THE EFFECT OF CLIMATE CHANGE ON SORGHUM YIELD IN THE TESO FARMING SYSTEM

By

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DECLARATION

This study is original and has not been submitted for any other degree award to any other University before.

Sign; ………………………………………….. Date;……………………………………….

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DEDICATION

This piece of work is dedicated to; my guardian Mrs Racheal Nakalema-Nsamba, my late mother Ms Deziranta Kayaga, my dear husband Mr. Kawooya Ronald, and my son Raamiah Victor Kawooya.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ECHAM	European Center Hamburg Model
GCM	Global Climate Model
IPCC	Intergovernmental Panel for Climate Change
PRECIS	Providing Regional Climates for Impacts Studies
RCM	Regional Climate Model
SRES	Special Report on Emissions
NAPA	National Adaptation Program of Actions
TESO FARMING SYSTEM	Teso Farming System
MAM	March, April and May
SON	September, October and November

ABSTRACT

Climate change is a serious environmental and livelihood challenge in Uganda, with the poor agro-based communities in the semi-arid areas being particularly more vulnerable. However, there is paucity of knowledge and information on the climate change impact on yields of major and key food security crops in the semi-arid zones of Uganda. Yet, this information is important in designing appropriate adaptive and coping practices to climate change. The thrust of this study was to assess the climate change impact on the yields of sorghum in the Teso farming system of Uganda. This study entailed a multiplicity of methods; first, a Regional Climate Model, PRECIS was used to downscale a Global Climate Model, ECHAM, and elicit projected future climate conditions for the study area. A crop model, AquaCrop, was then used to simulate sorghum yields under the projected climate regimes. The AquaCrop model was validated using observed sorghum yields of the *Edeidei* and *Serena* varieties based on the current climatic conditions. In addition to the simulations, household interviews and focus group discussions were undertaken to find out the farmers' perceptions of climate change, impact of climate change on crop production, and to analyze the coping and adaptive practices of the communities. The results from the study revealed that climate change, by the year 2040, will generally result in; 1) average increase in annual rainfall of 5%, and in terms of seasonal distribution, rainfall is expected to reduce for the first season (MAM), and increase for season the second season (SON); 2) average drop in annual minimum/maximum temperatures of 0.3^oC /1.0^oC respectively. These changes are expected to result in average increase in sorghum grain yield in the study area of 25% to 35% by the year 2040. Grain yield will increase for both seasons of the year except for season 1 of the year 2019, when the seasonal rainfall is expected to reduce by over 6%. Thus, climate change generally presents benefits to sorghum grain yields in this area, rather than risks as reported for most parts of the world, according to the climate models and climate change scenario used. Therefore, efforts/policies should be put in place to ensure maximum exploitation of this expected benefit. The results of the socio-economic survey showed that 100% of the respondents think the climate is changing, with change in seasons being one of the greatest indicators cited. High crop failure, reduction in yields and destruction of crops by unpredictable weather were the major impacts of climate change on crop production mentioned. The existing adaptation practices in the Teso farming system were found to be effective, although requiring external support such as climate information and free/subsidized improved seed. However, some coping practices employed are ineffective and/or have negative effects on the people's well-being ,and thus, can not be relied on to help members cope with the possible negative effects of climate change. Therefore, development projects, such as provision of micro-credit, to help farmers come up with alternative livelihood sources, should be conducted in this area to improve the farmers' resilience.

Key words: *Climate change, sorghum yields, Teso farming system.*

CHAPTER ONE – INTRODUCTION

1.1 Background of the study

Global awareness and recognition of climate change has grown significantly over the past several years. Sub-Saharan Africa in general and Uganda in particular, are vulnerable to the adverse impacts of climate change and variability because their economies are tightly bound to climate (Houghton *et al.,* 2001; IPCC, 2007c; Lukwiya, 2009). Agriculture is a major Gross Domestic Product (GDP) contributing sector of Uganda's economy (Nandozi *et al*., 2012). In 2001, the Intergovernmental Panel for Climate Change (IPCC) provided strong evidence of accelerating global warming (IPCC, 2001), and in 2005, the same panel reported that warming was expected to continue, with an increase in globally averaged temperatures of between 1.4 and 5.8° C, which would be 2-10 times larger than observed warming in the 20th century (IPCC, 2005). Certainly, evidence of changes in climate extremes, particularly with regard to temperature, was already emerging in Southern and West Africa by the year 2006 (New *et al*., 2006). In 2007, IPCC noted that most of the warming over the past 50 years is a result of greenhouse gas (GHG) emissions caused by human activity (IPCC, 2007c). It is now agreed with evidence that, even with current climate change mitigation policies and related sustainable development practices, global GHG gas emissions will continue to grow over the next few decades causing further warming and inducing many changes in the global climate system (IPCC, 2007c). With such sureness that the Earth's climate is changing and that significant warming is inevitable regardless of future emission reductions, it has become progressively more important to identify potential vulnerabilities and adaptive responses in managed ecosystems (Howden *et al*., 2007). 'Adaptation to climate change is therefore no longer a secondary and long-term response alternative only to be considered as a last resort; it is now prevalent and crucial, and for those communities already vulnerable to the impacts of present day climatic hazards, an urgent imperative' (IISD, 2003).

The negative effects of climate change on crop production are especially pronounced in Sub-Saharan Africa, as the agricultural sector accounts for a large share of GDP (32%), export earnings, and employment (65%) in most of these countries and, the vast majority of the poor reside in rural areas and depend on agriculture for their livelihoods (IFPRI, 2009); and further, because these countries suffer from weak economies and lack of technology that make it difficult for them to adapt to the adverse effects of climate change (IPCC, 2007a). In Uganda, where there is widespread reliance on rain-fed agriculture (approximately 80%), climate change poses adverse impacts on livelihoods, especially of the rural poor, who depend on agriculture for food and income**.** Uganda's National Adaptation Program of Actions (NAPA) suggests a trend of increasing frequency of drought events and also increased rainfall variability in the country, linking them to climate change (Ministry of Water and Environment, 2007). According to Hepworth and Goulden (2008), GCM generated data shows that temperatures are likely to increase in Uganda by up to 1.5 ºC in the next 20 years and by up to 4.3 ºC by the 2080s; changes in rainfall patterns and total annual rainfall amounts are also expected but these are less certain than changes in temperature. Regardless of changes in rainfall, changes in temperature are likely to have significant implications for water resources and food security. Hence, to reduce vulnerability to the deleterious effects of climate change on crop production in this region, adaptation plans including drought mitigation technologies and early warning systems need to be put in place. However, successful development of adaptation practices requires site specific information and knowledge on climate change impacts.

The IPCC report of 2007 reveals that the poor agro-based communities in the dryland areas are particularly more vulnerable to the adverse effects of climate change and climate variability (IPCC, 2007a). Such areas rely totally on rain-fed agriculture or pastoralism for their livelihoods, and yet usually suffer from droughts and floods, whose frequency and intensity could be increased by climate change and climate variability. These climate extremes are disastrous to crop and livestock production, thus endangering the livelihoods of the communities. The semi-arid regions in Uganda are therefore extremely likely to suffer greatly from climate change and climate variability. Despite this threat, there is paucity of studies addressing climate change impacts on yields of key food security crops in these regions. The thrust of this study was to assess the impact of climate change on sorghum yields in the Teso farming system, which is one of the semi-arid regions of Uganda.

1.2 Statement of the problem

Despite the fact that over 80% of livelihoods in the Teso farming system are agro-based; the expected impact of climate change on the yields of key crops crucial to food security in this system is not fully understood. Yet, this information is needed in the design of appropriate climate change adaptation and mitigation measures. Most of the available information is obtained from Global Climate Models (GCMs) which are run at coarse spatial resolutions (typically of the order 50,000 square kilometers). The coarse spatial resolutions make these models too ambiguous and hence unfit for local impact studies or for informing policy.

An effort was made by Wasige (2009) to study the effect of climate change on crop yields in Uganda but this was based on the GCM predicted temperature increases of 1.3 ^{o}C and 4.5^{o}C, and thus not very accurate, and his study also focused on maize only, which is not commonly grown in the Teso farming system. Further, Nandozi *et al*., 2012 carried out a regional climate model performance and prediction of seasonal rainfall and surface temperature for Uganda; this study revealed that temperatures are going to be considerably warmer over most parts of Uganda for 2071-2100 periods. However, this study did not provide the impact of the warmer temperatures on the yield of major food crops in Uganda. Therefore, there is a need to clearly understand the impact of climate change on the yields of important crops in the Uganda's highly climate change prone areas such as the Teso farming system, so as to facilitate the formulation of interventions and policy options to improve the adaptation capacities of the communities.

1.3.0 Objectives

1.3.1 General objective

To contribute to improved understanding of climate change impacts on cereal crops and adaptation to climate change in the semi-arid regions of Uganda.

1.3.2 Specific objectives

1. To assess the effect of climate change on yields of selected sorghum varieties in the Teso farming system.
2. To assess community perceptions of the impact of climate change on crop production in the Teso farming system.
3. To assess the existing coping and adaptation practices to climate change in the Teso farming system.

1.4 Hypotheses

1. Climate change will result in a 20% change in sorghum grain yield in the Teso farming system by the year 2040.

2. The community perceptions of the impact of climate change on crop production in the Teso farming system are not known
3. The existing coping practices to climate change in the Teso farming system are not known

1.5 Significance of the study

The changing climate is exacerbating existing vulnerabilities of the poorest people who depend on subsistence agriculture for their survival (Slingo *et al*., 2005; Nelson *et al*., 2009). This study was to contribute to improved understanding of climate change impacts in the semi-arid regions of Uganda. These areas are usually agro-pastoral with rural communities heavily dependent for their livelihoods on subsistence mixed annual cropping and livestock production. The poverty level in the Teso Sub region in Uganda is currently 40 percentage points compared to 20 percentage points poverty level in the Central and Western regions of Uganda (Uganda Bureau of Statistics, 2002; 2005). The Teso sub region was severely hit by two natural disasters in 2008, these included flooding and drought (Iteso Development Forum, 2009; Affarmative Action for Teso., 2011). The flooding caused economic loss and destruction of farm lands with an estimated 8,500 acres of crop being destoryed. Severe drought also hit the Teso sub region during the same period and it consequently meant having too little water to meet the intended needs, a condition that became difficult for both animals and humans resulting into health, social, and economic impacts with far reaching cosequences (Iteso Development Forum., 2009; Affarmative Action for Teso., 2011).

The information and knowledge obtained in this study are key to crafting necessary measures to build the resilience of communities in the area and are crucial in enhancing the National Adaptation Program of Actions (NAPA) which the government of Uganda has been developing overtime. The Government of Uganda is focusing on structural transformation of the economy and thus promotes economic growth, employment and prosperity in the National Development Plan (2010-2014). By working to achieve the outcomes jointly agreed between the Government and other partners such as the United Nations, efforts will be made to contribute to further integration of population dynamics and climate change concerns into the development process, thus accelerating progress towards reaching the Millennium Development Goals (MDGs) nationwide (United Nations, 2010 – 2014)

1.6 Justification

The study was justified based on the following;

- There is paucity of information and knowledge on climate change impacts on yields of key food security crops such as sorghum in the Teso farming system. This study was therefore meant to provide information required to in inform policy for improved adaptation.
- The perceptions of the people in the Teso farming system about climate change are not clearly understood, yet these affect the adaptation measures that the communities may adopt. This study was to unveil these perceptions.
- Little is known about the adaptation practices being employed by households in response to climate change shocks in the Teso farming system, and the effectiveness of such practices. This study was also meant to identify these practices, assess their effectiveness, and suggest possible options in a bid to improve adaptation to climate change.

1.7 Conceptual framework

In systems that are reliant on rainfall as the sole source of moisture for crop growth, climate change is inevitably mirrored in changed production levels. Some of the underlying causes of yield reduction as a result of climate change are illustrated in the conceptual framework below (Figure 1).

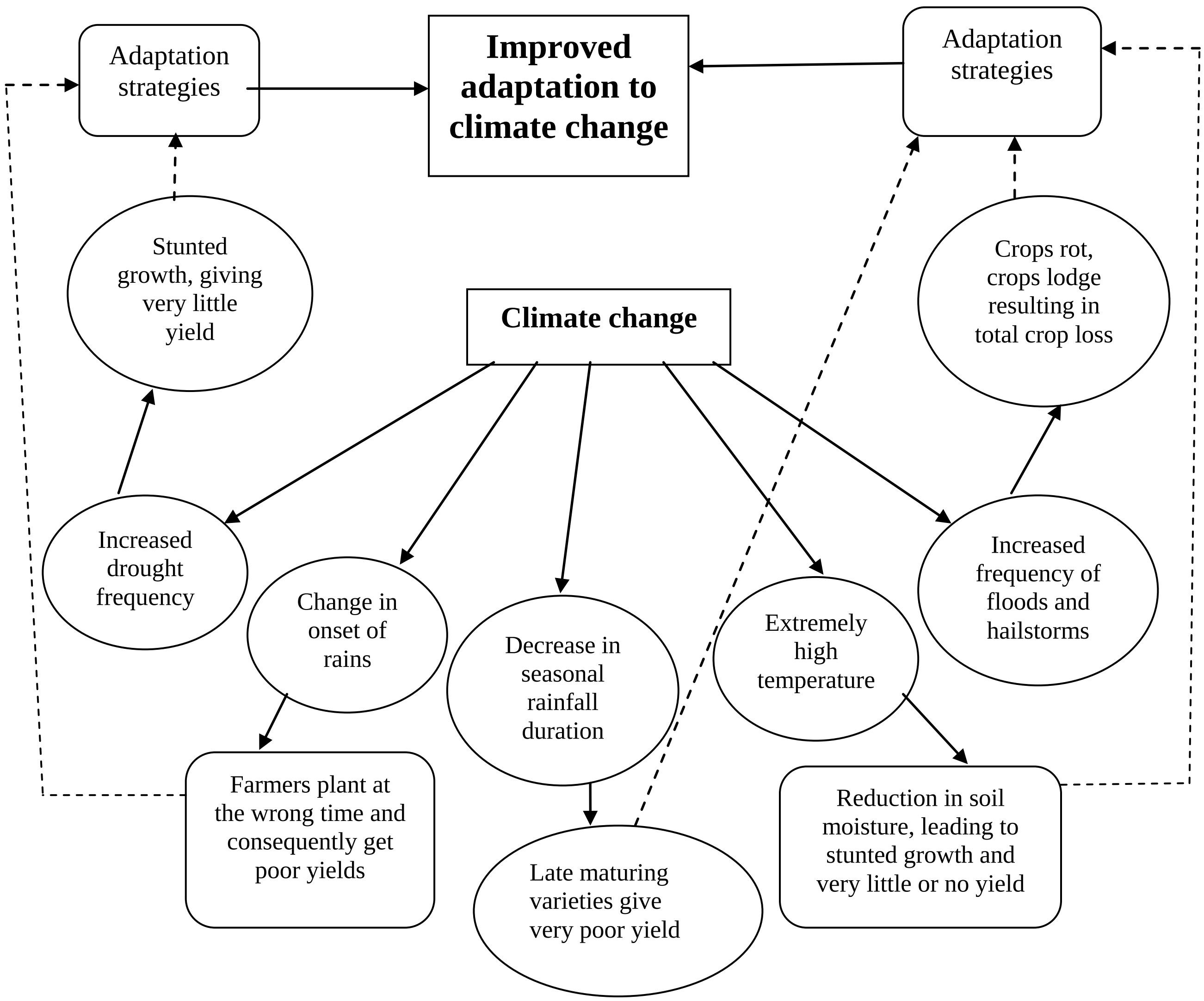


Figure 1: Conceptual framework for the study

Appropriate practices, such as; breeding for early maturing varieties, changing planting date, use of organic matter to conserve moisture, practicing irrigation, breeding for varieties with high water use efficiency and those which can tolerate moist conditions in case of floods, are some of the adaptive options that could improve the communities' adaptation to climate change, and consequently give assurance for survival (Figure 1).

1.8 Scope of the study

Spatially, the study covered the Teso farming System which comprises of eight districts, namely; Soroti, Katakwi, Kumi, Amuria, Bukedea, Kaberamaido, Ngora and Serere. It was however confined to Soroti district. In terms of the scientific scope, the study was confined to; i) quantification of sorghum grain yields under current climatic conditions, ii) downscaling and projecting future climatic conditions, iii) simulating changes in sorghum grain yields owing to the changed climatic conditions, and iv) assessing community perceptions of climate change and the effectiveness of the existing coping practices. The temporal scope of the study entailed two seasons for the experimental work, while the projections of future climate and yield covered a period of 14 selected years from 2016-2040.

CHAPTER TWO - LITERATURE REVIEW

2.1 Definition of climate change

“Climate change” refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer- It refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007e). And, according to the United Nations Framework Convention on Climate Change (UNFCCC), “Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFCCC, 2013).

2.2 Evidence of climate change

Over the previous 100 years (1900-2000), the temperature of the earth’s surface has risen (Figure 2), and most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic green has gas concentrations (IPCC, 2007c).

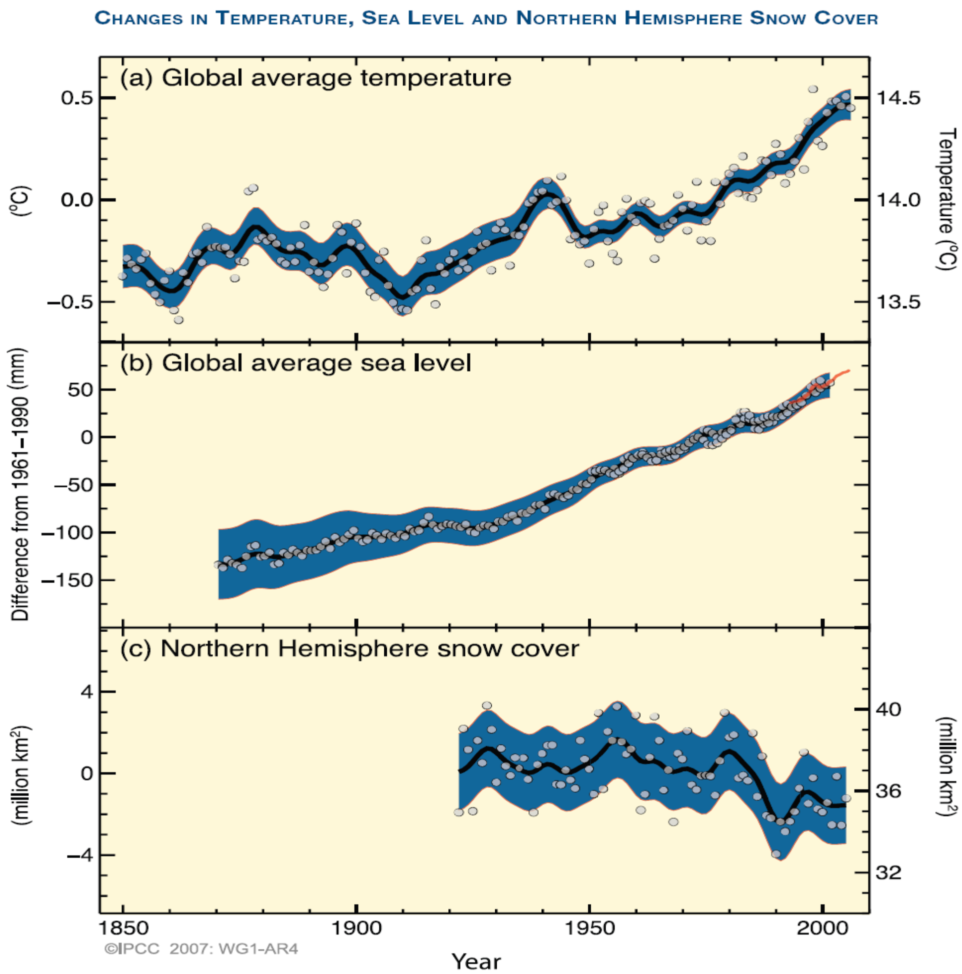


Figure 2: Observed changes in (a) global average surface temperature, (b) global average sea level, and c) Northern Hemisphere snow cover for March-April. Smoothed curves represent decadal average values while circles show yearly values. Source; IPCC 2007c.

According to IPCC (2007c), carbon dioxide is the most important anthropogenic greenhouse gas; the global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. An increase in greenhouse gas emissions was also unfolded by Olivier *et al*., 2006. It is now agreed with evidence that, even with current climate change mitigation policies and related sustainable development practices, global greenhouse gas emissions will continue to grow over the next few decades (IPCC, 2007b). The continued greenhouse gas emissions at or above current rates (379 ppm in 2005) would cause further warming (Figure 3) and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

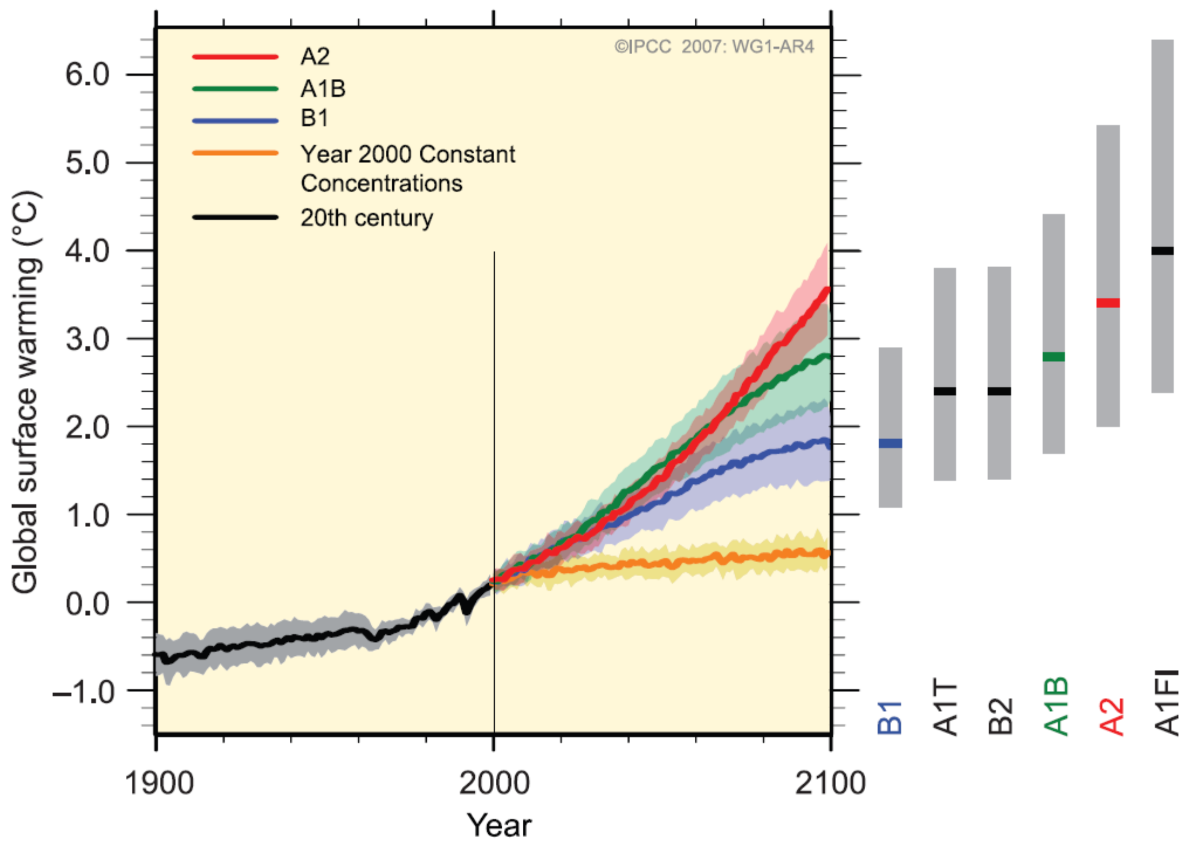


Figure 3: The expected increase in global surface temperatures by the year 2100: Solid lines are multi-model global averages of surface warming for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios.
(Source: IPCC, 2007c).

Model experiments have shown that even if all radiative forcing agents were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1°C per decade, due mainly to the slow response of the oceans, while about twice as much warming (0.2°C per decade) would be expected if emissions are within the range of the IPCC

SRES (IPCC Special Report on emissions) scenarios (IPCC, 2007c). Furthermore, estimates of global average surface temperature rise by the year 2095 range from 1.8 to 4.0°C, while increases in the amount of precipitation are expected in high latitudes and decreases of 20% are likely in most subtropical land regions by 2100. Therefore, climate change is a serious issue that requires our immediate attention, in order to ensure survival of the human race.

2.3 Climate change and variability in semi-arid areas

Climate change and variability are probably the biggest contemporary threats to agricultural productivity in the Sub Saharan Africa (SSA) region (Kabat *et al*., 2003). The poor agro-based communities in SSA are expected to suffer most from climate change impacts due to over reliance on rain-fed agriculture or pastoralism for their livelihoods (Cooper *et al*., 2008), and the low adaptive capacities resulting from weak economies and lack of technology (Nkomo *et al*., 2006). Studies show that mean rainfall amounts of the arid and semi-arid areas of SSA have steadily decreased (Hulme, 1992). Huq (2003) reported that deterioration of the physical, chemical and biological capacity of the soils owing to climate change is generally expected to increase in the semi-arid areas, worsening the threat presented by climate change to agricultural productivity in these areas. If this climate trend continues, it is likely to exacerbate the already precarious ecologically stressed dryland regions and undermine the ongoing poverty eradication efforts spelt out in the Poverty Eradication Action Plan (PEAP) for the case of Uganda, as well as realization of the Millennium Development Goal (MDG) targets for most SSA governments. The major semi-arid region in Uganda, of which the Teso farming system is part, is classified as "agro-pastoral", in Uganda's agro-ecological zoning. The inhabitants of this region depend primarily on the land resource and derive their livelihoods from cattle rearing and annual cropping (Orindi and Eriksen, 2005). The region is a predominantly small holder, rural poor, subsistence farming system, with largely rain-fed agriculture. Because of this agro-based structure, coupled with the frequent climate variability which often leads to either drought or flood incidences, the agricultural productivity of the region is likely to potentially suffer greatly from the added burden of climate change (McGuigan, *et. al* 2002). Therefore, there is a compelling need to understand the agricultural sensitivity of this region to climate change, so as to aid the formulation of interventions to enhance the adaptive capacities of the communities.

2.4 Adaptation and coping to climate change

Coping refers to the means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster, (In general, this involves managing resources, both in normal times as well as during crises or adverse conditions. And, the strengthening of coping capacities usually builds resilience to withstand the effects of natural and human-induced hazards. (UN/ISDR, 2004). On the other hand, adaptation refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC TAR, 2001 a). Coping is sometimes used as a synonym for adaptation; however coping measures are generally short-term actions to ward off immediate risk, rather than to adjust to continuous or permanent threats or changes. In some cases, coping practices can in fact deplete assets such that recurrent hazards pose a higher risk. It is therefore important to distinguish between coping and adapting.

