY**

Maize is a staple food for more than 300 million people in Africa (La Rovere *et al*, 2010). Case studies of the Drought-Tolerant Maize for Africa (DTMA) gives it such description as “maize is life” in sub-Saharan Africa (SSA) given its relevance for food security as well as economic well-being of majority of the continent’s populace who are largely food crop farmers (ibid). About 40% of Africa’s maize-growing areas have already started experiencing occasional climatic stress resulting in yield losses of 10–25%. Added to that about 25% of the current maize crops suffer recurrent drought leading to crop losses of at least half of the total harvest (ibid).

Maize is the number one crop in Ghana in terms of area planted and accounts for 50-60% of total cereal production. It is the second largest commodity crop cultivated in Ghana after cocoa (Millennium Development Authority, 2010). It accounts for over 20% of incomes earned by smallholder farmers in Ghana (Klutse et al, 2013) and food security not only to smallholder farmers in Ghana. According to Ministry of Food and Agriculture, (2011) it is produced mostly by smallholder resource poor farmers under rain-fed conditions subject to yield fluctuation due principally because it is determined by rainfall changes and to a much lesser extent market forces. Maize production according to Klutse *et al*, (2013) contributes to about 45% of agricultural production which remains the main source of livelihood for most Ghanaians and it provides employment to more than 60 percent of the population whilst accounting for 30% of Gross Domestic Product (GDP).

During 1997, more than half of Ghana's maize coverage (53.8%) was planted with improved maize varieties (MVs). Although little reliable data exist that permit comprehensive comparisons with neighbouring countries, adoption is relatively high in comparison with her neighbours of like status where maize is grown mostly by subsistence-oriented farmers. Out of several major crops about 59.7% of the cultivated land is planted with maize in savannah Sahel vegetation zone of Ghana where the study district is located. Maize production has taken more than half the percentage of agriculture land under cultivation (Morris *et al,* 1999).

In addition to the fact that it is widely-consumed as a food staple, maize is particularly considered important in Ghana from a nutritional point of view. Maize constitutes an important and major component of many widely-patronised weaning foods for infants (ibid). For this reason, the Ghana Grain Development Project (GGDP) has invested considerable effort in breeding Modern Maize Seed Varieties with enhanced nutritional quality to improve the nutritional status of the population. Varieties such as Obatanpa, released in 1992, is a so-called Quality Protein Maize (QPM) containing the opaque-2 gene, which confers unusually high levels of the amino acids lysine and tryptophan (Morris *et al.* 1999). It is also acknowledged that commendable effects have been recorded in controlled feeding trials of specialized populations including school children, soldiers and prisoners in Ghana with such variety (Morris *et al.* 1999). A more comprehensive study done by Afriyie *et al., (*1998) in Ghanaian children (0-15 months) fed with food supplemented with Quality Protein Maize and normal maize revealed that Quality Protein Maize fed children grew healthier, suffered fewer fatalities with relatively accelerated growth rates Osei *et al.* (1999) also conclude that QPM is superior to normal maize in terms of its protein content.

Mamaba, a drought tolerant variety which is often adopted by subsistence farmers in drought prone areas including Garu-Tempane. As a result of long dry spells and drought, drought tolerant variety including mamaba are often sold in the district. cannot be left out as it also satisfies the drought tolerant characteristic of climate-smart seed.

Judging from above, such improved seed varieties can be considered climate-smart maize thus has a lot of benefits to improving the livelihood of the district. It has the potential not only to combat food insecurity but also improve nutrition associated with several measures of well-being, among which improved health, increased life expectancy, enhanced intellectual capacity, and increased ability to perform physical work cannot be over emphasised.

In conclusion, if subsistence farmers adopted high yielding, drought tolerant varieties described as climate-smart varieties, they will harvest excess food beyond which they can consume and so surplus food can be sold to for income to support household expenditure.

# CHAPTER THREE

# MODEL DOCUMENTATION/DESCRIPTION

## 3.1 INTRODUCTION

This chapter of the thesis describes in detail, the structure of the model. It gives a vivid description of the assumptions based on which the model is developed. The chapter further presents a discussion on how the adoption of climate information and climate-smart seed, agricultural land under cultivation and food inventory operate individually as separate modules. It also discusses how the integrated interactions of these modules of the system culminate in improving the adaptive capacity of farmers to climate change.

## 3.2 MODEL DESCRIPTION

The model built for this thesis provides answers to how climate change has affected crop yields and its trickledown effect on availability of food, household income and adoption of agriculture technology (climate-smart seed and scientific climate information). Very critical in this study is the focus on dynamic precision rather than numerical precision. As proposed by Sterman (2000), it is more scientific to use one's judgement to estimate the numerical values of variables that do not have exact numerical values and this estimate is usually very useful in a system than to omit them. "To omit such variables is equivalent to saying they have zero effect- probably the only value that is known to be wrong!" (Forrester 1961, pp. 57). Nevertheless, it is very much important to use reliable statistical methods to estimate the numerical value of parameters in assessing the model's ability to replicate historical data when numerical data is available. Moreover, this must also be backed by evaluating the sensitivity of one's results to the uncertainty in the model's assumptions regardless of whether the model's parameters are estimated judgmentally or statistical (Sterman, 2000).

### 3.2.1 Explanatory and Policy Models

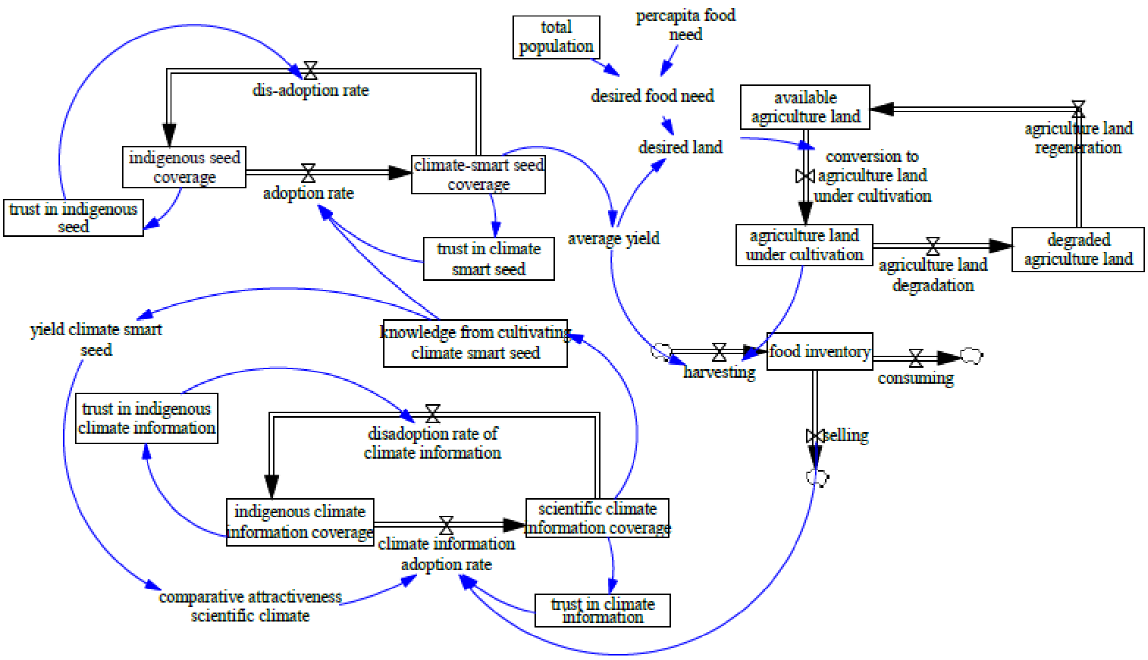
The core structure of the system described in this section represents the explanatory model of the real system. Central to the explanatory model is the stock; *food inventory*, *average crop yield* and the processes involved in refilling the stock through the inflow; *harvesting* when it is drained through the outflows; *consumption* and *selling*. This structure is guided by the stock adjustment/management structure in Sterman (2000).

The second section of the system represents the suggested policy options that could be implemented to improve the state of the system. Seed adoption and climate information are at the core of this process. The basic formulation regarding the adoption of climate information and seed adoption is based on the formulation of the Bass diffusion model of adoption of new technology (Sterman, 2000). Equally utilised is the formulations of the Malawi improved maize seed adoption model by Kopainsky *et al*, (2012).

### 3.2.2 Model Assumptions

This section discusses explicitly the assumptions based on which the model was built and the justification for utilising them in the model Models built without boundaries grow without limit which might render them vague. To prevent this, every model is built with some assumptions that indicate the boundaries beyond which the model may not be applicable. Based on the objective of this study as spelt out in chapter one, the researcher set out four major pillars relevant to this study: food production, agriculture land and adoption (two main stocks of seed and information coverage/share of land) and population. As described in chapter one the reference mode presented earlier and the subsystem diagram in this chapter further consolidates the model boundaries. Figure 4 indicates the four modules crucial to this study: *agriculture land under cultivation*, *food inventory*, *climate-smart seed adoption module*, *climate information adoption module* and the *population module.*

Figure 4:Sub-System Diagram




### Timeframe for Model Simulation

Improved seeds were introduced around the 1990s but widespread usage started in 2000 in the study district. The year 2010 is chosen as the base year because, there is no data available for the exact year of its introduction (Garu Tempane District Department of Agriculture, 2016).

This informs the choice of 2010 as the base year. This is supported by Sterman (2000), that modellers should trace as far back as data can be found to indicate the reference mode and motivation for the study. This model is simulated for a 20-year period (2010-2030).

**Indigenous Seed Variety (ISV)**

All varieties of indigenous seed are characterised by relatively low yield potential worsened by the continuous changes in climatic conditions. Farmers generally achieve very low crop yields which is a characteristic of the indigenous seed used (Muzari *et al.*, 2012). About 40% of Africa's maize-growing areas face occasional drought stress, resulting in yield losses of 10-25%. Also, about 25% of the maize crop suffers from frequent drought and farmers experience losses of about half the harvest to drought (La Rovere *et al.* 2010). The length and amount of rainfall necessary for farmers to realise the full potential of the indigenous seed is non-existence. This greatly affects the wellbeing of households since the expectation of farmers is to obtain at the end of the cultivating season, a harvest sufficient to feed their families and excess sold to take care of household expenditure. Since farmers do not have the capacity to circumvent these challenges, they resort to increasing agriculture land under cultivation but most often due to capacity constraint, this increase is less than the existing gap. A more sustainable approach by District Department of Agriculture has been the introduction of climate-smart seed varieties (drought/flood resistant, early maturing and high yielding crops) as well as the information and management practises that come along with such seed variety to realise its yield potential.

**Climate-Smart Seed Variety (CSSV)**

These are improved seed varieties that has relatively high yield potential compared to indigenous seed varieties. Thus, it has the potential to combat food insecurity whilst improving the income of households which qualifies improved seeds with such characteristics as climate-smart. With sustained optimistic adoption rates and yield increases of 10-34% over non-drought-tolerant varieties by 2016 such seeds could lead to a cumulative economic benefit of nearly USD 0.9 billion to farmers and consumers (La Rovere *et al.* 2010). It is also estimated that drought-tolerant maize variety could assist more than 4 million people to escape poverty while improving the livelihoods of many millions of people. Moreover, farmers are reporting a percentage increase in yields of 20–30% above what they would have harvested with their traditional varieties, even under moderate drought conditions (ibid).

**Climate-Smart Seed Variety, Harvest and Income Nexus**

It is assumed that when a farmer acquires the seed and climate information and related services, the farmer would obtain a relatively higher yield not necessarily equal to the yield potential of the seed at least for the first time. This conclusion because, maize is not entirely a new crop in the study area and farmers can transfer a considerable amount of knowledge from cultivation of indigenous maize seed. Higher yields would be attained as the famer continues to gain knowledge on the individual level and from group learning added to the information from adoption of climate information and applies it adequately. If the farmer can harvest sufficient food he will be in a better position to meet his domestic food needs with surplus food sold for some income. When income from the sales is increased, income surplus is accrued and then cost of information and seed and other relevant input cost is affordable to the farmer consequently influencing the adoption process. Given that the farmer continues to adopt the technology, food inventories and incomes will increase, eventually leading to breaking away from the vicious cycle of poverty.

Morris *et al.* (1999) argue that the use of an improved maize variety instead of a local maize seed variety results in a significant yield increase, even if fertilizer is not applied to the improved seed variety during cultivation. This, they found consistent with experimental data showing that well-adapted improved maize variety outperformed local varieties even under unfavourable production conditions. They also observed that when fertilizer is applied to both local and improved maize seed varieties, the size of the increase in yield is significantly greater for the improved maize seed variety relative to the local seed variety. This is attributed to the fact that most improved maize seed varieties have been tailored to respond to unfavourable production conditions. Consequently, if farmers can increase their yield so much with climate-smart seed varieties, they can sell of some because consumption needs will be satisfied to allow for sale of surplus.

Moreover, the fact that the farmer had more produce with the climate-smart seed would improve confidence in the climate-smart seed and this triggers the farmer's decision to implement the adoption of climate-smart seed during subsequent seasons.

In developing countries like Ethiopia, widespread adoption of yield-enhancing agricultural technologies has been one way to eradicate poverty and to ensure food security. However, adoption of new technologies is not enough but sustained and continuous use of such technology (Tura et al 2010). In spite of the anticipated benefits, the danger is that if unanticipated occurrence happens due to the uncertainty in rain forecast causing the farmer not to realise the higher yield as it was advertised, the farmer is likely to abandon the seed and perhaps the climate information he must pay for to upgrade his/her knowledge and crop management practises and return to the indigenous seed after some years of trial. Tura et al (2010) bring to the fore, the fact that farmer's decision to discontinue a technology could be as a result of dissatisfaction with its performance. Evidence of dis-adoption of use of improved agricultural technology is exemplified in Ethiopia where about 40% of farmers who adopted new inputs discontinued use (Tenkir *et al.* 2004).

Farmers consider the profitability of what they pay for because it is economically unwise to pay for a seed and other services which does not offer any extra benefits. If this is the case, they opt for indigenous seed and climate information which the farmer can easily get at no cost from colleague farmers or at relatively lower cost. Important characteristics of a technology such as its profitability account for its adoption and farmers will abandon unprofitable technologies. Farmers naturally buy into in technologies that present higher returns to scarce factors of production in Ghana (Morris *et al.* 1999).

### Sale of Food Crops

Food crops such as maize are grown mainly for consumption and sale if there is excess. However, there is a minimum sale of food that occurs even if they do not have excess since subsistence farming is the main source of livelihoods and they would need cash to attend to needs and to purchase what they do not produce. Again, major sales occur when there is excess after household consumption is satisfied. When this happens, then there is the financial boost to household income to cater for all other household expenditure and a budget for climate information and services. According to Ibrahim, (2014), the main purpose of production for subsistence farmers in Garu-Tempane is to address their immediate food consumption needs before other interests such as selling to raise income are considered

### Household Income in Garu-Tempane District

Household incomes are very low because they harvest little with the cultivation of indigenous seed varieties. It can be inferred that the very low yields account for the low levels of income. Crop farming is the main livelihood supplemented with forest-related activities suggesting that increase in yield will translate to sales once household food need is satisfied. It has been proven in several studies including Morris *et al* (1999) in Ghana that increase in yields increases income levels of farmers. Increased incomes then determine the affordability of the technology introduced. Farmers can make the decision to adopt based on their ability to spare some income to finance the adoption process because as observed by Sugri *et al* (2013), technology adoption is influenced by several factors among which price is significant. If farmers would adopt the new technology, its affordability determined by the incomes of farmers and the cost of the technology is critical.

### Subsistence Farming in Garu-Tempane District

The district under study is engaged in subsistence farming. As such the priority for crop cultivation is consumption. Food is sold if there is excess to meet other needs such as education, health care among others. It is relevant to know that, in case of poor harvest, farmer households must purchase food from the open market to survive through the lean season until the next harvest season. Therefore, if the household can cultivate and harvest enough food, the money that would have been used to purchase food from the open market is used for other household expenditure. When food produced is less than the family food consumption needs, there is an added expenditure to the household expenditure since they have to budget for food as well. Farmers have an interest to sell some of their produce if they have excess but this is ideally possible if the main purpose of production for them which is to address their immediate food consumption is satisfied (Ibrahim, 2014).

**Non-Adoption of Climate Smart-Seed and Information**

Non-adopters refer to the farmers who have never tried to experiment with the climate-smart seed due to varied reasons. In this study, all factors that could account for non-adoption, for instance preference for indigenous seed due to its characteristics, the need for some food crops for traditional performances are not explicitly modelled. All likely factors that explain why some farmers will cling to indigenous seed are aggregated and represented by the probability that some farmers would not adopt the climate- smart variety; *non-adoption potential* influenced by *trust in indigenous seed* as indicated in the model structure. Kopainsky *et al* (2012) capture it well in the statement: when farmers choose between different seed varieties, a range of information is available to them and their choice will involve trade-offs between numerous attributes of the different seeds involved.

**Time taken for total/ a large proportion of land to be put under climate-smart seed coverage.**

A farmer is likely to experiment on a small portion of his/her land with the climate-smart seed on the average 1 year after witnessing colleague(s) cultivate such seeds. However, it takes approximately 5 years between the first time of awareness and the time for a famer to have developed so much confidence in the climate-smart seed such that he/she will be willing to put a greater proportion of his land under cultivation with climate-smart seed (Kopainsky *et al*, 2012)

**Maize as a Representative of Climate-Smart Seed Varieties**

As described in the literature review in the chapter two, maize is chosen as a representative of other climate-smart seeds varieties because, "maize is life" due to its importance for food security and economic value to most locations in Sub-Saharan African countries including Garu-Tempane, Ghana (La Rovere *et al.* 2010). Moreover, there is considerable information and data on maize seed in the district in comparison with other largely grown crops such as guinea corn, enough to support the model for thesis.

It is worthy to note also that climate-smart maize varieties are made with attractive characteristics such as high yielding potential, enhanced nutritional value that satisfy food security, income and nutritional problems of the district and more importantly, it is a staple food crop (Morris *et al* 1999).

**Access to Public and Privately Disseminated Climate Information and Services**

Seasonal forecast needs to be modified as the season is being experienced because the short-term (weekly and day to day) forecast have higher levels of accuracy. It is important that this is made available and easily accessible by farmers (Hansen *et al.* 2011). This, the meteorological agency does not have the capacity to do in Ghana especially for the farmer (GMET, personal communication).

The Ghana Meteorological Agency (GMET) has the sole responsibility as a state institution to generate and disseminate reliable, efficient and timely climate information as a public good for decision making. However, GMET is only able to provide seasonal forecast and general daily forecast on the National television and radio networks due to capacity constraints. This affects individuals and agencies who require elaborate sector specific daily/hourly weather information and services to make informed decisions.

Helping to bridge the gap, some Non-Governmental Organisations (NGOs) organise programmes together with the GMET that bring agriculture specific climate information and services to the door-step of farmers but this just covers quite a few of the many. It then implies that any farmer outside the reach of these NGOs programmes would have to phone in for daily forecast (farmers would have to pay for call credit to access such detailed short-term forecast).

This detailed short-term forecast is necessary to inform crop management practises relevant for the realisation of the full potential of the climate-smart seed. For example, though the seasonal and daily forecast may state days on which to expect rain, it is however based on a much larger geographical location (regional forecast) which might not be applicable to every community in the region (GMET Official, Personal Communication). Therefore, if a farmer does not have access to extra detailed day to day climate information, he/she is likely to apply fertilizer on the day on which it rains and the fertilizer will be washed away. Therefore, farmers need short-term information that has relevant details which are not found in long term seasonal forecast as disseminated by the GMET. It is stated that as the time window prediction shifts forward so is the complexity, and as control declines, the reliability of predictions is doubtful. Similarly, the accuracy of predictions declines as the specificity of the prediction rises and weathermen among others serve as icons to the futility of long range prediction.

Realising the importance of short-term day to day, community specific climate information and services are made available to farmers by private services providers in such as Esoko and Ignitia in Ghana with coverage as encompasses Garu-Tempane. A beneficiary had this to say, “After receiving agricultural messages... from Esoko....The yields of my two favourite crops (maize and millet) have increased." (farmer, Personal Communication). However, this also means extra cost to the income constrained farmer.

**Contextual Definition of Factors Affecting Yield**

Crop yield does not only depend on the variety of seed but also on other variables such as water need, time of planting, soil fertility and other crop management practises. However, research indicates that quality of the seed of great importance to the agriculture production. For example, Morris *et al, (*1999) states that as much as other factors and inputs used in agriculture are equally important, none has the ability to affect productivity as much as the seed used. The seed is the foundation for determining the future plant development. Zecchinelli, (2009) argues that seed is more or less the master key to success with the cultivation process. Adding that quality seed is central and has the potential to increase agricultural productivity, food security and farmer incomes thereof (ibid). Seeds of higher quality dictates the upper limit of crop yields and the productivity of all other agricultural inputs necessary in the farming system (Kopainsky *et al,* 2012). Seeds are indispensable inputs in any crop-based farming system (Muthoni & Nyamongo, 2008). Louwaars and De Boef, (2012) present no different conclusion but in affirmation add that seed quality determines the overall grain yield and the market value of the final product. It is of no doubt that improved seeds and for that matter climate-smart seeds could be considered the most important technology that substantially contributes towards crop productivity irrespective of other inputs (Etwire *et al,* 2016).

For the purpose of this research, in as much as the researcher acknowledges the relevance of all other factors these are not explicitly considered in this model. This is because the purpose of this model/study is primarily to identify and assess how changes in climate has affected the yield of the indigenous seed. Consequently, how adequate indigenous climate information and seeds are performing amidst climate change; how best scientific climate information and climate-smart seed varieties augment the indigenous forecast and seed to reduce the level of vulnerability to climate change in agriculture.

**Agriculture Land under Cultivation**

There is a limitation on the land available for agriculture activity though land allocated to agriculture (about 57% of total district land area) may not be exhausted currently. In the long-run, it will be scarce due to expanding competing uses. Population growth is mainly responsible for this limitation since population growth translates into increasing demand for land in all sectors.