Ability to adapt at country, community or household level is characterized as adaptive capacity and is related to the assets that one has access to, and how well these are used (Hepworth and Goulden, 2008). Therefore, knowledge about how people have responded to past climate shocks such as floods and droughts is useful in understanding how to approach vulnerability reduction or in understanding where adaptation support should be prioritized. Hepworth and Goulden (2008) noted that households may adapt to climate change by diversifying their livelihoods whilst others depended on social bonds; however, a diverse mix of livelihood activities may not, on their own, be enough to provide a household with resilience to climatic stresses, partly because the majority of alternative livelihood activities are dependent on natural resources either directly or indirectly, which are also heavily influenced by climate. This indicates that there's need to deeply understand the existing coping and adaptation practices of a given community in order to assess the potential of such a community to adapt to expected future impacts of climate change on their communities.

2.5.0 Sorghum climatic requirements

2.5.1 Water requirement

Sorghum water use is mainly affected by its growth stages and environmental demands. Varietal differences in water use also exist (Kidabi *et al*., 1990) because of differences in growth habit and maturity. For high production, a medium-to-late maturing sorghum cultivar (maturity within 110 to 130 days) requires approximately 450 to 650 mm of water during a growing season (Tolk and Howell, 2001). However, the daily requirement varies greatly depending on the growth stage (Figure 4).

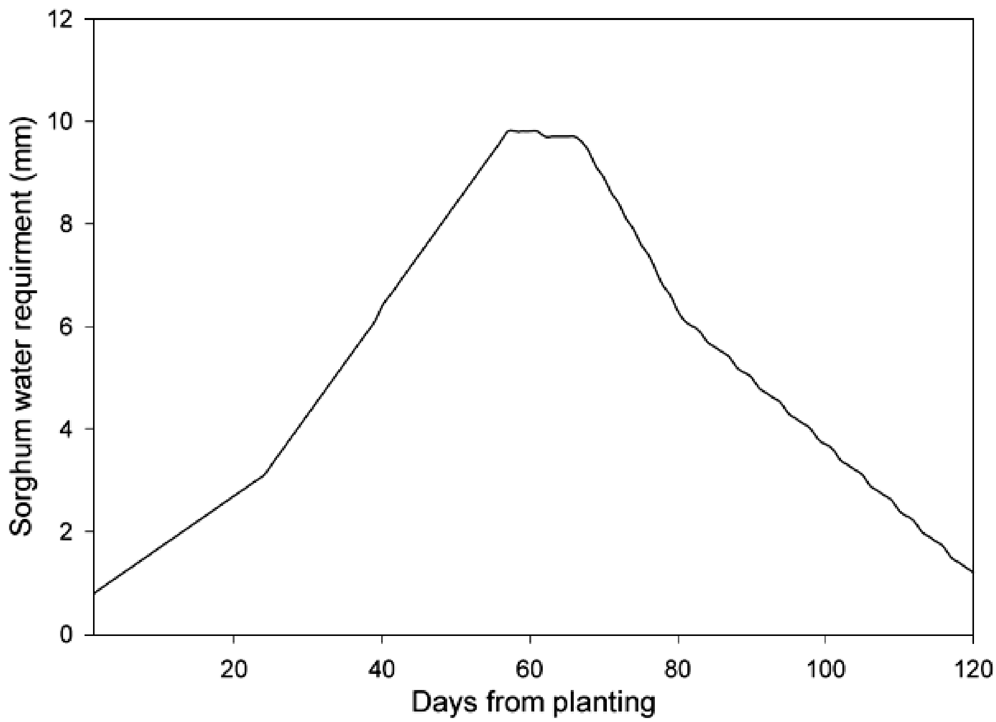


Figure 4: A hypothetical daily water requirement of grain sorghum maturing in 120 days from planting. Source: Stichler and Fipps, 2003.

Early in the growing season, average daily water use is low; approximately 1 to 2.5 mm/day could be enough to avoid water stress. This period is roughly the first 25 to 30 days (up to approximately the 7-leaf stage). The water requirement then increases to around 7 to 10 mm/day until the boot stage. Maximum daily water use occurs from the boot stage until after anthesis. The daily water requirement then decreases gradually during grain fill as the crop begins to senesce leaves and mature (Stichler and Fipps, 2003).

2.5.2 Temperature requirement

Differences occur in the critical temperature ranges for life cycle development for various crop species. There is a base temperature for vegetative development, at which growth commences, and an optimum temperature, at which the plant develops as fast as possible. Rising temperature generally accelerates progression of a crop through its life cycle (phenological) phases, up to a species-dependent optimum temperature. Beyond this optimum temperature, development (node and leaf appearance rate) slows. Maiti (1996) suggested that the optimum temperature for sorghum vegetative growth is between 26ºC and 34ºC, and for reproductive growth, 25ºC and 28ºC. It should be noted, however, that optimum values of temperature proposed for sorghum crop development are contradictory among different authors, and there are differences between genotypes.

2.6.0 Sorghum responses to changes in climatic factors

2.6.1 Response to water stress

As with all crops, sorghum grain yield is dependent on water supply (soil water at planting and in-season precipitation). A summary of 30 years of data indicated that every millimeter of water above 100 millimeter resulted in an additional 16.6 kg of grain (Stone *et al*., 2006). However, the relationship between grain yield and water is complex because yield is more sensitive to water deficits at certain growth stages (Garrity *et al*., 1982). Therefore, grain yield is more dependent on rainfall or irrigation well distributed over the growing season depending on demand at each stage than on total water available through the growing season. Howell and Hiler (1975) reported that yield response of grain sorghum was not strongly correlated to seasonal evapotranspiration but was highly dependent on timing of the evapotranspiration deficit.

Sorghum can tolerate short periods of less severe water deficit. However, long-term and severe stress can affect sorghum growth and the final yield. Eck and Musick (1979) studied effect of various periods of water stress on irrigated grain sorghum at early boot, heading, and early grain filling stages. Their report indicated that 13 to 15 days of stress did not affect grain yield. A 27-

to 28-day stress, however, reduced yield at early boot, heading, and early grain fill by 27, 27, and 12%, respectively. Stress period of 35 and 42 days beginning at boot stage reduced yield by 43 and 54%, respectively. Lewis *et al*. (1974) showed that a soil water potential drop to −13 bars from late vegetative to boot stage reduced grain sorghum yield by 17%. The same water potential drop from boot to bloom and milk through soft dough stages caused 34 and 10% yield reductions, respectively. Inuyama *et al*. (1976) reported 16 and 36% yield reduction due to 16 days and 28 days of water deficit, respectively, during the vegetative stage of sorghum. In the same study, 12 days of water deficit during boot stage resulted in 36% yield reduction. Withholding 100 millimeter of irrigation water at the early 6- to 8- leaf stage and at heading and bloom reduced sorghum grain yield by about 10 and 50%, respectively (Jordan and Sweeten, 1987.)

2.6.2 Response to temperature increase

As already mentioned, Maiti (1996) reported that the optimum temperature for sorghum vegetative growth is between 26ºC and 34ºC, and for reproductive growth, 25ºC and 28ºC. As temperature increases above 36/26ºC to 40/30ºC (diurnal maximum/minimum), panicle emergence is delayed by 20 days, and no panicles are formed at 44/34ºC (Prasad *et al*., 2006). Prasad *et al.* (2006) further discovered that grain yield, harvest index, pollen viability, and percent seed-set are highest at 32/22ºC, and progressively reduce as temperature increases, falling to zero at 40/30ºC. According to this same study, vegetative biomass is highest at 40/30ºC and photosynthesis is high up to 44/34ºC. Seed size was reduced above 36/26ºC. Lobell and Field (2007)'s results of the 8.4% decrease in global mean sorghum yield per 1ºC increase in temperature also support the former results. Therefore, there's sufficient evidence that increase in temperature is likely to result in reduced sorghum yields.

2.6.3 Response to carbon dioxide increase

Sorghum, particularly, gave 9, 34 and 8 % increases in leaf photosynthesis, biomass and grain yield, respectively, with doubling of CO_2 (350-700 ppm) when grown in 1-by-2 meter sunlight controlled double (Prasad *et al*., 2006). In another study, over an entire season with a CO_2 increase from 368 to 561 ppm sorghum gave 3 and 15 % increases in biomass and -4% and +20% change in grain yield under irrigated versus water limited conditions respectively (Ottman *et al*., 2001); thus, the increase in sorghum grain yield due to increased carbon dioxide concentration is greater under water limited conditions.

2.6.4 Response to CO_2 Increase in combination with temperature increase

There are no reported beneficial interactions in grain yield caused by the combined effects of CO_2 and temperature increase for sorghum (Prasad *et al*., 2005), i.e., the separate main effects of CO_2 and temperature were present, but yield response to CO_2 was not enhanced as temperature increased. Elevated CO_2 causes greater sensitivity of fertility to temperature (Prasad *et al*., 2006a); the failure point temperature (i.e., the point at which reproduction fails) is about 1-2ºC lower at elevated CO_2 than at ambient CO_2. This likely occurs because elevated CO_2 causes warming of the foliage. Prasad *et al*. (2006a) further noted higher canopy temperature of sorghum adversely affected fertility and grain set.

CHAPTER THREE – MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The study was conducted in Soroti district. Soroti district was selected because it is located in the center of this farming system and has suffered from frequent climate variability leading to droughts and floods in recent years (2007-2010). The district is located in eastern Uganda (Figure 5), lying nearly on latitudes 1^{o} 33" and 2^{o} 23" N, 30^{o} 01" and 34^{o} 18" E, and is over 2500m above sea level. The district boarders Kumi and Palisa districts, and Lake Kyoga in the south; Kaberamaido district in the west; and Katakwi district in the Northeast. Soroti district roughly covers a total land area of 2,662.5 square kilometers of which 2,256.5 km^2 is land while 406 km^2 is water (Okori *et al*., 2002).

The specific study site for the field experiments was Tosoro village in Gweri sub-county, while the socio-economic research was conducted in two sub-counties, Gweri and Kamuda (Figure 5). These sub-counties were chosen because they are basically rural and the major activities there are livestock keeping and crop production, and also because of their characteristic features: Gweri sub-county, boarders the Awoja swamp and thus suffers from flooding or drying when this swamp faces the same. Similarly, Kamuda sub-county nears part of Lake Kyoga, and when this lake floods, the excess water invades the villages causing loss of entire crops in the field migration of people.

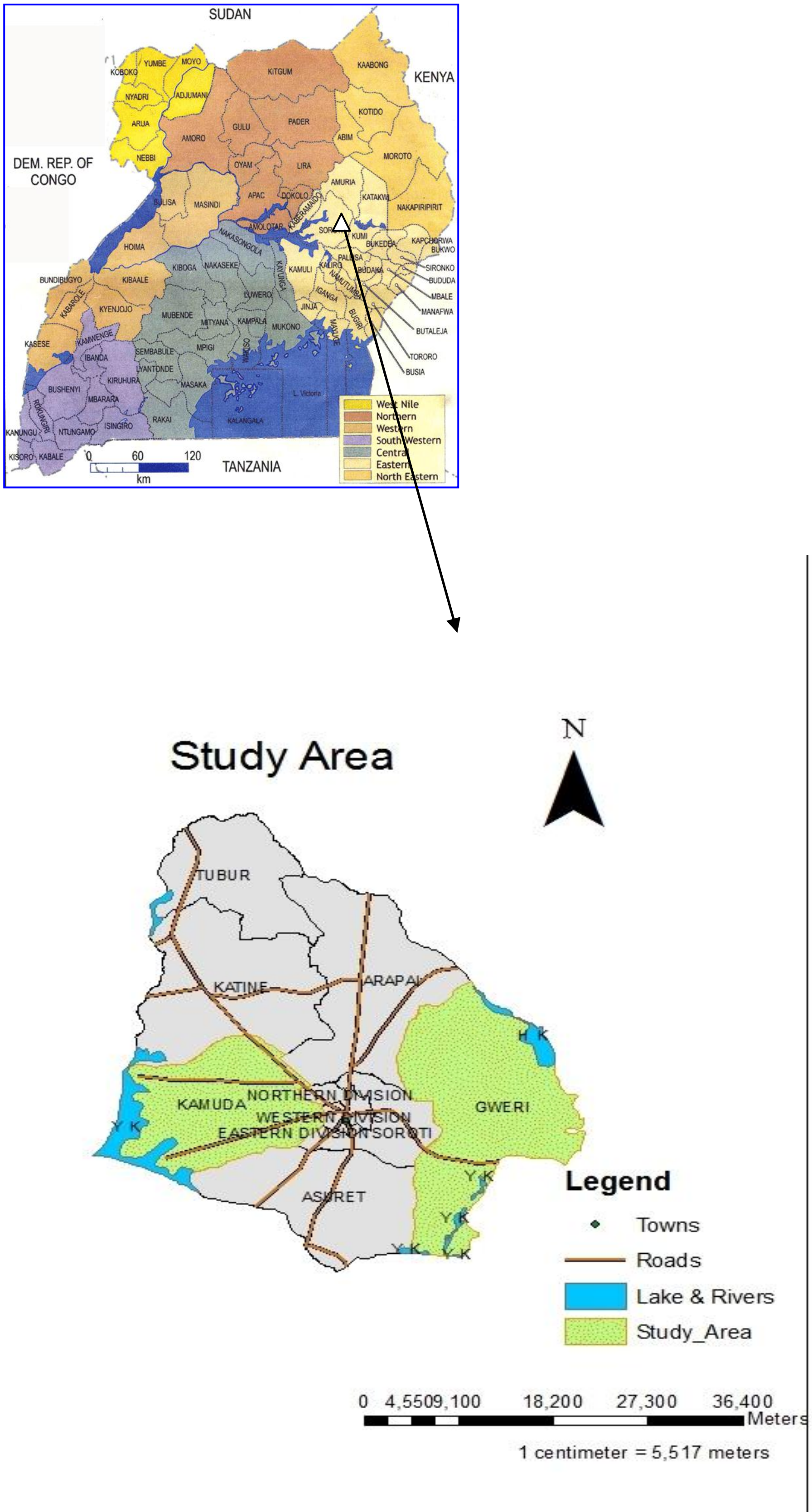


Figure 5: Location of the Study area

3.1.2 Climate

The climate of the area is semi-arid dominated by wooded savannah grasslands characterized with thorny Acacia species. The district receives an annual rainfall of between 1,000mm-1500mm, with much rain being experienced between March-May, decreasing to light showers between June-August and again to heavy rains between September-November. Thus, the area has two growing seasons. There is a short dry spell between the two rainy seasons i.e. mid June-mid July, while the long dry spell starts from late November to early March. Figure 6 shows the average monthly rainfall received in this area from 1990 to 2010.

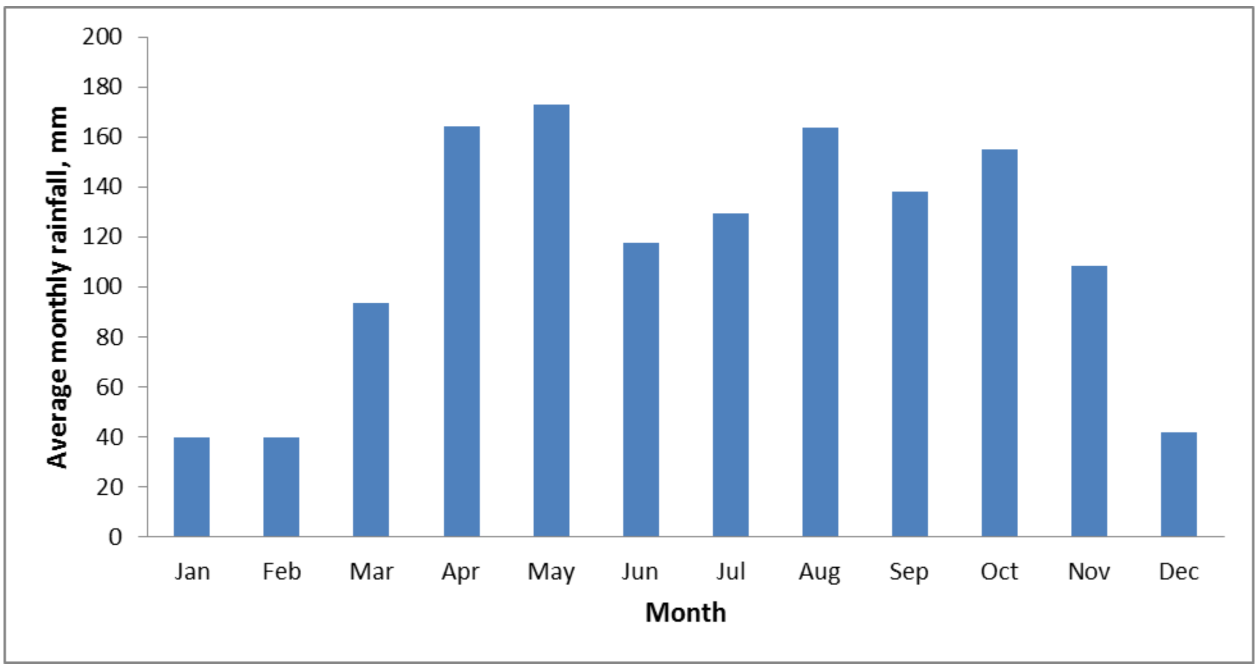


Figure 6: Average monthly rainfall received in soroti district from 1990 to 2010. Source; Soroti district production office, 2011.

The average minimum and maximum temperatures recorded for Soroti district for the year 2010 were; 19.3^{o}C and 29.9^{o}C respectively (giving an average temperature of 24.6 ^{o}C) (Source; Soroti flying school). Extreme highest temperatures in this district are usually in the month of February.

3.1.3 Soils

According to FAO, the type of soil in Soroti district belongs to the group of soils reffered to as "Karamoja surfaces": this group of soil covers the North Eastern part of the country and embrace two soil types of sandy clay loams and black clays with very low productivity, (FAO, 2009). The specific soils for Soroti district are mainly of the ferralitic type (sandy sediments and sandy loam): these soils are to a large extent, poor, shallow and light textured with large sandy loam contents traversed by numerous swamps and ravine wetlands. They are also well drained and friable.

3.1.4 Land use

The system is agro-pastoral with rural communities heavily dependent for their livelihoods on subsistence mixed annual cropping and livestock production. The major land uses are; crop production, animal rearing, fishing, charcoal burning, brick making and sand mining.

3.1.5 Crops and Cropping Systems

The major food crops grown in Soroti district are; cassava, sorghum and sweet potatoes in that order. Other crops grown include; cowpeas, millet, ground nuts, maize, green grams and vegetables. The cash crops grown include cotton and citrus. The cropping system in this area is mainly subsistence mixed annual cropping.

3.2 Methodological framework

The methodological framework entailed a combination of methods and techniques as illustrated in Figure 7. First, a Regional Climate Model (RCM) PRECIS was used to downscale climate projections given by the Global Climate Model (GCM) ECHAM in order to provide temperature and rainfall projections specific for Soroti district. The downscaled weather data was input in the AquaCrop model, and the model run to obtain sorghum yields under changed climate. PRECIS was chosen over other widely available RCMs as it is designed specifically for use by non-climate scientists to produce detailed climate scenarios for impact assessment studies. On the other hand, AquaCrop model was selected over other crop models since its software is freely available on-line and was designed for yield prediction under climate change scenarios, among its other applications. In order to obtain input data for the AquaCrop model, and to determine sorghum yields under current climates, field experiments in 2 seasons using *Edeidei* and *Serena* varieties were conducted in the study area (Gweri sub-county). 80 Household interviews and 2 Focus Group Discussions (FGDs) consosting of atleast 20 people were used to obtain data concerning farmers' climate change perceptions and the existing coping and adaptation practices.

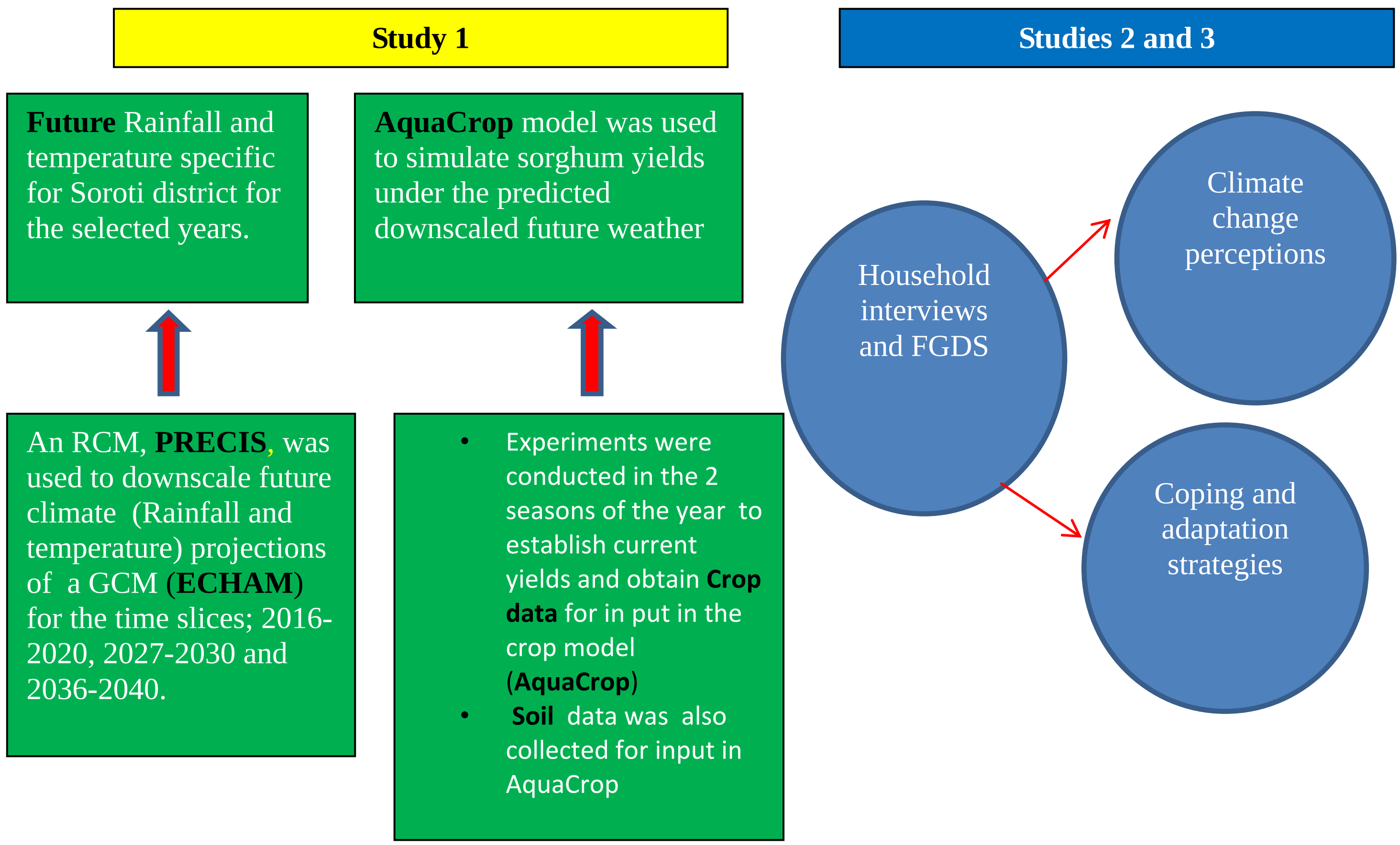


Figure 7: Methodological framework for the study

3.3 Research design

The study entailed both a survey and an experiment: the experiment was conducted in the field, on a farmer's land, using the Randomized Complete Block Design (RCBD). This design was chosen in order to cater for soil differences at the experimental site. So, the blocking factor was location i.e. each block was at least 0.5km away from another block. Only two blocks were established due to the high cost of the research i.e. the research involved many activities and since expensive soil analyses had to be conducted, only two blocks could be managed with the research funds provided. Two varieties of sorghum, namely, *Serena* and *Edeidei* were grown: each variety appeared once in each block, giving a total of two replicates per variety. These varieties were selected because they are the mainly grown varieties by the majority resource poor farmers in the district. Each variety occupied a plot of 5m by 10m in each block and was separated from the other variety by a distance of 1 meter. The seeds were planted in rows at spacing of 70cm by 15cm with 1 plant per hill.

For the survey; structured household interviews and focus group discussions were used to conduct a descriptive socioeconomic survey, in the two selected sub-counties, to obtain data relating to community perceptions about the impact of climate change on crop production, and the efficacy of their coping practices. Questionnaires/interview guides having open-ended questions were used to elicit responses from respondents, while a checklist was used to guide the Focus Group Discussions.

3.4 Sample size

The unit of analysis for the study was a household. The sample size was therefore determined on the basis of the total number of households in the study area.

To calculate the sample size, the following formula of Yamane (1967) was used;

$$n= \frac{N}{1+N\left(e^{2}\right)}$$

Where; n=sample size, N= population size, and *e*= level of precision.

An 11.2% level of precision was considered (i.e. *e* = 0.112).

The total 2011 projected population for Gweri sub-county was 50,400 persons, while that of Kamuda sub-county was 36,300 persons (Source: Soroti district production office, 2011). Thus, the total number of people in these two sub-counties was 86,700. According to the preliminary survey that was made by the RUFORUM climate change project in 2010, the average number of persons in a household was eight. Thus, the average number of households in these two sub-counties was;

$$= \frac{86700}{8}$$

= 10837.5 households.

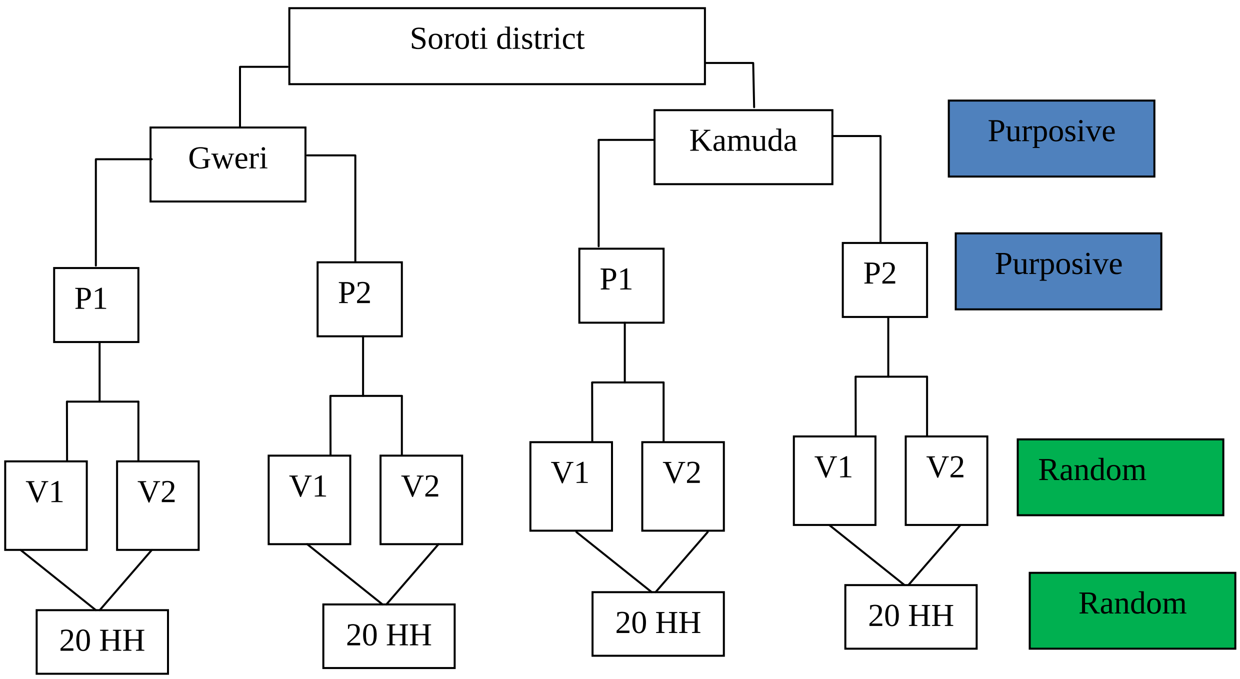
Therefore, sample size n was,

$$n = \frac{10837.5}{1 + 10837.5(0.112^2)} = 79.14$$

The sample size was taken as 80.