**Indigenous knowledge/Knowledge from Experience**

This is the knowledge that farmers accumulate from several years of experience in crop cultivation. It also includes knowledge from social learning and word of mouth. This knowledge is adequate for the cultivation of indigenous seeds given that climatic and environmental conditions remain the same over long periods. However, where climatic conditions have altered, this accumulated indigenous knowledge becomes redundant and inadequate to realise the full potential of the indigenous seed. Therefore, if farmers adopt other seed varieties such as climate-smart varieties though not entirely new, they need to upgrade their knowledge and other crop management practises that are commensurate with the new seed variety to enable them to reap the full potential of the adopted climate-smart seed.

**Knowledge from Scientific Sources of Climate Information.**

This stock of knowledge refers to the climate information and crop management practises; advisories from the agriculture extension services based on the seasonal rain forecast. Such knowledge demonstrates the best ways to realise the full potential of the climate-smart seed variety. This is very relevant because, indigenous forecast is inadequate to realise the full yield potential of even the indigenous seed. Suggesting therefore that there is the need for other sources of knowledge to augment the existing knowledge. Such includes information about onset days of rain, amount of rain expected within the season, whether to plough across or along contours, weedicide applications, appropriate planting times, what kind, when and how to apply fertilizer as well as when to harvest to avoid losses in case of floods. The more knowledge farmers have of a technology, the better they can derive much benefit from it which then influences the continued use of the new technology. Consequently, adoption is linked to the experience in using it (Tura et al, 2010).

**Initial Trust in Seed**

It is assumed that once there is an advertisement on climate-smart seed, some farmers would initially develop some level of trust in the seed advertised. Sterman, (2000) has it that when an innovation is introduced, the only source of adoption will be external influences such as advertising to increase the adopters from zero. Farmers cannot adopt improved technologies until they first hear about them. Implementation of the adoption decision is determined also by access to detailed and accurate technical information" (Morris *et al*, 1999).

Initial trust is expected to increase by the continuous adoption and implementation based on which the farmer confirms higher yield potential of the climate-smart seed variety as advertised. If indeed the farmer harvests as much as it was advertised and more than he does with the cultivation of the indigenous seed, his/her level of trust for the climate-smart seed variety is further deepen. This also engenders trust of other colleague farmers in the climate-smart seed thus serving as a driving force that pulls the potential adopters/ non-adopters to adopt base on the experiences of the others who have succeeded (social learning/word of mouth loop).

## 3.3 MODEL STRUCTURE

Model structure in system dynamics describes the set of decision rules and decisions illustrated through stocks, flows and independent variables/constants together with the instantaneous and accumulative effects embedded in every system. This structure gives a quantitative and qualitative structural description based on which a behaviour is generated to describe the system under study. "Model structure represents both the qualitative dimension of the system, through the causal linking of variables, and its quantitative dimension, through the formal definition of these causal links through equations" (Bou Schreiber, 2015). Sterman (2000) presents an elaborate explanation on the basic structure and building blocks of the system dynamics methodology. The entire model overview is illustrated in appendix.

### 3.3.1 Food Inventory Module

*Food inventory (tonnes)* is the main stock affected by changes in climatic conditions — the motivation behind the development of this model/study. This is increased or refilled by the inflow of harvested food at the end of the cultivating season and depleted by two outflows: *consumption a*nd *selling*. The two outflows are governed by a basic decision rule that specifies that, the main outflow (*consumption*) which also takes care of an implicit outflow: *reservation for seed* must be satisfied before the *selling (Tonnes/Year)* outflow can be allowed. However, food is sold through *minimum food sale* in terms of urgent need for money even if the *food inventory* is not adequate to satisfy *consumption*. The outflow; *selling* is therefore restraint to *minimum food sale* only, when the *food inventory* is not adequate to satisfy *consumption* with excess to be sold. The *selling* outflow is thus equal to *minimum sales* plus *remaining food sales* when *consumption* is satisfied with excess. Income from such sale is used to take care of major expenditure of the household including but not limited to health, education and general household upkeep. This decision rule is premised on the principles of subsistence farming that the priority of farmers in crop cultivation is to meet the food consumption needs of their households.

To refill the stock of food, households must harvest food represented by the *harvesting (tonnes/year*) inflow. This represents the farm produce from the agriculture land cultivated at the end of the planting season (May-August). It is the product of all the process that take place from sowing seed all through to the period of harvesting produce from the farm through which the *food inventory*/food available is filled up. *Harvesting* is dependent on how much agriculture land was put under cultivation in the previous planting season and the *average yield* of the seed variety used during that season, all things being equal. As stated in the assumptions above, though there are many factors that affect the quantity of harvest, for this study it is limited to the size of land and the yield potential of the seed variety used.

Food is cultivated mainly for a reason that is consumption. Therefore *consumption (in tonnes/year)* is the main outflow which needs to be met first before any other outflow is allowed. However, farmers will at the time of harvesting already reserve some grain purposively for seed for the next season. This grain reserved will not be consumed unless the household runs out of food for consumption without any nearest possible resort to meet its food consumption need. Households will prefer to purchase food from the open market than consume seeds reserved for cultivation during the next season. This confirms the importance of the quality and attributes of seed cultivated as iterated in the chapter two.

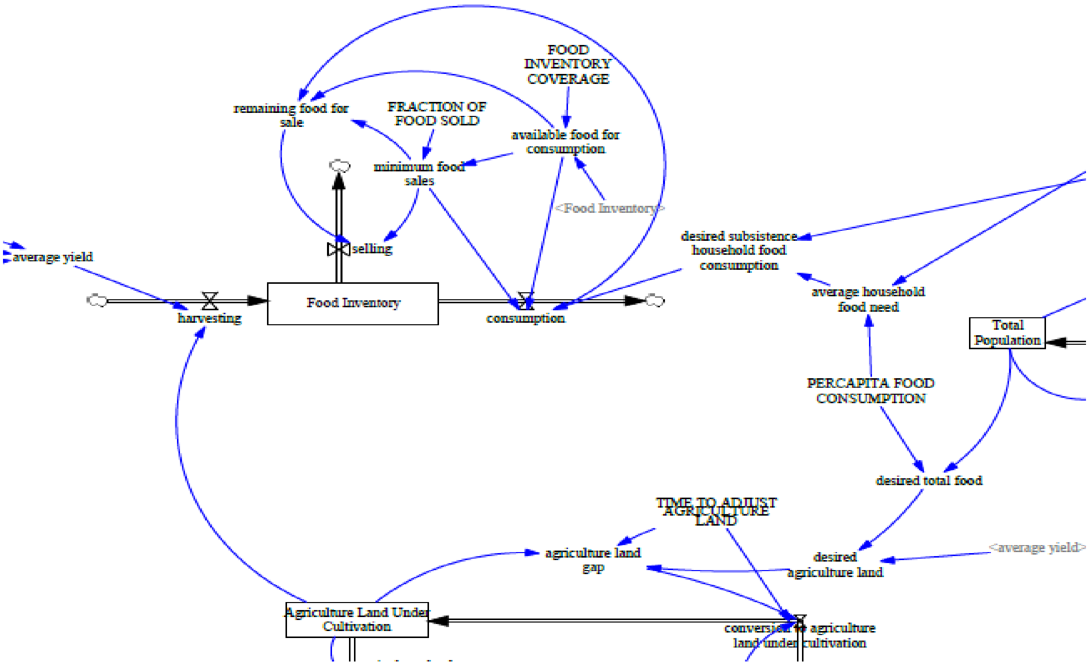
The quantity of food consumed considers the desired quantity of food needed to be consumed based on the population and the food need per individual: *food need per capita*. When the desired food consumption is equal to the consumption, then the household can make sales.

When *desired food consumption* increases, the *desired agriculture land under cultivation* increases taken into consideration, the *average yield*. This increase in *desired agriculture land* consequently creates a gap (*agriculture land under cultivation gap)* between *the desired agriculture land under cultivation* and *agriculture land under cultivation* indicating the need for *conversion to agriculture land under cultivation* to increase accordingly in other to be able to harvest enough food into the *food inventory* for consumption and possible sale. However, it is important to note that when *desired agriculture land under cultivation* increases, the gap in *agriculture land under cultivation* is adjusted over a 10-year period (*agriculture land adjustment time)* because of the capacity constraint in increasing farm size by these farmers.

If the indigenous seed cultivated yielded enough proceeds as it used to, there would be little need for cultivation of so much land to meet the food consumption need of the people. The contrary is true, all things being equal.

In this regard, climate-smart seed with its relatively higher yield potential (4-6 Tonnes/Ha) is introduced to help produce more food even if little land were converted into agriculture land under cultivation. This is a very sustainable and prudent way to minimise the competition for land since it will not always be available to be converted for agriculture use as population grows accompanied by other competing land uses such as for housing. Figure 5 illustrates this module.

Figure 5: Food Inventory Module




### 3.3.2 Climate-Smart Seed Adoption Module

The seed adoption module describes the processes involved in the adoption of climate-smart seed to support farmers overcome the increasingly low yields produced by the indigenous maize seeds. The module is basically developed based on the formulation of the Bass diffusion of new technology (Sterman, 2000 pp. 332.) and a practical example by Kopainsky *et al* 2012. It is made up of two main stocks and two flows with auxiliary variables influencing the rate of flows which in turn affect the stocks.

Central to this module is the stock; *indigenous seed coverage*. This stock contains the total hectarage of land under cultivation with only indigenous seed variety. This is synonymous to the stock of non-adopters/potential adopters in the bass diffusion model. It represents the land that is available and can be cultivated with climate-smart seed. The rate of adoption is influenced by social learning/word of mouth (the trust development loop in this project model) and the advertising effect (*potential adoption from relative utility of seed loop*) based on the time (*time to implement adoption decision*) within which this process of adoption takes place.

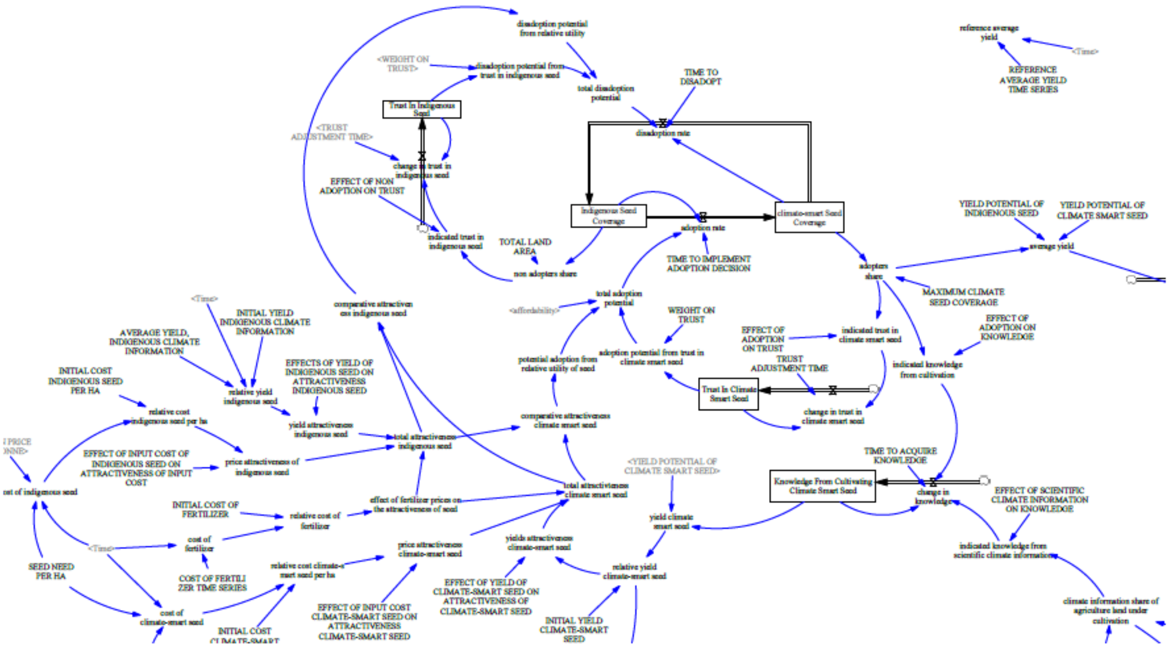
*Indigenous seed coverage* is also increased by *total dis-adoption potential* influenced by *dis-adoption potential from relative utility of climate-smart seed* and *dis-adoption potential from trust in indigenous seed*. *Indigenous seed coverage* thus represents the land that can be cultivated with climate-smart seed variety. This is indicative of the fact that, though farmers are aware of the relatively high yielding potential of the climate-smart seed, there are some characteristics of the indigenous seed that farmers are attracted to and they cannot get rid of such indigenous crops. Moreover, some of these indigenous crop varieties are needed for traditional performances and they cannot afford to stop cultivating them. Added to that, such indigenous varieties for instance pearl millet does not have climate-smart seed varieties yet. For this reason, there will always be some portion of land reserved in the stock of indigenous seed coverage no matter how relatively attractive or profitable, climate-smart seed varieties are.

As farmers implement their adoption decision, land cultivated with climate-smart seed represented with the stock; *climate-smart seed coverage* is increased. This stock accumulates the percentage of land cultivated with climate-smart seed. It is increased by the rate at which the climate-smart seed is adopted and implemented, thus moving land from the stock of *indigenous seed coverage* based on the social learning loop (trust adjustment) and the advertising loop (relative utility loop) and time taken to implement the adoption decision.

This stock is also decreased by the outflow known as *"dis-adoption rate"* synonymous with the "discard rate" in the Bass diffusion model (Sterman, 2000 pp. 332). It represents the flow of land that is reverted to the *indigenous seed coverage* after four years of subjecting the land which was originally from indigenous land coverage to climate-smart seed coverage. Dis-adoption occurs because of distrust in the seed; if the farmer realises after 4 planting seasons that the climate-smart seed did not perform as it was advertised. It could also occur because the farmer does not have the financial resources to purchase the climate-smart seed and other services related to it. As such the farmer is compelled to resort to the indigenous seed variety which is relatively less expensive as discussed in chapter two.

All other factors contributing to dis-adoption potential from trust in indigenous seed as mentioned earlier are not explicitly modelled in this study but represented by the probability that some farmers would not even adopt the climate- smart seed variety *(potential dis-adoption from trust in indigenous seed).* Figure 6 gives an overview of this module.

Figure 6: Climate-Smart Seed Adoption Module



### 3.3.3 Climate Information Adoption Module

Drawing from the climate-smart seed adoption module above, farmers need to have knowledge of the changing climate supplemented by dissemination of scientific climate information to realise the need to adopt a new variety of seed. This awareness and access to scientific climate information and services is represented by the climate information adoption module described in this section.

Like the climate-smart seed adoption process, the climate-information adoption module is governed by two main stocks and two main flows. The main stock represented by *indigenous climate information coverage* represents the percentage of agricultural land that is being cultivated with the use of indigenous climate information and crop management practises such that farmers rely on their own knowledge and forecast of the season which is usually done by traditional “rain callers”. The outflow; *climate information adoption rate* causes a decrease in this stock of cultivated land with only indigenous knowledge. This outflow moves land into the percentage of cultivated land subjected to scientific climate information and advisories that are embedded in such information known as *scientific climate information coverage*. This stock is determined by the time it takes for the adoption decision to be implemented (*climate information adoption time*), the *potential adoption from trust in scientific climate information, potential adoption from relative utility of scientific climate information* and *affordability*.

Farmers experiment with scientific climate information and the climate-smart seed varieties that come along as advisories based on the climate information delivered initially through the advertising loop. However, trust is further built based on how well the advisory (climate-smart seed) performed during the previous season of initial adoption. The seasonal forecast comes along with advisories in the form of climate-smart seed specific to the prevailing season, trust in the seasonal scientific forecast disseminated is dependent on the reliability of such information i.e. whether the advisories given to farmers the previous year was successful or not. This measure based on the *yield of climate-smart seed*. Therefore, if farmers will adopt the climate information in the next season, they would consider how well they fared the previous year with the information and advisories they received. Moreover, if a farmer adopts the seed, it is ideal to apply all other crop management practices that include climate information that comes along with it; onset of rains and appropriate time to sow/plant, when and what type of fertilizer to apply and when to harvest in order to realise the full potential of the climate-smart seed. For this reason, an adoption of the climate-smart seed informs the adoption of scientific climate information. This then suggests that reliability and trust in the climate information is relevant in enhancing the adoption of climate information and seed.

Relevant to know about this process too is the role of the level of household income which for this model specifies that, farmers will be willing and able to invest in climate information: the purchase of climate-smart seed and all other inputs required if household income is above expenditure such that they can take care of basic household needs (food, health care, school fees among others) and still have some income to spare (*household income surplus)*. Adoption from this loop is represented with *affordability* in this model.

Equally important, adoption rates and coverage of scientific climate information for that matter declines when household income is very low because farmers cannot invest in detail scientific climate information. However, such a happening will lead to an increase in the stock; *indigenous information coverage* through the dis-adoption outflow from the *scientific climate-information coverage*. It does not result to non-adoption because the Ghana Meteorological Agency (GMET) makes it possible for households to have access to some level of climate information though not as detailed and user specific as other private climate information and service providers with a target group provide. Such a forecast comes with a much higher level of uncertainty. This is because, such climate information and seasonal forecast are usually general (not farmer specific) and for a given region instead of a specific community.

This *affordability loop* indicates that with higher incomes, farmers' budget for climate information and services is increased such that farmers can subscribe to private climate information service provider platforms (Esoko, Ignitia) for detailed day to day climate information or call officers of the GMET to request climate information in order to make better decisions instead of totally relying on the general seasonal forecast (call charges represent the payment for climate information in this case).

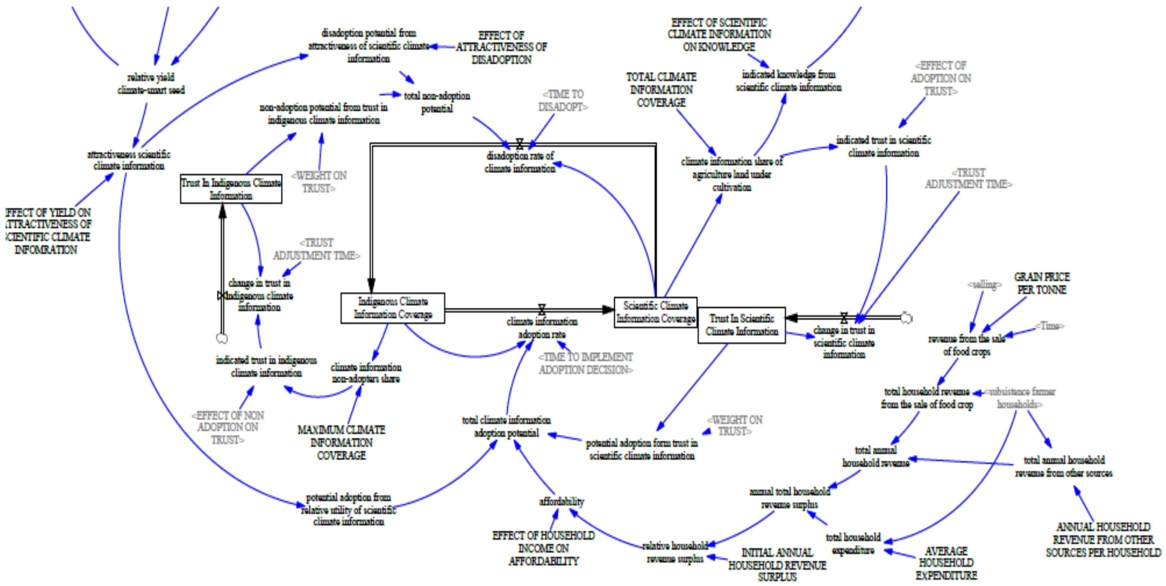
It is important to acknowledge that household income affects only the extra detailed information relevant to maximising farm produce (day to day or weekly information provided by the private climate information providers). This is because farmers have access to general seasonal climate forecast from the Ghana Meteorological Agency (GMET) which comes with almost no cost except the cost of acquiring a television or radio set. But even in that case, after being given the seasonal forecast by the Ghana Meteorological Agency, farmers still need some level of continues update throughout the duration of the season and this requires that farmers have some level of income to be able to subscribe to private climate information service providers for update and to purchase the climate-smart seed variety and all other inputs such as fertilizer among others. The will help to acquire the knowledge and crop management practises relevant for the realisation of the full potential of the climate-smart seed. For example, the seasonal forecast does not state specifically on which days to expect rain in a specific community but in a region. Therefore, if a farmer does not have access to extra detailed day to day climate information, he/she is likely to apply fertilizer on the day on which it rains in his/her community and the fertilizer will be washed away.

Other factors that play a very crucial role in the adoption process include trust in climate information which is based on how reliable the seasonal scientific forecast is. Reliability is measured based on the occurrence of rainfall onset dates, cessation dates, dry spell of rainfall as presented by the scientific forecast/ climate information provided.

Also, if the seasonal forecast is disseminated through a participatory scenario planning workshop where local farmers are brought on board to plan for the season given their own forecast and that of the scientific forecast, then they own it and are highly likely to adopt it. Moreover, such planning sessions are usually done in the local language which enhances their understanding, thus engenders adoption and implementation of advisories for the season appropriately.

The medium of communication is equally important as it determines the level of trust and adoption. For example, if seasonal forecast is disseminated via a radio with panel discussion by District Agriculture Officers and some experienced farmers, other community members will trust the potency of the climate information and services much more because those experienced farmers are testimonies to the workability of the information and services advertised to them. The medium of communication is dependent on the level of household income i.e. if households have enough income to be able to meet their basic needs/expenditure, then they can afford to purchase mobile phones, televisions and radio in other to enhance their access to scientific climate information and services.

Figure 7: Climate Information Adoption Module




### 3.3.4 Agriculture Land Module

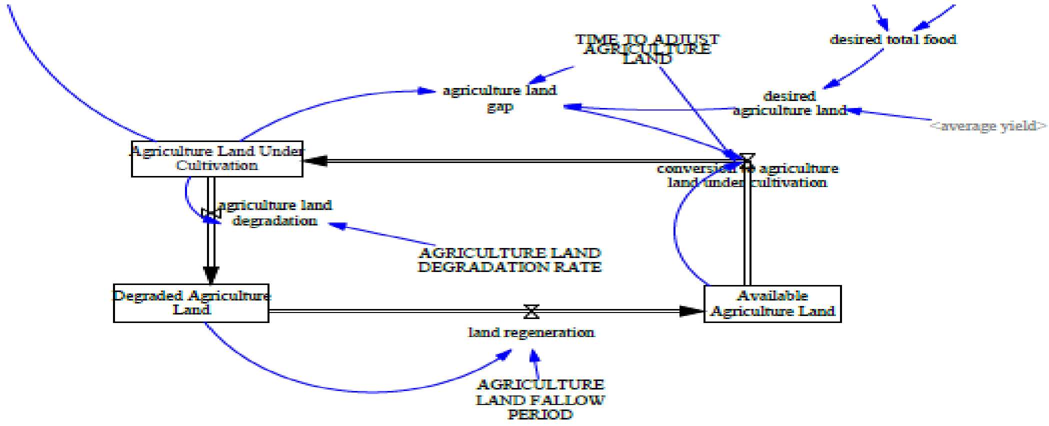
Land is an inevitable factor for food production/cultivation to occur. The land module represents the internal processes involved in the conversion of agriculture land into agriculture land under cultivation given the need for an increase in the hectarage of cultivated agriculture land as a result of population which also triggers the need to increase food production to meet the desired food need of the population.

To begin with, D*esired total food* dictates the *desired agriculture land under cultivation* given the *average yield* which introduces a gap between *agriculture land under cultivation* and its desired value. This gap is adjusted based on the time that is takes for farmers to be able to increase farm size (*agricultural land adjustment time).*

The gap induces *conversion into agriculture land* based on capacity, thereby reducing the *available land for agriculture*. The stock of *agriculture land under cultivation* accumulates the total agriculture land that is currently being used in food production. This is increased by the inflow; *Conversion into Agriculture land* and decreased by the outflow; *agriculture land degradation* depending on the prevailing rate of degradation over time. This is accumulated into the stock: *degraded land* that adds up to the *available agriculture land* after some time of fallow

All things being equal, on the one hand sufficient food could be harvested if a large size of land is cultivated. On the other hand, a small size of land could be cultivated with a seed variety that has got a relatively high yield potential. Figure 8 represent this sub model.

Figure 8: Agriculture Land Module




### 3.3.5 Population Growth and Demand for Land Module

The size of land required to produce the desired amount of food also depends on the average yield. If the average yield of the seed cultivated is relatively higher, less land is needed to cultivate enough food for the population. However, this does not seem to be feasible with indigenous seed variety amidst climate change.

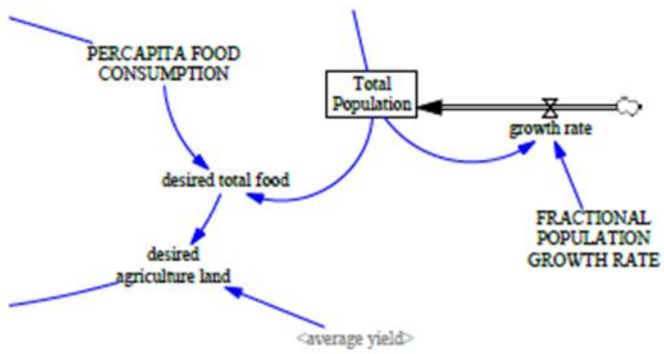
Also, population growth implies a competition for the conversion of land into other needs that demand land. Most especially the competition for land between and among the forest, housing/ residential use and the agriculture land.

The *desired total food* is determined by the *per capita food consumption* and the *total population. Desired food need* and the *average yield* then determines the *desired agriculture land* necessary to produce the needed food but taking in to account, the *average yield.*

The adjustment for more land is activated by the *desired agriculture land* in order not to convert so much land than needed. This formulation reflects the stock adjustment structure as presented in in Sterman, (2000) as illustrated in Figure 9.

It is relevant to note that in the short run, there is enough land in the district to be converted to agriculture land. However, it might be very difficult to easily convert land into agriculture use in the future. This then necessitate the need to look out for innovative ways that would not require increasing the size of land for cultivation but the amount of food produced out of the land. Such a promising solution is the introduction of the climate-smart seed with relatively minimal cost compared to other sophisticated and expensive technology which are needed to reclaim land as a means of increasing the available land size. With climate-smart seed less land is needed to produce sufficient food to feed the population and to transform subsistence agriculture to commercial agriculture for food security as well as increased household income for the improvement of livelihoods and consequently adaptation to climate change.

Figure 9: Population Growth and Demand for Agriculture Land



# CHAPTER FOUR

# VALIDATION AND ANALYSIS

## 4.1 INTRODUCTION

Model validity is a very crucial component of the system dynamics methodology and it must be rigorously conducted. It serves as the concrete basis upon which any model can be treated as an authentic and credible theory that explains the subject under study whiles creating a framework for further processes of the methodology. Validation gives both the user and the modeler a way of assessing how useful the model is in relation to its purpose; it puts the modeler in check and gives the model consumer the opportunity to accept or not to accept the model. Validity thus helps to develop the confidence that a model is appropriate for the specific purpose for which it was developed (Sterman, 2000).

This chapter takes a closer look at how the model represents the system under study, thus establishing confidence in the model as a useful representation of the system as described in previous chapters.

## 4.2 INTERNAL VALIDITY

The research methodology used in this thesis serves as a good basis for the internal validation of this model. Participatory learning approaches and tools including focus group discussions and pair-wise ranking were useful in this research. Community members/farmers, focus group discussants were interacted with to arrive at the critical basis for this model. Added to that were interviews with key stakeholders (climate information service providers, agriculture departments) to consolidate the researcher's knowledge/observation of the real system. The research also made use of secondary data from credible international and national reports. This rigorous data triangulation makes this model a concrete framework for studying the adoption dynamics of climate-smart seed and climate information and its impact on food security and incomes. In cases where data neither existed from primary sources nor secondary sources specific to the district of study, estimates were made from studies within similar environments. The role of the researcher was to represent as much as possible in system dynamics principles, the views of the respondents in this study.

## 4.3 EXTERNAL VALIDITY

This form of validation is basically conducted to test the robustness of the model. As captured by Forrester & Senge (1980), model validation is a procedural process of establishing confidence in the soundness and usefulness of a model. In a similar view, Barlas (1996) presents model validity as making known the usefulness of the model taking into consideration its purpose. It is relevant to note that model validation and testing does not begin only when the structure of the model has been completed but even right from the first equation though testing may be seen as comparing the simulated behaviour of the model with historical data. It is imperative to demonstrate how true the system is represented with the model since it entails much more of building confidence in the model structure than trying to establish how true a model. This is because all models both mental and formal are wrong and they are simplification of the real world. "They differ from reality in ways large and small, infinite in number" (Sterman, 2000 pp.846).

There are varied forms of validation which all enhance confidence in the model as it indicates its robustness, Barlas (1996) states that, three categories of tests can be conducted on a model to determine its robustness. These categories include direct structure tests, structure-oriented behaviour tests, and behaviour pattern tests. However, the category of test to be conducted first is very important. It is only relevant to proceed to perform structure-oriented behaviour tests, and behaviour pattern tests if the model passes the direct structure tests and structure-oriented behaviour tests. "The ultimate objective of system dynamics model validation is to establish the validity of the structure of the model. Accuracy of the model behaviour reproduction of real behaviour is also evaluated, but this is meaningful only if we already have sufficient confidence in the structure of the model" (Barlas, 1996 pp. 188).

### 4.3.1 Direct Structure Test

Structure assessment is conducted to reconcile the model structure with descriptive knowledge of the system. It also aids in the assessment of how well the behaviour of the principal elements of a given system have been represented in the model. Another dimension of this assessment is to find out how well basic decision rules modelled represent those in the real world (Sterman, 2000). "Direct structure tests assess the validity of the model structure, by direct comparison with knowledge about the real system's structure. This involves taking each relationship (mathematical equation or any form of logical relationship) individually and comparing it with available knowledge about the real system." Barlas (1996, pp.189-190). Therefore, to conduct a useful structural assessment, emphasis is on the endogenously modelled variables of the system because such variables are the underlying determinants of the behaviour generated by the system. It thus helps to uncover flaws in the model structure in comparison with real systems and to resolve them appropriately.

Direct structure test entails empirical test and theoretical test. Empirical test including structure verification test, parameter verification test whereas theoretical test entails direct extreme-condition test including boundary adequacy and dimensional consistency tests as presented in subsequent sections.

***Structure Verification Test***

Structure verification test is conducted to ensure that there is no contradiction between theory about the real system and the model. Based on literature and theory on subsistence farming in the district (District Department of Agriculture)), adoption of agriculture technology among farmers (Kopainsky *et al*, 2012) and agriculture land use (Ministry of Food and Agriculture, 2015), the researcher's observation, interactions with communities and climate information services providers, structure-wise, this model is valid. There is reason to make such conclusion since main principles of subsistence farming which suggest that the focus of farmers is to satisfy their consumption needs and later sell off surplus is clearly represented. It is also explicitly modelled in this system, the inevitable fact that since the main source of livelihood of these farmers is subsistence farming, a minimum sale of food must occur in other to purchase what they do not produce and to attend to emergencies.

The relationship between household income levels and farmers ability to adopt or not to adopt agriculture technology (climate-smart seed and scientific climate information) is equally shown through the introduction of affordability as an important determinant of adoption

Regarding the processes that inform adoption and diffusion, key factors including trust in seed (representing the priority characteristic choice: yield potential) and the knowledge adequate to cultivate leading to further trust and diffusion are clearly indicated.

It is also modelled in this system, land as a main factor of production. The agriculture land module indicates the restriction in land available for agriculture and thus points to the fact that the carrying capacity of the land could be exceeded as population continuous to increase.

***Parameter Confirmation Test***

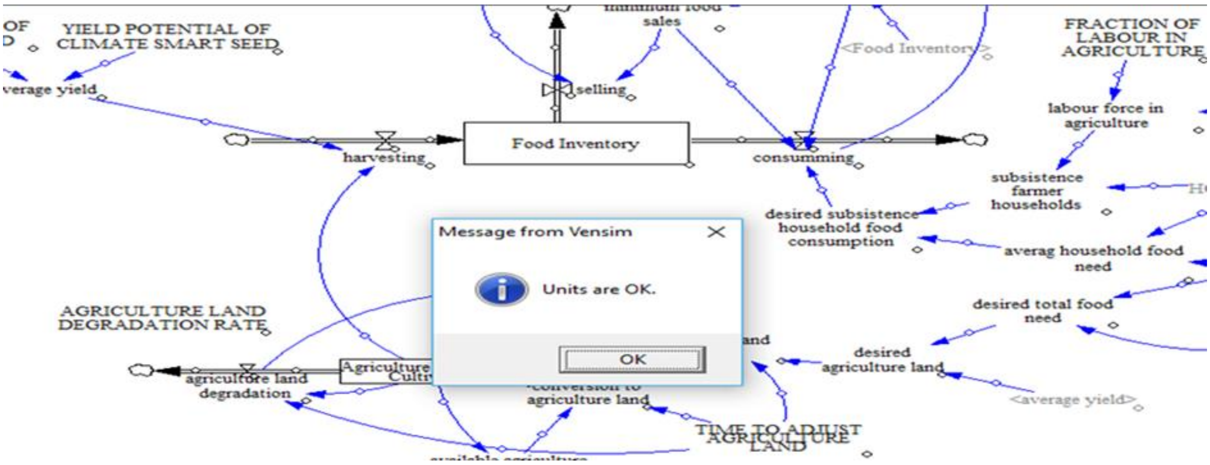
This entails checking to confirm if the parameter values of the structure of the system are consistent with relevant descriptive and numerical knowledge of the system. Parameter assessment puts a check on the model to ensure that all parameters used have real world equivalents. It entails an evaluation of the constant parameters against knowledge of the real system, both conceptually and numerically. Conceptual and numerical confirmation require being able to identify real system elements that correspond to the parameters used in the model and being able to estimate the numerical value of the parameters with high degree of accuracy (Barlas ,1996).

In this regard, the model passes the validation test, all parameter values were estimated based on farmers responses, literature and data specific to the district and where such did not exist, an estimation was done based on national data. Values estimated for effects are based on literature which suggests that trust building and knowledge development depends nonlinearly on the area cultivated with improved seeds (Kopainsky *et al*, 2012). Moreover, the sources of data for model calibration in the model documentation helps to prove the validity of this model. Confidence in the model in this regard is guaranteed since parameterisation is not arbitrarily done.

***Dimensional Consistency***

Dimensional consistency requires an assessment of the individual equations and units of measurements making sure that they are consistent without the use of parameters and variables that have no real world meaning (Sterman, 2000). It is often a test that lacks much attention but however a powerful test when conducted together with parameter confirmation test in doing away with parameters that have no real world meaning. In as much as this is a useful validity test to conduct on a model, Barlas, (1996) cautions that such checks are only suitable and useful once every variable of the model has been checked for "real world equivalents" through parameter confirmation test to weed out all dummy parameters. This was performed automatically by the vensim modelling software indicating all units are consistent as illustrated by figure 10 below.

Figure 10: Unit Consistency Test



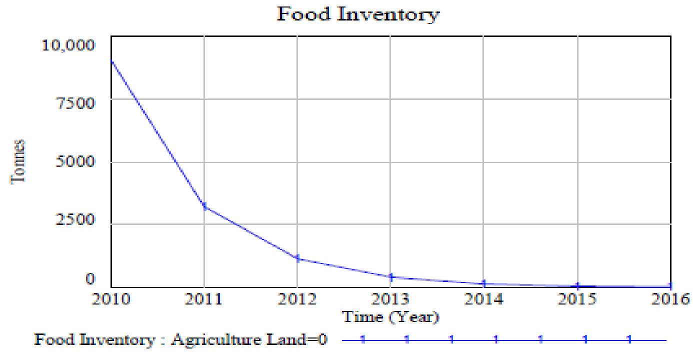
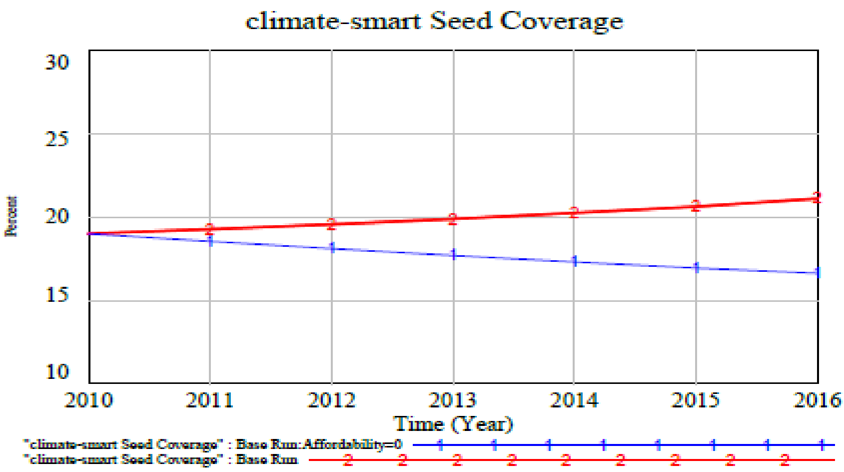
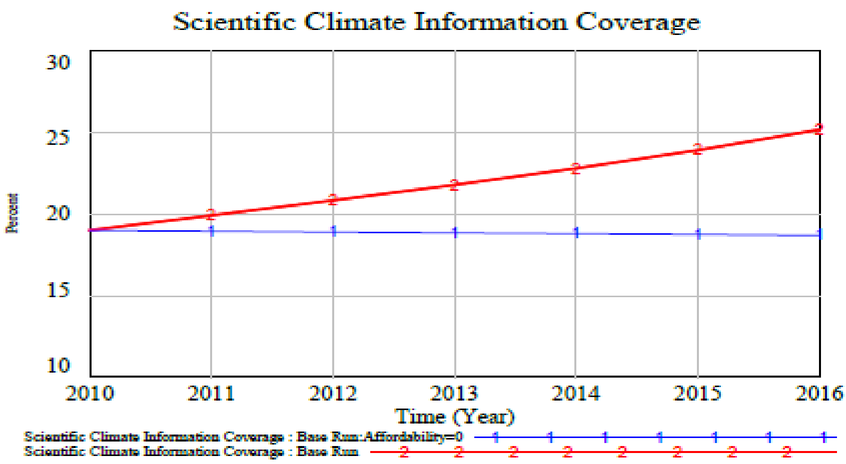

### *Extreme Conditions Validation*

This is usually done to confirm the robustness of equations and how the model would respond if parameters take on extreme values as well as its response to extreme policies, shocks and parameter values in comparison with the actual model generated behaviour (Sterman, 2000). It is useful in determining the validity of the model when its equations are put in extreme conditions to assess the plausibility of the resulting values in comparison with what is expected under similar conditions in real world phenomena (Barlas, 1996). Some issues dealt with under this relates to regulating the stocks and not allowing them to go to zero or attain negative values because even in the extreme case of so much stress, stocks in real-world systems do not attain negative values. From the behaviour generated by the model backed by literature, it is observed that though subsistence farmer household are unable to produce enough for their families, there is still some food sold., When food produced runs out, food inventory attains zero as households that can afford to purchase food live from hand to mouth to endure the period of inadequate food till they harvest. Moreover, when agriculture land is equal to zero, food inventory attains zero values because without land no food can be produced.

Generally, any division by zero results in a floating error.

Specific to the adoption module, if there is no mechanism for building trust and knowledge, there will be no further adoption and this will cause climate-smart seed/ scientific climate information coverage to gradually decrease towards zero since trust in the high yielding characteristic of the climate-smart seed is a salient driving force for the adoption of climate-smart seed. The same is true for a shift from indigenous climate information to scientific climate information.

Table 4.1: Extreme Condition Test

<table>
<tr><td>Parameter Value</td><td>Simulation Results</td></tr>
<tr><td>Agriculture Land Under Cultivation=0</td><td>
</td></tr>
<tr><td>Affordability= 0<br><br>In the event that household incomes surplus is zero, there would not be further adoption. Some initial adopters would discontinue the use of both seed and information.<br><br>This implies there would be large coverage of indigenous seed and then the resultant low yield.</td><td>
<br>
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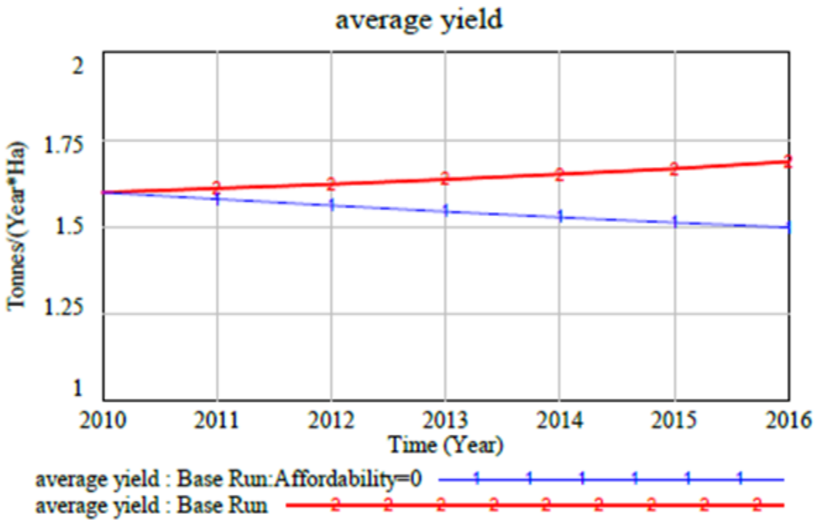
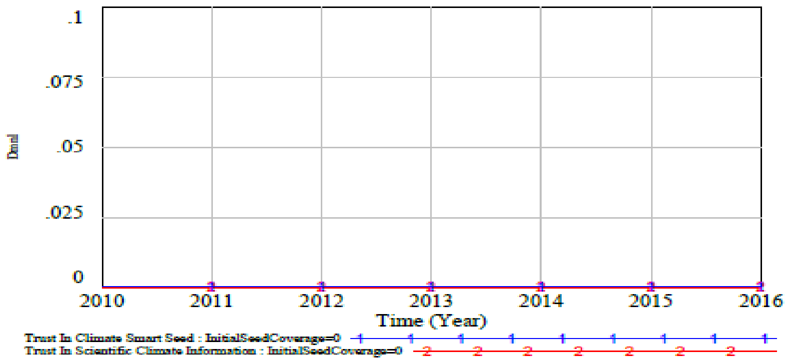
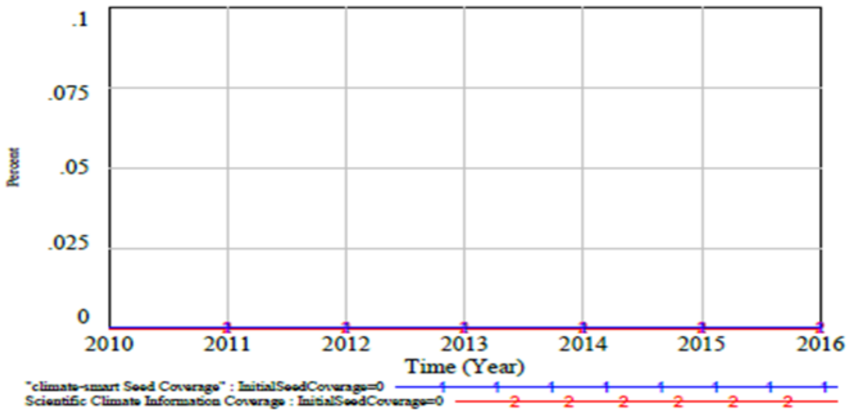
<td>
</td>
</tr>
<tr>
<td>If there is no way of building trust and knowledge at zero initial coverage, climate-smart seed and climate information coverage should be equal to zero because trust in the higher yielding potential and knowledge adequate to attain the actual yield potential of the climate-smart seed plays a vital role in the adoption and dis-adoption processes. Initial adoption</td>
<td>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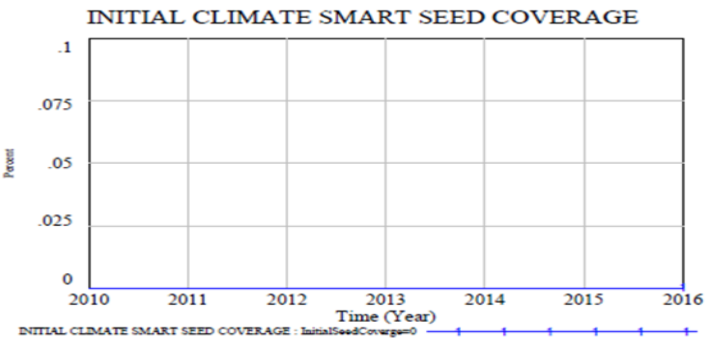
| | |
|---|---|
| from advertisement is necessary for adoption and diffusion to begin |   |

***Boundary Adequacy Test***

Boundary adequacy test is conducted to determine whether very crucial elements relevant in addressing the problem are endogenized; the effect of changes in boundary assumptions on changes in the behaviour of the model; changes in the policy recommendations when model boundaries are extended (Sterman, 2000). This test also contributes to verifying the purpose of the model against the structure and thus the research questions to be answered in the study and ultimately if the model is adequate to do this. The purpose of this model is to determine what hinders the adoption of climate information and climate smart-seed and how enhanced adoption of both seed and information could improve food security and incomes of the population under study.