3.5 Sampling strategy

A multistage purposive and random sampling strategy was used to conduct household interviews (Figure 8). First, two sub-counties were selected purposively based on specific characteristic features (section 3.1.1); two parishes were selected from each sub-county, also purposively, basing on information that was provided by local leaders regarding the parishes that have suffered more from climate shocks like floods and drought in the last thirty years. From each parish, two villages were selected randomly. A total of 10 random households were interviewed in each selected village, giving 20 households per parish, 40 households per sub-county, and 80 households in the whole district.



P1 = Parish 1, P2 = Parish 2, V1 = Village 1, V2 = Village 2 and HH = Household

Figure 8: The sampling procedure for the household interviews

3.6 Data collection methods

3.6.1 Objective 1: Assessing the impact of climate change on the yield of sorghum in the Teso Farming system.

Assessing the impact of climate change on the yield of sorghum in the Teso Farming system involved two steps; i) downscaling of a Global Climate Model (GCM) projected climate changes, and ii) simulating sorghum yields using a crop model.

3.6.1.1 Climate downscaling

A Regional Climate Model, PRECIS (Providing Regional Climates for Impacts Studies), was used to downscale climate projections of the Global Climate Model, ECHAM (European Center

Hamburg Model), at a scale of 25 km^2 in order to generate the expected daily rainfall and temperature data, under changed climate, for the Teso Farming System.

PRECIS is an atmospheric and land surface Regional Climate Model (RCM) developed by the Hadley Centre in the UK (Wilson *et al*., 2010). The aim of this model is to enable developing countries or groups of developing countries to generate their own national scenarios of climate change for use in impact studies. The model allows the user to define an area of interest which is surrounded by a 250 km buffer zone for which initial conditions are generated for runs. The PRECIS modeling system can be run on a cheap, easily available personal computer, and can be validated for a specific country using the observations thereof. The climate of a particular region is determined by local and remote processes with external forcing provided by solar radiation. The effect of the radiation is modulated by the composition of the atmosphere and various feedback processes within the global climate system. Thus, a regional climate model such as PRECIS requires, as input; boundary conditions providing the remote forcing of the regional climate and consistent information on atmospheric composition. More specifically, the boundary conditions comprise lateral boundary conditions of surface pressure, winds, temperature and humidity (and aerosol concentrations if available) and surface boundary conditions over the sea of temperature and sea-ice fractions. The atmospheric composition is represented by prescribed concentrations of the most important greenhouse and other gases derived from scenarios of their emissions. The emission scenario considered in this study was the A1B scenario. This scenario is derived from the A1 scenario family which describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. This family is divided into three groups distinguished by their technological emphasis, these groups are; fossil intensive (A1FI), nonfossil energy sources (A1T), and a balance across all sources (A1B) (where balanced refers to not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies). The A1B scenario is a better choice since it considers an intermediate between the two energy sources, which is the most likely case. Further, this scenario was selected because it is already inbuilt in the PRECIS model and also in the AquaCrop model.

Training on how to use PRECIS was obtained from the Technical manual (distributed as part of the PRECIS software) which points out the steps needed to install, Configure and use PRECIS (Wilson *et al*., 2010). Examples of PRECIS applications can be found in; Niger (Beraki, 2005), India (Kolli *et al*., 2006), South Africa (Tadross *et al*., 2005) and Uganda (Mileham. 2008), all of which focused on the future precipitation and temperature changes and their impacts relative to management and adaptation practices.

Historical observed monthly rainfall for soroti district, for the years 1990 to 1998 (Appendix 3c), and PRECIS model generated monthly rainfall for Soroti district for the same period (Appendix 4) were used to determine the fitness of the PRECIS model for rainfall prediction in the Teso Farming System, using simple Linear Regression, Correlation analysis, and the Average Absolute Error (AAE) - Model fitness was determined by the adjusted R^2value (the closer this value is to 1, the more accurate/fit the model would be); the mean deviation of observed values from generated values was determined by the value of the Average Absolute Error (AAE); while, the correlation coefficient indicated the degree of closeness between observed values and generated values (as the correlation coefficient approaches to 1, the better the correlation). However, only the months of April, June, September and November were used since the

PRECIS model output for historical rainfall considered only 30 days for each month; hence a total of 36 observations were used (Appendix 5). The Average Absolute Error between PRECIS generated rainfall and observed rainfall was calculated using the equation below;

$$AAE = \frac{\sum_{i=1}^{n} |O_i - S_i|}{n}$$

Where;

S_i = simulated or Model generated value
O_i = observed value,
n = number of observations

For the calculation of Average Absolute Error (AAE), the monthly values were divided by 30 to convert them to rainfall in millimeters per day (mm/day). The AAE was selected since it avoids changes in the direction of the difference between observed and Model generated rainfall; in some cases, observed rainfall was higher than Model generated rainfall, yet in other cases, the reverse was true.

Model generated monthly rainfall for these years (1990-1998) was obtained by downscaling the GCM predictions for that period, using PRECIS. PRECIS generated climate data for Soroti district were obtained from the high-resolution (daily time-step, 0.22^o grid) climate data for Uganda and the surrounding region, that are available from the Regional Climate Model experiments conducted in UCL Geography by Lucinda Mileham using the PRECIS model (Lucinda, 2008). These experiments were conducted to cover the region defined by the latitudes 7.3^{o}S to 8.0^{o}N and longitudes 26.0^{o}E to 39.0^{o}E; since Soroti district lies on co-ordinates 1.77^{o}N and 33.66^{o}E, it can be covered in this region. The file names in the data directory reflect both the climate variable and model run used to generate that variable. Data files are available in netcdf format and can be read by all common climate data analysis tools such as GRADS, CDO, NCL, R, MatLab and IDL. In this study, GRADS was used to read the data files. The model run (experiment) used to generate the data was; *Uclax*: 1957 to 1990 baseline experiment using ERA-40 boundary conditions, and the file that were obtained was; uclax.05216.1960-90.nc, for historical mean monthly rainfall. Thus by inputting the coordinates for Soroti district, the data specific to this district was obtained. This generated data (Appendix 4) was then compared to the observed values (obtained from the department of Meteorology) using Simple Linear Regression, Spearman's Correlation analysis, and AAE. After Model evaluation, climate projections (daily rainfall and, maximum and minimum temperature) for the years 2016-2020, 2027-2030 and 2037-2040 were made.

The predicted daily rainfall and temperature for the Teso Farming System obtained were input in the AquaCrop model and the corresponding yields simulated. For purposes of comparison, the planting dates used for simulating future yields were maintained as those for the years when the experiments were conducted. The simulated sorghum grain yields under changed climate were compared to the current yields, and, the magnitude and direction of the change was used to determine the impact of climate change on sorghum yield.

3.6.1.2 AquaCrop model

AquaCrop 3.1+ (Raes *et al*., 2009) is a crop water productivity model developed by the Land and Water Division of FAO. It simulates yield response to water of several crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. AquaCrop is a companion tool for a wide range of users and applications including yield prediction under climate change scenarios.

AquaCrop; (i) divides Evapo-Transpiration (ET) in soil evaporation (E) and crop transpiration (Tr), to avoid the confounding effect of the non-productive consumptive use of water (E), (ii) obtains biomass (B) from the product of water productivity (WP) and cumulated crop transpiration, iii) expresses the final yield (Y) as the product of B and Harvest Index (HI), (iv) normalizes Tr with reference evapotranspiration (ETo), to make the B-Tr relationship applicable to different climatic regimes, and (v) runs with daily time steps (either calendar or growing degree days), to more realistically account for the dynamic nature of water stress effects and crop responses. AquaCrop is water-driven, meaning that the crop growth and production are driven by the amount of water transpired (Tr). Most importantly, AquaCrop focuses on the fundamental relation between B and Tr rather than Y and ET, as in the Ky approach (where relative yield (Y) loss is proportional to relative evapotranspiration (ET) decline, with Ky as the yield response proportional factor) (Doorenbos and Kassam,1979). A schematic representation of these evolutionary steps is reported in the Figure 9.

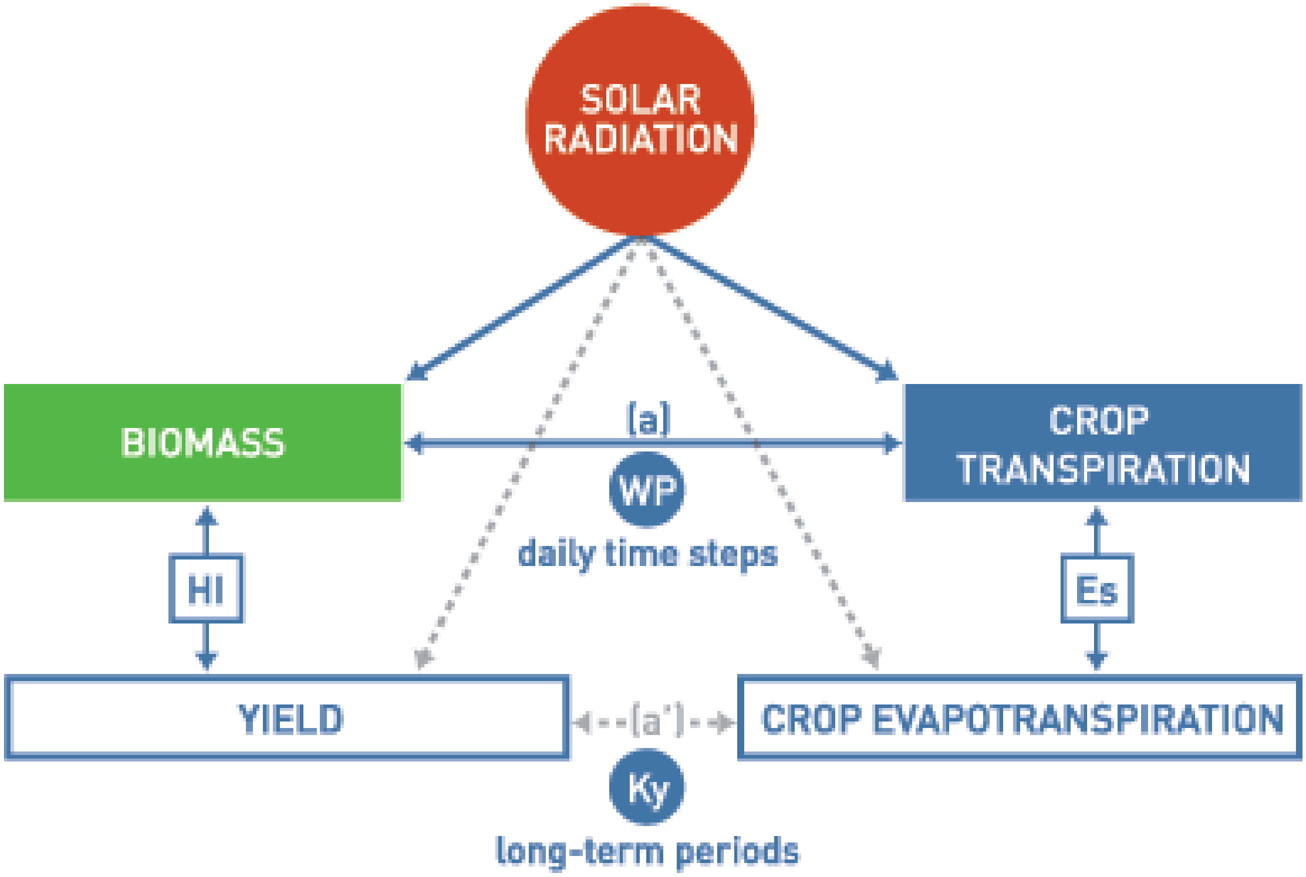


Figure 9: The Schematic presentation of the steps involved in the AquaCrop model. Source; Raes *et al*., 2009

AquaCrop includes the following sub-model components: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and CO_2 concentration; and the management, with its major agronomic practice such as irrigation and fertilization. Soil salinity and capillary rise from shallow water tables are not yet implemented in AquaCrop 3.1+. AquaCrop version 3.1+, used in this study was issued in February 2011. It runs under Microsoft Windows operating system (Version 98 and higher) and no special hardware or supporting software is required. The software, and reference manual for AquaCrop 3.1+ (Raes *et al*., 2011) were downloaded at a free cost from http://www.fao.org/nr/water/AquaCrop.html . Applications of the AquaCrop model can be found in; Hamidreza *et al*., 2011, and Saadati *et al*., 2011.

3.6.1.3 Field experiments

Two field experiments (one in each of 2 seasons of 2010b and 2011a), using two sorghum varieties, namely; *Serena* and *Edeidei*, were carried out in the study area based on a Randomized Complete Block Design (RCBD), to obtain the input data for use in running the AquaCrop model. *Serena* is an improved variety (bred for higher yield) released by the Semi-Arid Resources Research Institute (SARRI) – Serere in 1960, while *Edeidei* is a traditional variety. These varieties were chosen because they are the most commonly grown in the study area. The expected yield of Serena is about 3 tons/ha, varying depending on the soil conditions and this variety is expected to mature in 100-110 days. The expected yield and maturity days of Edeidei are not established since this is a local variety not experimented at the research institute (Source: SARRI Sorghum Program office, 2011). In addition, Serena is a short variety while Edeidei is a relatively taller variety.

3.6.1.4 Input data for running the AquaCrop model

3.6.1.4.1 Crop in-put data

3.6.1.4.1.1 Method of sowing, plant density and development in-put

The row method of sowing was used at a spacing of 30cm X 70cm, giving a plant density of 95,238 plants/ha. The development of the crop was considered in terms of calendar days from sowing to; Emergence, Maximum canopy cover (taken as days to 50% heading), Flowering, Start of canopy senescence, Maximum rooting, and depth Maturity. The first 3 and last variables were obtained from the field experiments, while, Start of canopy senescence was calculated automatically by the model, and, maximum rooting was adopted as 88 days.

3.6.1.4.1.1 : Water productivity; water, temperature and fertility stresses; and harvest index input.

This input data is shown in table 1.

Table 1: Water productivity; water, temperature and fertility stresses; and harvest index input.

Variable	**In-put**
Crop Water Productivity	33.7 g/m^2
Water stress	
1. *Canopy expansion*	Sensitive to water stress
2. *Stomatal closure*	Moderately tolerant to water stress
1. *Early canopy senescence*	Tolerant to water stress
2. *Aeration stress*	Sensitive to water logging
3. *Harvest Index (HI)*	
• Before flowering	No positive effect on HI as a result of limited growth in the vegetative period
• Duration of flowering	Sensitive to water stress
• During yield formation	No positive effect on HI as a result of water stress affecting leaf expansion, and, Moderate negative effect on HI as a result of water stress inducing stomatal closure
Fertility stress	55%
Temperature stress	As given in the model
Harvest Index (%)	
i. *Serena season Aug-Dec block 1*	38
ii. *Seerena season Aug-Dec block 2*	59
iii. *Edeidei season Aug-Dec block 1*	27
iv. *Edeidei season Aug-Dec block 2*	32
v. *Serena season May-Aug block 1*	39
vi. *Seerena season May-Aug block 2*	54
vii. *Edeidei season May-Aug block 1*	23
viii. *Edeidei season May-Aug block 2*	32

The values of the Harvest Index were obtained by dividing the grain yield by the straw yields, (Table 4) obtained from the field experiments conducted.

3.6.1.4.2 Atmospheric input data

The atmospheric input data in the AquaCrop model is; rainfall, Temperature (maximum and minimum), reference evapotranspiration and carbon dioxide concentration. Daily rainfall and temperature data for Soroti district for the years 2010 and 2011 (Appendix 2) were obtained from the Department of Meteorology. Reference evapotranspiration (ETo) was calculated from daily maximum and minimum temperature using the ETo Calculator (FAO, 2009). The software for the ETo calculator can be downloaded at a free cost from http://www.fao.org/nr/water/ETo.html , while carbon dioxide concentration was obtained from the in-built files. The combination of these variables that were used to make climate files for the base year and the years under climate change are given in the Table 2.

Table 1: Atmospheric input data for running the AquaCrop model

Atmospheric variable	**Experiment**	
	Base experiment	**Climate change experiments**
Temperature	Daily maximum and minimum temperature Jan 2010- Aug 2011	Daily maximum and minimum temperature Jan-Dec for the specific year.
Rainfall	Daily rainfall; Jan 2010- Aug 2011	Daily rainfall Jan-Dec for the specific year.
Reference Evapotranspiration	Daily values calculated from daily maximum and minimum temperature Jan 2010- Aug 2011	Daily values calculated from daily maximum and minimum temperature Jan-Dec for the specific year.
Carbon dioxide concentration	MaunaLoa CO_2; Default atmospheric CO_2 concentration from 1902 to 2099.	A1B.CO_2; Yearly Atmospheric CO_2 concentration-IPCC: SRES Scenario A1B.

3.6.1.4.3 Soil input data

The soil data required for this model is the moisture content at; Lower Limit, Drained Upper Limit and Saturation, and the soil depth of the different soil layers. Composite soil samples were obtained at three layers for each block and the soil texture of each layer for each block was determined at the Soil Science Lab of Makerere University. The obtained percentages of sand, silt and clay were then used in Soil moisture content software to determine the moisture content at three mentioned levels (degrees). The depth of each layer was determined using a ruler. The observed soil data is showed in Appendix 1.

3.6.1.4.4 Management input

The management input data in AquaCrop is in relation to irrigation, fertilizer application, mulching and use of bands. However, this was not applicable under this study.

At harvest, grain yields and straw yields were obtained by harvesting three samples of $1m^2$ sub-plots from each plot, followed by determination of yield components. All the panicles were threshed, the grains were floated to get rid of the empty grains and the obtained filled grains were dried thoroughly. Finally the yield per m^2 was determined and then converted to yield per hectare. The dry matter/straw yield was obtained by drying the sorghum residues under hot sun for three days. The average of the three samples provided the yield for each plot.

In order to validate the model (determining the degree to which a computer model is an accurate representation of the real world from the perspective of the intended model applications (ASME, 2006, U.S. DOE, 2000, AIAA, 1998)), which is accomplished through the comparison of predictions from a model to experimental results, yield simulations were performed for the two varieties in the two seasons, Aug-Dec and May-Aug; the simulated yields were compared with the observed yields for the same seasons, using Simple Linear Regression, Spearman's correlation analysis, and Average Absolute Error (AAE), as in the case of PRECIS model. To avoid the effect of the AAE of one variety being increased/reduced by the counterpart's error, each variety was dealt with individually, i.e., AAE was calculated separately for each variety. The obtained AAE was then used to correct the simulated yields for the future years i.e. by subtracting this value from the simulated yields. Thus, the true expected yields were obtained.

3.6.2 Objective 2: Identifying community perceptions of the impact of climate change on crop production, in the Teso Farming system.

Focus Group Discussions (FGDs) and household interviews were conducted in the selected areas to obtain data relating to whether the communities have experienced climate change, and how they perceive these to have affected crop production in the area. A structured questionnaire (Appendix 9) was used to conduct the household interviews. The questionnaire was pre-tested first before use in order to identify any gaps that it may have. Enumerators were trained thoroughly before participating in data collection. The focus group discussions and household interviews were conducted in two sub-counties - Gweri and Kamuda, following the sampling strategy described earlier above. The household was defined as those living in the same compound, and who work or contribute food or income to the unit. Elders were purposely targeted (as respondents) so as to obtain data relating to climatic conditions in the past 30 years. During the interview sessions, the respondents provided their knowledge and experience about climate change in their area. The information gathered from the household interviews was analyzed, and the outcomes were validated by conducting FGDs. One FGD was conducted in each sub-county; a maximum of twenty people participated in each FGD, including local leaders (LC1, LC2 and LC3 chairpersons), the sub-county NAADS coordinator and women representatives.

3.6.3 Objective 3: Assessing the efficacy of the existing coping and adaptation practices to climate change in the Teso Farming system.

The household interviews and Focus Group Discussions (FGDs) that were employed to achieve objective 2 were also used to identify the coping and adaptation practices that the farmers have developed in response to climate change. During the household interviews, respondents mentioned the coping and adaptation practices that they have employed in response to the climate change effects and shocks experienced. These practices were later assessed for effectiveness.

3.7 Data analysis

Analysis of variance (ANOVA) was conducted to determine varietal and seasonal differences in yield. A 5% level of significance was used. The one-sample t-test was used to determine if significant differences occurred between the observed current and the corresponding future AquaCrop simulated yields, under climate change. The direction of the change and whether it was significant or not was then used to deduce the impact of climate change on the yield.

A one-sample t-test for proportions was used to test the hypothesis stated, i.e.,

H_o; Proportions/percentage change = 0.2

H_1; Proportions/ percentage change ≠ 0.2

The test statistic *t* was calculated as; $t = \frac{p - p_0}{\sqrt{\frac{pq}{n}}} \sim t_{n-1}$ under $H_{o.}$

Where;

> *p* = Observed percentage change (i.e. the predicted percentage change in yield obtained)
> P_o = Hypothesized percentage change (i.e. 0.2 in this case)
> $q = 1\text{-}p$
> *n* = number of observations (i.e. 14 in this case)

The average percentage changes in sorghum grain yield by the year 2040 for each variety for each season were compared with the hypothesized value. A higher calculated test statistic than the tabulated t-value would imply a significant difference between the observed (i.e. predicted) percentage change in sorghum yield and the hypothesized value.

The socio-economic data collected during the FGDs and household interviews using questionnaires, was checked for completeness, coded and entered in a computer using SPSS software. The data was cleaned and finally analyzed using the SPSS software for descriptive summaries.

CHAPTER FOUR – RESULTS

4.0 Introduction

This chapter presents the results obtained during data collection and it is arranged following the order of the specific objectives of the study**.** For ojective 1, the results include; presentation and interpretation of the sorghum grain yields obtained from the field experiments, analysis of historical weather for the study area, evaluation of both the Crop and Climate models, presentation of the expected future climate and sorghum yield, and finally an analysis of the effect of the obtained climate change on sorghum yield. For objectives 2 and 3, the results provide the demographic information about the study area, the people's perceptions and experiences with climate change, and finallly their coping practices.

4.1 Seasonal variations in growth and yield of two sorghum varieties

4.1.1 Variations in yield

The results covering grain and straw yields obtained from the experimental study of two sorghum varieties i.e. *Serena* and *Edeidei* are shown in Table 3. Both grain and straw yields for each of the varieties were higher in season Aug-Dec than in season May-Aug, though analysis of variance did not show significant differences in seasonal yields for any of the varieties at 5% level of significance. In terms of grain yield, *Serena* always performed relatively better than *Edeidei* (0.83 ton/ha higher and 1.27 ton/ha higher in seasons Aug-Dec and May- Aug respectively); however, these differences were not statistically significant at 0.05 level of significance ($P \leq 0.05$). The grain yields of both varieties in both seasons were high above the average sorghum yields for Uganda, i.e.1.5 t/ha (FAOSTAT, 2009), implying that sorghum generally performs well in the study area. For straw, *Edeidei* always produced slightly higher yield than *Serena* (0.33 ton/ha higher and 0.31 ton/ha in seasons Aug-Dec and May-Aug respectively). However, as for grain yield, analysis of variance did not show significant differences in these yields at 5% level of significance (P ≤ 0.05).

Table 3: Means of the sorghum yields for the two seasons

Variety	Season Aug-Dec		Season May-Aug	
	Grain yield (t/ha)	Straw yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)
Edeidei	2.62^{a}	6.14^{b}	2.06^{a}	5.62^{b}
Serena	3.43^{a}	3.77^{b}	3.22^{a}	3.62^{b}

Figures in the same column with the same letters imply no significant difference at 5% level of significance.

The interaction between variety yield and season was not statistically signigicant (P≤0.05).

4.1.2. Variations in number of days taken to reach the various growth stages

Table 4 shows the number of days taken for each variety to reach a particular growth stage in each of the seasons. *Serena* always matured slightly earlier than *Edeidei* and, both varieties matured slightly earlier in season May-Aug than in the Aug-Dec counterpart. However, at 5% level of significance, no significant differences occurred between the two varieties with regard to days taken to reach any stage in any of the seasons. In addition, no significant differences were observed in the days taken to reach any stage between the two seasons for any of the varieties.

Table 4: Mean days afterplanting taken for the crop to reach its growth stages

	Season Aug-Dec		Season May-Aug	
Growth stage	**Edeidei**	**Serena**	**Edeidei**	**Serena**
Emergence	4	4	4	4
50% heading	72.00	71.50	72.0	70.0
50% flowering	78.50	76.50	79.0	76.0
Maturity	100.00	97.50	97.00	95.50

Thus, although *Serena* is an improved variety while *Edeidei* is not, its difference from *Edeidei* in terms of grain yield and earlinesswas not statistically significant.

4.2 Rainfall and Temperature during the growing seasons

In the Aug-Dec season; the crop (sorghum) was planted on 24th August and harvested on 15th December 2010, while in the May-Aug season; the crop was planted on 3rd May and harvested on 13th August 2011. The growing season of the first months of the year (i.e. the first season of the year) was usually expected to begin in March; however, due to the delay of rainfall onset, planting could only be done in May. For the second season of the year, usually Aug-Dec, the rains came in the expected month i.e. August. The total rainfall amounts received were 463.60 mm in season Aug-Dec and 373.40 mm in season May-Aug. The daily rainfall distribution during the growing season (from planting to physiological maturity) for each of the two seasons is shown in Figure and 11. For season Aug-Dec, the rainfall distribution to a great extent followed that required for optimum sorghum growth, however, the distribution in season May-Aug did not effectively meet the requirement of the crop, and hence lower yields were observed.