In the light of this, the model has four modules; *food inventory, agriculture land under cultivation, climate-smart seed adoption and climate information adoption.* These make it possible to include as much as possible the feedback process between and among population changes and agriculture land under cultivation, food inventory/ food available for consumption, sale of food and household income, climate-smart seed and climate information cost to determine the holistic interaction among and between these. Thus, a framework is developed for informed policy options that fosters the adoption process. The model structure as presented in chapter three and the appendix is a verification that the model passes this test.

That notwithstanding, the model will reflect reality better if some extensions are done. These include; a detail modelling of food purchases by subsistence farmer households when food produced by these farmers runs out. Another relevant extension of the model should also focus on the detail modelling of household revenue and expenditure, the feedback process between population growth, increase food production and land use, market demand for maize and the willingness of farmers to produce maize as well as the entire policy suggestions for addressing the problem presented by the explanatory model.

### 4.3.2 Structure-Oriented Behaviour Validation

Structure-oriented behaviour test is done to assess whether the behaviour produced by the model qualitatively and quantitatively reflect the desired behaviour reflecting the motivation for studying the given system. It is also done as a check to determine whether the model reproduces the modes of behaviour observed in the real system; whether the modelled relationships among variables match historical data/the observed behaviour in the real system being modelled (Sterman, 2000). Unlike direct structure test, it assesses the validity of the structure indirectly by applying certain behaviour on model generated behaviour patterns (Barlas, 1996).

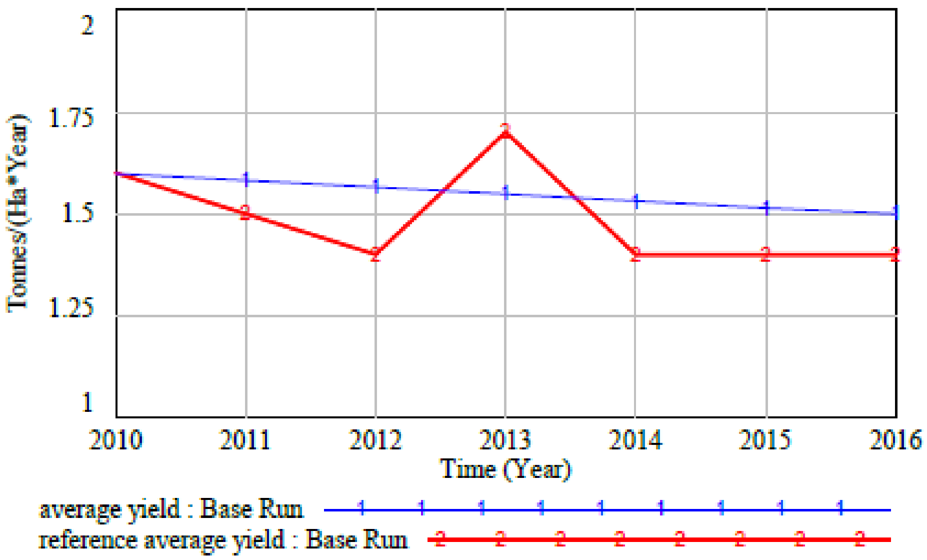
***Symptom Generation Test***

This test determines if the model reproduces the symptomatic behaviour of difficulty in the real system which motivated the study based on credible reasons in the calibration of the model (Forrester & Senge, 1980). For this test, the model is run based on the "business as usual scenario"/ base run in comparison with the reference data for the following central variables in this study.

*Average yield*

As described in the problem statement, all things being equal, average yield will continue to decrease over the years with fluctuations which are a true reflection of uncertainty in climatic conditions. Added to that farmers do not have the capacity to cope with such uncertainties at the moment. They rely on the continuous use of indigenous seed and climate information to inform their decision making for each season as indicated in Figure 11.

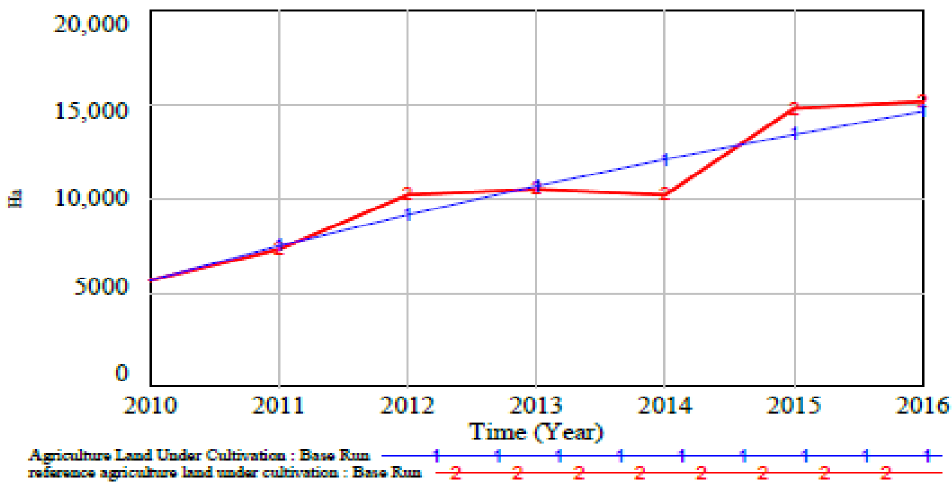
Figure 11: Average Yield



*Agriculture Land under Cultivation*

As portrayed in Figure 12, agriculture land under cultivation is gradually increasing to make up for the decreasing yield and this increase is with a delay because of the capacity constraint in increasing agriculture land under cultivation. The increase could also be as a result of just a few farmers who have the capacity to increase farm size because it requires a great deal of resources to increase farm size. The real system portrays the system archetype, shifting the burden to the intervener; farmers basically try to cultivate more land as long as their capacity allows them because the indigenous seed use produces relatively low average yield. Also as population increases, coupled with the decreasing average yield, the close substitute is to increase land under cultivation since farmers do not have the capacity to increase average yield. However, this can only sustain them for a while because population growth would exceed the carrying capacity of the agriculture land available with time which would of no doubt lead to competition for land among land use.

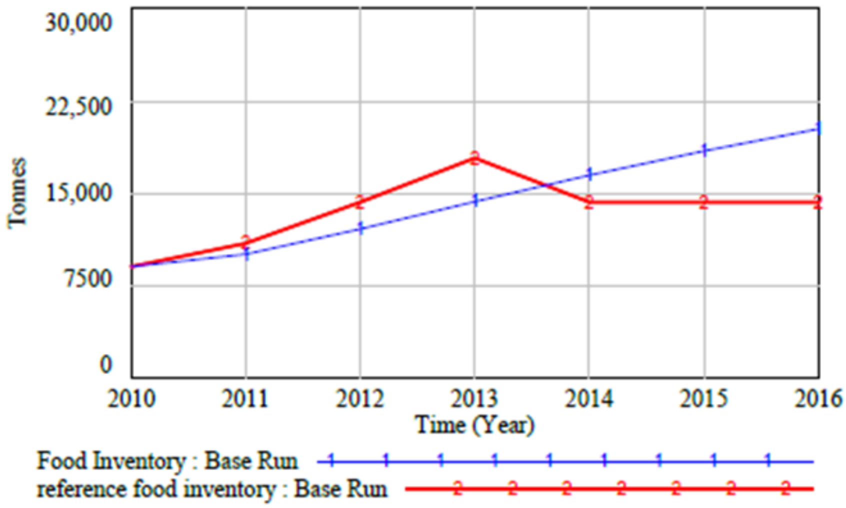
Figure 12: Agriculture Land under Cultivation




*Food Inventory*

From a comparison of the reference mode with the model generated behaviour, it can be clearly seen that the model replicates the reference behaviour of the real system. A significant observation here in comparison with the decreasing yield as described above is the fact that food inventory is increasing when average yield is decreasing which is an interesting point of analysis in preceding sections of this study. It is though important to mention that food inventory is only increasing in absolute terms but is not enough to meet the desired food need of the population. A detailed analysis of this observation would be done in preceding chapters.

Figure 13: Food Inventory

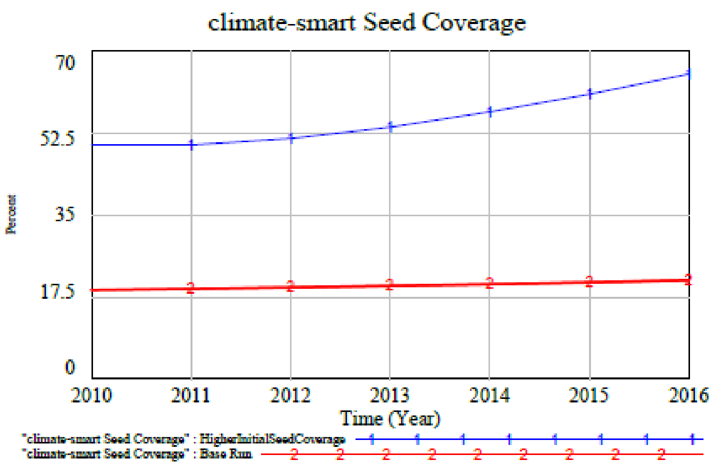


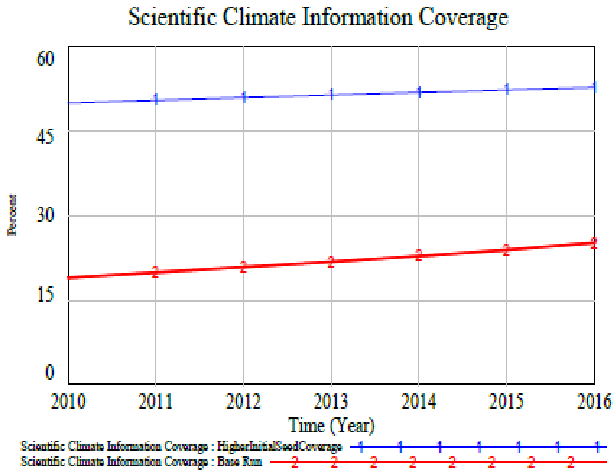

Haven considered these three central variables above, there is reason to conclude that the model passes the symptom/behaviour reproduction test.

**Pattern/Event Prediction Test**

Pattern prediction test allows to find out if the model will behave in the same way with calibration with different plausible values. Evidence of the model validity in this regard is presented in table 0.2.

Table 0:2 Pattern/Event Prediction Test

| Model Parameter/Specified Value | Behaviour Produced |
|---|---|
| Initial climate-smart Seed coverage<br><br>Run 1=50% coverage<br><br>Run 2 (Base Run) =19% coverage |   |

<table>
<tr>
<td>Initial scientific climate information coverage</td>
<td>
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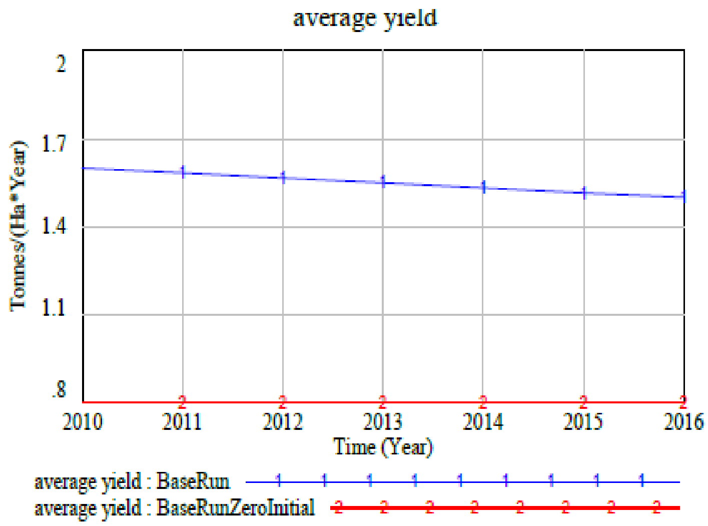
<tr>
<td>Average yield should be equal to the yield potential of indigenous seed if initial climate-smart seed coverage is equal to zero.</td>
<td>
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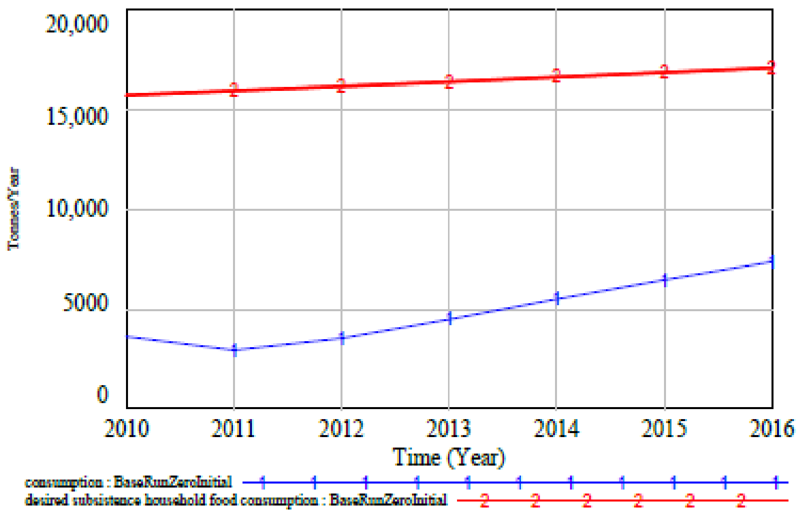
<tr>
<td>If average yield =potential yield of Indigenous Seed, desired consumption will not be met.</td>
<td>
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Different initial conditions for both climate-smart seed and climate information lead to changes in the behaviour of climate -smart seed and information coverage as indicated in the graphs in table 0.2. This behaviour change is as a result of the fact that initial coverage is a major determinant of the adoption and diffusion of both the Climate-Smart seed and climate information. The higher the initial coverage, the more farmers would become knowledgeable of the profitability of adopting it. Moreover, a significant initial coverage speeds up the dominance of the "trust loop (word of mouth loop)".

Average yield should be equal to the yield potential of indigenous seed if Climate-Smart Seed Coverage is equal to zero. As indicated in the table 0.2. If there is no introduction of climate-smart seed into the district, the highest average yield attainable is equal to the yield potential of the indigenous seed. Even so, the yield potential of the indigenous seed is not attained due to the variability and changes in climatic conditions.

The expected consequence then is that if average yield is always equal to potential yield of indigenous seed, which is likely not to be attained, desired consumption will not be met raising questions of food insecurity in the district.

Also of importance in pattern prediction test is the initialisation of the process of adoption by the adoption from advertisement. This is the basis for the process of adoption to begin though it is easily taken over by the "trust loop" (word of mouth loop). It is needed to help start the process of adoption by farmers who can afford to take the risk. The risk-averse farmers begin to adopt as their colleagues succeed with the new seed. Learning from individual and group experiences fuels this further.

It is however important to note that in as much as advertisement plays a role in the initialisation of adoption, in this model, coverage do not decrease to zero if initial coverage is equal to zero. This is because maize is not entirely a new crop. As a result, maize farmers already have some level of knowledge and trust in the cultivation of maize even before the adoption process begins. The knowledge only need to be updated. This explains why there is some level of coverage even if initial coverage of zero.

### 4.3.3 Sensitivity Analysis

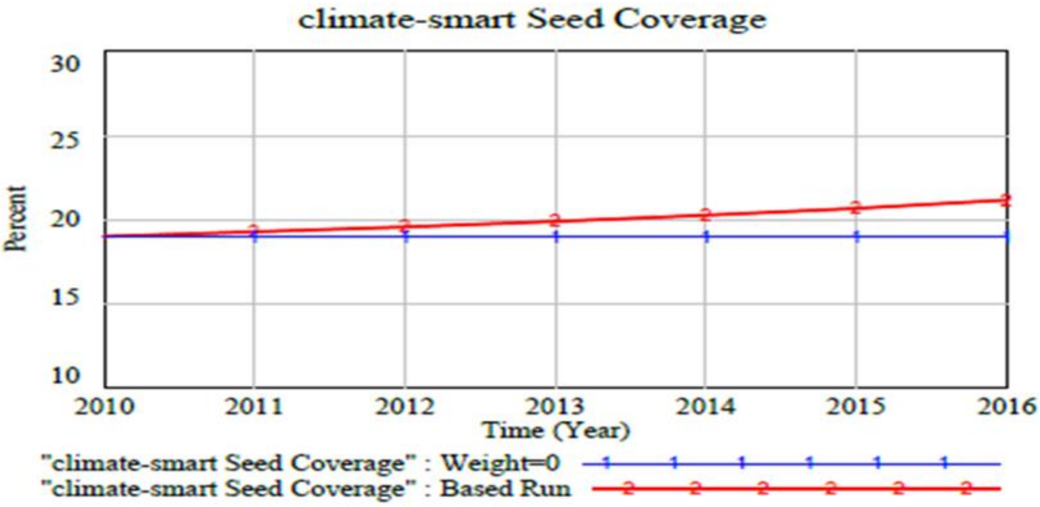
#### Behaviour Sensitivity Analysis

This involves two types of validity, thus numerical sensitivity and behavioural sensitivity. The model is tested to see if numerical value changes lead to some significant modes of behaviour change or whether the policy implications change significantly when assumptions based on which the model is built are changed over the plausible range of uncertainty (Sterman, 2000). It is thus a way of determining parameters of the model which are highly sensitive and trying to find out if the real system would behave in similar high sensitivity to the corresponding parameters (Barlas, 1996). Most often than not modelers would want to consider exogenous variable changes and the impact on the model built so that what is usually considered as side effects as a result of narrow model boundaries are minimised as much as possible.

### Weight on Trust

Different weights on trust produces different behaviour modes as indicated in fig 4:6, if farmers placed no priority on the yield potential of the seed, adoption will remain at its initial coverage based on the assumption that farmers are in search of high yielding varieties. That is, farmers would have never bothered to inquire from their colleagues about the new seed to the extent of also cultivating it. However, since they categorise the yield of the climate-smart seed as a priority, the "trust loop" is a sensitive point/policy entry point because any adjustment in the value of the weight causes significant changes as illustrated in figure 14.

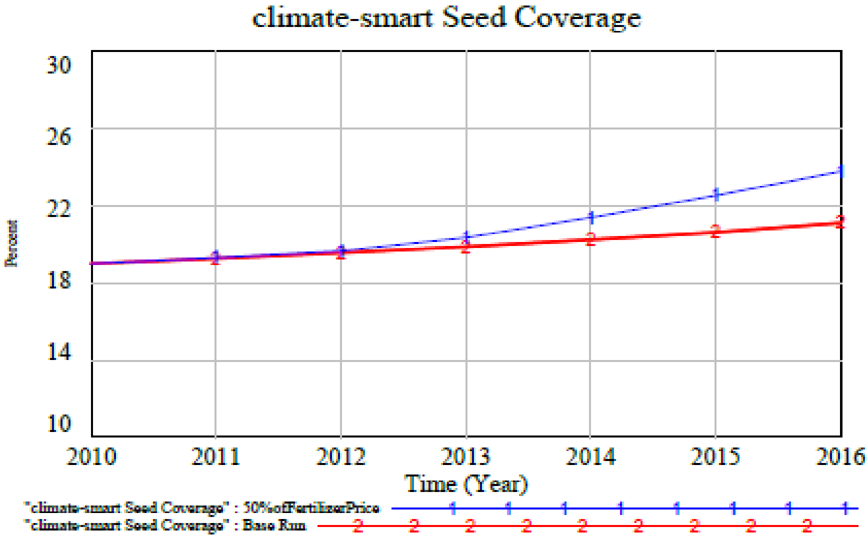
Figure 14: Weight on Trust




### Input Cost

Input cost is equally a sensitive parameter in this model as it determines the difference in cost of the two variety of seeds and their attractiveness. An increase in the input cost of indigenous seed relative to its low yield makes it less attractive and thus leads to a reduction in its adoption. This however, leads to an increase in adoption of climate-smart seed mainly due to its higher yield potential. It is also the case that high fertilizer price is a disincentive to the cultivation of both seeds. Maize in general does well when fertilizer is applied on the field. Figure 15 reflects this adequate as a 50% decrease in the prices of fertilizer leads to an increase in seed coverage.

Figure 15: Impact of Fertilizer Cost

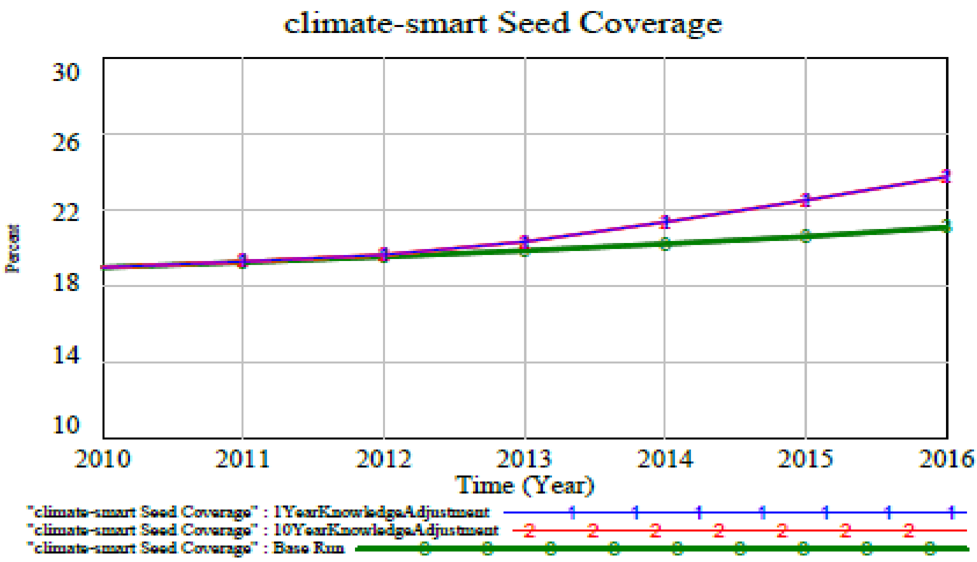



## Knowledge adjustment time

The delay in developing knowledge adequate to achieve the yield potential of the Climate Smart-Seed is equally a sensitive parameter and leverage point for enhancing adoption. As indicated in the figure below if it takes a shorter period of time to develop the knowledge required to attain the yield potential, adoption of both climate-smart seed and climate information is quickened because with adequate knowledge, farmers are able to implement the best farm management practises. With their ability to manage crops appropriately, they achieve much higher yield than they would have otherwise achieved. An achievement of higher yield leads to further adoption as farmers begin to trust in the profitability of climate-smart seed.

Instead of allowing farmers to experiment over a 10-year period to accumulate the needed knowledge to increase average yield, it is efficient to institute programmes that will enable them to achieve the same amount of knowledge within a short period of 1 year to achieve the same increase in yield as in Figure 16. This will help solve food security issues in the shortest possible time.

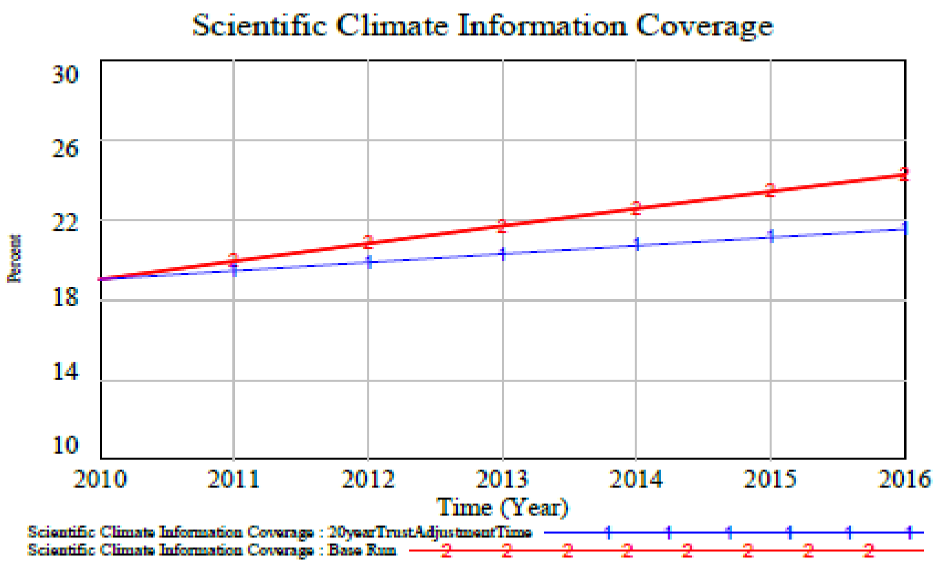
Figure 16: Knowledge Adjustment




### Trust Adjustment time

In the same way, as in the adjustment of knowledge, trust adjustment time is sensitive to changes thus serving as another leverage point of intervention. If it took longer for people to adjust their trust after first adoption they would learn enough from experience in order not to abandon/dis-adopt climate information and climate-smart seed so quickly. At the same time, a longer trust adjustment time means initial adoption; delayed decision to cultivate a larger portion of land with climate-smart seed after initially getting to know about it.

Figure 17: Trust Adjustment



## 4.4 CONCLUSION

It can be concluded given the above results that the model is robust and useful for its purpose. Internal validity based on interaction with relevant stakeholders in the real system contributed to making the model useful. In terms of external validation, the direct structure test and structure-oriented behaviour tests shows the logic behind the structure and the model behaviour thereof. The structure-oriented behaviour tests affirm further the validity of the structure of the model. Combining all assessments together, it can be concluded the model meets it purpose and it is a valid representation of the real system. This passes the model as a concrete basis for scenario and policy analysis.

# CHAPTER FIVE

# MODEL BEHAVIOUR AND POLICY ANALYSIS

## 5.1 INTRODUCTION

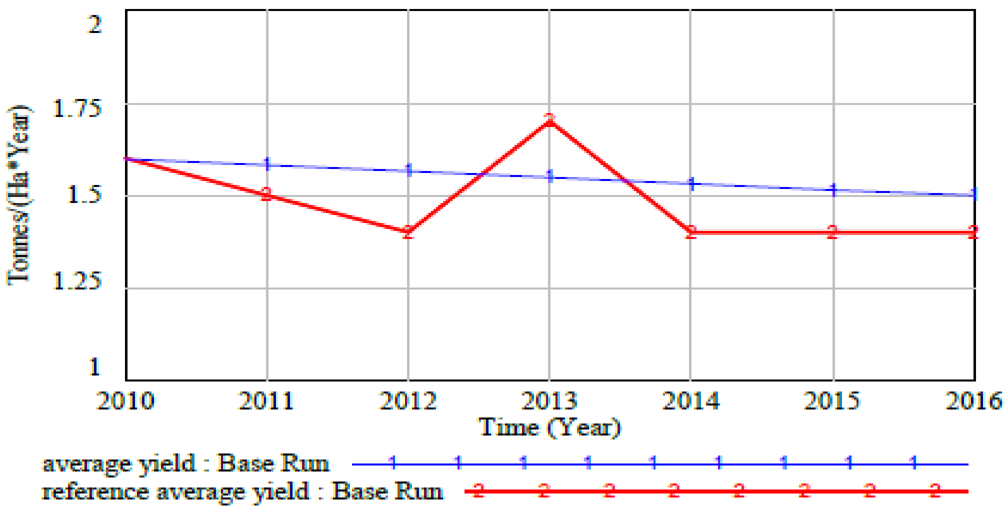
Chapter four concluded with a useful model valid for its purposes. There is confidence therefore to carry out behaviour and policy analysis using the validated structure as a guide. Chapter five presents a discussion on the behaviour of the explanatory model/business as usual scenario based on data used in the calibration of the model. The latter section discusses proposed feasible policies that could be implemented to attain a desirable system behaviour.

## 5.2 SIMULATION RESULTS

### 5.2.1 Business as Usual

Average yield

Figure 18: Average Yield




Reference to chapter one, the dynamics in average yield is the motivation for this study. The behaviour of average crop yield transcends to what to expect in food available for consumption and household incomes. A comparison of model behaviour with the reference behaviour gives a clear sense of a continuous decrease in average crop yield in the district. The main reason as discussed extensively in the background to this study, is the variability and changes in climatic conditions. This is coupled with the low adoption rate of climate-smart seed which is resilient to these changes. Farmers continue to rely on indigenous seed that has since the onset of climate change and variability produced increasingly low yield.

One thing is sure however, that is several years back, farmers planted with indigenous seed and they harvested enough to meet their consumption needs and little was spoken about food insecurity. This was possible because farmers could determine appropriate planting dates to get the required weather conditions to support their production.  Farmers are no longer able to forecast appropriately, the onset and cessation of rainfall for their planting decision making. It is no doubt that the fluctuations in average yield as illustrated in figure 18 is attributable mainly to the uncertainty and the seasonal variability in climatic conditions.

The simulated behaviour of the model is unable to reflect the fluctuations. However, it is able to follow the trend. This is accounted for by other factors including the inability of the model to capture the effect of other factors such as the degrading soil fertility which are outside it boundary for this study.

Figure 18 indicates that from 2010 to 2012, yields continue to decrease because, a greater percentage was cultivated with indigenous seed. Moreover, around this period farmers had limited access to climate information (onset and cessation dates of rainfall) necessary to support high yield potential. These farmers continued to rely on their indigenous forecast. Added to that is short duration of rainfalls that did not last long enough to support the maturation of crops.

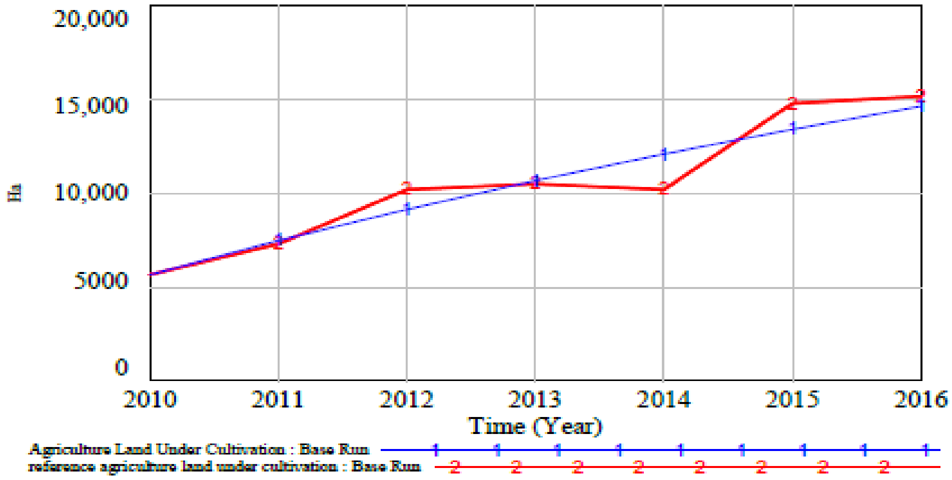
In 2013, there was an appreciable level of subsidy on the prices of fertilizer and seed that supported the cultivation of maize and recorded rainfalls were quite good compared to other years. Knowledge of climate resilient seeds kept building up as farmers learn from colleagues and advertisement. Early adopters of such seed also continued to cultivate thus encouraging further adoption as they are able to recycle seed of open pollinated variety even if they could not afford new seeds from extension service, thus the increase of average yield in 2013.

In 2014, rains were inadequate to meet the crop water requirement. Rains started late with long periods of dry spell and lasted very short to allow crops to mature. In 2015, the story was no different in terms of rainfall. Making the situation worse, fertilizer prices were relatively high and the subsidy was not significant accounting for the decrease in average yield recorded in 2015 and 2016.

***Agriculture Land***

Faced with continuous decreasing yield, farmers resort to a solution close in time though not efficient, that is increasing agriculture land under cultivation. It is however important to note that this increase does not necessarily mean that every farmer is able to increase their farm size mainly because there is a capacity constraint. This is indicated with a 10-year agriculture land adjustment time. Such increase in agriculture land is more a temporal than sustainable approach to alleviating the problem. Thereby shifting the burden of increasing average yield to increase in agriculture land under cultivation. Figure 19 indicates there is a continuous increase in the hectarage of agriculture land under cultivation.

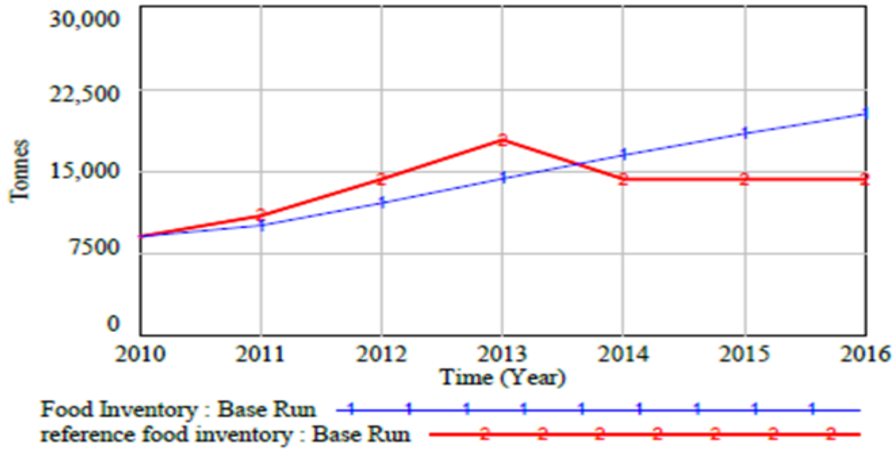
Figure 19: Agricultural Land under Cultivation




***Food Inventory***

Food Inventory is however increasing in absolute terms. Judging from the face value of increasing food inventory as illustrated in figure 20, it will not be totally wrong to conclude that farmers are food secure. However, it is deceptive to make such conclusions based on the absolute increment in such a variable until a comparison of the desired food need and the actual food consumed is done.

Figure 20: Food Inventory




***Consumption and Desired Consumption***

A comparison of actual consumption and the desired consumption gives much more insight to the food insecurity predicament of farmers than food inventory explains. Figure 21 indicates that even though food inventory as indicated in figure 5.4 is increasing, the food consumption needs of the populace is not met. The observed incessant decrease in the average yield makes it not surprising that the desired food consumption need of even subsistence farmers is not met and not to mention the entire district population. Food produced within the district runs out even before the planting season approaches.

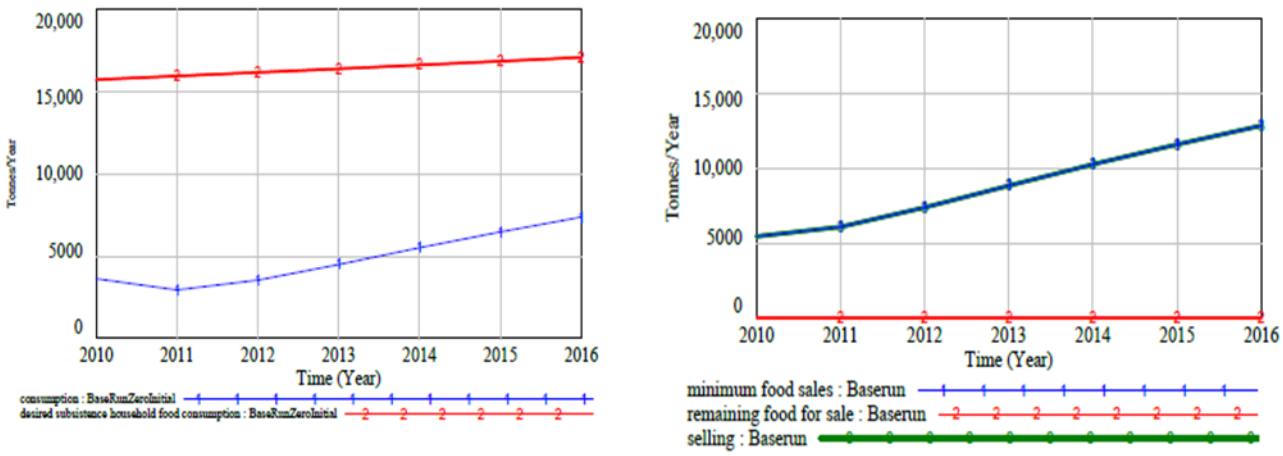
This implies food must be brought in from other parts of the country. Thus, the income that subsistence farmers would have earned from the sale of excess produce is lost to other food producers outside the district.

It is then the case that subsistence farmer households are battling with inadequate food for consumption. Added to that they also lose an opportunity to earn income from their very own source of revenue to others, keeping them trapped in the vicious cycle of poverty.

From Figure 21, subsistence farmers are only able to make the minimum sales but unable to make any significant sales from surplus because their food consumption need is not met. Selling (Run 1) = Minimum sale (Run 2)-food sales graph because remaining food for sale after consumption is equal to zero

In the midst of all these, population is growing indicating yet the need to increase food production.

Figure 21: The Gap between Consumption and Desired Consumption

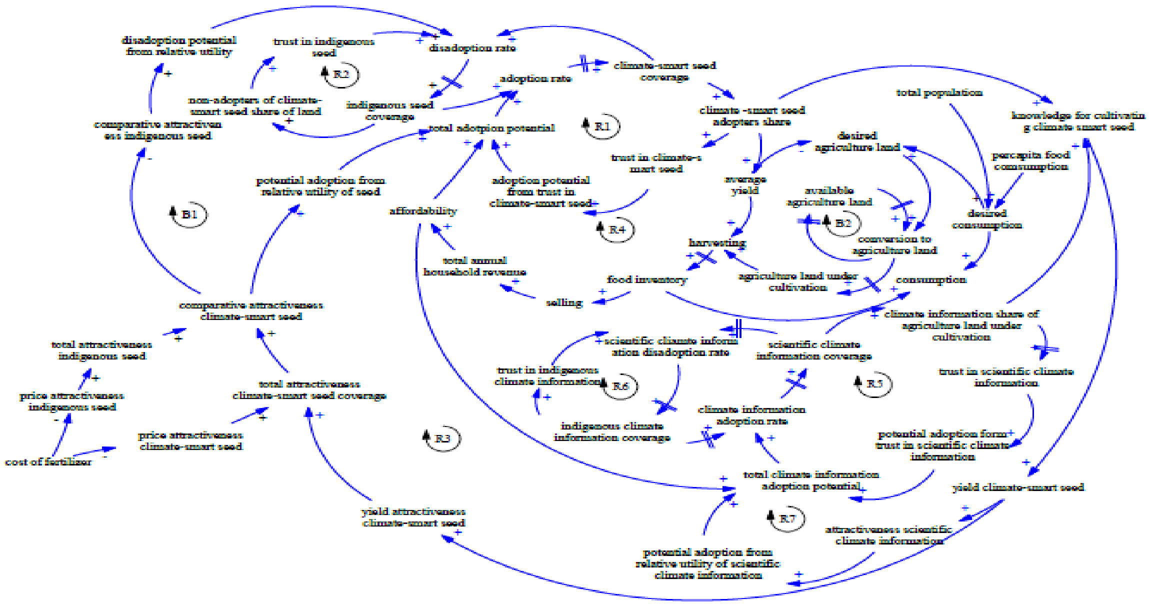



### 5.3 CAUSAL LOOP DIAGRAM

To guide the behaviour analysis of the model, it is useful to explain the cause-effect relationship and interaction between model variables and parameters that culminate in the motivation for this study as illustrated in figure 22.

The causal loop diagram helps to simplify the four modules of the system in seven reinforcing loops and two main balancing loops.

Figure 22: Causal Loop Diagram




### 5.3.1 Average Yield, Food Inventory and Agricultural Land under Cultivation

The decreasing average yield coupled with increasing population continues to make subsistence farmers and the entire district food insecure. This induces an increase in the desired agriculture land under cultivation. However, there is a capacity constraint on farmers to increase the agriculture land under cultivation resulting in a gap between the agriculture land under cultivation and the desired land. The widening gap between the desired and actual land gap coupled with decreasing yield, leads to the conversion of more land from the agriculture land available to agriculture land under cultivation. However, as a result of capacity constraints, it takes about 10 years for farmers to adjust the gap of agriculture land under cultivation.

Agriculture land under cultivation increases relative to decreasing average yield. This increase in land serves as a buffer for the incessant decreasing yield experienced over the years. However, such recorded increase in hectarage does not even ensure that desired consumption is met because an increase in the hectarage of land does not guarantee increased harvest even though farmers have tried this. This leaves questions to be answered in the search for the root causes of the decreasing average crop yield and thus the two adoption modules discussed in the subsequent sections.