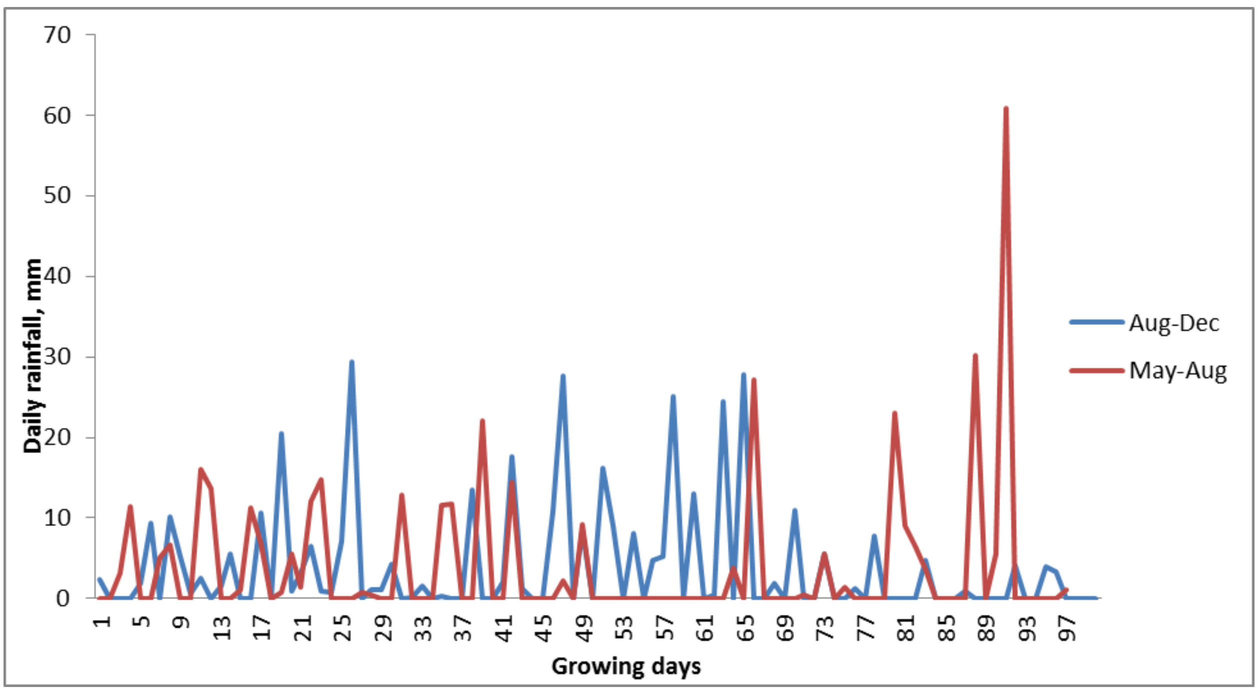


Figure 10: The daily rainfall distribution for seasons Aug-Dec 2010 and May-Aug 2011 for the year 2010 for Soroti district.

The average seasonal minimum/maximum temperatures observed were; 18.8/29.7ºC and 19.0/28.7ºC for the seasons Aug-Dec and May-Aug respectively. These temperatures are within the optimum ranges suggested by Maiti (1996) i.e. between 26ºC and 34ºC for vegetative growth, and between 25ºC and 28ºC for reproductive growth; therefore, sorghum could grow well in the area during these seasons.

4.3 Observed historical climate

4.3.1 Observed historical temperature

The historical observed average monthly temperature data for Soroti district for the years 1992-2009 is presented in Appendix 3 (a and b). The trend shows that from the year 2001, there was a steady rise in annual average temperatures (Figure 11). This temperature rise is in agreement with the IPCC report of 2001 (IPCC, 2001) that suggested that accelerating global warming was observed in this year (2001).

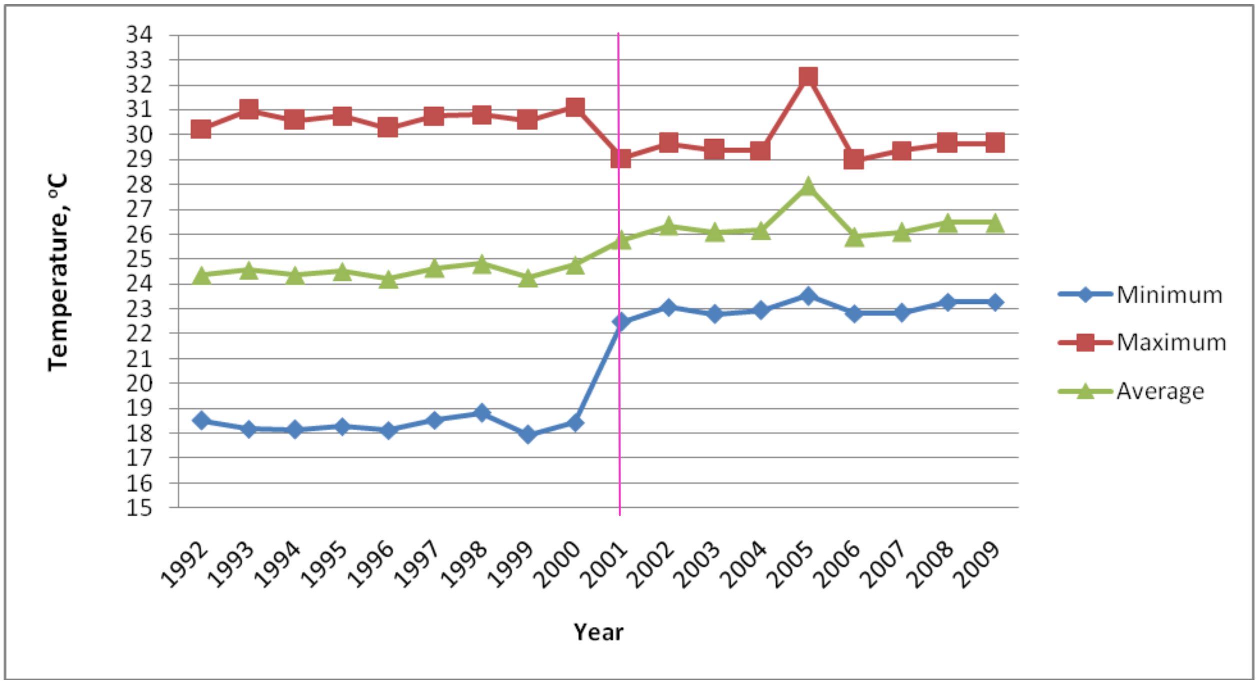


Figure 11: The variation in annual average temperatures for Soroti district, 1992-2009

The main contributor to the rise in average temperatures in this area has been the rise in average minimum temperatures; the average maximum temperatures on the contrary have generally reduced since the year 2001, except for the year 2005 when there was a rise in the same over all the previous values. Thus since the year 2001, the average maximum/minimum temperatures in this area have ranged between 29-30^{o}C/22-24^{o}C respectively, compared to the 30-31^{o}C/18-19^{o}C respectively before this year.

4.3.2 Observed historical rainfall

The historical observed monthly rainfall data for Soroti district for the years 1990-2010 is presented in Appendix 3(c). The annual rainfall ranged from 1022 to 1800mm; the highest annual rainfall was registered in 1996, followed by the years 2001, 1991 and 2010, while the least was registered in 2004 (Figure 12). The trend shows that variations have occurred in annual rainfall; however, annual rainfall is not a limiting factor for crop production as is the case for seasonal rainfall.

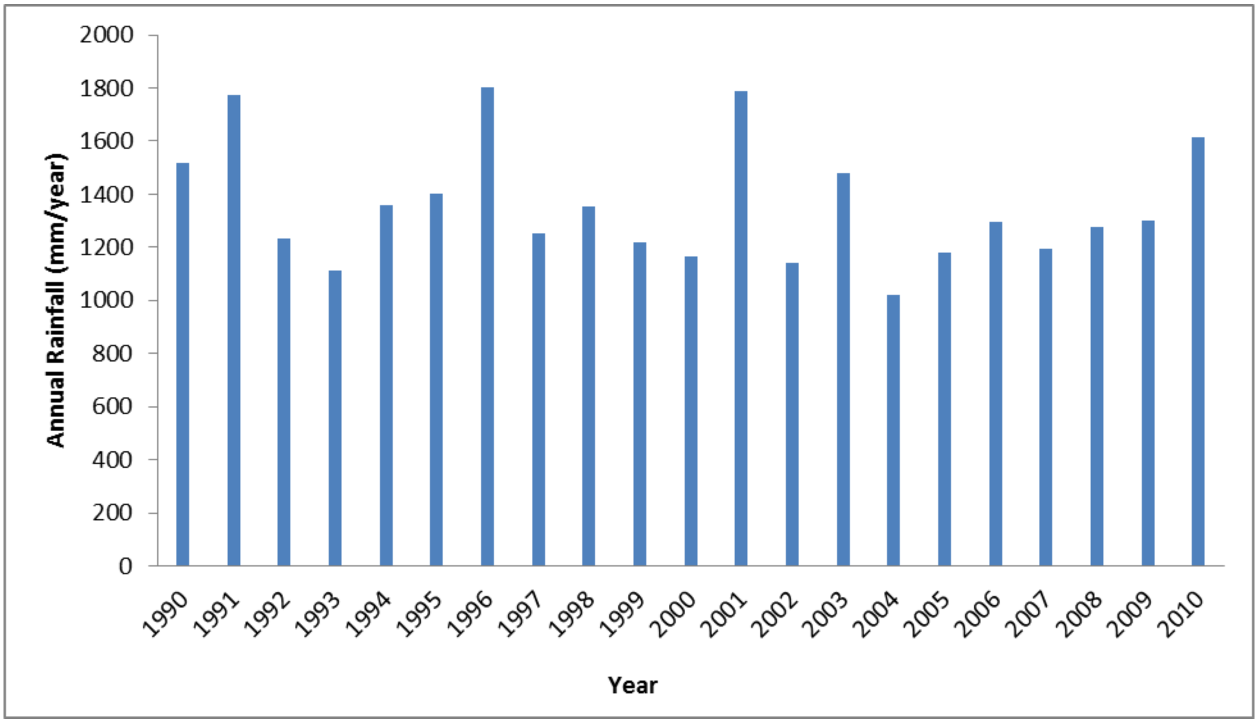


Figure 12: The annual rainfall for Soroti district for the years 1990-2010

Out of the 21 years (i.e. 1991-2010), 12 had more rainfall in the first season (March, April, May i.e. MAM) than in the second season (September, October and November i.e. SON) of the year (Figure13), while for the rest of the years (9), the reverse happened. Variations between seasons occurred over the years. Thus, climate variations have occurred over the years.

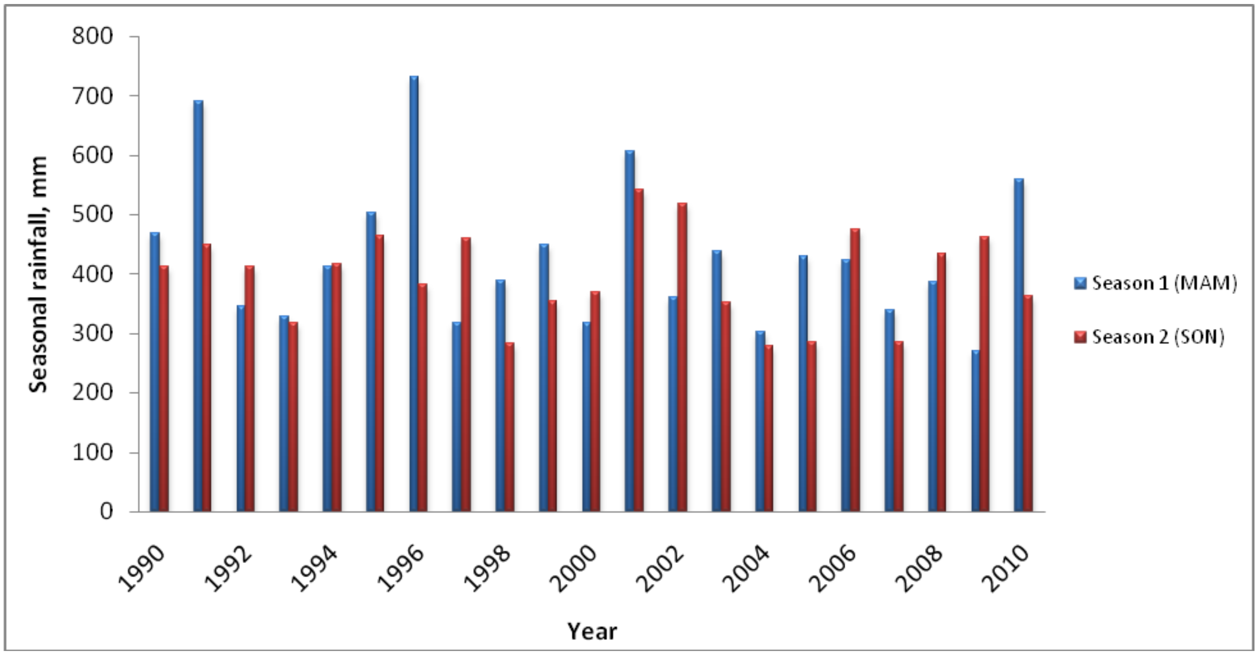


Figure 13: Soroti Seasonal rainfall for the years 1990-2010

A certain farmer called the MAM season "the good season", having good rains. However, during the FGDs, the community members revealed that recently, the seasons have changed; the MAM season which used to have longer and more reliable rains has become minor, while the SON season which used to be minor has become major. This situation can be observed in the years 2008 and 2009, where the SON season had higher rains for two consecutive years (Figure 13). This had not happened before as it can be observed from this Figure (13) that the variations in the seasonal rainfall amounts would occur in a sequence of commonly two or more years of higher MAM followed by one year of higher SON rains or at worst a one year sequence. Thus, the 2008-2009 occurrences shocked the residents who concluded that seasons have changed, although the year 2010 provided the expected normal trend.

4.4 Validation of PRECIS model

The data used for evaluation of this model is presented in Appendix 5. Generally, there was a positive linear relationship between observed and PRECIS generated monthly rainfall for Soroti district (Figure 14). The R^2 value of 0.467 implies that 46.7% of the variability in the PRECIS generated monthly rainfall is explained by the relationship between this rainfall (PRECIS generated monthly rainfall) and the observed values. Therefore PRECIS model was 46.7% fit for prediction of monthly rainfall.

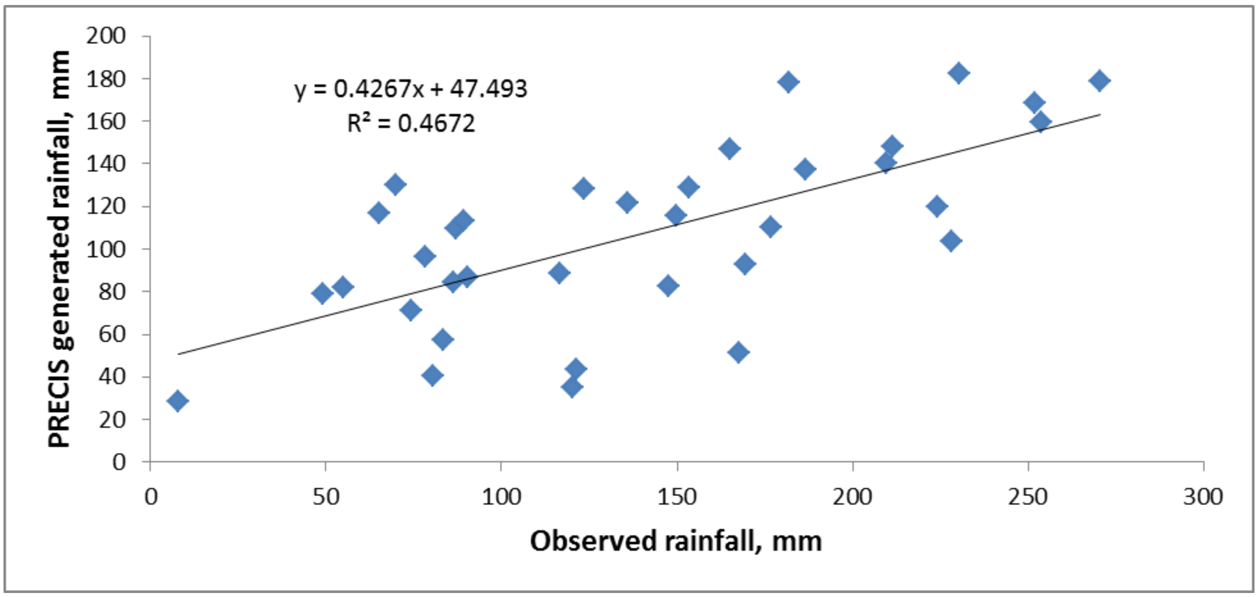


Figure 14: Observed and PRECIS generated monthly rainfall (mm) for Soroti district (1990-1998). The line across is the Regression line

The correlation results showed that there was a relatively high positive linear relationship between observed and PRECIS generated monthly rainfall for Soroti district, for the years 1990-1998, and this correlation was statistically significant 1% level ($P< 0.01$) (Table 5).

Table 5: The correlation between observed and PRECIS generated monthly rainfall for Soroti district (1990-1998)

Variables	Correlation coefficient	P-value
Observed monthly rainfall	0.684**	0.000
PRECIS generated monthly rainfall		

***Correlation is significant at the 0.01 level (2-tailed)*

From the data used for evaluation (Appendix 5), and after dividing all these values by 30 to obtain data in mm/day, the Average Absolute Error (AAE) obtained was 1.59 mm/day. Therefore, the mean deviation between observed and PRECIS generated rainfall is 1.59 mm/day. However, this error couldn't be used to validate the PRECIS model for use in the study area since the direction of the error was not definite i.e., in some cases it was negative while in others, it was positive.

4.5 Expected future climate

The PRECIS projected future annual rainfall for Soroti district (co-ordinates: 1.77^{o}N and 33.66^{o}S) for the years 2016-2020, 2027-2030 and 2036-2040 is presented in Figure 15. The results indicate that in comparison with 2010 rainfall, there will be a general increase in annual rainfall in Soroti district according to this Model (Figure 15). However, as already mentioned, annual rainfall amounts do not have a direct implication on crop yields. Greater rains will be expected but their distribution is what matters for crop yields. The highest percentage change in rainfall (14.5%) was observed in the year 2040, followed by 2019 (14.48%) while the least was observed in 2036 (0.22%), (Figure 16). Variations in the direction of change in rainfall were only observed in first two time slices i.e. 2016-2020 and 2027- 2030 (where the years; 2016,2018 and 2029 produced annual rainfall amounts lower than that of 2010. In the last time slice i.e. 2036-

2040, annual rainfall is expected to be always higher than that that received in 2010. The average precentage change in annual rainfall over this period of 14 years was +5%.

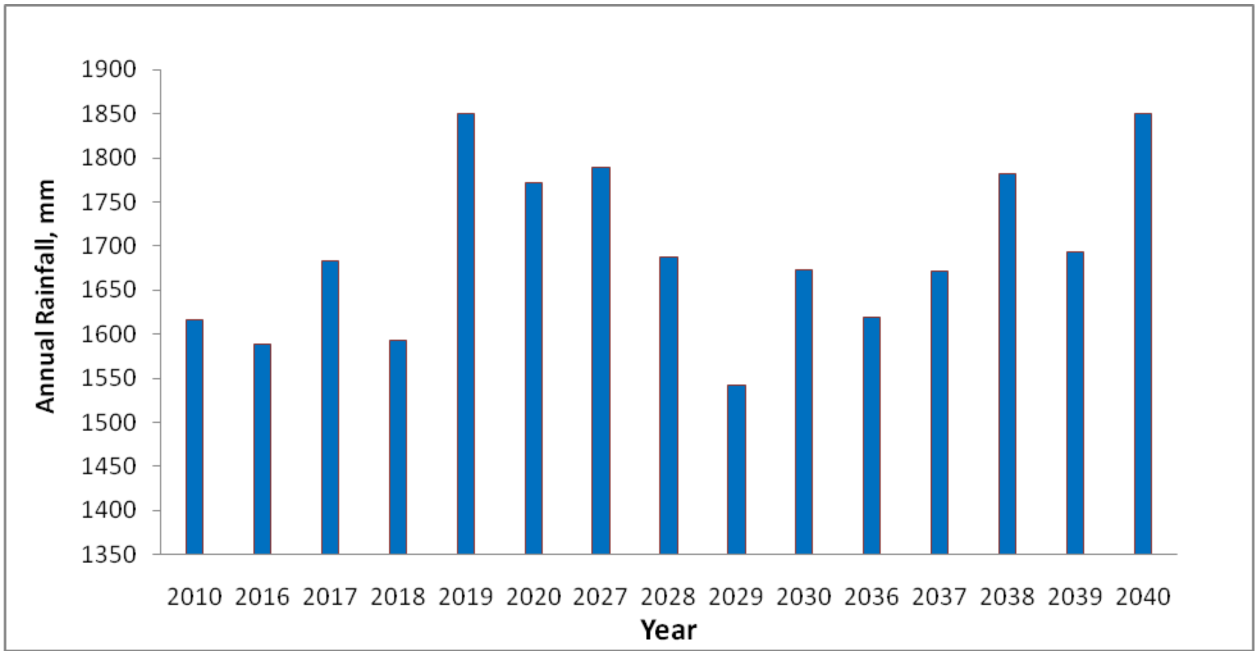


Figure 15: The PRECIS projected future annual rainfall for Soroti district for selected years

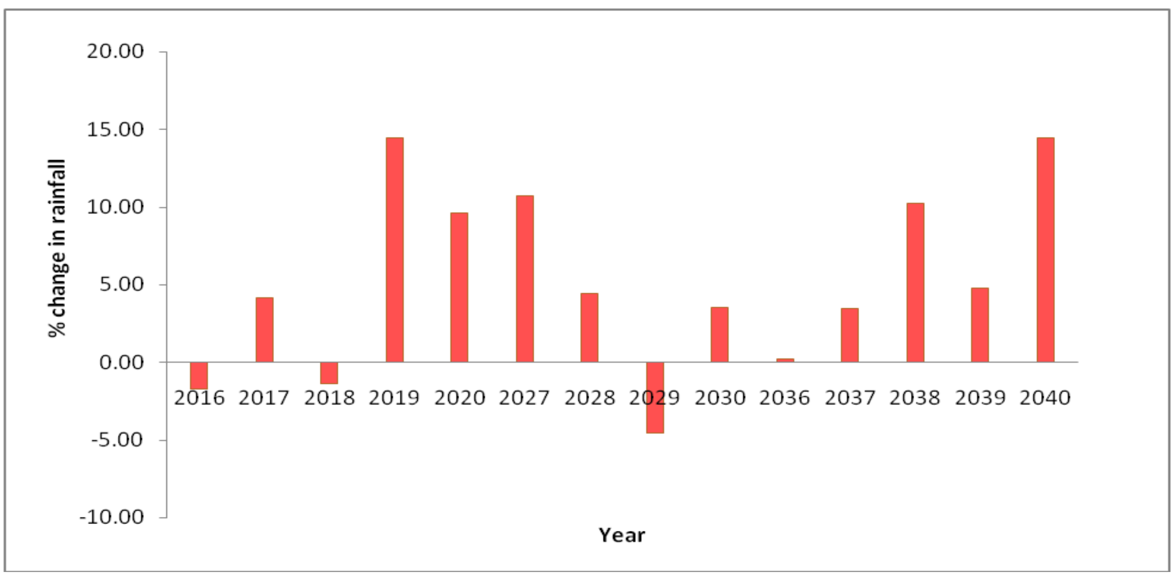


Figure 16: The percentage change in annual rainfall for selected years, in comparison to the year 2010 observed value

A comparison between historical and future Mean annual Rainfall (MAR) for 5-year periods, after a period of 30 years revealed an increase in MAR (Table 6). This comparison showed that by the year 2030, the MAR for soroti district will have changed by +34%.

Table 6: The change in MAR for Soroti district by the year 2030

Time slice	Mean Annual Rainfall (MAR)	% Change in MAR
a) 2006-2010	1335.72	
b) 2036-2040	1723.64	a and b) 29.04
c) 1997-2000	1248.03	
d) 2027-2030	1673.26	c and d) 34.07

Considering seasonal rainfall; in comparison with the year 2010, there will generally be a reduction in the amount of rainfall received in the first season of the year i.e. the months; March, April and May (MAM) while, there will be an increase in the amount of rainfall received in the second season of the year, i.e the months; September, October and November (SON) (Figure 17). This implies that a change in seasons is expected in the study area, where the MAM season which used to be the major and more favourable season will become the minor one, while the SON season which used to be minor will become the major one.

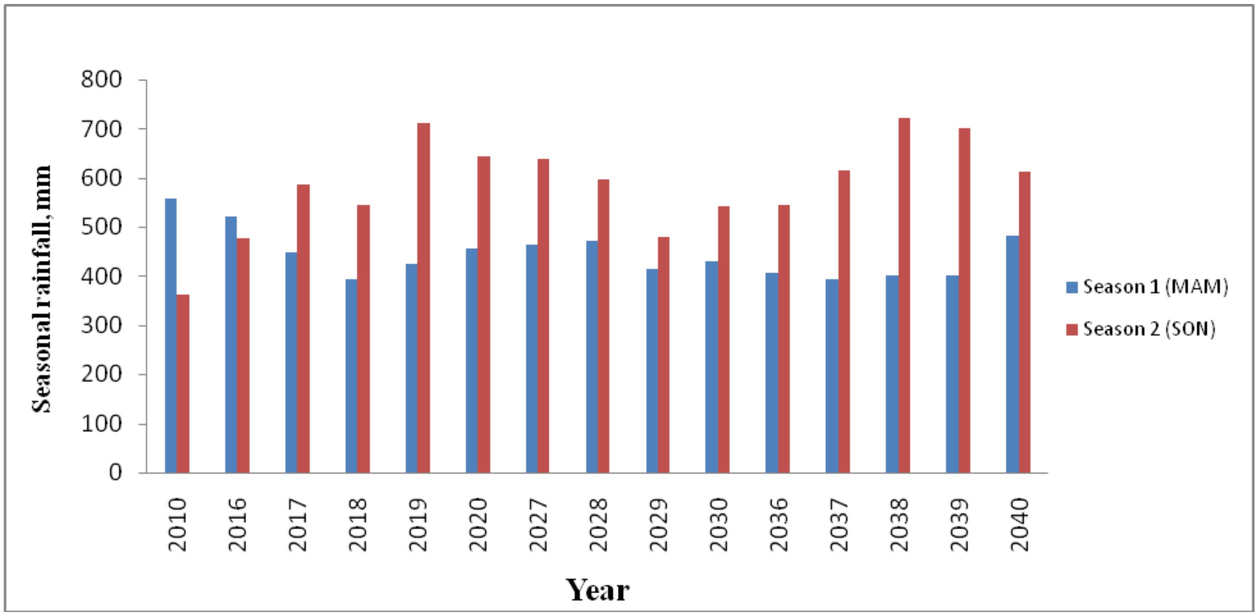


Figure 17: PECIS projected seasonal rainfall for Soroti district for selected years, in comparison with 2010 amounts

Figure 18 actually confirms that with climate change, the SON season is expected to have greater rainfall amounts than the MAM counterpart. The trend revealed in this graph is strikingly different from that given by Figure 6 (the monthly rainfall distribution for the study area in the historical years, 1990-2010).

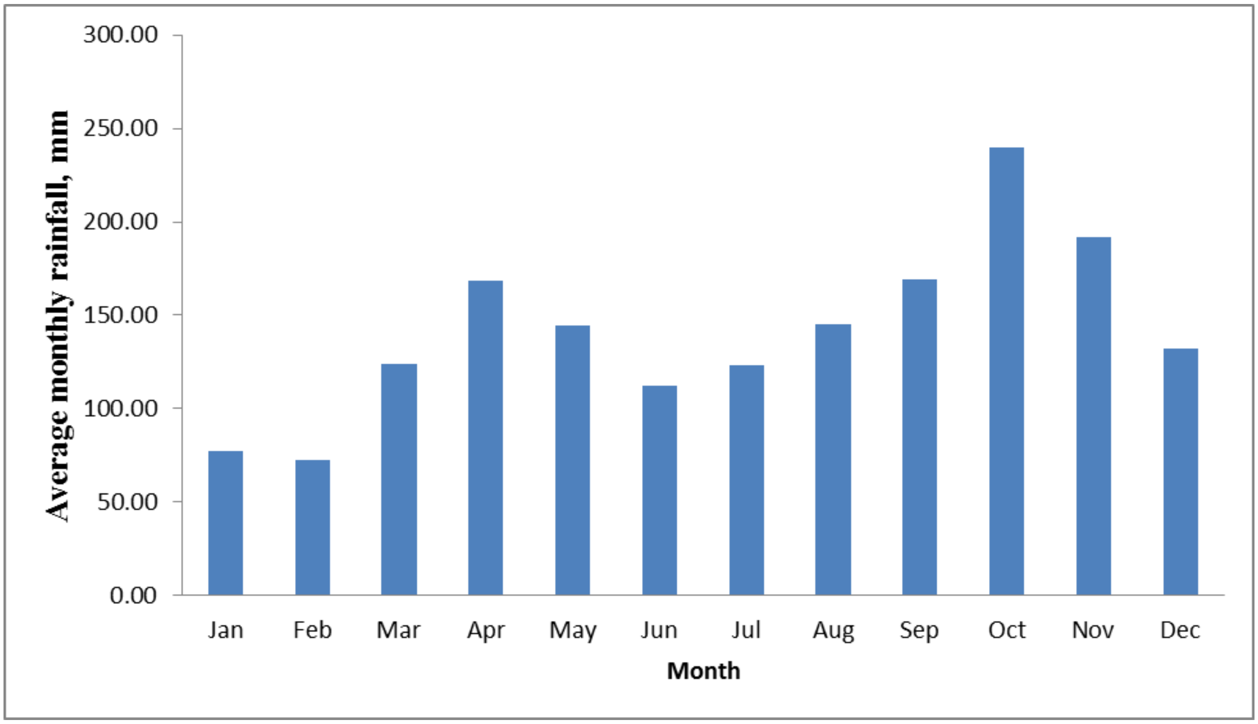


Figure 18: Average monthly rainfall expected in soroti district from for the years 2016-2020, 2027-2030 and 2036-2040

On the other hand, the PRECIS projected future temperature for Soroti district generally shows a decline in both annual average maximum and minimum temperatures by the year 2040 in comparison to the year 2010 observed values, although increase in only annual average minimum temperature is expected to occur in the years 2039 and 2040 (Figure 19). Thus, Soroti district is expected to be generally cooler in the future years according to this model. However since the maximum temperatures did not go below 26 ^{o}C, the temperatures still remain in the optimum ranges for sorghum growth as suggested by Maiti (1996) and thus the area is expected to continue supporting sorghum growth. The expected average changes in the annual average minimum and maximum temperatures by the year 2040 were -0.3^{o}C and -1.0^{o}C repectively (considering the average of the individual annual percentage changes for the 14 years simulated) (Appendix 6). Thus, in the next 30 years, the annual average mimimum and maximum temperatures in soroti district are expected to drop by 0.3^{o}C and 1.0 ^{o}C, respectively. These temperature changes are contrary to those suggested by Hepworth and Goulden, 2008, who reported that in Uganda, temperatures are likely to increase by up to 1.5 ºC in the next 20 years (i.e. at least by the year 2028).

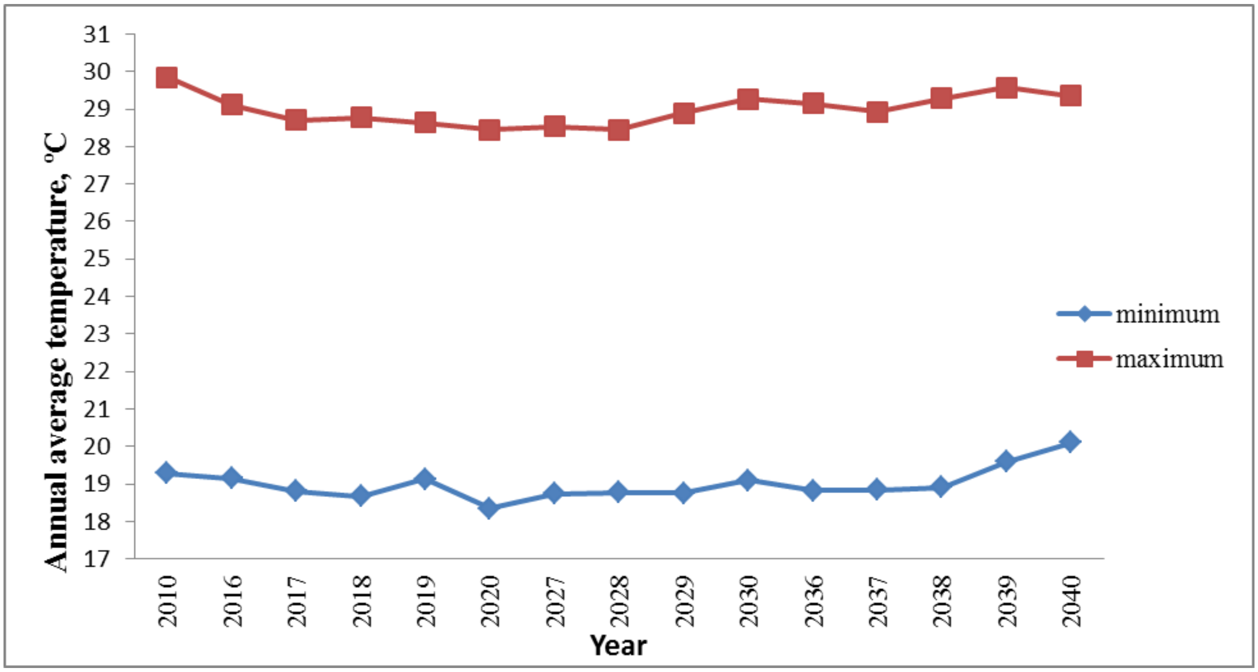


Figure 19: The PRECIS projected future annual average minimumm and maximum temperatures for Soroti district for selected years; in comparison with the 2010 observed values.

4.6 Validation of AQUACROP model

The data used for validation of this model is presented in Table 8.

Table 7: Sorghum grain yield data used for Evaluation of AquaCrop model

Season	Variety	Replication (Block)	Observed grain yield (ton/ha)	Simulated grain yield (ton/ha)	Error
Aug-Dec	*Edeidei*	1	2.349	4.708	-2.359
	Edeidei	2	2.878	5.364	-2.486
	Serena	1	2.791	6.576	-3.785
	Serena	2	4.095	10.651	-6.556
May-Aug	*Edeidei*	1	2.150	3.728	-1.578
	Edeidei	2	1.933	5.147	-3.214
	Serena	1	2.229	6.064	-3.835
	Serena	2	4.384	9.133	-4.749

Generally, there was a positive linear relationship between observed and Aqucarop simulated sorghum grain yields for the two seasons, Aug-Dec and May-Aug (Figure 20). The R^2 value of 0.811 implies that 81.1% of the variability in the AquaCrop simulated sorghum grain yield is explained by the relationship between this yield (AquaCrop simulated sorghum grain yield) and the observed values. Therefore, AquaCrop model is up to 81.1% fit for prediction of sorghum grain yield.

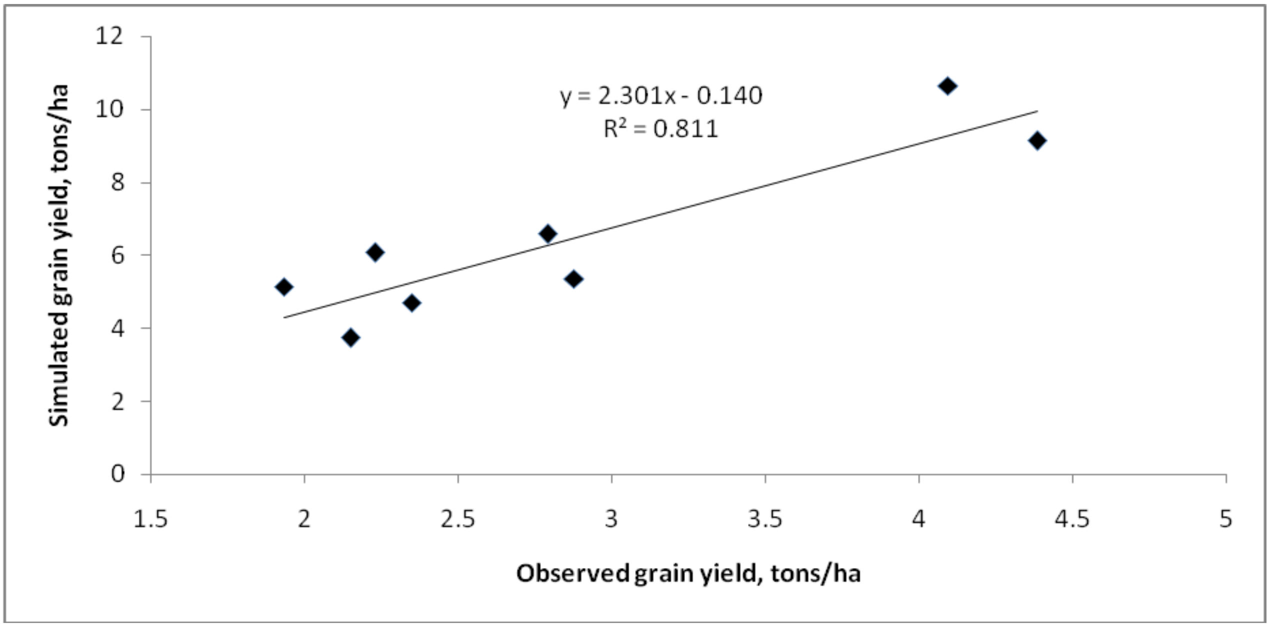


Figure 20: Observed and Aqucarop simulated sorghum grain yields for Soroti district for the two varieties, for the two seasons Aug-Dec and May-Aug; the line across is the Regression line

The correlation results also revealed a very high positive linear relationship between the observed and AquaCrop simulated sorghum grain yields, and, this correlation was statistically significant at 1% level of significance ($P<0.01$) (Table 8).

Table 8: Correlation between observed and AquaCrop simulated sorghum grain yields for Soroti district for the two seasons Aug-Dec and May-Aug

Variables	Correlation coefficient	P-value
Observed grain yield	0.901**	0.002
AquaCrop simulated grain yield		

***Correlation is significant at the 0.01 level (2-tailed)*

The AAE calculated was 2.409 ton/ha for *Edeidei* variety and 4.731 ton/ha for *Serena* variety. Therefore, the mean deviation between observed and AquaCrop simulated sorghum grain yields was 2.409 ton/ha for *Edeidei* variety and 4.731 ton/ha for *Serena* variety. Positive values of AAE implied that the model over predicted the grain yield. To adjust for this over prediction, the values of the AAE were to be subtracted from each simulated value of future sorghum grain yield, for the corresponding variety, and this served to validate the AquaCrop model for use in Soroti district.

The AquaCrop simulated sorghum grains yields under climate change for the years 2016-2020, 2027-2030, and 2037-2040, for both seasons, and for both blocks 1 and 2 are presented in Appendix 7. From each of these obtained values, the appropriate AAE obtained during evaluation and validation of AquaCrop model (i.e. 2.409 ton/ha for *Edeidei* variety and 4.731 ton/ha for *Serena* variety) was subtracted and the true values of the expected sorghum grain yields were obtained (Table 9).

4.7 Expected future sorghum grain yields under climate change

The true expected future sorghum grain yields, under climate change, for Soroti district are presented in table 9.

Table 9: The true simulated expected average sorghum grain yields (ton/ha) under climate change, for Soroti district, for selected years

Year	Season Aug-Dec		Season May-Aug	
	Serena	***Edeidei***	***Serena***	***Edeidei***
2016	4.051	2.664	3.843	2.623
2017	4.512	3.193	4.243	2.799
2018	4.539	3.22	4.224	2.841
2019	4.650	3.337	2.723	1.995
2020	4.644	3.334	4.162	2.807
2027	4.727	3.373	4.339	2.908
2028	4.770	3.406	4.128	2.784
2029	4.727	3.355	3.837	2.836
2030	4.800	3.429	4.400	2.943
2036	4.404	2.873	4.293	2.880
2037	4.875	3.472	4.477	2.987
2038	4.740	3.392	4.221	2.833
2039	4.905	3.493	4.225	2.845
2040	4.852	3.416	4.488	2.972

The average expected sorghum grain yields by the year 2040 are 4.6/3.28 ton/ha and 4.11/2.79 ton/ha for *Serena/Edeidei* varieties for the Aug-Dec and May-Aug seasons, respectively (considering the average of all the 14 years simulated).

In comparison with the 2010/2011 observed values, i.e. 3.43/2.62 ton/ha and 3.22/2.06 ton/ha for *Serena/Edeidei* varieties for the Aug-Dec and May-Aug seasons respectively (Table 4), the percentage changes in sorghum grain yield for both varieties for both seasons are presented in Table 10.

Table 10: Percentage change in the sorghum grain yields of the two varieties in the two seasons of the year

Year	Season Aug-Dec				Season May-Aug			
	Serena		Edeidei		Serena		Edeidei	
	Change	% change	Change	% change	Change	% change	Change	% change
2016	0.61	17.75	0.05	2.07	0.53	16.10	0.58	28.58
2017	1.07	31.15	0.58	22.34	0.93	28.19	0.76	37.21
2018	1.10	31.93	0.61	23.35	0.91	27.61	0.80	39.26
2019	1.21	35.16	0.73	27.85	-0.59	-17.75	-0.05	-2.23
2020	1.20	35.00	0.72	27.72	0.85	25.74	0.77	37.60
2027	1.29	37.41	0.76	29.23	1.03	31.09	0.87	42.52
2028	1.33	38.65	0.80	30.48	0.82	24.71	0.74	36.45
2029	1.29	37.41	0.74	28.52	0.53	15.92	0.80	39.02
2030	1.36	39.53	0.82	31.36	1.09	32.92	0.90	44.24
2036	0.96	28.02	0.26	10.06	0.98	29.68	0.84	41.15
2037	1.44	41.72	0.86	33.03	1.17	35.24	0.95	46.42
2038	1.30	37.79	0.78	29.94	0.91	27.52	0.79	38.85
2039	1.46	42.57	0.88	33.81	0.92	27.64	0.80	39.44
2040	1.41	41.03	0.81	30.88	1.18	35.59	0.93	45.66

Thus, there will generally be an incease in sorghum grain yields for both varieties in both seasons, and, this increase was statistically significant ($P \leq 0.001$ for both varieties in both seasons) according to the one-sample t-test conducted.

The expected future sorghum grain yields are also well above the average yields for Uganda i.e. 1.5 tons/ha (FAO STAT,2009), thus the study area is expected to have great potential for sorghum production. However, in the year 2019, there will be a reduction in the grain yields of both varieties although in only the season 1 (May-Aug) of the year.

A comparison of the average expected sorghum grain yields by the year 2040 with the average observed sorghum grain yields in the years 2010/2011 revealed that by the year 2040, the sorghum grain yield will have increased by 25% to 35% (Table 11).

Table 11: The Percentage change in the sorghum grain yields of the two varieties in the two seasons of the year, by the year 2040

	Aug-Dec season		**May-Aug season**	
	Serena	***Edeidei***	***Serena***	***Edeidei***
Current observed grain yield (ton/ha)	3.43	2.62	3.22	2.06
Future simulated grain yield (ton/ha)	4.6	3.28	4.11	2.79
% change in yield	34	25	28	35

These results are in contrast with those of IPCC 2007, that suggest that with climate change, the yield potential in arid and Semi-arid areas is expected to decrease (IPCC 2007d). The results are also in contrast with Wasige's report (Wasige, 2009) that showed that climate change will lead to 10% to 50% decline in crop yields in Uganda in the coming decades.

According to the stated hypothesis, the calculated t values (t-tests) obtained for each variety for each season are presented in Table 12.The tabulated t value, i.e. t_{n-1}, i.e. the t value at 13 (14-1) degrees of freedom under two tails at the 5% level of significance was 2.16. Since all the calculated t-values are less than the tabulated value, the null hypothesis (section 3.7) is not rejected, for both varieties and for both seasons. Hence, there's no significant difference between the predicted percentage changes in sorghum grain yield under climate change (by the year 2040) and the hypothesised figure of 20%. Therefore, it is statistically significant that by the year 2040, under the projected climate change, sorghum grain yield in Soroti district will increase by 20%.

Table 12: Hypothesis test results

Season	Variety	% change in grain yield	t-test	t_{n-1}	*n*	*Df*
2	*Serena*	34	1.11	2.16	14	13
2	*Edeidei*	25	0.43	2.16	14	13
1	*Serena*	28	0.67	2.16	14	13
1	*Edeidei*	35	1.18	2.16	14	13

Figure 21 shows that for *Serena* variety, the percentage increase in grain yield was always greater in season 2 (Aug-Dec) of the year than in 1, except for the year 2036; while for *Edeidei* variety, the reverse was true . In season 1 of the year, the yield of *Edeidei* variety increased higher than that of Serena, while in season 2, the reverse was true. Infact, in the year 2019 where there was a reduction in grain yield for both tvarieties in season 1 of the year, the reduction was smaller for *Edeidei* compared that of *Serena*. Therefore, *Edeidei* seems to be more favoured by the changes in season 1 of the year, while *Serena* is more favoured by the changes in season 2 of the year.

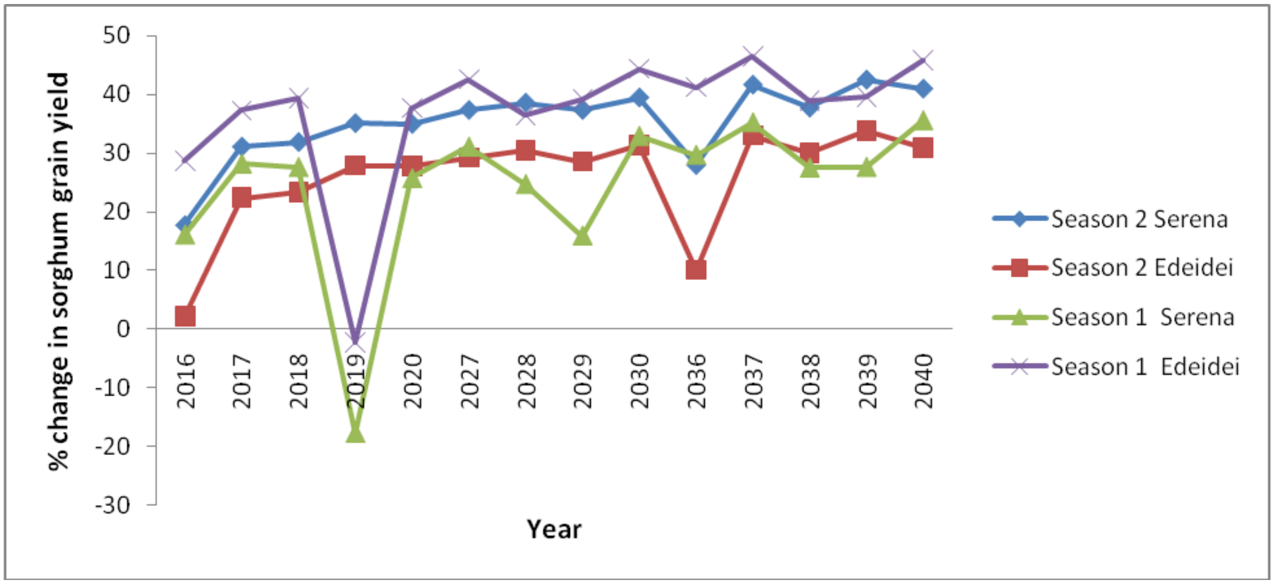


Figure 21: Percentage change in sorghum grain yields for the 2 varieties in both seasons of the year

4.8 Relationship between percentage change in sorghum grain and percentage change in seasonal rainfall.

A comparison between the percentage the change in sorghum grain and the percentage change in seasonal rainfall revealed that generally, the higher the percentage change in seasonal rainfall, the higher the percentage change in sorghum grain yield obtained (Figures 22 and 23).

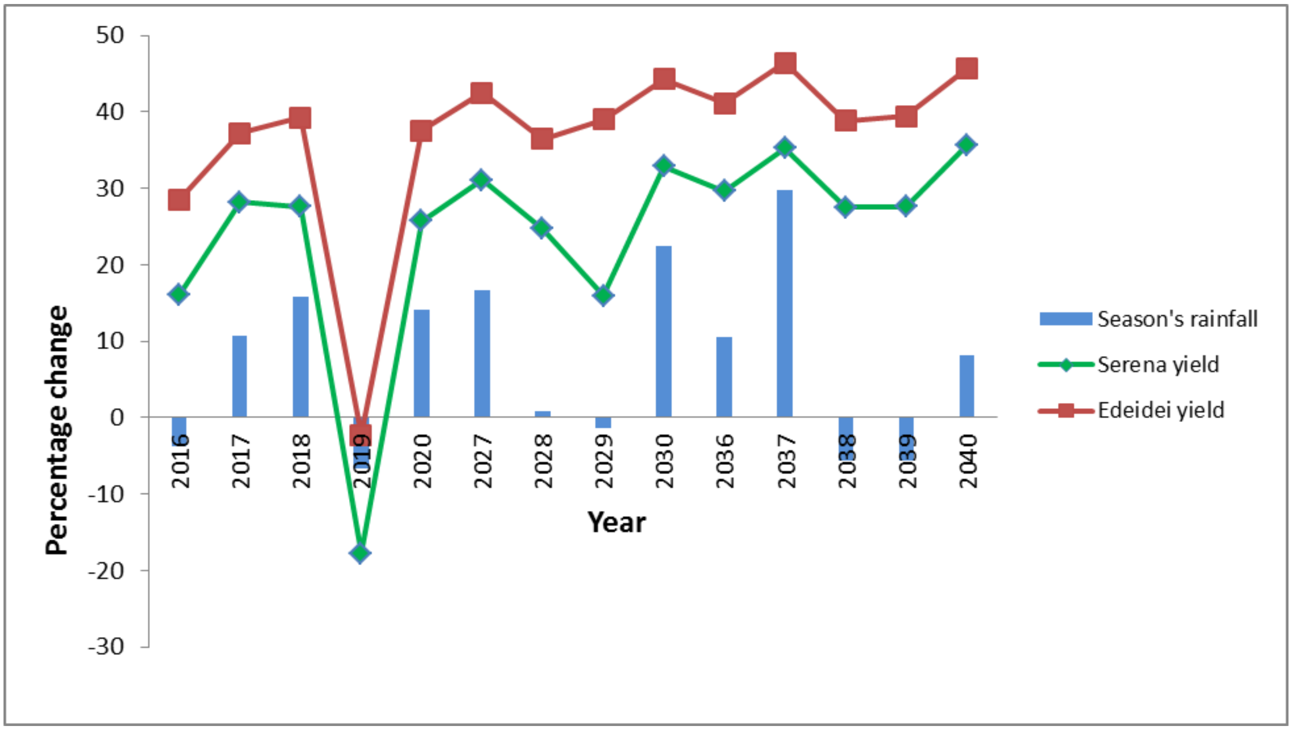


Figure 22: The variation of the percentage change in seasonal sorghum grain yields with the percentage change in the May-Aug rainfall in the study area

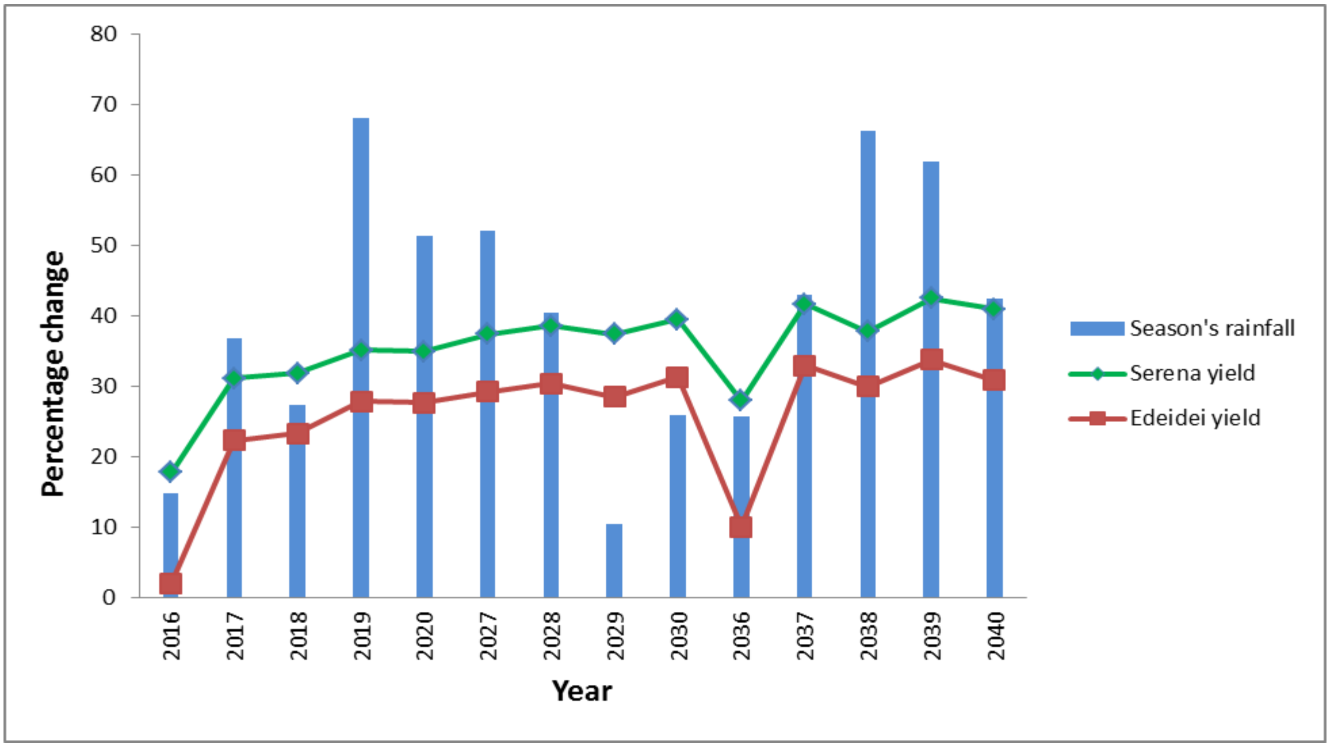


Figure 23: The variation of the percentage change in seasonal sorghum grain yields with the percentage change in the Aug-Dec rainfall in the study area

Further, a regression of grain yields on seasonal rainfall for the two growing seasons for all the years simulated revealed generally positive relationships (Figure 24). Therefore, increase in seasonal rainfall, is expected to increase sorghum grain yields. The R^2 values were greater for season Aug-Dec than May-Aug since the former generally had greater rainfall compared to the later.