### 5.3.2 Climate-Smart Seed Adoption

#### *Trust in Climate-Smart Seed (R1)*

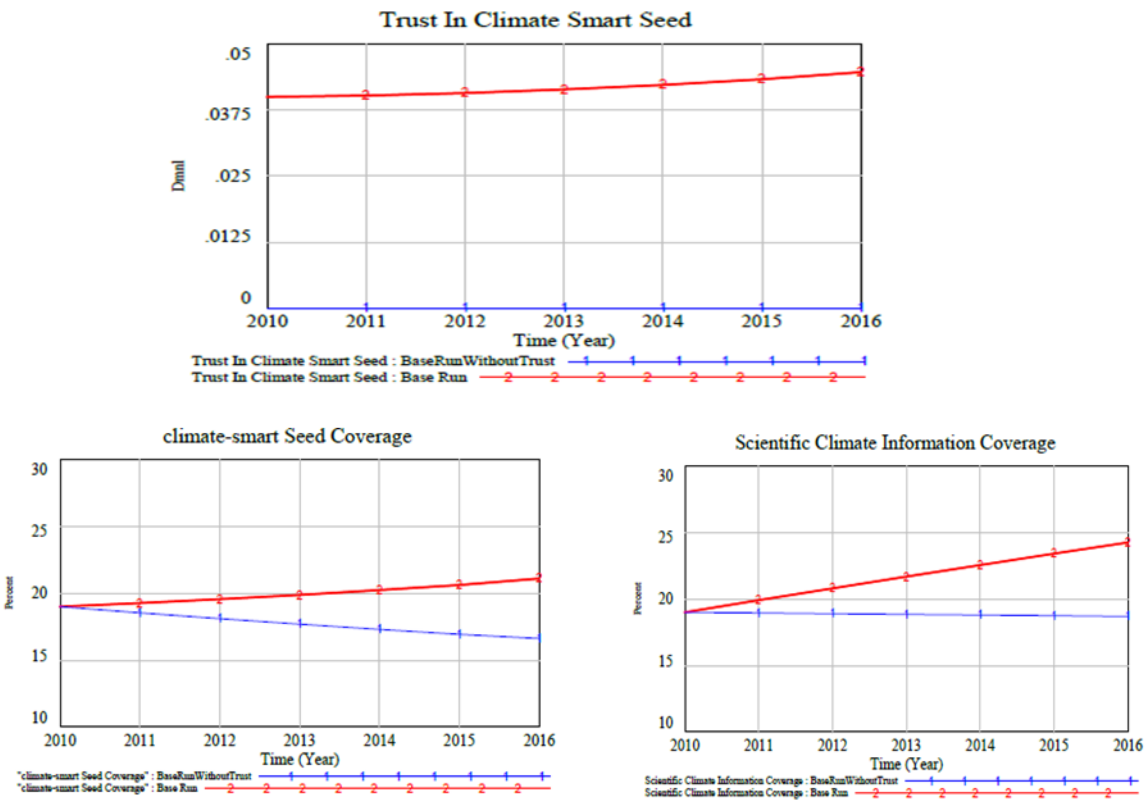
Trust in climate-smart seed (R1) represents the reinforcing trust adjustment in the higher yielding potential of the climate-smart seed. Given an initial climate-smart seed coverage of 19%, this trust adjustment (word of mouth loop) takes over. As the initial adopters succeed, the risk averse farmers develop confidence in the climate-smart varieties and they adopt because of the success of their colleagues. Individual learning from experience also induces in initial adopters the confidence to cultivate a greater percentage of their land with climate-smart seed.

The dominance of this loop further speeds up adoption easily because farmers learn very quickly and trust in the successful experiences of their colleagues.

In terms of the climate-information, responses from the field reveal that when farmers who have access to such forecast do not begin to prepare their land, colleagues who do not have such access in their vicinity are sceptical about preparing their fields. This loop has the potential to foster adoption of climate smart-seed and information towards increased yield and eventually food security and income improvement.

As shown in Figure 23, if the assumption on trust is taken out, there is an observed decline in the coverage of both seed and information. Climate-smart seed coverage decreases from an initial 19% to 16% between 2010 and 2016. Climate information coverage decreases also from an initial 19% to 18% within the same period.  This points to fact that programmes that create awareness of availability and profitability of such resources as well as encourage learning are relevant in increasing coverage because such have the potential to increase trust in climate-smart seed and information.

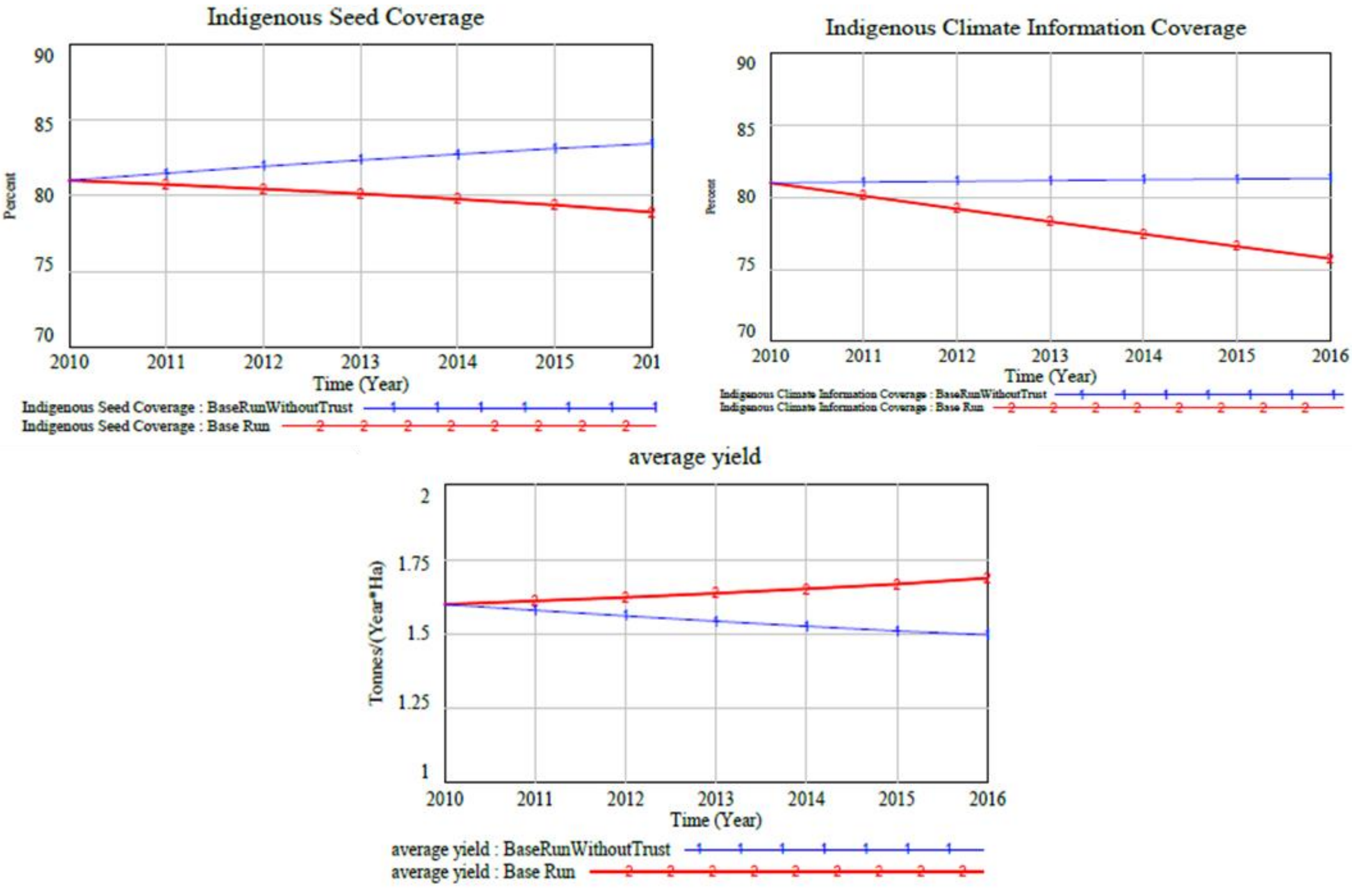
Figure 23: The Relevance of Trust in In Increasing Climate-Smart Seed Coverage



**Trust in Indigenous Seed (R2)**

Trust in indigenous seed represented by loop R2 plays a similar role but directly counteracting the process of increasing the adoption rate of climate-smart seed with the potential to lock up the system to local seed coverage and then the continual decrease in yields will persist. As depicted in figure 24, if there is no trust in climate-smart seed (run 1), indigenous seed coverage rises from its initial value of 81% coverage in 2010 to about 84% coverage in 2016 after the adjustment time elapses. As indicated with the graph of average yields, there is a decrease of yields from an initial average of 1.5 tonnes/ha/year to 1.4 tonnes/ha/year after 2010. The implications of this occurrence are obvious: severity of food insecurity and low incomes levels of these farmers.

Figure 24: Trust in Indigenous Seed




**Knowledge Accumulation and Update (R3)**

The adoption process is also influenced by the farmer's level of knowledge in the cultivation of climate-smart seed. As maize is not entirely new, farmers already have some level of knowledge in the cultivation processes though this knowledge must be upgraded to match prevailing conditions. The adoption of climate-smart seed from trust also adds to the initial knowledge as farmers gather experience from individual and group best practises over time.

There has also been a focus on block farm projects in the district focused on introducing new varieties of maize to farmers and education on best farm management practises to boost food production. But the coverage of this education is limited due to the woefully inadequate extension officer-farmer ratio.

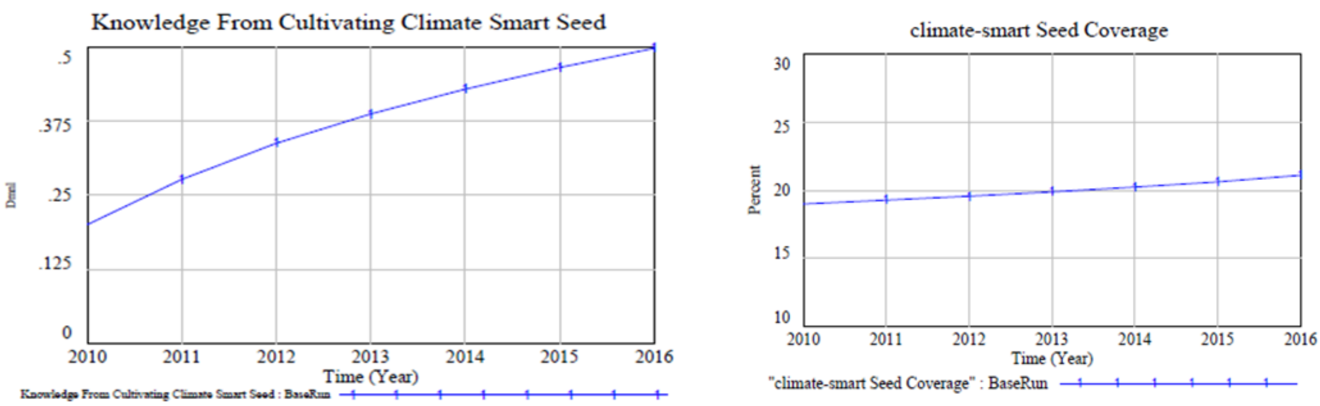
Also, adoption results from relatively low fertilizer prices averaging about GH₵ 350.00 per fertilizer need per ha between 2010 and 2013 making it possible to acquire a considerable amount of knowledge in addition to farmers' indigenous knowledge in the cultivation process. From 2013 to 2016, where fertilizer prices increased to about GH₵ 667.00 per fertilizer need per ha, though many farmers could not afford it, some could pay the price and encouraged by the accumulated increased knowledge continued to implement the adoption decision.

Added to that, farmers would usually purchase open pollinated seeds that can be recycled for a number of years to avoid the cost of purchasing new seeds every season. This also contributes to the increase in coverage.

Moreover, within this period farmers started becoming knowledgeable of the availability and profitability of scientific climate information. Some farmers had access to scientific climate information accompanied by advisories based on the seasonal forecast from programmes organised by climate change adaptation inclined NGOs operating in the district.

Consequently, this loop also took its turn leading to modest increase in coverage of climate-smart seed as farmers who took the risk shared information about the new seed and experiences upon cultivation. As such continuous adoption fosters the accumulation of knowledge adequate to support the achievement of the yield potential of the climate-smart seed as portrayed in Figure 25.

Figure 25: Knowledge in Cultivating Climate-Smart Seed



**Adoption of Climate-Smart Seed, Scientific Climate Information and Impact on Food Inventory (R4)**

This loop illustrates that sustained optimistic adoption rates accounts for increased harvest. This explains why food inventory is increasing though with fairly modest adoption rates coupled with the increase in agriculture land under cultivation. As food inventory increases, farmers are able to sell at least the minimum percentage of food sold (60%). As long as the inventory increases, the tonnes of food that constitute this percentage also increases. Thus, the revenue resulting in increased earnings from the sale of crops though with a delay as this takes years to accumulate. This increase makes climate-smart seed and information coverage affordable because such increased incomes from the sale of crops also increases income surplus all things being equal and a further increase in adoption. Farmers as the years go by are then able to pay for detailed useful information and seed at its actual cost making subsidies almost irrelevant.

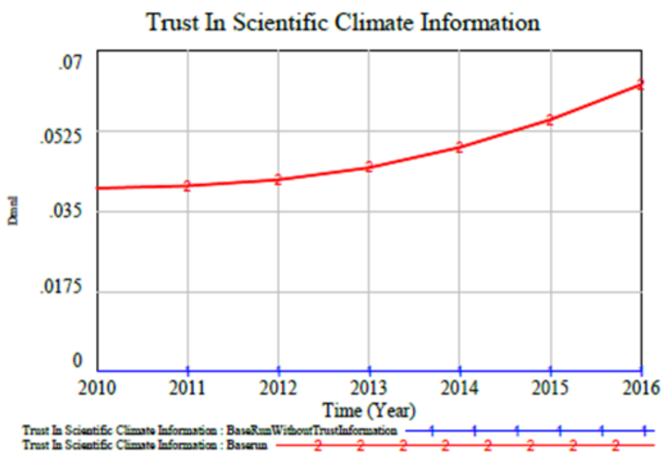
Figure 26: Climate-Smart Seed, Information, Food Inventory and Incomes

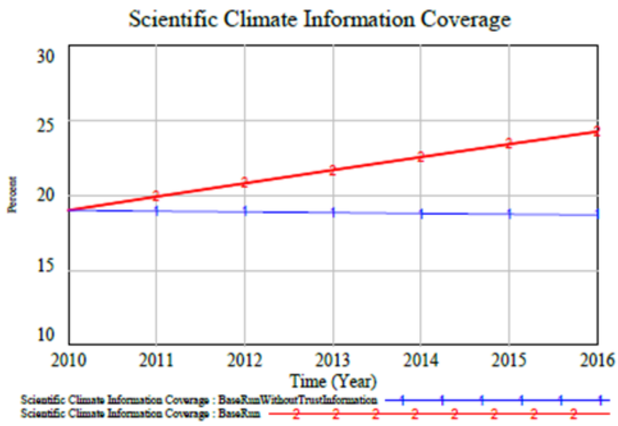
### 5.3.3 Climate Information Adoption

**Trust in Scientific Climate Information (R5)**

Trust in scientific climate information explains the reinforcing causal relationship between scientific climate information coverage and trust developed in the reliability and profitability of this information. This loop like the trust in climate-smart seed adoption explains the strength of social learning from colleague farmers who heeded to the forecast in previous seasons. This increases the adoption rate as knew adopters learn about it from colleagues and also, initial adopters develop the confidence to cultivate a greater proportion of their land with scientific climate information. As farmers are increasingly becoming aware of this information in the district those who do know the importance of this information but do not have access to it would usually wait for those who can access this information to start preparing their land before they would also do so. There is no further adoption when trust in scientific climate information is zero.

Figure 27: Trust in Climate Information Coverage

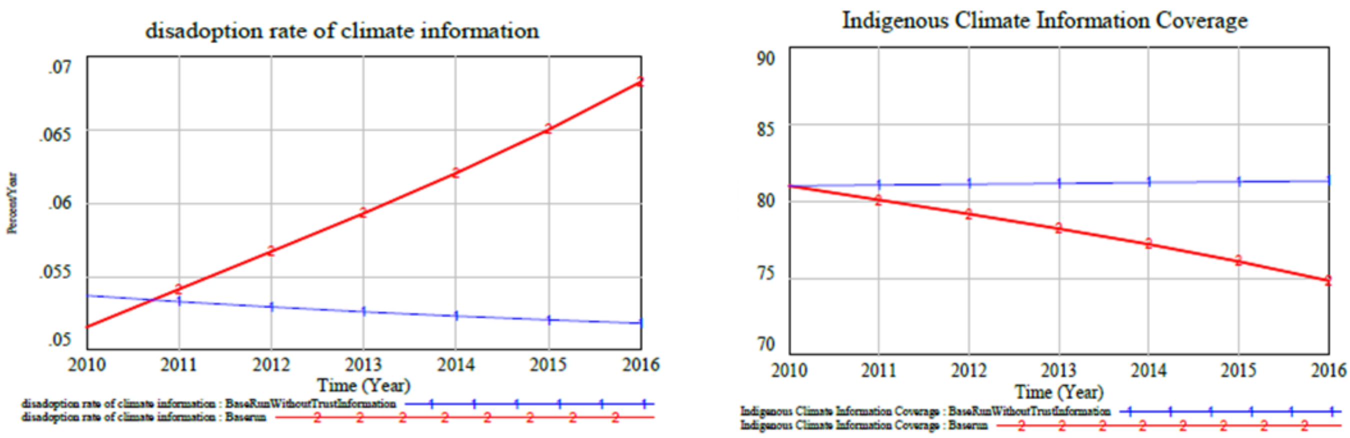



**Trust in Indigenous Climate Information (R6)**

Similar in causality but directly opposite in effect is the loop R5. It is operationalised based on the confidence of farmers in indigenous climate information. As long as farmers have confidence in indigenous climate information regardless of the yield as compared to climate smart seed, this loop is reinforced. It plays a major role in increasing the dis-adoption rate of climate information and it locks the system to the utilisation of indigenous climate information. This points to need to make available short term (daily/weekly) forecast that have less uncertainty seasonal forecast has more uncertainty. This would make it more attractive for farmers to adopt scientific climate information and consequently speed up the adoption of scientific climate information.

Figure 28: Trust in Indigenous Climate Information

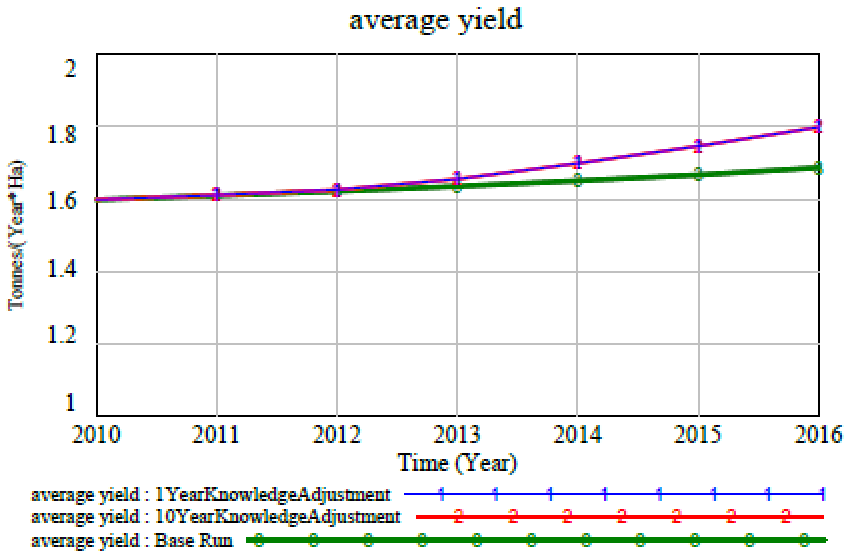



**Attractiveness and Utility of Scientific Climate Information (R7)**

Reliability of climate information originates from this loop because farmers can only measure its reliability based on its useful in meeting their objective that is yield measured on yearly basis. Actual yield realised depends on the level of knowledge adequacy (scientific climate information accessible in addition to crop management practises). This also enhances trust in scientific climate information constitutes an integral part of the knowledge adequate to realise the full potential/higher yields with climate smart-seed. Consequently, farmers build trust in scientific climate information based on how it contributed to harvest in the previous years. Farmers interviewed agree to the fact that colleagues who actually took up proposed planting dates and the type of crop to plant actually harvested more than colleagues who did not. It also helps to understand why the stock of knowledge is adjusted by experience in cultivation and scientific climate information coverage. It helps to answer the research question: *What is the impact of the adoption of climate information and climate-smart seed on crop yield and farmers income?*

As illustrated in Figure 29, the faster the scientific climate information coverage increases, the faster the stock of knowledge in cultivating the seed increases. It thus takes for example, one year to attain an amount of knowledge with increase in coverage of scientific climate information as it would take to attain the same increase in coverage in 10 years if all the knowledge was attained from experience in cultivation. This points to a relevant leverage point to tackling the knowledge gap in cultivating climate-smart seed as shown in figure 5.12.

Figure 29: Knowledge Adjustment




**Comparative Attractiveness, Fertilizer Prices and Dis-adoption (B1)**

As the major counteracting feedback loop in this system, it locks the system to an indigenous seed trajectory. As the share of land under climate-smart seed increases, the knowledge and crop management practises also increases, this makes it possible to achieve continuously increasing yields towards achieving the yield potential of climate-smart seed. As the achieved yields of the seed increases, attractiveness of climate -smart seed increases relative to the attractiveness of indigenous seed fostering the adoption rate of climate-smart seed coverage in the ideal scenario. However, B1 indicates that when the total attractiveness of indigenous seed (price attractiveness and yield attractiveness) are greater than the total attractiveness of climate-smart seed, comparatively dis-adoption potential of climate-smart seed increases leading to increase in the coverage of indigenous seed keeping the balance in the system.

Very important in the strength of this loop is the effect of fertilizer prices on the price attractiveness of both seeds. Farmers confirmed that maize does well when fertilizer is applied to field which it is cultivated. Therefore, if farmers cannot afford to pay for the cost of fertilizer they would under normal circumstances opt for crops that do not require the application of fertilizer. Increased fertilizer prices reduce the utility of both seeds.

Secondly, the difference in cost of the two seed varieties account for the price attractiveness of the seed. As described in chapter two, indigenous seed varieties can easily be obtained at virtually no cost from colleague farmers or bought at a lower price in comparison with climate-smart seeds. In terms of price, it is less attractive when its price is increasing because its yield potential relative to climate-smart seed is low. Thus, weakening the effect of this loop with increase indigenous seed prices. This is however different with the cost of climate-smart seed. Its attractiveness is not affected significantly by the prices because of its higher yields potential. The benefits of a high yield will pay off after paying for the initial cost of seed. This answers the question: *What factors shape understanding and adoption of climate information among subsistence farmers in Garu-Tempane District?*

Figure 30: Comparative Attractiveness, Utility and Seed Coverage

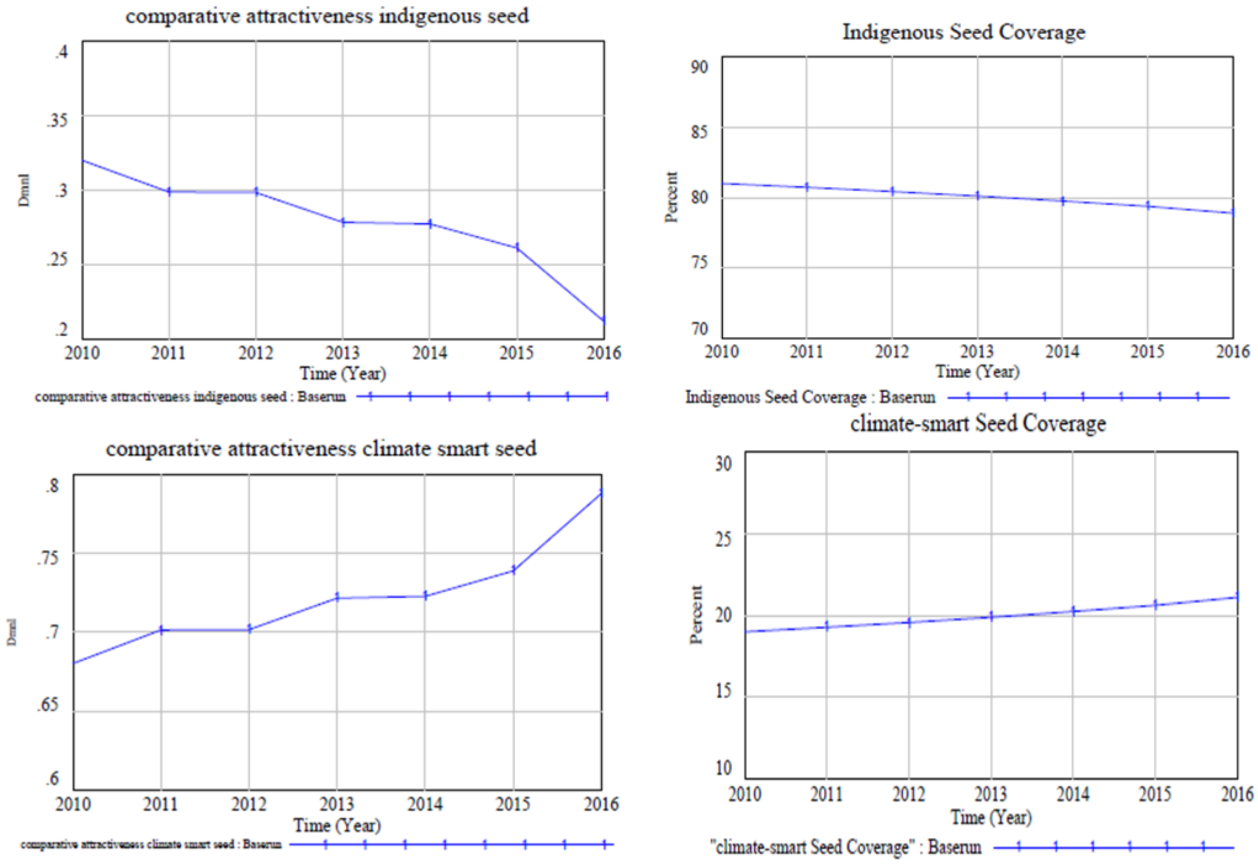
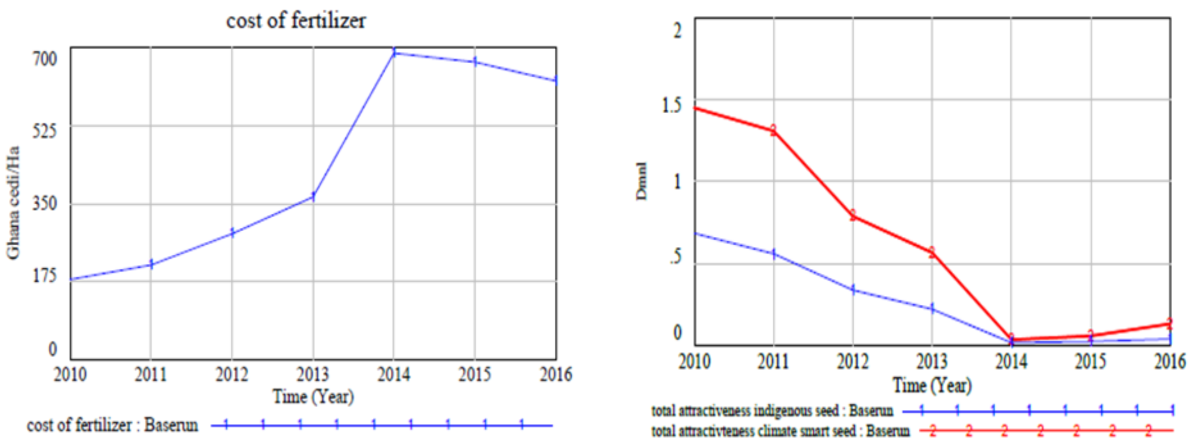


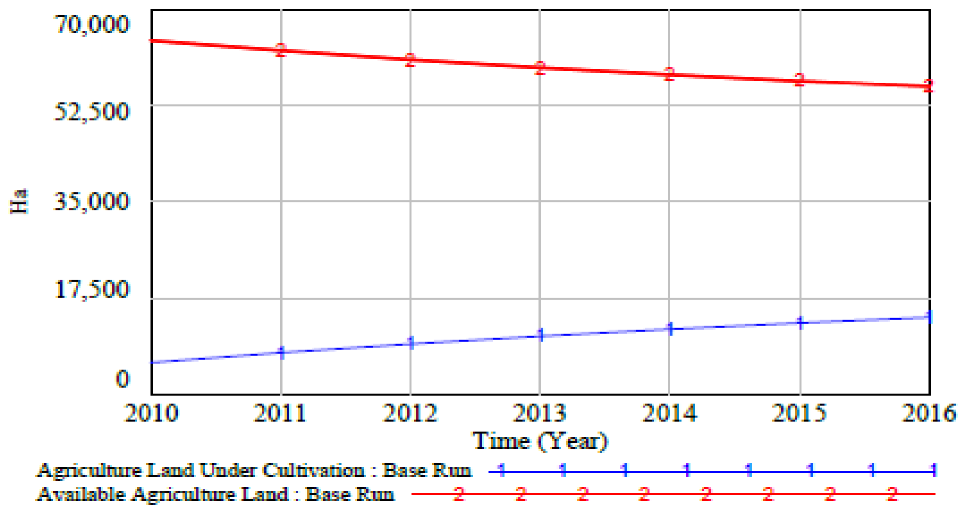

Figure 31: Cost Fertilizer and Seed Attractiveness




## Agriculture Land Adjustment (B2)

Balancing loop B2 is a reflection of the agriculture land gap adjustment process. In the event that average yield decreases, the closest substitute available to farmers based on their capacity is to increase the land under cultivation. Also coupled with continual population growth, there is the need to increase land under cultivation in other to meet the desired food need. However, this obviously is not a sustainable approach to the problem because as more and more land is converted into agriculture land, available land for agriculture runs outs and with time there would be no land left to increase production. Loop B2 thus the quick fix to the problem. This brings the discussion to a more sustainable and efficient food production approach, that is by increasing average yield through the adoption of climate information and climate-smart seed.

Figure 32: Agricultural Land under Cultivation and Available Agriculture Land




## 5.4: LEVERAGE POINTS/POLICY ANALYSIS

This section discusses policy options that could alleviate the problematic behaviour of the system. The explanatory model indicates that adoption of climate - smart seed and scientific climate information are crucial to attaining a desirable system behaviour. Places to intervene in this system include subsidising fertilizer cost, instituting training/farmer field schools that helps increase knowledge as well as providing farmers with short term forecast to enable them to make informed decision. Discussed below are the policy proposal

- **Policy Option One-Fertilizer subsidy**

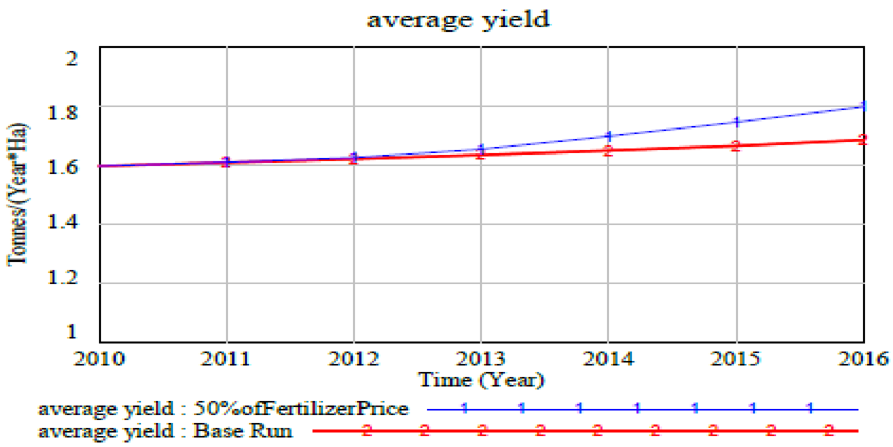
Drawing from analysis in the earlier section of this chapter, an increase in fertilizer prices makes both seed varieties less attractive. Farmers would always make an initial choice to cultivate maize on their ability to purchase fertilizer informed by depleting soil fertility. Therefore, if policies seek to ensure food security through adoption of climate-smart seeds especially maize, one option is to ensure that fertilizer prices are subsidised further to make it affordable for farmers to purchase. For example, a 50% subsidy as in figure 5.16 increases climate-smart seed coverage relative to original cost of fertilizer would as in base case.

The simulation model provides evidence that though increasing cost of seed may be a disincentive, in comparison with increasing fertilizer prices, adoption of climate-smart seed is highly influenced by the cost of fertilizer than cost of seed. This is reflected in data available that as at 2015, the crop unit of the district department of agriculture sold out about 2.7 tonnes of improved maize seeds at GH₵ 4.00 to farmers. This increased to 5 tonnes in 2017 at GH₵ 6.00. The increase is not surprising because this year there is a subsidy on fertilizers.

If fertilizer prices are subsidised, the extra expenses on unsubsidised fertilizer prices is transferred to pay for the cost of the seed. Any feasible policy would be to focus on subsiding fertilizer prices and not necessarily the cost of seed.

It is important to mention that farmers would often purchase open pollinated seeds which they can be recycled for a number of years even though the yield in recycled years are not as much as yield in the first year of use. Adoption is highly influenced by affordability.

Figure 33: Fertilizer Subsidy



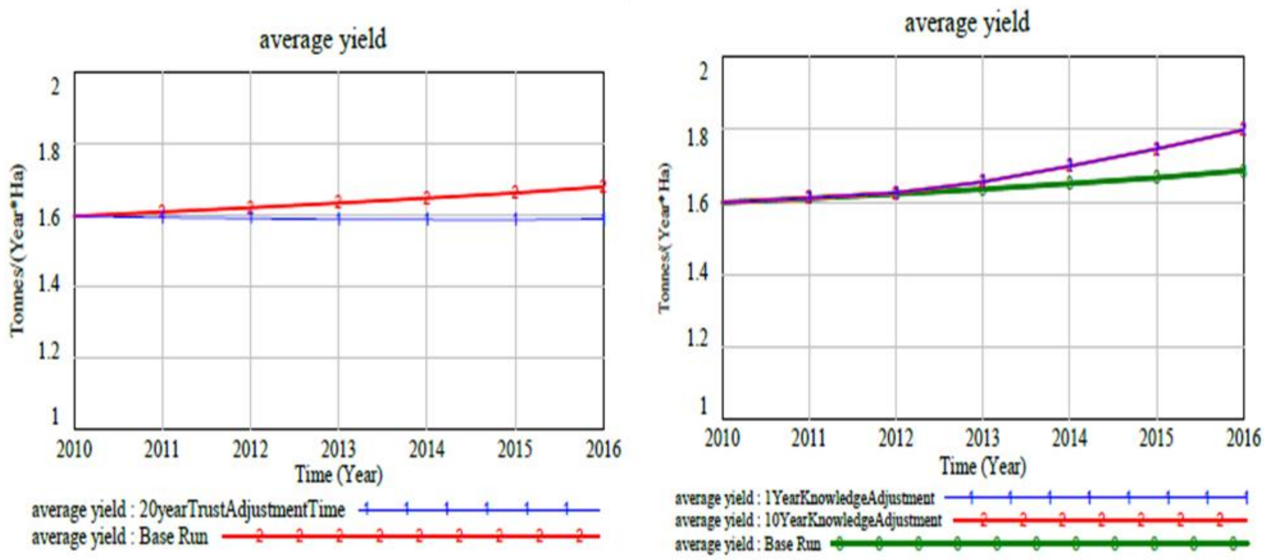

**Policy Option 2: Knowledge and Trust Adjustment: Making Farmer Specific Climate Information Available**

- Organise participatory planning workshops to update and increase knowledge and disseminate climate information/seasonal forecast accompanied by advisories for the season.
- Construct climate information centres in communities that are linked to meteorological station for weather updates. These could also serve as market information centres for farm produce.
- Institute programmes on local/ district radio stations for farmers to share experiences and best practises with colleagues.

Implementation of the above would lead to increasing knowledge and trust and consequently adoption rates. Knowledge includes knowledge of efficient and current farm management practices and information about the weather/ climatic conditions especially during the season. The crucial component is appropriate advisories(seeds) based on the seasonal forecast and short - term updates within the season to match the prevailing season, onset and cassation dates of rainfall which farmers cannot use indigenous ways of forecasting.

Results as presented in figure 34 tells that the shorter the adjustment time in trust the faster the increase in climate-smart seed coverage. This is attainable if farmers had adequate knowledge that made them achieve higher yields. If it takes 5 years (base-run) to adjust trust, coverage increases faster and a 20-year trust adjustment leads to a very slow increment in coverage.

Figure 34: Trust, Knowledge Adjustment and Average Yield




Based on the behaviour analysis and policy options in above discussion, there is reason to conclude that, for sustained increased adoption rates, trust building in the climate-smart seed and scientific climate information is necessary. Upgrading indigenous knowledge with scientific climate information is equally important to enable farmers to acquire the knowledge adequate to attain the yield potential of climate smart-seed. This will intern enhance trust in the climate-smart seed and at the same time increase and stabilise incomes. Thus, making climate information and services affordable. In the short run, it is necessary to subsidise fertilizer cost by 50% to increase incomes to a point when farmers have accumulated income enough to be able to pay the actual cost of these inputs.

It is very important to note also that the implementation of these suggested policies together has the greatest benefit. It is not enough to subsidise input cost only. Farmers need knowledge to be able to optimise the subsidy. In the same way, if famers have the knowledge adequate to achieve the yield potential of climate-smart seed but they cannot purchase inputs and at the same time do not trust both seed and information, there would be no adoption.

# CHAPTER SIX

# CONCLUSION AND RECOMMENDATION

## 6.1 INTRODUCTION

Motivated by an observed continual decrease in average yield and implications to food security and farmer incomes, the researcher set out with an objective to develop a simulation model that explains the reference behaviour and to identify robust policy options for effective adaptation to climate change among subsistence farmers in the Garu-Tempane District.

Chapter six presents the researcher's conclusion on the findings and discussions in the previous chapters. Recommendation for further studies on this subject is also presented

## 6.2. CONCLUSION

From the thorough data collection and rigorous analysis, the research found that even in the midst of increasing awareness of the relevance of scientific climate information and climate-smart seed among farmers, there are critical factors that account for the low adoption rates. These factors include trust in the higher yielding potential of seed and reliability in climate information, knowledge in the cultivation of adopted seed and the affordability of both seed and related input cost information. Scenarios from the simulation model lead to the conclusions that:

With sustained optimistic adoption rates of climate-smart seed and scientifically generated climate information farmers would attain increased incomes and food security. This would result from increased yield which allows them to harvest enough food for domestic consumption with a surplus sold for incomes.

From the simulation results, high cost of seed is a disincentive but high fertilizer prices are more a disincentive in comparison with cost of seed. Farmers make the decision to cultivate maize if they have the capacity to pay for the cost of fertilizer. Thus, with lower fertilizer prices farmers can adopt both seed and information and so the relevance of affordability to foster the adoption process.

Also yield potential represented in this study as trust in the seeds is a major determinant of the adoption of climate-information and advisories that accompany it. Trust building in the adoption process is equally important and if farmers do not trust comparative advantage of climate-smart seed, the share of land cultivated with indigenous seed will continue to be greater than that cultivated with climate-smart seed. To ensure that farmers develop trust, knowledge must be upgraded to make it possible for farmers to achieve the higher yield.

In as much as maize is not a new crop, knowledge in the cultivation process of climate-smart seed must be upgraded to meet current trends in weather patterns. This knowledge comprises both knowledge in terms of best crop management practises from experience and farmer specific climate information. It is important to note however that access to climate information including the onset dates of rainfall, cessation and periods of dry spell communicated in short-term updates is a priority. This should be a major place to intervene because, farmers have experiences in farm management practices that are transferable but they are unable to carry out accurate forecast with changing climatic conditions. Organising participatory scenario planning workshops to disseminate seasonal forecast, instituting radio programmes to share best practises, constructing climate information centres in communities to provide climate information to communities' a to avoid cost of individual subscription for such information, field demonstration/farmer field schools could also be helpful in this regard.

When farmers' knowledge in cultivation is up to date with current occurrences, yields attained will be increased, all things being equal and then trust in the higher yield potential of climate-smart seed will be engendered leading to sustained adoption rates. The se subsistence farmers would become food secure with increased income that makes these services affordable without the need for subsidies in the long run, all things being equal.

## 6.3 RECOMMENDATION FOR FURTHER STUDY

The following could be done to complement the relevance of this study.

- Though useful and valid for its purpose in this thesis, the model will reflect reality better if some extensions are done. These include; a detail modelling of food purchases by subsistence farmer households when food produced by these farmers runs out. Another relevant extension of the model should focus on the detail modelling of household revenue and expenditure, the feedback process between population growth, increase food production and land use as well as the entire policy suggestions for addressing the problems presented in this research.
- Relevant also is to model a detailed implementation structure to determine the cost of policy options.

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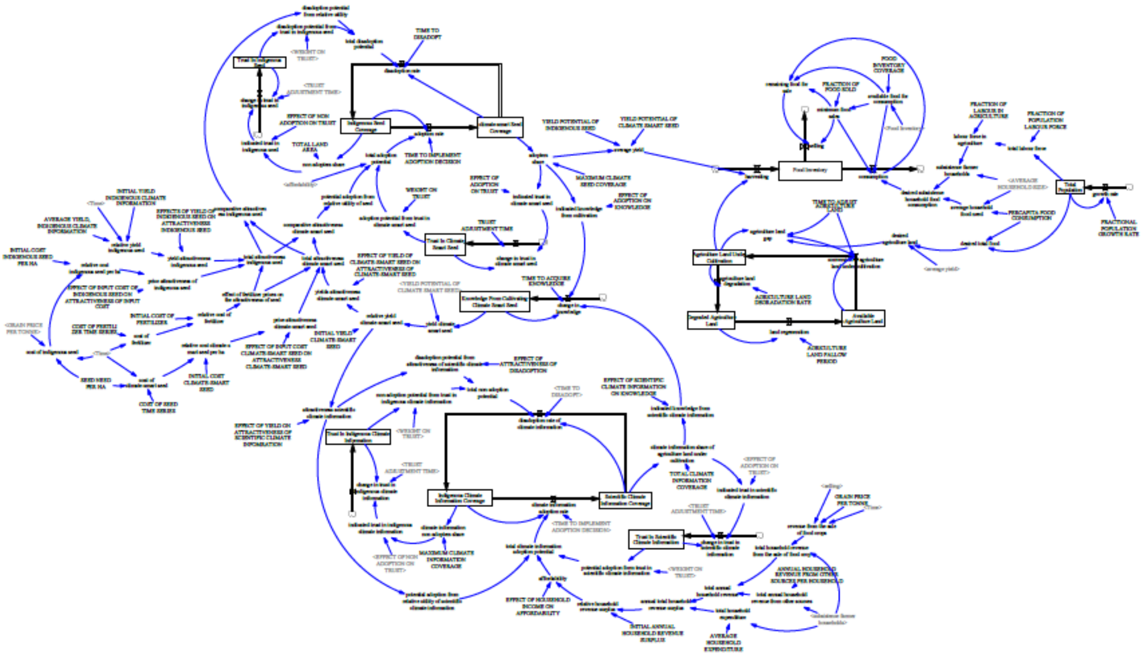
## APENDIX I- OVER VIEW OF SIMULATION MODEL



## APENDIX II-MODEL EQUATION

adopters share= ("climate-smart Seed Coverage"/MAXIMUM CLIMATE SEED COVERAGE)

Units: Dmnl

adoption potential from trust in climate smart seed= (Trust In Climate Smart Seed*WEIGHT ON TRUST)

Units: Dmnl

adoption rate= (Indigenous Seed Coverage/TIME TO IMPLEMENT ADOPTION DECISION)*total adoption potential

Units: Percent/Year

affordability= EFFECT OF HOUSEHOLD INCOME ON AFFORDABILITY(relative household revenue surplus)

Units: Dmnl

agriculture land degradation= Agriculture Land Under Cultivation*AGRICULTURE LAND DEGRADATION RATE

Units: Ha/Year

AGRICULTURE LAND DEGRADATION RATE= 0.025

Units: Dmnl/Year

AGRICULTURE LAND FALLOW PERIOD= 1

Units: Year

agriculture land gap= ((desired agriculture land-Agriculture Land Under Cultivation)/TIME TO ADJUST AGRICULTURE LAND)

Units: Ha/Year

Agriculture Land Under Cultivation= INTEG (conversion to agriculture land under cultivation-agriculture land degradation ,INITIAL AGRICULTURE LAND UNDER CULTIVATION)

Units: Ha

AGRICULTURE LAND UNDER CULTIVATION TIME SERIES([(2010,0)-(2016,15169)],(2010,5660),(2011,7300),(2012,10200),(2013,10500),(2014,10200),(2015,14790),(2016,15169))