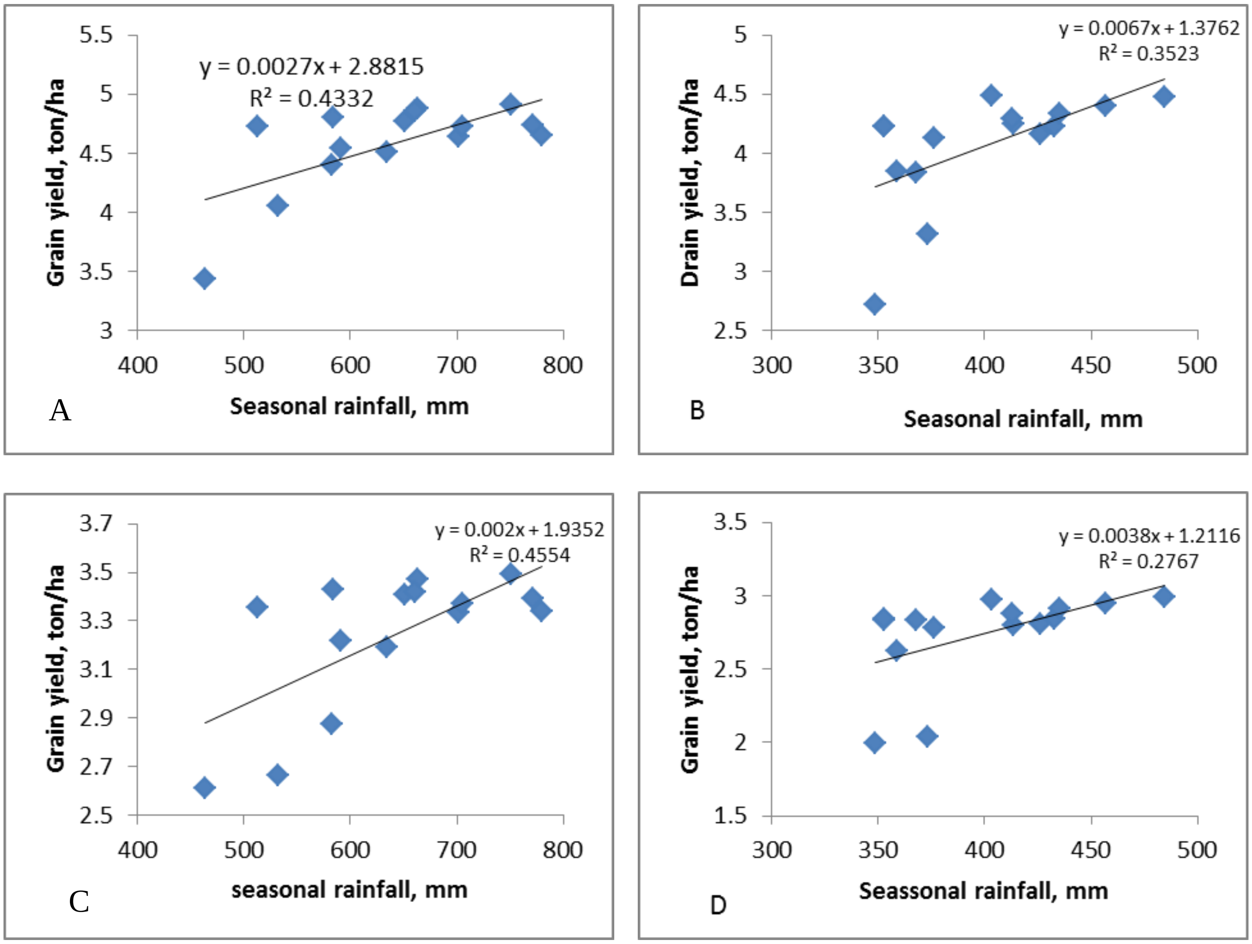


Figure 24: Relationship between seasonal rainfall and sorghum grain yield of the two sorghum varieties in the two seasons of the year. A and B: *Serena* yield for seasons Aug-Dec and May-Aug of the year respectively. C and D: *Edeidei* yield for seasons Aug-Dec and May-Aug of the year respectively. Data recorded in appendix 8

4.9 The communities' perceptions about climate change and its impact on crop production, and the existing coping mechanisms in the study area.

4.9.1 Background demographic information

This section describes some few attributes of the respondents that provided information on the community perceptions of climate change (Table 13). The study sought to achieve atleast 30%

participation of women, and this was achieved as even more women 38% were interviewed. Majority of the respondents (65%) had attained primary level as their highest level of education. The age of the respondents was so variable; although many youths below 40 years were interviewed (61%), at least 39% of the respondents were aged above 40 years and these would give more reliable information about climate changes in their area. Agriculture was found to be the number 1 income source for majority of the respondents (91%).

Table 13: The background demographic information of the respondents

Attribute	Frequency	Percent (n=80)
Sex		
Male	50	62
Female	30	38
Education level		
Never	8	10
Pre-primary	1	1
Primary	52	65
O level	13	16
A level	1	1
Tertiary education	5	6
Age		
< 18	1	1
19-30	27	34
31-40	21	26
41-50	14	17
51-60	9	11
>60	8	10
Number 1 income source		
Crop production	73	91
Livestock production	4	5
Commerce/trade	1	1
Fishing	1	1
Crop dealing	1	1

The background demographic information revealed a community of mainly peasant farmers with low levels of education and depending heavily on crop production for their livelihood. Further, the study received a good coverage of gender i.e. women who are the more active sex in rural agriculture were satisfactorily covered.

4.9.2 The farmers' perceptions of climate change and its effect on crop production

4.9.2.1 Climate change awareness among the respondents

The results from the household interviews conducted (n=80) revealed that majority (89%) of the respondents have heard about climate change. Considering gender, many more men have heard about climate change (56%) than women (33%), while a little fewer women (5%) have not heard of climate change than men (6%). However, the Chi square test for associations did not indicate a significant association between gender and climate change awareness ($P > 0.05$). The radio was found to be the greatest source of climate change awareness (80%), followed by villagemates (13%), (Figure 25). Among the respondents who had ever heard of climate change, there was a great variation with regards to the time of climate change awareness as seen in Table 14. However, majority of the repondents (34%) got to know about climate change in the year 2010.

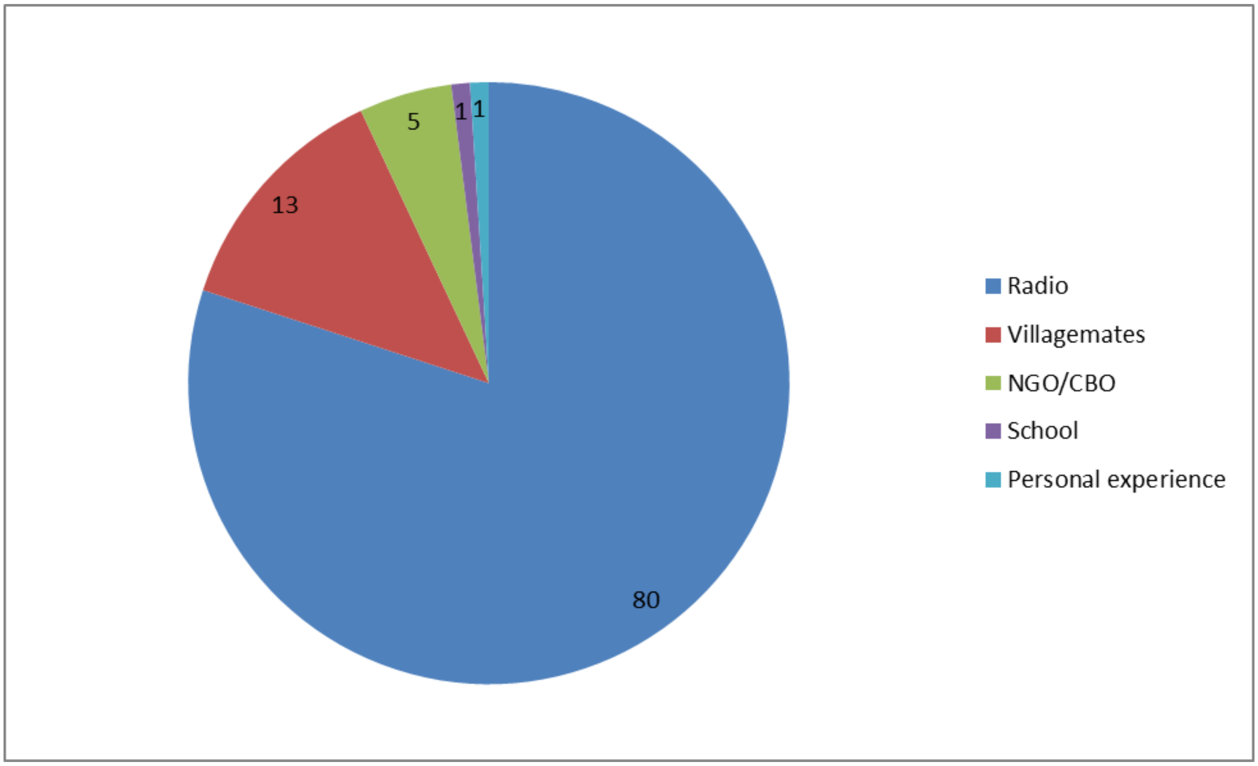


Figure 25: The relative importance (%) of the different sources of climate change knowledge (n=71)

Table 14: The respondents' time of climate change awareness

Time of climate change awareness	Number of respondents	Percentage (n=67)
2010	23	34
2-3 years ago	11	16
2011	9	13
7-10 years ago	8	12
4-6 years ago	5	8
11-15 years ago	5	8
Over 20 years ago	4	6
16-20 years ago	2	3

4.9.2.2 Key indicators of climate change

All the respondents (100%) indicated that the climate in their area was changing. The following were the key indicators of climate change cited;

i. **Change in wind direction and strength;** according to the respondents, winds that signaled the beginning of the rainy season in the past used to blow from East to West and these used to be calm. Today, the winds blow from West to East or North to South, and are very strong and destructive. Thus, prediction of rainfall is now a challenge. And, usually, the rains that follow after these strong winds are characterized by hailstorms and lightening, killing humans and livestock, and also destroying crops.

ii. **Change in timing of the dry spell;** in the past, the dry spell occurred from November to February and the rains would start in March. Today, this period has become longer, going on from November to May, and being intensive in July. This extensive drought causes total crop losses, increases the incidence of disease such as coughs, fever, flu, and Diarrhea (due to poor water quality and poor food), and leads to death of livestock due to lack of sufficient pasture and water.

iii. **Change in flood occurrence**; in the past, floods used to be an uncommon occurrence (with a 5-10 years return period) and would only occur near the swamps. Today, floods have become very common, occurring nearly every year, and affecting both near the swamps and on upland. However, the citizens attribute increase in flood incidence to; the poor ploughing methods that some farmers use today, i.e ploughing downslope instead of across and making larger plough trenches; burning of bushes; and lack of grass bans, all these leading to high water speed.

iv. **Change in seasons**; in the past there used to be two distinct seasons, the first season beginning from March to June (i.e. July would be dry for harvesting), and the second season beginning from late August to early November (December used to be completely dry). Today, the seasons are not distinct; sometimes, there are prolonged rains even up to November and December. These changes have resulted in high post-harvest crop losses i.e. the too much rain that occurs towards the end of the season makes it hard for the harvest to be dried leading to moulding of the harvested produce, and may also result into rotting of the crops in the garden before they are harvested. The change in seasons, according to the respondents has led to 80% losses in crops. Also in the past, the first season used to be the most important with longer duration and more reliable rainfall; today, this season has become inferior instead, and now, the second season has more dependable rains. This was vividly observed in the first season of 2011 where the rains did not stabilize until May.

The magnitude (relative importance) of the different indicators of climate change on a scale of 1 to 10 is shown in Table 15.

Table 15: The relative importance of the indicators of climate change in Soroti district

Climate change Indictor	**Magnitude;** 1 (very weak) - 10 (very strong)
Change in timing of the dry spell	8
Change in flood occurrence	8
Change in seasons	8
Change in wind direction and strength	7

4.9.2.3 The perceived causes of climate change

Cutting of trees was the major perceived cause of climate change among the respondents (51%), (Figure 26). The respondents have been told and believe that trees are very important in rainfall formation; thus their destruction would be the cause of the excessive droughts. However, some respondents (15%) think that climate change is God's own making. Cultivation in wetlands then followed in importance as a possible cause of climate change. According to the communities, cultivation in wetlands destroys swamp vegetation which plays a big role in rainfall formation, and water reservation and purification. Other suggested causes of climate change (below 6% each) included; burning bushes, pollution by industries, wars, strong winds, poor farming methods, high population growth, new livestock with high milk yield, crops that require a lot of water, and natural seasonal changes.

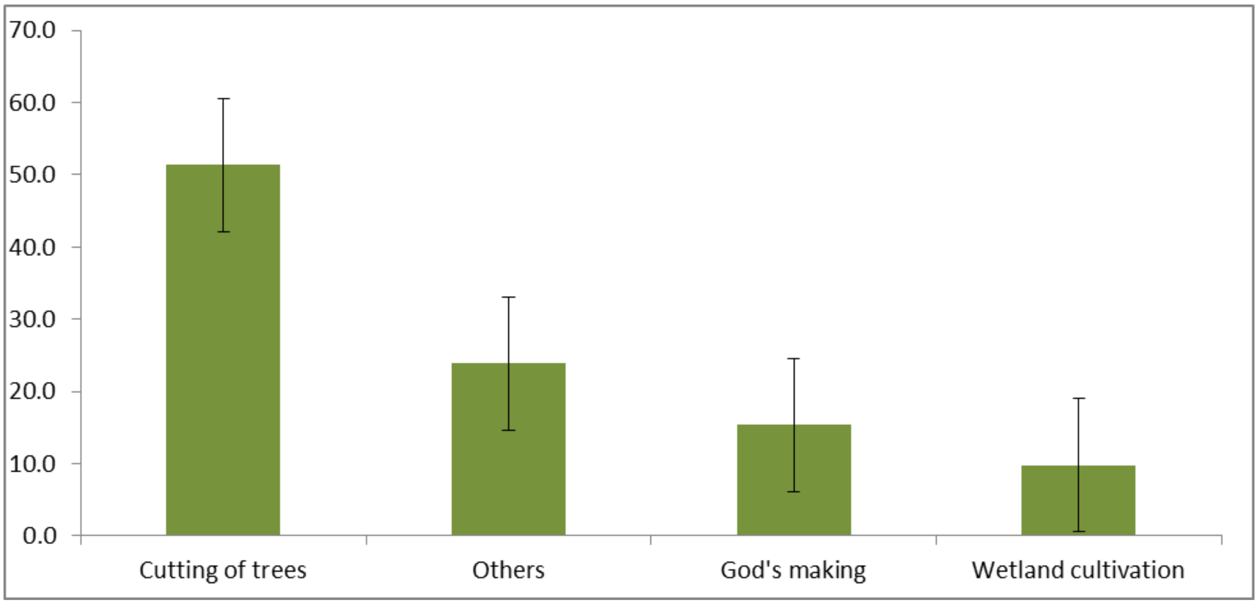


Figure 26: The percentage importnce of the percieved causes of climate change in Soroti district (n=72)

4.9.2.4 Perceived impact of climate change on crop production

High crop failure was the main perceived effect of climate change on crop production (Figure 27). This comes as a result of unpredictable weather which is realized in changes in the timing of rainfall onset and/or cessation (i.e. change in seasons). The high crop failure eventually leads to a reduction in seasonal yields. The respondents also cited change in varieties in terms of their yields over the years as an effect of climate change.

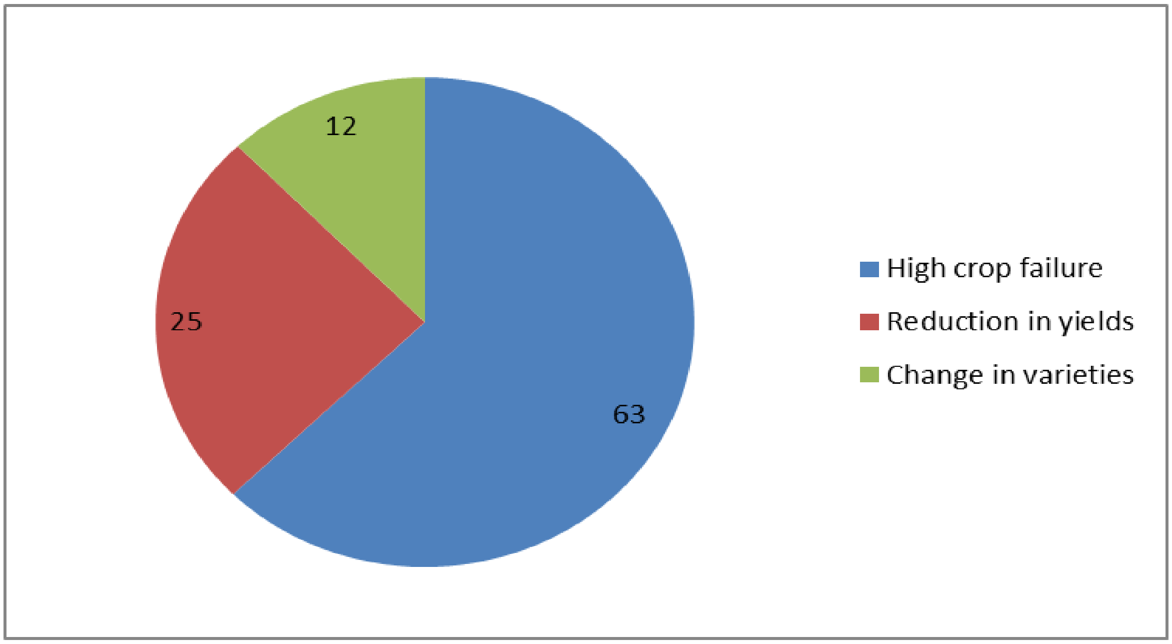


Figure 27: The Percentage importance of the perceived effects of climate change on crop production in Soroti district

4.9.3 Existing coping/adaptation practices to climate change, and, changes in farming ways after climate shocks

4.9.3.1 The adaptation/coping practices to the effects of climate change.

Tables 16 and 17 present the adaptation and coping practices (respectively) to the effects of climate change on crop production such as; change in rainfall amounts, timing and duration; reduction in yields; change in varieties; high crop failure and destruction of crops by unpredictable weather. While, 26 out of the 80 respondents did nothing about the climate change problems; Planting as early as the rains start, Growing improved seed and varieties, Early garden preparation, Growing drought resistant crops, Growing Early maturing crops, and waiting until the rain stabilizes were the major adaptation options cited by the respondents. On the other hand;

Avoiding the sale of food, and Seeking off farm jobs, were the major coping options. Environment enhancing practices such as soil and water conservation, and planting of trees received very little attention i.e. 4% and 1% respectively.

Table 16: Adaptation practices to the effects of climate change on crop production in Soroti district

Practice	Relative importance (%) (n=54)
Plant as early as the rains start	20
Grow new/improved varieties	13
Early garden preparation	10
Grow Drought resistant crops	9
Grow Early maturing crops	9
Wait until rain stabilizes	7
water/soil conservation	4
Re-planting	4
Alter crop types	3
Planting trees	1
Cultivate in high areas	1

Table 17: Coping practices to the effects of climate change on crop production in Soroti district

Practice	Relative importance (%) (n=54)
Avoid selling food	8
seek off farm job	7
Report to sub-county	3
Reducing granary size	1
consume food sparingly	1

4.9.3.2 Change in farming ways after climate shocks

The respondents were also asked to provide information on how they may change their farming ways after the occurrence of a climate shock (drought or flood). Reducing livestock size, planting improved seed, fast maturing varieties and drought tolerant varieties were the major forms of change in farming ways after a drought (Table 18). However, majority of the respondents (71 out of 80) did not change their farming ways after a drought.

Table 18: Change in farming ways after a drought in Soroti district

Change in farming ways	Percentage (n=9)
Reduced livestock size	22
Planted improved seed	22
Planted fast maturing varieties	22
Planted drought tolerant crops	17
Planted twice after the drought	6
Farmed in low lands	6
Prepared early	6

In the occurrence of a flood**,** cultivation in raised areas, reducing livestock size and ploughing across contours were the major forms of change in farming (Table 19). However, as for drought occurrence, majority of the respondents (59 out of 80) did not change their farming ways after a flood.

Table 19: Change in farming ways after a flood in Soroti district

Change in farming ways	Percentage (n=21)
Cultivated in raised areas	72
Reduced livestock size	9
Ploughed across contours	9
Harvested early	5
Planted improved seed	5

The respondents were also asked to cite the challenges that prevent them from changing their farming behaviors after the occurrence of a climate shock. In this regard, lack of information about the appropriate adaptation responses in terms of changing farming ways, and land shortage seemed to be the major constraints to change in farming ways after a flood or drought (Table 20). Those who said they had no constraint in changing farming probably had no information on the appropriate responses.

Table 20: Constraints to changing farming ways

Constraint	Percentage (n=80)
Lack of information about appropriate adaptation responses	27
None	26
Land shortage	25
No water for irrigation	8
Lack of access to credit	7
Shortage of labour	7

CHAPTER FIVE-DISCUSSION

5.0 Introduction

This section presents an interpretation and implication of the results in light of the stated objectives.

5.1 Current sorghum yields in the study area, and the seasonal variation in yield

The current sorghum yields established for the two growing seasons for the two varieties considered in the study area were above the average yield averages expected for Uganda by FAO (2009); this implies that Soroti district has potential for great sorghum production. Of the two varieties, *Serena* always produced higher grain than *Edeidei*. A variety that yields better than another should be able to partition more dry matter to grain development than its counterpart. Therefore, *Serena*, being a relatively shorter variety than *Edeidei*, is capable of partioning more dry matter to grain development (since it doesn't waste a lot of substrates on growing taller), hence, always producing slightly higher grain yield than *Edeidei* although the difference was not statistically significant.

Tolk and Howell (2001) established that in order to achieve high yields of sorghum, cultivars with cycle from 110 to 130 days require 450 - 650mm of water. This means that the cultivars used in this study require even less amounts of water since they have shorter cycles (95-100 days). The total rainfall amounts received were 463.60 mm in season Aug-Dec and 373.40 mm in season May-Aug. Thus, the Aug-Dec rain was within the required range while the May-Aug one was below optimum. The lower rainfall received in season May-Aug coupled with its poor distribution within the growing season (Figure 10) therefore, accounts for the lower sorghum yields obtained in this season than in the Aug-Dec counterpart where total rain received was sufficient and its distribution (Figure 10) was close to the sorghum water requirement per growth stage as suggested by Stichler and Fipps (2003) (Figure 4).

5.2 Expected future climate for Soroti district

5.2.1 Expected future rainfall

It's important to note that most future climate projections in literature have been made for the years 2070-2100. Nonetheless, although the time frame is different, the expected general increase in future annual rainfall obtained in this study agrees with results of several authors; for example, Christensen *et al*. (2007) found out that with the SRES A1B emissions scenario, for 2080-2099, mean annual rainfall is likely increase in tropical and eastern Africa (of which Soroti district is part) by around +7%. Further, the summary output of 21 GCMs used by IPCC (2007d) reported that for the East African region, by the end of the 21st century, there will be a 25% increase in annual rainfall. The expected change in seasonal rainfall that was found in this study is in agreement with the responses obtained from the survey conducted in the study area, where the respondents narrated that they have noticed of recent that the second season (SON) which used to be the minor (while MAM was major) is now becoming the major with greater amounts and more reliable rains. In comparison with a study conducted by Nandozi *et al*. (2007), both studies predict changes in seasons in the future, although, the former considered the years 2070-2100; in contrast, the seasonal rainfall distribution changes observed in this study totally disagree with Nandozi *et al*.'s (2007) where they suggested that the MAM season will show an increase in rainfall received in future (2070-2100), while the SON season experiences a reduction in the same.

5.2.2 Expected future temperature

The expected reduction in average temperatures over Soroti district observed in this study could probably be due to the generally increased rainfall amounts that bring about a cooling effect. Besides the cooling effect, the increased rainfall amounts might lead to increased vegetation density, and, as demonstrated by Bounoua *et al*. (2000), an increase in vegetation density, could partially compensate for greenhouse warming, and lead to a cooling of 0.8°C per year in the tropics, including Africa. However, it should also be noted that Regional Climate Model (RCM) experiments generally give smaller temperature increases (Kamga *et al*., 2005), and these might have stretched to decreases in this case.

5.3 The effect of climate change on sorghum yield in Soroti district

The results of yield simulations under the changed rainfall and temperature revealed an increase in sorghum grain yields for both varieties in both seasons of the year, except for season May-Aug of the year 2019, where a reduction in the grain yields of both varieties is expected. The increase in sorghum grain yield is certainly due to the increased rainfall in the study area.

Noteworthy was the fact that even for some reduction in rainfall, there was an increase in grainyield. This implies that there are other factors that affect yield in this case, other than rainfall. So, the increase in atmospheric carbondioxide concentration could also have an effect on grain yield. The AquaCrop model database showed that in the A1B scenario, the atmospheric carbondioxide conncentration increased from the 2010 level of about 400 ppm to about 500 pm (i.e. 1.25 times) by the year 2040. Thus, an increase in atmospheric carbondioxide concentration could also have contributed to the increase in sorghum grain yield by increasing on the rate of photosynthesis. Kimball (1983) reported that the C4 species response to doubling of CO_2 (when doubling meant increase from 330 to 660 ppm CO_2) was 10 percent. The same author however noted that high temperature stress during reproductive development can negate CO_2's beneficial effects on yield. Thus, the reduced temperatures in the study area could provide suitable environments for the crop to benefit from the little carbon dioxide increase, resulting in increased grain yield. However, when there was a reduction in rainfall of above 6.0%, i.e. in the May-Aug season of 2019, there was a reduction in yield. This implies that, for low seasonal rainfall as that of the former season i.e. below 350 mm (Appendix 8), the benefits from increased CO_2 concentration are not realized.

5.4 The farmers' perceptions of climate change and its effect on crop production

The results of the respondents' climate change perceptions imply that although the rural people do not know the science behind climate change, they have observed changes in their local weather and seasons. The citizens relate climate change to only environmental degradation in and around their areas; for example cutting of trees and cultivation in wetlands to be responsible for increased drought; and, poor ploughing methods, bush burning and lack of grass bands being responsible for increased floods. Thus, the citizens are not aware of the global warming caused by the greenhouse gases emitted by industries and vehicles elsewhere, including places outside Uganda. These results are similar to those of the research conducted by the BBC World Service Trust, 2009, that found that most Ugandans often make little distinction between environmental degradation and climate change. In the same study, the media of which the radio is part was found to be the major source of climate change awareness (similar to findings from this study). The radio assumes the number 1 position in creating climate change awareness because many environment activists today use radio programs (due to their wide coverage and affordability to all classes of people) to sensitize the masses about climate change. This information is later dissseminated by the village members who listened to the program to their fellows who may or may not have listened to the same, during their usual conversations; hence village members become the second ranked source of climate change information. BBC WST (2009) further discovered that crop failure is one of the climate change effects that have frustrated most farmers; this is in accordance with the findings of this study since crop failure was the major perceived effect on climate change on crop production. Crop failures come due to; excessive droughts that make crops dry in the fields and frequent floods that carry crops away or make crops rot in the field. The crop failures consequently result in reduction in crop yields or complete crop loss.

5.5 Efficacy of the existing climate change coping and adaptation practices

The high number of respondents who say they have done nothing about the climate change problems implies that there hasn't been sufficient sensitization concerning possible adaptation practices, or that the framers do not have enough resources to venture into adaptation measures such as planting improved seed.

Early garden preparation as an adaptation to late rainfall onset enables the farmer to plant immediately when the rain starts so that the crop benefits sufficiently from the short rain period that may follow after. This practice is therefore effective.

Planting as early as the rains start is effective since it ensures that the growing crop benefits sufficiently from the available rainfall. However, many farmers often fail to achieve this due to labour shortage in their homes. This is especially true for small sized families with very young children who cannot participate in gardening. Thus, some portions of the land are tilled late, leading to poor harvest. This practice also requires sufficient information on the expected rainfall pattern. Otherwise one is at risk of losing their planted crops in case the rain stops suddenly.

Drought resistant crops, early maturing crops/varieties and improved seed are a crucial adaptation mechanism as such crops may have the capacity to produce considerable yield even when the rains are not sufficient/come late. However very few farmers have access to the early maturing varieties and improved seed as these usually come at a cost which the resource poor farmers may not afford. Most farmers keep growing their traditional varieties, making this practice applicable to only a small fraction of the society.

Avoiding the sale of food, due to the reduced harvest per season would increase the family's food reserves. However, this has a negative access to other needs of the family such as medication, clothing and education, since crop production is the number one income source of most of the rural households. Therefore, families that stop selling their produce are at a risk of having their children drop out of school (resulting into early marriages and a generation which may not help their parents during old age), being unable to buy clothing and mosquito nets for their members (resulting in malaria and pneumonia infections), and being unable to seek medical attention in case of sickness (resulting in miserable deaths). All these will eventually result in setbacks in the development of the communities. Another practice related to this was consuming food sparingly; this would allow the household to "survive" with little harvested produce but also puts the family members, especially children, at a risk of malnutrition that may escalate into death.

Reduction of granary size in response to the reduced seasonal produce seems to be a redundant option that doesn't help in any way in adaptation to climate change. This is likely to be an effect of stress on the farmer who is disappointed with his/her produces.

Waiting for rain to stabilize until one can plant their crop /altering planting to the changes in weather is a good practice since it avoids crop failure due to lack of sufficient soil moisture at the seedling stage. However this practice is still associated with the uncertainty of weather the duration of the rainy period after the rain has stabilized will be sufficient for the crop to reach maturity. Such a situation would require a short maturing variety, which the resource poor farmer may not afford.

Altering crop types depending on the rainfall situation in a given season is an effective adaptation measure as some crops are able to tolerate drought/excessive rainfall more than others. For example if there's too much rainfall, the farmers grow sorghum instead of cassava since cassava is very susceptible to rotting.

Some farmers mentioned that they sometimes decide to re-plant crops when the original ones are scorched and killed by lack of rainfall; this could be a good option though it has great implications on labour demand which is now diminishing as many people are seeking off-farm activities.

A small fraction of the farmers mentioned soil and water conservation as a means of adapting to droughts and floods. It was evident from many gardens that farmers maintain grass bans between gardens with the purpose of conserving water and soil, and also ensuring that flood water can sink in these bans. The farmers, however, complained of some few citizens that are failing to adhere to this practice. This is such a commendable practice that should be encouraged. Other environmental conservation practices such as agro-forestry and application of manure are potential climate change adaptation practices although they are not widespread. Water harvesting was also mentioned as an adaptation measure; however, this water seems to be used in the household and not for crop production since no farmer was found to be practicing small-scale irrigation.

Seeking off farm jobs can be a saving option for the lucky peasants who may be able to find a job or employ themselves in other ways. In southwestern Nigeria, this was found to be the most common adaptation practice among the arable food crop farmers (Apat *et al*., 2009). However, it is worthwhile to note that all these "mouths" that abandon crop production will have to be fed by the remaining few farmers. Consequently, the amount of food produced will reduce and the food market prices will go high, since more food from other areas will have to be supplied. This will eventually cripple the progress of those that have abandoned agriculture as they will be spending most of their income on food supplies. During the FGDs, the participants lamented that many young people have abandoned crop production; there are more mouths to feed that those engaged in food production.

Cultivation in high areas is an effective adaptation measure to flood occurrence for those who have plots in such areas. This practice on the other hand is a dream for the people whose areas become entirely affected by floods (i.e. those who do not have access to high areas), warranting re-location.

Finally, the community members also mentioned that they report to the sub-county officials for help when calamities such as floods and drought destroy their crops. The sub-county officials later forward the reports to government and NGOs who usually provide food aid (maize flour and beans) and some seed. Nonetheless, the food aid usually provided is usually insufficient i.e. it cannot feed the households for the several months they take without any harvest. The households have to seek help elsewhere, such as from relatives who have employment in towns. Some farmer lamented that a lot of maize floor may be sent by NGOs but each household may receive only 2 cup-fulls. A Sub-county chairperson also lamented that his reports are usually not responded to immediately by the government department of disaster preparedness.

CHAPTER SIX – CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the data collected, analysed and discussed, the following conclusions can be drawn;

1. According to the regional climate change projections obtained by downscaling the projections of GCM, ECHAM, using the RCM, PRECIS, under the A1B climate change scenario, climate change is expected to generally result in increased sorghum grain yield in the Teso farming system by the year 2040.
2. The farmers' perception of climate change differs from climate change science; the rural people relate climate change to only environmental degradation in and around their areas. However, they have noticed that the climate in their area has changed mainly due to change in seasons (i.e. on-set and cessation of rains, and the duration and reliability of the rains), and that this change has led to increased crop failure in their land.
3. The adaptation practices employed by the communities in the Teso farming system are effective, although they require external support such as climate information and free/subsidized improved seed. However, some coping practices employed are ineffective and/or have negative effects on the people's well-being ,and thus, can not be relied on to help members cope with the possible negative effects of climate change.

Recommendations

The following recommendations emanate from this study:

1. If the expected yield increase comes to pass, it should be utilised by encouraging farmers to engage in sorghum production. To achieve this, the government, through its agricultural

extension service should provide; free or subsidised improved seed, oxen and disc ploughs, and, subsidised fertilizer, and create market (with attractive prices) for the harvest.

2. Since the future remains uncertain, especially in terms of rainfall variability, more development projects should be conducted in this area to help farmers come up with efficient adaptation practices to the possible negative effects of climate change. Such practices include the following;

i. **Promotion of agroforestry**

Agroforestry has a potential of mitigating the negative effects of climate change since the grown trees help to improve the micro-climate and also control soil erosion. Therefore agroforestry research and implementation should be strenthened in the Teso farming system so as to reducce crop failure that comes with droughts and floods. The citizens mentioned during the FGDs that they are argued to plant trees; however some haven't received any tree seedlings, and even for those who have received, sometimes trees are supplied during periods when there's not enough rain to make them grow. Farmers also need techical information on how to manage their tree seedlings to ensure that they establish properly.

ii. **Establishment of small scale irrigation**

The excessive rainwater that flows in the study area during flood periods could be harvested by digging of shallow wells/retention basins. Such water reseviours can provide supplemental irrigation for field crops in the occurrence of dry spells.

iii. **Practising soil and water conservation**

Soil and water conservation through techinques such as conservational tillage, maintainence of grass bans between garden and application of organic matter have the capacity to; enhance soil fertility, improve soil moisture retention and buffer crops against flood and droughts. Therefore, this practice should be given special attention by agricultural advisors in the rural areas in order to improve adaptation to climate change.

iv. Dissemination of climate information to guide decision making

The meteorology department in Uganda is already doing a good job of informing the public about the expected time for rains and other climate events. This pracice should be strengthened by improved collaboration between the climate experts and agricultural advisors, so that the information desseminated by the climate experts is backed with alternative practices that the farmers shold employ (by the agricultural advisors)

v. **Development and promotion of improved crop varieties**

In the face of climate change, it is important that research institutes venture into the development of drought or rot tolerant varieties of the major crops grown in the study area i.e. cassava, potatoes, sorghum and cowpea. The developed crop varieties should be availed to resource poor farmers through well designed implementation programs.

vi. Provision of rural micro-credit schemes for the farmers

From the adaptation practices named by the farmers, it was observed that oly 8.5% of the farmers resorted to growing improved seed due to changes in climate. This implies that the rest of the farmers are economically constrained and thererfore can not afford improved seed. If such farmers had access to credit, they would probably buy the improved seed. Most banks do not offer loans to poor farmers since they do not expect them to pay back easily. Most farmers can only access credit from their relatives who also have little for themselves, and therefore cant offer sufficient funds. Thus, rural micro-credit schemes specifically directed to increasing the capital base of the small scale farmer would greatly increase their chances of accessing improved seed, which may yield considerably in the occurence of climate change.

3. Although this study has provided hope that climate change may lead to an increase in sorghum grain yield, these results should not make the the concerned parties to relax. This is because climate projections and crop simulations are prone to many errors. Forexample, different climate models can provide different projected results for the same location, and in addition, it was already found out that Regional Climate Model experiments generally give smaller temperature increases (Kamga *et al*., 2005), which may have progressed into decreases in the case of this study. Further, the Crop model used in tis study was developed in the USA and thus could have inbuilt non-changeable coefficients that are not appropriate for use in other continents especially Africa, with completely different seasons. Therefore, more research on this topic could be done using other models to provide more surity to the stake holders.

4. It is recommended that more research be conducted so as to completely customise the AquaCrop model for use in African studies; this will improve the accuracy of the simulations.

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APPENDICES

Appendix 1: Soil input data

a) **Soil Physical and chemical properties, and percentage moisture content**

Block 1

a) **Physical and chemical soil properties**

	% sand	%clay	%silt	pH	% N	CEC (Cmol/kg)	% OC	BD	K(SAT)	Depth of layers	TC
Layer 1	84	10	6	4.71	0.025	43.5	0.72	1.64	28.6	27	S
Layer 2	60	34	6	4.21	0.038	54.3	0.78	1.79	21.5	23	SCL
Layer 3	50	48	2	4.14	0.05	97.8	1.44	1.70	12.4	27	C

b) **Percentage Moisture content (%MC)**

	%MC at Upper Limit (UL)	%MC at Lower Limit (LL)	%MC at Saturation (SAT)
Layer 1	16.6	8.6	39.9
Layer 2	28.0	19.1	48.7
Layer 3	34.9	25.7	52.8

Block 2

a) **Physical and chemical soil properties**

	% sand	%clay	%silt	pH	%N	CEC (Cmol/kg)	% OC	BD	K(SAT)	Depth of layers	TC
Layer 1	84	12	4	5.11	0.038	54.3	0.6	1.76	36.2	23	S
Layer 2	64	32	4	4.55	0.038	65.2	0.96	1.69	29.3	21	SCL
Layer 3	56	40	4	4.6	0.05	54.3	0.96	1.72	20.3	22	CL

a) **Percentage Moisture content (%MC)**

	%MC at Upper Limit (UL)	%MC at Lower Limit (LL)	%MC at Saturation (SAT)
Layer 1	17.2	9.5	40.7
Layer 2	27.0	18.3	48.6
Layer 3	30.8	21.8	50.4

Appendix 2. Soroti district observed daily weather data; Jan 2010 – Aug 2011.

a) **Soroti daily maximum temperature (^oC) Jan – Dec 2010**

Days	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	27.2	35.6	24	29.8	28.7	29.9	29.2	27.6	27.7	28.2	31	30.7
2	26.6	36.2	29.4	28.5	29.5	29	28.3	29.6	27.9	30.3	27.9	31
3	29.8	36.2	30.2	29.4	29.5	28.4	28.9	29.2	29.8	31.4	30.5	32.2
4	30.7	31.3	27.7	30.7	29	29.2	26.6	29.3	30.4	31.4	31.2	32.3
5	30.1	29.3	31	30.7	28.3	29.2	28.7	29.9	30.3	29.8	30.8	33
6	30.2	30.9	30.3	31.4	30	27	28.9	30.9	28.2	28.8	31.8	31.8
7	30.4	29.9	30.9	31.5	28.5	29.7	29.5	30.9	28.7	28	30.8	29.7
8	31.2	30.1	27.7	31.7	29.5	29.7	27.9	29.5	28.8	30.9	28.3	28.8
9	30.4	32.1	30.5	31.5	25.4	30.1	28	28.2	30.1	29.3	30	28.8
10	29.6	33.9	31.5	32.2	27.2	30.8	27.7	27.7	28	29.8	29.6	27.9
11	30.9	33.7	32.8	32.2	28.1	29.6	29.5	28.9	28.7	30.7	31	29.2
12	30.9	35	32.6	31.9	30.1	28.5	29.9	27.8	26.7	29.1	31	27.2
13	30.2	35.3	32.2	29.7	30.7	28.7	30.8	29.2	27.7	29.8	29.8	30
14	31	35.1	33.1	31.3	29.2	30.3	28.5	27.9	29.1	31.1	28.6	32.5
15	30.7	35.6	32.6	29.6	28.4	29.6	29.3	28.4	28	29.4	30.5	32.7
16	32.1	26.7	33.4	26.9	27.6	29.5	29.1	29.2	29.4	29.3	30.7	32.5
17	32.1	26.8	32.6	29	28.4	28	30.1	26.4	29.9	28.7	30.5	33
18	32.9	32.1	32.4	31	30	27.1	29.9	29.2	29.2	29.8	30.8	34.5
19	32.6	34.2	31.9	29	28.5	27.9	29.7	30.2	28.3	29.6	31.3	33.6
20	32.4	27.4	29.7	31.4	29.2	28.4	28.9	30.3	28.5	29.3	30.3	33
21	31.8	31.9	30.1	31.5	31	28.6	27.2	29.7	29.2	29.1	31.5	31.4
22	27.6	25.5	30.4	31.4	31	29.8	27.6	25.6	28.7	29.3	31.5	30
23	31.2	31.6	28.8	30.1	31	30.3	22.4	28.2	29.4	29.3	30.7	31.2
24	31.6	31.6	25.8	28.1	28.6	29.4	25.9	27.6	28.8	29.8	29	30.8
25	32.2	28.6	27.8	29.6	29.5	28.3	27.6	26.9	26.4	28.2	31.7	30.2
26	32.9	20.5	29.2	31	30.5	28.7	24.2	28.9	29.8	29.7	31	30.2
27	33.1	28.7	29.3	30.3	30.2	29.4	28.7	26.4	30.3	31	32	31
28	32.9	27.8	28.5	31	30	28.7	26	29.4	31	29.9	31.9	29.1
29	33.9		29.7	29.8	31	27.4	27.8	29.6	31.4	29.6	31.7	28.3
30	34.6		28.6	27.5	28.5	28	28.4	28.2	29.3	30.7	31.8	31.2
31	34.5		29.2		29.4		28.8	28.4		31.2		30.2
Mean	**31.2**	**31.2**	**30.1**	**30.3**	**29.2**	**29.0**	**28.2**	**28.7**	**29**	**29.8**	**30.6**	**30.9**

b) Soroti daily minimum temperature (oC) Jan – Dec 2010

Days	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	18.5	19.2	18	19.5	19	19.8	19.5	18.5	18.6	18.2	19.6	19.3
2	18.2	20.3	18.5	20.4	20.4	19.5	20	18.7	18.8	18.7	19.2	18.8
3	17.7	19.9	20.9	18.2	19.8	18.7	20.3	19.4	19.6	19.7	18.6	18.8
4	18.2	19.6	19.2	21.2	20.6	18.8	19	19.7	18.5	19.8	21.3	18.7
5	19.5	20.2	19.2	20.9	20.2	19.4	18.4	19.4	18.9	17.7	20	19.4
6	19.3	20	19	21.5	19.7	20.2	19.2	19.8	18.4	19	19.2	19.4
7	19.2	20.7	19.7	21	18.8	18	19.8	18.9	17.7	18.9	20	19.8
8	19.6	19.6	19.7	20.3	20.2	18.5	19.6	19.8	17.7	20.4	19.9	19.2
9	19.9	19.1	18.9	20.2	20.4	20.3	20.1	17.4	19	18.4	18.4	18.5
10	19.8	19.1	20.2	19.9	20	20.6	18.8	18.7	18.9	17	18.6	18.9
11	20.9	21.7	19.4	19.7	18.8	19.4	18.9	19.9	18.4	18.8	20.4	19.2
12	19.5	22.4	18.8	21.8	18.4	18.5	20.5	18.8	17.8	19.3	20	19.7
13	18.5	21.6	19	19.2	19.4	18.4	18.8	18.7	19.5	19.2	19.2	18.8
14	19.6	23.5	21.4	18.6	19.9	18.8	20.2	19.7	18.8	18	18.9	17.5
15	19.6	21.1	20.2	20.5	19.9	19.9	17.9	19.1	16.7	17.9	18.8	19.9
16	19.4	22.4	20.5	18.5	18.9	19.4	17.2	19.4	17.9	18.9	18.4	18.8
17	19.6	17.6	21.8	20	18.8	20	18.3	18.5	18.4	18.4	19.2	17.5
18	20	19.7	20.4	20.4	20	18	18.1	17.3	18.3	18.8	18.2	19.5
19	20	21	21.2	20.2	20.4	19	18.5	19.8	18.2	18.6	19	19.7
20	19.2	22	19.2	20.4	19.5	17.7	18.2	19.5	18.8	18.4	17.8	18.7
21	19.3	19.4	20.2	21.9	20.4	20.2	17.4	19.2	18.2	17.7	18.6	17.9
22	20.2	21	17.5	19	20.3	20.5	19.3	17.5	18.2	18.3	20	21.4
23	18.3	19.7	20.2	19.8	20.8	20.4	19.9	18.5	19.3	18	19	17.8
24	20.5	20.5	17.2	18.9	20.4	19.7	17.5	19	19.4	18.7	18.6	19.5
25	19.4	21.5	17.5	19.2	20.4	18.7	18	18.2	19.3	19.5	18.8	18.4
26	19	19.2	19.5	20.7	20.2	18.4	16.7	18.1	18.4	17.5	20.6	17.7
27	18	18.8	19.7	19.7	19.9	19	17.9	18.7	19.7	19.2	18	18.9
28	19.4	19.9	19.1	19.8	20.5	18.8	19.9	18.7	17.7	18.6	19.3	18.8
29	20.4		19.8	20.3	20.6	18.3	18.8	18.6	20	18.2	19	18.3
30	19.8		19.8	18.5	18.2	18.4	18.5	18.6	19.3	19	20.2	18.4
31	20.6		20.3		19.4		19.5	20.4		19.1		18.8
Mean	**19.4**	**20.4**	**19.5**	**20**	**19.8**	**19.2**	**18.9**	**18.9**	**18.6**	**18.6**	**19.2**	**18.9**

c) Soroti daily rainfall (mm) Jan – Dec 2010

Days	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	3.9	0.0	14.3	0.0	3.3	0.0	0.0	0.0	5.2	TR	10.9	0.0
2	0.0	0.0	0.0	17.2	0.0	14.5	0.0	7.5	0.6	0.0	0.0	0.0
3	0.0	0.0	1.0	0.0	0.0	0.0	17.9	4.5	2.5	2.0	0.0	0.0
4	0.0	0.0	0.0	0.0	1.0	0.0	10.5	0.0	0.0	17.6	5.5	0.0
5	0.0	7.2	13.3	0.0	8.8	6.9	0.0	1.9	1.5	1.3	0.0	0.0
6	0.0	0.0	0.0	0.0	5.6	46.1	0.0	0.0	5.5	TR	0.0	0.0
7	0.0	3.7	4.5	0.0	TR	5.5	4.0	0.4	TR	0.0	1.3	0.0
8	0.0	1.6	0.0	0.0	14.8	0.0	0.0	66.2	0.0	10.8	0.0	8.4
9	24.7	0.0	0.0	0.0	0.3	0.0	TR	0.0	10.6	27.7	7.8	TR
10	0.0	0.0	0.0	0.0	37.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	37.7	0.0	0.0	1.9	20.4	8.5	0.0	0.0
12	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0	0.9	TR	0.0	0.0
13	0.0	0.0	0.0	1.3	21.6	TR	0.0	0.0	3.1	16.2	0.0	0.0
14	0.0	0.0	0.0	TR	0.0	2.2	13.8	0.0	6.5	9.1	4.8	0.0
15	0.0	3.6	0.0	2.3	24.8	0.0	21.1	0.0	1.0	TR	0.0	0.0
16	0.0	11.9	0.0	0.0	5.8	0.0	0.0	0.0	0.7	8.1	0.0	0.0
17	0.0	0.0	0.0	0.5	11.6	44.7	0.0	0.0	7.1	0.0	TR	0.0
18	0.0	0.0	0.0	0.4	0.0	5.7	0.0	0.0	29.4	4.8	0.9	0.0
19	1.5	0.0	8.2	0.0	4.6	27.1	0.0	0.0	0.0	5.2	0.0	0.0
20	0.0	0.0	2.0	4.3	0.0	0.0	28.4	0.0	1.1	25.1	0.0	0.0
21	0.0	0.0	63.2	3.5	0.0	0.0	2.4	15.0	1.1	TR	0.0	0.0
22	26.9	3.6	2.3	TR	0.0	0.0	0.0	0.4	4.3	13.0	0.0	0.0
23	0.0	1.2	77.7	0.5	0.0	TR	18.5	0.0	0.0	0.0	4.1	0.0
24	0.0	0.0	32.4	TR	0.0	3.4	8.5	2.4	0.2	0.4	0.0	0.0
25	0.0	15.4	0.0	0.0	10.2	3.1	77.4	0.0	1.5	24.4	0.0	TR
26	0.0	2.5	5.3	10.2	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0
27	0.0	0.0	5.5	1.0	0.0	1.5	1.8	0.0	0.3	27.8	3.3	2.0
28	0.0	43.3	0.0	14.5	0.0	30.0	7.9	1.8	0.0	TR	0.0	8.1
29	0.0		2.1	21.7	36.9	1.4	0.0	9.3	0.0	0.0	0.0	0.0
30	0.0		0.6	7.4	3.7	TR	0.0	0.0	13.5	1.8	0.0	0.0
31	0.0		1.2		0.0		0.0	10.2		0.0		0.0
Totals	**57**	**94**	**233.6**	**96.3**	**227.8**	**192**	**212**	**121.6**	**117**	**203.8**	**42.5**	**18.5**

NB: TR = Rainfall <0.05mm

d) Soroti daily maximum temperature (^{o}c) Jan – August 2011

Days	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	31.4	29.4	24.0	29.0	30.5	29.5	29.2	28.9
2	32.0	32.4	29.4	32.6	27.3	30.0	28.3	29.4
3	33.0	32.9	30.2	32.2	26.2	29.8	28.9	28.9
4	33.6	33.3	27.7	32.8	26.0	30.4	26.6	26.9
5	33.0	33.5	31.0	32.7	29.4	30.3	28.7	29.3
6	33.4	34.5	30.3	32.5	28.4	29.5	28.9	29.3
7	32.3	35.5	30.9	31.7	30.5	28.2	29.5	27.8
8	32.7	36.0	27.7	28.6	29.6	29.8	27.9	28.0
9	29.8	32.8	30.5	31.2	31.4	30.0	28.0	28.0
10	29.6	33.4	31.5	32.7	31.3	27.2	27.7	27.4
11	32.1	35.2	34.0	34.0	28.7	25.2	29.3	27.8
12	32.5	33.5	34.0	34.5	30.2	27.0	29.0	29.5
13	31.5	31.4	33.3	33.7	30.4	28.2	28.7	30.4
14	27.7	32.1	33.8	31.7	34.5	28.8	29.6	25.0
15	31.7	32.6	27.7	32.7	31.4	28.8	29.3	27.3
16	27.4	32.0	28.9	31.5	31.4	30.0	30.6	27.5
17	29.8	33.5	28.0	33.5	29.6	30.2	30.2	26.7
18	31.7	31.7	32.0	34.5	29.5	30.0	30.0	27.0
19	31.5	35.8	26.7	34.7	29.4	27.6	30.2	29.8
20	32.4	35.0	28.3	33.7	28.2	28.2	30.1	26.6
21	32.3	34.9	29.5	33.0	26.2	27.5	27.2	30.0
22	33.4	34.8	30.0	31.8	28.2	28.8	27.6	29.4
23	33.8	34.5	30.6	29.6	27.4	29.2	22.4	30.0
24	33.9	35.5	32.0	31.8	29.0	29.0	25.9	29.7
25	34.7	36.0	33.2	28.0	28.0	26.8	27.6	29.3
26	34.4	35.8	31.7	30.7	28.7	29.0	24.2	27.2
27	34.0	35.5	31.0	30.7	29.5	28.5	28.7	30.0
28	32.7	36.0	31.0	28.2	30.0	27.5	26.0	26.0
29	35.2		32.9	30.2	30.0	27.0	27.8	27.0
30	35.7		28.8	30.1	29.2	29.3	28.4	28.2
31	34.2		31.6		30.2		28.8	30.2
Average	**32.4**	**33.9**	**30.4**	**31.8**	**29.4**	**28.7**	**28.2**	**28.3**

e) Soroti daily minimum temperature (^oC) Jan – August 2011

Days	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	18.7	20.4	18.0	19.3	19.5	19.8	19.4	18.8
2	18.7	19.5	18.5	18.5	18.6	20.5	19.7	17.3
3	12.0	18.7	20.9	21.0	18.0	20.3	19.8	18.9
4	18.3	19.3	19.2	20.8	19.7	20.5	18.7	19.8
5	20.1	18.4	19.2	20.3	19.5	20.2	19.0	19.3
6	19.2	18.2	19.0	19.2	19.4	19.8	17.5	18.9
7	18.4	17.4	19.7	19.4	19.4	17.5	19.4	18.9
8	18.5	17.5	19.7	19.5	19.8	19.0	17.3	19.0
9	20.3	16.3	18.9	17.7	19.5	20.4	19.3	17.2
10	18.7	19.7	20.2	19.4	19.6	20.2	19.2	18.7
11	18.3	21.4	20.7	19.3	19.3	18.3	17.9	19.4
12	20.5	21.0	22.5	19.5	20.4	18.4	18.8	19.0
13	19.0	19.2	22.0	19.4	20.5	19.0	18.4	18.3
14	19.8	19.3	20.0	19.9	18.0	18.3	17.9	19.2
15	16.7	19.4	18.0	18.9	19.7	19.0	18.0	20.0
16	19.8	19.8	19.7	18.9	20.6	19.8	20.8	18.4
17	17.0	20.7	19.6	20.0	18.5	19.7	17.7	18.4
18	16.5	22.3	19.6	19.5	20.4	20.0	18.8	19.5
19	19.2	18.5	19.5	22.4	18.8	18.5	19.0	17.4
20	17.2	21.3	18.7	19.8	19.0	19.7	19.9	17.0
21	19.2	20.4	19.2	20.4	19.5	18.7	18.2	19.4
22	18.8	20.0	17.2	18.7	19.4	19.4	17.4	18.3
23	19.2	20.6	19.5	18.8	19.7	18.7	19.3	18.9
24	21.7	19.0	19.9	20.8	19.5	18.5	19.9	19.2
25	19.2	21.0	20.5	19.2	17.4	20.3	17.5	19.4
26	19.7	20.6	19.2	18.2	18.0	18.2	18.0	17.5
27	18.0	19.0	18.8	19.6	19.7	19.6	16.7	18.7
28	18.0	20.3	20.0	18.7	19.7	17.0	17.9	18.0
29	16.3		20.5	18.7	19.0	18.5	19.9	17.3
30	19.6		21.0	18.9	20.3	19.7	18.8	18.7
31	21.0		19.9		18.8		18.5	19.8
Average	**18.6**	**19.6**	**19.7**	**19.5**	**19.3**	**19.3**	**18.7**	**18.7**

f) Soroti daily rainfall (mm) Jan – August 2011

Days	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	0.0	5.5	0.0	0.0	6.5	0.0	0.0	60.9
2	0.0	0.0	0.0	2.5	34.1	12.9	0.0	0.0
3	0.0	0.0	0.0	TR	0.0	0.0	TR	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	TR	TR
5	0.0	0.0	TR	12.9	3.2	0.0	3.8	0.0
6	0.0	0.0	13.5	0.4	11.4	11.5	0.0	0.0
7	0.0	0.0	TR	TR	0.0	11.7	27.2	1.1
8	0.0	0.0	0.0	12.4	TR	0.0	0.0	22.7
9	0.0	4.2	0.0	TR	5.1	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	6.7	22.1	TR	30.0
11	0.0	0.0	0.0	0.0	0.0	0.0	TR	1.3
12	9.5	0.0	0.0	0.0	0.0	0.0	0.5	8.3
13	0.0	0.0	TR	0.0	16.1	14.4	0.0	28.2
14	1.8	0.0	34.0	0.0	13.7	0.0	5.6	TR
15	0.0	0.0	TR	0.0	0.0	0.0	0.0	52.7
16	8.2	0.0	0.0	0.0	TR	0.0	1.4	0.0
17	0.0	0.0	0.0	0.0	1.1	0.0	0.0	TR
18	0.0	TR	0.0	0.0	11.3	2.2	0.0	0.9
19	0.0	0.0	TR	0.0	6.8	0.0	0.0	0.3
20	0.0	0.0	9.2	1.9	TR	9.2	0.0	0.0
21	0.0	0.0	41.6	0.4	0.8	0.0	23.0	0.0
22	0.0	0.0	0.0	8.9	5.5	0.0	9.0	0.0
23	0.0	0.0	0.0	7.4	1.4	0.0	6.5	0.4
24	0.0	0.0	0.9	TR	12.0	TR	3.6	TR
25	0.0	0.0	0.0	14.4	14.8	0.0	0.0	27.8
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	9.7	TR	0.0	0.0	6.1
28	0.0	0.0	0.0	10.8	TR	TR	TR	47.6
29	0.0		TR	9.5	0.7	0.0	30.2	0.5
30	0.0		0.0	5.1	0.5	0.0	0.0	0.0
31	TR		TR		0.0		5.5	22.5
Totals	**19.5**	**9.7**	**99.2**	**96.3**	**151.7**	**84.0**	**116.3**	**311.3**

NB: TR = Rainfall <0.05mm

Appendix 3: Soroti district historical climate

a) Soroti average monthly minimum temperatures (^oC), 1992-2009.