Units: Ha

ANNUAL HOUSEHOLD REVENUE FROM OTHER SOURCES PER HOUSEHOLD=3323.38

Units: Ghana cedi/Year

annual total household revenue surplus=MAX(total annual household revenue-total household expenditure,0)

Units: Ghana cedi/Year

attractiveness scientific climate information=EFFECT OF YIELD ON ATTRACTIVENESS OF SCIENTIFIC CLIMATE INFOMRATION("relative yield climate-smart seed")

Units: Dmnl

Available Agriculture Land= INTEG (land regeneration-conversion to agriculture land under cultivation, initial total agriculture land)

Units: Ha

available food for consumption= Food Inventory/FOOD INVENTORY COVERAGE

Units: Tonnes/Year

AVERAGE HOUSEHOLD EXPENDITURE=7152

Units: Ghana cedi/Year

average household food need=AVERAGE HOUSEHOLD SIZE*PERCAPITA FOOD CONSUMPTION

Units: Tonnes/Year

AVERAGE HOUSEHOLD SIZE=7

Units: Person

average yield= (adopters share*YIELD POTENTIAL OF CLIMATE SMART SEED)+((1-adopters share)*YIELD POTENTIAL OF INDIGENOUS SEED)

Units: Tonnes/Ha/Year

"AVERAGE YIELD, INDIGENOUS CLIMATE INFORMATION"( [(2010,0)-(2014,0.7)],(2010,0.8),(2011,0.75),(2012,0.7),(2013,0.85),(2014,0.7))

Units: Dmnl

change in knowledge= ((indicated knowledge from cultivation indicated knowledge from scientific climate information -Knowledge From Cultivating Climate Smart Seed)/TIME TO ACQUIRE KNOWLEDGE)

Units: Dmnl/Year

change in trust in climate smart seed= ((indicated trust in climate smart seed-Trust In Climate Smart Seed)/TRUST ADJUSTMENT TIME)

Units: Dmnl/Year

change in trust in indigenous climate information= (indicated trust in indigenous climate information-Trust In Indigenous Climate Information)/TRUST ADJUSTMENT TIME

Units: Dmnl/Year

change in trust in indigenous seed= (indicated trust in indigenous seed-Trust In Indigenous Seed)/TRUST ADJUSTMENT TIME

Units: Dmnl/Year

change in trust in scientific climate information=((indicated trust in scientific climate information-Trust In Scientific Climate Information)/TRUST ADJUSTMENT TIME)

Units: Dmnl/Year

climate information adoption rate=(Indigenous Climate Information Coverage/TIME TO IMPLEMENT ADOPTION DECISION)*total climate information adoption potential

Units: Percent/Year

"climate information non-adopters share"=Indigenous Climate Information Coverage/MAXIMUM CLIMATE INFORMATION COVERAGE

Units: 1

climate information share of agriculture land under cultivation=Scientific Climate Information Coverage/TOTAL CLIMATE INFORMATION COVERAGE

Units: Dmnl

"climate-smart Seed Coverage"= INTEG (adoption rate-disadoption rate, INITIAL CLIMATE SMART SEED COVERAGE)

Units: Percent

comparative attractiveness climate smart seed=total attractiveness climate smart seed/(total attractiveness climate smart seed +total attractiveness indigenous seed)

Units: Dmnl

comparative attractiveness indigenous seed= total attractiveness indigenous seed/(total attractiveness indigenous seed+total attractiveness climate smart seed)

Units: Dmnl

consumption= MIN(desired subsistence household food consumption, available food for consumption

-minimum food sales)

Units: Tonnes/Year

conversion to agriculture land under cultivation=MIN(agriculture land gap, Available Agriculture Land/TIME TO ADJUST AGRICULTURE LAND)

Units: Ha/Year

"cost of climate-smart seed"=COST OF SEED TIME SERIES(Time)*SEED NEED PER HA

Units: Ghana cedi/Ha

cost of fertilizer=COST OF FERTILIZER TIME SERIES(Time)

Units: Ghana cedi/Ha

COST OF FERTILIZER TIME SERIES ([(2010,180)-(2017,402.5)],(2010,180),(2011,212.5),(2012,282.5),(2013,365),(2014,687.5),(2015,667.5),(2016,62), (2017,402.5))

Units: Ghana cedi/Ha

cost of indigenous seed=GRAIN PRICE PER TONNE(Time)*SEED NEED PER HA

Units: Ghana cedi/Ha

COST OF SEED TIME SERIES ([(2010,2500)-(2017,6000)],(2010,2500),(2011,3000),(2012,3000),(2013,3500),(2014,3500),(2015,4000),(2016,6000),(2017,6000))

Units: Ghana cedi/Tonnes

Degraded Agriculture Land= INTEG (agriculture land degradation-land regeneration, initial degraded agriculture land)

Units: Ha

desired agriculture land=desired total food/average yield

Units: Ha

desired subsistence household food consumption= average household food need*subsistence farmer households

Units: Tonnes/Year

desired total food= Total Population*PERCAPITA FOOD CONSUMPTION

Units: Tonnes/Year

disadoption potential from attractiveness of scientific climate information =EFFECT OF ATTRACTIVENESS OF DISADOPTION(attractiveness scientific climate information)

Units: Dmnl

disadoption potential from relative utility= comparative attractiveness indigenous seed

Units: Dmnl

disadoption potential from trust in indigenous seed=Trust In Indigenous Seed*WEIGHT ON TRUST

Units: 1

disadoption rate=("climate-smart Seed Coverage"/TIME TO DISADOPT)*total disadoption potential

Units: Percent/Year

disadoption rate of climate information=(Scientific Climate Information Coverage/TIME TO DISADOPT)*"total non-adoption potential"

Units: Percent/Year

EFFECT OF ADOPTION ON KNOWLEDGE ([(0,0.05)-(1,1)],(0,0.05),(0.165138,0.175),(0.29052,0.3625),(0.5,0.7),(0.746177,0.908333),(1,1))

Units: Dmnl

EFFECT OF ADOPTION ON TRUST ([(0,0)-(1,1)],(0,0),(0.088685,0.01),(0.149847,0.02),(0.207951,0.05),(0.302752,0.17),(0.412844,0.473684),(0.501529,0.741228),(0.574924,0.846491),(0.706422,0.934211),(0.810398,0.969298),(1,1))

Units: Dmnl

EFFECT OF ATTRACTIVENESS OF DISADOPTION([(0,0)-(1,1)],(0.0030581,0.921053),(0.131498,0.903509),(0.278287,0.776316),(0.385321,0.592105),(0.510703,0.359649),(0.681957,0.153509),(0.807339,0.0614035),(0.993884,0.00877193))

Units: Dmnl

effect of fertilizer prices on the attractiveness of seed= WITH LOOKUP (relative cost of fertilizer,
([(0,0)(4,1)],(0.0244648,0.899123),(0.954128,0.780702),(1.46789,0.394737),(2.15291,0.20614),(2.97248,0.0745614),(4,0) ))

Units: Dmnl

EFFECT OF HOUSEHOLD INCOME ON AFFORDABILITY ([(0,0)-(1,1)],(0,0),(0.088685,0.01),(0.149847,0.02),(0.207951,0.05),(0.302752,0.17),(0.412844,0.473684),(0.501529,0.741228),(0.574924,0.846491),(0.706422,0.934211),(0.816514,0.964912),(1,1))

Units: Dmnl

"EFFECT OF INPUT COST CLIMATE-SMART SEED ON ATTRACTIVENESS CLIMATE-SMART SEED"=1

Units: Dmnl

EFFECT OF INPUT COST OF INDIGENOUS SEED ON ATTRACTIVENESS OF INPUT COST([(0,0)-(1,1)],(-0.0030581,0.907895),(0.146789,0.868421),(0.269113,0.688596

),(0.400612,0.429825),(0.565749,0.175439),(0.785933,0.0745614),(0.993884,0.00877193))

Units: Dmnl EFFECT OF NON ADOPTION ON TRUST([(0,0)-(1,1)],(0,0),(0.088685,0.01),(0.149847,0.02),(0.207951,0.05),(0.302752,0.17),(0.412844,0.473684),(0.501529,0.741228),(0.574924,0.846491),(0.706422,0.934211),(0.813456,0.973684),(1,1))

Units: Dmnl

EFFECT OF SCIENTIFIC CLIMATE INFORMATION ON KNOWLEDGE([(0,0)(1,1)],(0,0),(0.11315,0.0833333),(0.192661,0.25),(0.324159,0.508772),(0.501529,0.719298),(0.740061,0.916667),(1,1))

Units: Dmnl

"EFFECT OF YIELD OF CLIMATE-SMART SEED ON ATTRACTIVENESS OF CLIMATE-SMARTSEED"([(0,0)(1,1)],(0.00611621,0.00438596),(0.250765,0.144737),(0.409786,0.390351),(0.556575,0.72807),(0.740061,0.907895),(0.993884,0.942982))

Units: Dmnl

EFFECT OF YIELD ON ATTRACTIVENESS OF SCIENTIFIC CLIMATE INFOMRATION([(0,0)-(1,1)],(0,0.00438596),(0.232416,0.118421),(0.409786,0.315789),(0.544343

,0.649123),(0.654434,0.780702),(0.810398, 0.894737),(0.993884,0.903509))

Units: Dmnl

EFFECTS OF YIELD OF INDIGENOUS SEED ON ATTRACTIVENESS INDIGENOUS SEED([(0,0)(1,1)],(0.00611621,0.00877193),(0.16208,0.0526316),(0.321101,0.135965),(0.452599,0.27193),(0.590214,0.574561),(0.779817,0.855263),(0.993884,0.907895))

Units: Dmnl

Food Inventory= INTEG (harvesting-consumption-selling, INITIAL FOOD INVENTORY)

Units: Tonnes

FOOD INVENTORY COVERAGE=1

Units: Year

FOOD INVENTORY TIME SERIES ([(2010,0)-(2014,14280)],(2010,9056),(2011,10950),(2012,14280),(2013,17850) ,(2014,14280))

Units: Tonnes

FRACTION OF FOOD SOLD= 0.6

Units: Dmnl

FRACTION OF LABOUR IN AGRICULTURE=0.7

Units: Dmnl

FRACTION OF LAND TO AGRICULTURE=0.57

Units: Dmnl

FRACTION OF POPULATION LABOUR FORCE=0.54

Units: Dmnl

FRACTIONAL POPULATION GROWTH RATE=0.0137

Units: Dmnl/Year

GRAIN PRICE PER TONNE ([(2010,140.19)-(2015,941.45)],(2010,140.19),(2011,216.6),(2012,274.15),(2013,690.59),(2014,930.68),(2015,941.45)

Units: Ghana cedi/Tonnes

growth rate=Total Population*FRACTIONAL POPULATION GROWTH RATE

Units: Person/Year

harvesting=Agriculture Land Under Cultivation*average yield

Units: Tonnes/Year

indicated knowledge from cultivation=EFFECT OF ADOPTION ON KNOWLEDGE (adopters share)

Units: Dmnl

indicated knowledge from scientific climate information=EFFECT OF SCIENTIFIC CLIMATE INFORMATION ON KNOWLEDGE (climate information share of agriculture land under cultivation)

Units: Dmnl

indicated trust in climate smart seed=EFFECT OF ADOPTION ON TRUST(adopters share)

Units: Dmnl

indicated trust in indigenous climate information=EFFECT OF NON ADOPTION ON TRUST("climate information non-adopters share")

Units: Dmnl

indicated trust in indigenous seed=EFFECT OF NON ADOPTION ON TRUST(non adopters share)

Units: Dmnl

indicated trust in scientific climate information=EFFECT OF ADOPTION ON TRUST(climate information share of agriculture land under cultivation)

Units: Dmnl

Indigenous Climate Information Coverage= INTEG (disadoption rate of climate information-climate information adoption rate,initial indigenous climate information coverage)

Units: Percent

Indigenous Seed Coverage= INTEG (disadoption rate-adoption rate,initial indigenous seed coverage)

Units: Percent

INITIAL AGRICULTURE LAND UNDER CULTIVATION= INITIAL( AGRICULTURE LAND UNDER CULTIVATION TIME SERIES(Time))

Units: Ha

INITIAL ANNUAL HOUSEHOLD REVENUE SURPLUS= INITIAL(annual total household revenue surplus)

Units: Ghana cedi/Year

INITIAL CLIMATE SMART SEED COVERAGE=19

Units: Percent

"INITIAL COST CLIMATE-SMART SEED"= INITIAL("cost of climate-smart seed")

Units: Ghana cedi/Ha

INITIAL COST INDIGENOUS SEED PER HA= INITIAL(cost of indigenous seed)

Units: Ghana cedi/Ha

INITIAL COST OF FERTILIZER= INITIAL(cost of fertilizer)

Units: Ghana cedi/Ha

initial degraded agriculture land=INITIAL AGRICULTURE LAND UNDER CULTIVATION*0.025

Units: Ha

INITIAL FOOD INVENTORY=9056

Units: Tonnes

initial indigenous climate information coverage=100-initial scientific climate information coverage

Units: Percent

initial indigenous seed coverage=100-INITIAL CLIMATE SMART SEED COVERAGE

Units: Percent

INITIAL KNOWLEDGE FOR CULTIVATING CLIMATE SMART SEED=0.2

Units: Dmnl

initial scientific climate information coverage=INITIAL CLIMATE SMART SEED COVERAGE

Units: Percent

initial total agriculture land=total land for agriculture-INITIAL AGRICULTURE LAND UNDER CULTIVATION

Units: Ha

INITIAL TOTAL POPULATION=130003

Units: Person

initial trust in climate information=INITIAL TRUST IN CLIMATE SMART SEED

Units: Dmnl

INITIAL TRUST IN CLIMATE SMART SEED=0.04

Units: Dmnl

initial trust in indigenous climate information=1-initial trust in climate information

Units: Dmnl

initial trust in indigenous seed=1-INITIAL TRUST IN CLIMATE SMART SEED

Units: Dmnl

"INITIAL YIELD CLIMATE-SMART SEED"= INITIAL(yield climate smart seed)

Units: Tonnes/(Year*Ha)

INITIAL YIELD INDIGENOUS CLIMATE INFORMATION= INITIAL("AVERAGE YIELD, INDIGENOUS CLIMATE INFORMATION"(Time))

Units: Dmnl

Knowledge From Cultivating Climate Smart Seed= INTEG (change in knowledge,

INITIAL KNOWLEDGE FOR CULTIVATING CLIMATE SMART SEED)

Units: Dmnl

labour force in agriculture=total labour force*FRACTION OF LABOUR IN AGRICULTURE

Units: Person

land regeneration=Degraded Agriculture Land/AGRICULTURE LAND FALLOW PERIOD

Units: Ha/Year

MAXIMUM CLIMATE INFORMATION COVERAGE=100

Units: Percent

MAXIMUM CLIMATE SEED COVERAGE=100

Units: Percent

minimum food sales=available food for consumption*FRACTION OF FOOD SOLD

Units: Tonnes/Year

non adopters share=Indigenous Seed Coverage/TOTAL LAND AREA

Units: Dmnl

"non-adoption potential from trust in indigenous climate information"=Trust In Indigenous Climate Information*WEIGHT ON TRUST

Units: 1

PERCAPITA FOOD CONSUMPTION=0.32

Units: Tonnes/Person/Year

potential adoption form trust in scientific climate information=Trust In Scientific Climate Information*WEIGHT ON TRUST

Units: Dmnl

potential adoption from relative utility of scientific climate information=attractiveness scientific climate information

Units: Dmnl

potential adoption from relative utility of seed=(comparative attractiveness climate smart seed)

Units: Dmnl

"price attractiveness climate-smart seed"="EFFECT OF INPUT COST CLIMATE-SMART SEED ON ATTRACTIVENESS CLIMATE-SMART SEED"*"relative cost climate-smart seed per ha"

Units: Dmnl

price attractiveness of indigenous seed=EFFECT OF INPUT COST OF INDIGENOUS SEED ON ATTRACTIVENESS OF INPUT COST(relative cost indigenous seed per ha)

Units: Dmnl

reference agriculture land under cultivation=AGRICULTURE LAND UNDER CULTIVATION TIME SERIES(Time)

Units: Ha

reference average yield=REFERENCE AVERAGE YIELD TIME SERIES(Time)

Units: Tonnes/(Ha*Year)

REFERENCE AVERAGE YIELD TIME SERIES([(2010,0)-(2014,1.4)],(2010,1.6),(2011,1.5),(2012,1.4),(2013,1.7),(2014,1.4))

Units: Tonnes/(Ha*Year)

reference food inventory=FOOD INVENTORY TIME SERIES(Time)

Units: Tonnes

"relative cost climate-smart seed per ha"=("cost of climate-smart seed"/"INITIAL COST CLIMATE-SMART SEED")

Units: Dmnl

relative cost indigenous seed per ha=(cost of indigenous seed/INITIAL COST INDIGENOUS SEED PER HA)/100

Units: Dmnl

relative cost of fertilizer=(cost of fertilizer/INITIAL COST OF FERTILIZER)

Units: Dmnl

relative household revenue surplus=(annual total household revenue surplus/INITIAL ANNUAL HOUSEHOLD REVENUE SURPLUS)

Units: Dmnl

"relative yield climate-smart seed"=yield climate smart seed/"INITIAL YIELD CLIMATE-SMART SEED"

Units: 1

relative yield indigenous seed=("AVERAGE YIELD, INDIGENOUS CLIMATE INFORMATION"(Time)/INITIAL YIELD INDIGENOUS CLIMATE INFORMATION)/100

Units: Dmnl

remaining food for sale=MAX(0,available food for consumption-consumption-minimum food sales )

Units: Tonnes/Year

revenue from the sale of food crops=GRAIN PRICE PER TONNE(Time)*selling

Units: Ghana cedi/Year

Scientific Climate Information Coverage= INTEG (climate information adoption rate-disadoption rate of climate information, initial scientific climate information coverage)

Units: Percent

SEED NEED PER HA=0.025

Units: Tonnes/Ha

selling=minimum food sales + remaining food for sale

Units: Tonnes/Year

subsistence farmer households=labour force in agriculture/AVERAGE HOUSEHOLD SIZE

Units: 1

TIME TO ACQUIRE KNOWLEDGE=10

Units: Year

TIME TO ADJUST AGRICULTURE LAND=10

Units: Year

TIME TO DISADOPT=4

Units: Year

TIME TO IMPLEMENT ADOPTION DECISION=1

Units: Year

total adoption potential=adoption potential from trust in climate smart seed*potential adoption from relative utility of seed*affordability

Units: Dmnl

total annual household revenue=total annual household revenue from other sources+ total household revenue from the sale of food crop

Units: Ghana cedi/Year

total annual household revenue from other sources= ANNUAL HOUSEHOLD REVENUE FROM OTHER SOURCES PER HOUSEHOLD*subsistence farmer households

Units: Ghana cedi/Year

total attractiveness indigenous seed= effect of fertilizer prices on the attractiveness of seed*(price attractiveness of indigenous seed+ yield attractiveness indigenous seed)

Units: Dmnl

total attractivteness climate smart seed= effect of fertilizer prices on the attractiveness of seed*("price attractiveness climate-smart seed"+"yields attractiveness climate-smart seed")

Units: Dmnl

total climate information adoption potential= affordability*potential adoption from relative utility of scientific climate information*potential adoption form trust in scientific climate information

Units: Dmnl

TOTAL CLIMATE INFORMATION COVERAGE=100

Units: Percent

total disadoption potential= (disadoption potential from trust in indigenous seed*disadoption potential from relative utility)

Units: Dmnl

TOTAL DISTRICT LAND AREA=

123000

Units: Ha

Total Land Area of GTD= 123000ha

total household expenditure=AVERAGE HOUSEHOLD EXPENDITURE*subsistence farmer households

Units: Ghana cedi/Year

total household revenue from the sale of food crop=revenue from the sale of food crops*subsistence farmer households

Units: Ghana cedi/Year

total labour force=Total Population*FRACTION OF POPULATION LABOUR FORCE

Units: Person

TOTAL LAND AREA=100

Units: Percent

total land for agriculture=TOTAL DISTRICT LAND AREA*FRACTION OF LAND TO AGRICULTURE

Units: Ha

"total non-adoption potential"="non-adoption potential from trust in indigenous climate information"*disadoption potential from attractiveness of scientific climate information

Units: Dmnl

Total Population= INTEG (growth rate,INITIAL TOTAL POPULATION)

Units: Person

TRUST ADJUSTMENT TIME=5

Units: Year

Trust In Climate Smart Seed= INTEG (change in trust in climate smart seed, INITIAL TRUST IN CLIMATE SMART SEED)

Units: Dmnl

Trust In Indigenous Climate Information= INTEG (change in trust in indigenous climate information, initial trust in indigenous climate information)

Units: Dmnl

Trust In Indigenous Seed= INTEG (change in trust in indigenous seed, initial trust in indigenous seed)

Units: Dmnl

Trust In Scientific Climate Information= INTEG (change in trust in scientific climate information, initial trust in climate information)

Units: Dmnl

WEIGHT ON TRUST= 0.33

Units: Dmnl

yield attractiveness indigenous seed=EFFECTS OF YIELD OF INDIGENOUS SEED ON ATTRACTIVENESS INDIGENOUS SEED (relative yield indigenous seed)

Units: Dmnl

yield climate smart seed= (Knowledge From Cultivating Climate Smart Seed*YIELD POTENTIAL OF CLIMATE SMART SEED)

Units: Tonnes/Ha/Year

YIELD POTENTIAL OF CLIMATE SMART SEED=5

Units: Tonnes/Ha/Year

YIELD POTENTIAL OF INDIGENOUS SEED=0.8

Units: Tonnes/Ha/Year

"yields attractiveness climate-smart seed"="EFFECT OF YIELD OF CLIMATE-SMART SEED ON ATTRACTIVENESS OF CLIMATE-SMART SEED"("relative yield climate-smart seed")

Units: Dmnl

## APPENDIX III: PHOTOGRAPHS OF FIELD WORK