	Jan	Feb	Mar	Apr	Aay	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Average**
1992	18.7	20.3	20.4	19.8	19.2	18.4	17.6	17.8	17.8	17.5	17.4	17.1	**18.5**
1993	17.7	18.6	18.6	19.5	18.4	18.6	17.6	17.4	17.5	17.8	17.7	18.6	**18.2**
1994	18.3	19.1	19.1	19	18.2	18.1	17.9	17.5	17.9	17.6	17.7	17.4	**18.2**
1995	18.4	18.9	18.8	19.2	18.5	18.3	17.8	17.7	18.1	17.9	18.2	17.5	**18.3**
1996	17.8	19.2	18	19.5	18.6	18	17.8	17.6	17.7	17.7	18	17.7	**18.1**
1997	18	18.5	20.2	18.9	18.6	18.5	17.7	18	18.4	18.8	18.5	18.4	**18.5**
1998	18.3	19.4	20.5	20.3	19.6	18.8	18.2	18.1	18.2	18.4	18.2	17.9	**18.8**
1999	18.1	17.8	18.8	18.6	18.4	18	17.4	17.4	17.6	17.6	17.9	17.6	**17.9**
2000	17.9	18.4	19.7	19.3	18.8	18.6	18.1	17.6	17.9	18.2	18.2	18.4	**18.4**
2001	22	24.3	22.9	22.8	22.5	21.5	21.3	21.3	21.5	23	22	24.6	**22.5**
2002	23.2	25.3	23.5	23.4	22.8	22.4	22.5	22	23.1	22.9	22.9	22.8	**23.1**
2003	23.5	24.5	23.4	23.4	22.5	21.7	20.8	21	22.3	23.4	23.3	23.5	**22.8**
2004	23.7	23.4	24.2	22.6	23	22.1	22.2	21.8	22.1	23.3	23.1	23.9	**23.0**
2005	24.2	25.4	24.9	23.8	22.4	22.7	21.6	22	23.3	22.9	24	25.1	**23.5**
2006	25	25.2	23	22.6	22.5	22.1	21.5	21.8	22.3	23.4	22.1	22.4	**22.8**
2007	23.3	22.7	24.1	23.9	23.1	21.6	21.3	21.3	21.8	23.3	23.5	24.1	**22.8**
2008	24.1	24.3	24.9	22.6	23	23.5	22.1	22.8	22.9	23	23.3	22.8	**23.3**
2009	24.1	24.3	24.9	22.6	23	23.5	22.1	22.8	22.9	23	23.3	22.8	**23.3**

b) Soroti average monthly maximum temperatures (^oC), 1992-2009.

	Jan	Feb	Mar	Apr	Aay	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Average**
1992	33	32.2	34.1	30.5	29.7	28.7	28	28.5	29.9	29.1	30	29.2	**30.2**
1993	31.1	31.6	33	32	29.2	28.8	29.1	29.9	31.1	31.4	31.8	32.8	**31.0**
1994	33.8	33.8	31.6	30.8	29.2	28.9	28.2	28	31	30.6	29.5	31.3	**30.6**
1995	33.7	32.6	31.6	30.7	30.2	30	28.6	29.6	30.1	30	30.4	31.4	**30.7**
1996	31.2	30.2	29.3	32.9	29.3	28.3	28.4	29.5	30	30.9	30.9	32.2	**30.3**
1997	32.6	34.5	34.4	29.2	29.7	29.7	28.7	29.7	33.5	30.3	28.4	28.4	**30.8**
1998	30.4	32.5	34.4	32.2	29.8	29	28.1	29	30.9	29.6	30.7	33	**30.8**
1999	32.2	34.6	30.5	29.6	29.3	29.4	28.5	29.4	29.9	30.7	31.6	31.2	**30.6**
2000	34	35.5	33.3	31	29.9	29.7	29	29	30.7	29.8	30.2	31.2	**31.1**
2001	29.7	32.2	30.2	28.8	28.4	27.4	26.7	27.5	28.8	28.7	28.5	31.8	**29.1**
2002	30	33.5	30.1	29.4	28.2	28.3	29.3	28.7	30	29.1	29	30	**29.6**
2003	30.9	33	31	29.8	28.2	27.5	27.1	27	28.5	30.2	29.5	29.8	**29.4**
2004	30.9	29.5	32.2	28.4	28.9	28.4	28.2	28.2	28.6	29.9	28.9	30.2	**29.4**
2005	31.3	33.9	30.5	30	27.1	28.2	27.4	28.4	28.8	49.4	40.5	32.7	**32.4**
2006	32.7	32	29.2	28.6	27.9	28.2	27.8	28	28.9	29.2	27	28	**29.0**
2007	30.1	29.4	32	34.5	28.8	26.4	26.6	27.2	27.1	29.3	29.9	31	**29.4**
2008	31.6	31.7	32.3	28.8	28.7	29.4	28.5	29.6	29.2	28.6	28.5	28.8	**29.6**
2009	31.6	31.7	32.3	28.8	28.7	29.4	28.5	29.6	29.2	28.6	28.5	28.8	**29.6**

c) Soroti observed monthly rainfall, 1990-2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	62.8	168	138.8	209.8	120	49.3	96.6	180	149.9	192.8	70.1	79.6	**1518.1**
1991	56.2	57.9	97.4	165	427.2	123.4	97.6	292	228.1	140.4	80.4	6.8	**1772.8**
1992	5.9	2.3	40.1	169.6	135.2	186.7	77.4	117	90.3	201.1	121.5	86.1	**1233.2**
1993	24.7	31.5	12.7	153.3	161.8	224.3	45.7	112	83.4	146.4	86.3	28.6	**1110.8**
1994	6.1	0	126.4	147.5	137.9	176.9	123.3	207	120.3	113.3	181.9	19.9	**1360.4**
1995	0	36.8	139.2	253.9	109.6	74.4	182.3	87.8	116.6	257.9	89.3	52.8	**1400.6**
1996	106	82.7	171.4	211.5	349	136	101.7	244	270.6	33.8	78.2	16.7	**1801.3**
1997	23	0	42.8	251.8	23	65.3	112.3	172	7.8	220.6	230.5	104.3	**1253.5**
1998	48.3	56.3	19.7	108.7	259.3	86.9	284.7	132	55.1	130.3	167.8	2.3	**1351.4**
1999	88.7	0	176.6	113.3	159.8	46.6	146.9	169	108.3	138.1	35.8	37.3	**1220.6**
2000	0.2	12.6	49.2	117.6	151.2	102.6	104.3	234	169.9	141	57.9	26	**1166.6**
2001	56.7	3.9	188.2	180.2	237.6	171.4	230.8	165	101.4	350.5	88.5	13.7	**1788.3**
2002	16.1	5.7	78.2	117.6	164.2	50.2	34.8	51.4	171.2	228.9	117.7	103.4	**1139.4**
2003	52.5	48	31.3	219.2	188.4	301.8	83.7	184	171	74.6	106.6	19	**1480**
2004	78.9	50	44.5	137.6	119.9	98.6	51.4	129	121.1	46.8	109.9	35	**1022.8**
2005	14.5	17.1	90.6	117.6	220.4	77.8	208.8	147	164.6	88.1	32.5	0	**1179.1**
2006	11.3	28.9	147.2	160.5	114.4	39.5	154.6	101	161	163.1	150	62.4	**1293.8**
2007	64.1	59.2	20.1	181.4	136.7	79.4	144	223	144.9	61.6	77.3	3.6	**1195.4**
2008	8.7	31.6	158.5	163.7	63.6	76.1	157	182	121.3	124.3	187.6	0	**1274.5**
2009	96.9	5.1	38.2	123.5	108.3	35.7	83.5	189	190.9	177.8	92.3	157.7	**1298.8**
2010	57	94	233.6	96.3	227.8	192.1	212.2	122	117	203.8	42.5	18.5	**1616.4**

Appendix 4: **PRECIS generated historical monthly rainfall (mm) for Soroti district from1990 to 1998 (1.77^{o} N 33.66^{o}E).**

	1990	1991	1992	1993	1994	1995	1996	1997	1998
Jan	68.68	68.64	30.14	35.7	14.31	42.55	109.88	39.79	158.72
Feb	156.09	86.16	59.56	81.56	72.47	117.33	106.65	10.47	42.05
Mar	229.64	93.01	94.37	58.51	189.47	108.07	280.85	84.42	91.97
Apr	140.18	146.9	92.76	129.13	82.49	159.61	147.93	168.34	225.64
May	145.25	163.29	105.47	149.99	138.87	140.69	114.87	101.65	134.42
Jun	79.15	128.48	137.32	119.93	110.38	71.02	121.68	116.74	109.73
Jul	89.32	123.07	108.97	76.29	106.68	144.49	112.24	69.79	96.78
Aug	163.67	101.89	74.71	86.99	124.73	85.55	116.42	140.47	117.15
Sep	115.65	103.62	86.47	57.36	35.33	88.41	178.91	28.5	82.09
Oct	123.04	133.18	159.33	75.9	145.51	217.02	131.98	277.2	134.56
Nov	129.94	40.6	43.66	84.6	178.29	113.19	96.21	182.64	51.54
Dec	93.41	49.62	21.54	21.07	7.1	44.05	42.63	154.93	4.58

Appendix 5: Rainfall data used for Evaluation of PRECIS model

		1990	1991	1992	1993	1994	1995	1996	1997	1998
Apr	**Observed rainfall (x)**	209.8	165	169.6	153.3	147.5	253.9	211.5	251.8	109
	Simulated rainfall (y)	140.2	146.9	92.76	129.13	82.49	159.61	147.9	168.34	226
Jun	**Observed rainfall (x)**	49.3	123.4	186.7	224.3	176.9	74.4	136	65.3	86.9
	Simulated rainfall (y)	79.15	128.48	137.32	119.93	110.4	71.02	121.7	116.74	110
Sep	**Observed rainfall (x)**	149.9	228.1	90.3	83.4	120.3	116.6	270.6	7.8	55.1
	Simulated rainfall (y)	115.7	103.62	86.47	57.36	35.33	88.41	178.9	28.5	82.1
Nov	**Observed rainfall (x)**	70.1	80.4	121.5	86.3	181.9	89.3	78.2	230.5	168
	Simulated rainfall (y)	129.9	40.6	43.66	84.6	178.3	113.19	96.21	182.64	51.5

Appendix 6: PRECIS generated future annual average minimum and maximum temperatures for Soroti district for selected years.

	Annual average temperature, °C	
	Minimum	Maximum
2016	19.1	29.1
2017	18.8	28.7
2018	18.7	28.8
2019	19.1	28.6
2020	18.3	28.5
2027	18.7	28.5
2028	18.8	28.4
2029	18.8	28.9
2030	19.1	29.3
2036	18.8	29.1
2037	18.8	28.9
2038	18.9	29.3
2039	19.6	29.6
2040	20.1	29.4

Appendix 7: The future AquaCrop simulated sorghum grain yields (ton/ha) for Soroti district (before subtraction of the AAE).

Year	Season Aug-Dec				Season May-Aug			
	Block 1		Block 2		Block 1		Block 2	
	Serena	Edeidei	Serena	Edeidei	Serena	Edeidei	Serena	Edeidei
2016	6.429	4.682	11.134	5.464	6.828	4.243	10.32	5.821
2017	7.092	5.149	11.393	6.055	7.006	4.356	10.942	6.06
2018	7.121	5.17	11.418	6.087	7.068	4.391	10.842	6.109
2019	7.276	5.28	11.485	6.212	6.008	3.703	8.899	5.104
2020	7.272	5.277	11.478	6.208	7.014	4.363	10.772	6.069
2027	7.322	5.313	11.594	6.251	7.156	4.447	10.984	6.186
2028	7.361	5.342	11.64	6.287	7.019	4.369	10.699	6.016
2029	7.316	5.31	11.6	6.217	7.045	4.39	10.091	6.1
2030	7.393	5.364	11.669	6.311	7.203	4.476	11.058	6.227
2036	6.86	4.989	11.41	5.574	7.161	4.456	10.886	6.121
2037	7.447	5.404	11.765	6.358	7.264	4.513	11.151	6.279
2038	7.347	5.33	11.595	6.271	7.125	4.429	10.779	6.054
2039	7.474	5.423	11.797	6.38	7.153	4.441	10.759	6.066
2040	7.392	5.352	11.773	6.298	7.255	4.5	11.183	6.261

Appendix 8: Compariaon bettween; Percentage changes in sorghum grain yield, the total rainfall received in the growing season, and, the percentage changes the received rainfall as compared to the base years i.e 2010 and 2011 for the selected years.

Year	Season a (03-May to 07-aug)				Season b (24-Aug to 02-Dec)			
			% change in grain yield				% change in grain yield	
	Total Season's rainfall	% change in season's rainfall	Serena	Edeidei	Total Season's rainfall	% change in season's rainfall	Serena	Edeidei
2010/ 2011	373.4				463.6			
2016	359.13	-3.82	16.1	28.58	532.32	14.82	17.75	2.07
2017	413.54	10.75	28.19	37.21	634.49	36.86	31.15	22.34
2018	432.68	15.88	27.61	39.26	590.62	27.4	31.93	23.35
2019	348.89	-6.56	-17.75	-2.23	779.81	68.21	35.16	27.85
2020	426.25	14.15	25.74	37.6	702.3	51.49	35	27.72
2027	435.33	16.59	31.09	42.52	705.13	52.1	37.41	29.23
2028	376.26	0.77	24.71	36.45	651.14	40.45	38.65	30.48
2029	368.23	-1.38	15.92	39.02	512.51	10.55	37.41	28.52
2030	456.96	22.38	32.92	44.24	583.8	25.93	39.53	31.36
2036	412.85	10.56	29.68	41.15	582.74	25.7	28.02	10.06
2037	484.83	29.84	35.24	46.42	663.29	43.07	41.72	33.03
2038	352.67	-5.55	27.52	38.85	771.02	66.31	37.79	29.94
2039	352.67	-5.55	27.64	39.44	750.65	61.92	42.57	33.81
2040	403.64	8.1	35.59	45.66	660.36	42.44	41.03	30.88

Appendix 9: The Questionnaire used for the household interviews.

Questionnaire Number Interviewer

Dear respondent
This questionnaire is designed to generate information on climate change impacts on livelihoods and identify adaptation practices in the Teso farming system of Uganda. It is used strictly for research purposes and the information gathered from the respondent will be kept confidential. The study is being supported by the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM). We request for your time to answer some questions and thank you for the cooperation.

District: ………………Sub-county: ……………Parish: ………………Village: ……………….
Date: …………………………………….. GPS coordinates: …………………………………………..
Start time: ………………………………………. Finish time: ……………………………………………..

SECTION A: HOUSEHOLD CHARACTERISTICS

1. Name of household head; ……………………Name of respondent; ……………………………………….

2. Sex of respondent: 1= male, 2= Female

3. Age of the respondent: 1. <18 2. 18-30 3. 31-40 4. 41-50 5. 51-60 6. >60

4. Marital status: 1= married, 2= divorced, 3= widow, 4= widower, 5= single (for members of above 15 years). 6= not applicable (for children of 15 years and below).

5. Education level: 1=Never, 2=Pre-primary, 3= Primary, 4= O level, 5= A level, 6=Tertiary education, 7=adult education, 8= others, specify _______________

6. Household size; …………………………………..

7. **HOUSEHOLD STRUCTURE**

No.	Name of HH member	Age	Sex:	Relation[1]	Marital status[2]	Education level[3]	Primary activity[4]
1							
2							
3							
4							
5							
6							
7							
8							
9							

10							
11							
12							
13							
14							
15							

Relationship of HH to household: 1=Head of household, 2 =Spouse 1, 3= spouse 2, 4= spouse 3, 5=Child, 6= Grandchild, 7=Mother/father, 8= Brother/Sister, 9=nephew/niece, 10= cousin 11= others, specify_______________
Primary activity: 1= crop production, 2= livestock production, 3= commerce, 4= formal employment, 5=housework, 6= craft, 7= none, 8= other specify _______________
N.B: For the table above, use the codes in questions 2, 4 and 5.

SECTION B: LIVELIHOOD SOURCES AND ACTIVITIES

8. How large is your land in acres? …………………………………………..
9. What is your land tenure system? ....
10. What do use the land for? 1=Livestock, 2=Crop production,3=Bee keeping, 4= Fish farming 5= others (specify) _______________
11. What are the major sources of household income (Rank with 1 as the most important)? 1. Crop growing 2. Livestock rearing, 3. Remittances, 4. Off farm activities, 5. Forest products, 6. Wild animals, 7. Formal employment, 8. Bee keeping, 9. Others (specify)

12. What is your average income from crop production in one year? 1. <10,000 shs 2. 10,000-20,000 3. 20,000-50,000 4. 50,000-100,000 5. >100,000
13. What is your average income from livestock production in one year? 1. <10,000 shs 2. 10,000-20,000 3. 20,000-50,000 4. 50,000-100,000 5. >100,000
14. What is your average non-farm income per year? 1. <10,000 shs 2. 10,000-20,000 3. 20,000-50,000 4. 50,000-100,000 5. >100,000

15. Crop heritage (major crops)

Crops grown before (10 years ago)	Crops grown currently	Crops abandoned	Reasons for abandoning	New crops adopted in the last 5 years	Why did you adopt these new crops?	Who introduced these ne crops?

Crop codes: 1=sorghum, 2=maize, 3=cassava, 4=potatoes, 5=beans, 6=G.nuts, 7=Fruits, 8=Vegetables, 9=Bananas, 10=millet, 11=cowpeas, 12=rice, 13= others (specify) _______________

16. Do you use the following agro- inputs? 1. Fertilizers, 2. Pesticides, 3.Irrigation 4.Herbicides

17. How many livestock units do you have?

1. Cattle (--------exotic, --------local) 2. Goats (--------exotic, --------local) 3. Pigs (--------exotic, --------local) 4. Poultry (--------exotic, --------local) 5. Rabbits (--------exotic,----------)

18. Major crops grown for food and income: Rank according to order of importance.

Crop	Rank as a food crop	Rank as a cash crop

19. Major livestock kept for consumption and income

Livestock	Rank as income source	Rank for consumption

20. What problems are you facing with crop enterprise? Please rank. 1. Diseases, 2. Pests, 3. Rainfall failure, 4. Inadequate rains, 6. Poor soils, 7. Low yields, 8. Poor prices, 7. Inadequate markets, 8. Poor storage facilities, 9. Inadequate extension, 10. Soil erosion, 11. Floods, 12. Land shortage 13. Poor seed 14. Poor supply of agro-inputs 15. Others (specify)

21. What problems are you facing with the livestock enterprise? Please rank. 1. Diseases, 2. Low yields (Specify), 3. Feed shortage, 4. Water shortage, 5. Lack of water storage facilities, 6. Drought, 7. Parasites, 8. Poor access to markets 9. Lack of drugs, 10. Poor veterinary services, 11. Land shortage, 12. Poor breeds 13. Others (specify ……………………………….

SECTION C: CLIMATE CHANGE TRENDS AND PERCEPTIONS

22. Have you heard about climate change? 1. Yes 2. No.

23. If yes, from where? 1. Radio 2.Newspaper 3.From place of work 4.From a member of the village 5.From a seminar/workshop, 6.NGO/CBO, 7.Others (specify)

24. When did you become aware of climate change? 1. 0-2 yrs, 2. 2-4 yrs, 3. 4-6 yrs, 4. 6-8 yrs, 5. 8-10yrs, 6. Over 10 yrs ago

25. Do you think the climate is changing? 1. Yes, 2. No, 3. Not sure

26. What features in this area reflect the occurrence of climate change? 1. Too much rainfall 2. Little rainfall 3. Drought 4. Floods 5. Early rainfall onset 6. Late rainfall onset 7. Early rainfall ceassation 8. Late rainfall ceassation 9. Others (specify)

27. What do you think is the cause of climate change? ……………………………………………..............................
…….

28. Which climate shocks have affected your household during the last 15 years?

Type of shock	**Year of shock**	**Result from shock**	**Who was affected *(Child, woman, Man, elderly, All)***	**Actions taken**			**How widespread was the shock?**

Key for shock types: 1. Drought 2. Flood 3. Erratic rainfall pattern 4. Hailstorm 5. Too much rain 6. Landslide
Key for shock outcome: 1. Loss of assets 2. Loss of income 3. Decline in crop yield 4. Loss of entire crop 5. Death of livestock 6. Food shortage/insecurity 7. Food price increase
Key for action taken: 1. Did nothing 2. Sold livestock 3. Sold crops 4. Sold land/home 5. Sold assets 6. Borrowed from relatives or friends 7. Borrowed from bank 8. Borrowed from private money lenders 9. Received food aid 10. Participated in food for work 11. HH head migrated to other rural area 12. HH plus others migrated to rural area 13. Migrated to urban area 14. Sought off-farm employment 15. Bought food 16. Ate less 17. Ate different foods 18. Kept children home from school
Key for widespread of shock: 1. only my household 2. some households in village 3. most households in the village 4. all households in the village 5. many households in the district 6. all households in the district

29. Which person or institution helped you to overcome the shock? 1. Relatives, friends, neighbours 2. Community group 3 .Government 4. NGO 5. None 6. Religious organizations 7. Politicians, e.g. MPs 8. A local community group that you are a member of 9.others, specify

30. What kind of assistance did you get?

Climate change shock	**Source of assistance**	**Kind of assistance**

SECTION D: COPING AND ADAPTATION PRACTICES

31. How has climate change and its effects affected your cropping enterprise and what adjustments in your crop production have you made in reaction to these effects?

	Change/Effect	Tick	Adaptive measures
1	Rainfall amounts have changed		
2	Rainfall timing has changed		
3	Rainfall duration has changed		
4	Yields have changed (specify)		
5	Varieties have changed		
6	Crop failure is high		
7	Crops are destroyed by unpredictable weather		
8	Others (specify)		

32. How has climate change affected your livestock and what measures you have undertaken to overcome it.

	Effect	Tick	Adaptive measures
1	Pastures are not enough (no longer available)		
2	Livestock growth rate has changed (specify)		
3	Pasture types in the area have changed (specify)		
4	New diseases have emerged (specify)		
5	Disease incidences are high		
6	Disease outbreaks have increased		
7	Yields (milk and meat) have changed (Specify)		
8	Animal health is poor		
9	Breeds have changed		
10	Water is not available		
11	Accessibility to markets has been affected (specify)		

33. CLIMATE CHANGE SHOCKS AND OTHER SHOCKS TO THE HOUSEHOLD

When was the last major drought you experienced? _______________ (year)		**When was the last year you had too much rain resulting in flooding or water logging? _____________(year)**		**When was the last year you experienced a land slide? _____________(year**	
During the last large drought, did you change your farming practice (crop and livestock)? ________ (yes: 1, no: 2)		During the last year with too much rain, did you change your farming practice (crop and livestock)? _________ (yes:1, no: 2)		During the last year the land slide did you change your farming practice (crop and livestock)? _________ (yes:1, no: 2)	
If yes, what did you do? ***(key)***	If yes, how?	If yes, what did you do? ***(key)***	If yes, how?	If yes, what did you do? ***(key)***	If yes, how?

Keys for change: 1.No change, 2.Change crop variety, 3.Change crop type, 4.Change planting dates, 5.Increase amount of land under production, 6.Reduce amount of land under production, 7.Change field location, 8.Implement soil and water management techniques, 9.Change fertilizer application, 10.Build a water harvesting scheme, 11.Build a diversion ditch, 12.Plant trees for shading, 13.Irrigate, Irrigate more, 14.Buy insurance, 15.Mix crop and livestock production, 16.Change from crop to livestock production, 17.Change from livestock to crop production, 18.Change pattern of crop consumption, 19.Change pattern of animal consumption, 20.Increase the number of livestock, 21.Decrease the number of livestock-de-stocking, 22.Diversify livestock feeds, 23.Change livestock feeds, 24.Supplement livestock feeds, 25.Change veterinary interventions, 26.Change portfolio of animal species, 27.Change animal breeds, 28.Move animals to another site, 29.Seek off farm employment, 30.Migrate to another piece of land, 31.Set up communal seed banks/food storage facilities.

34. Do you have access to crop and/or livestock extension services? 1. Yes 2. No

35. If yes, who gives you these services and what type of services do you get?

----

36. Do you have access to information on climate change? Or have you ever received information on climate change?

Source of information	Type of information

37. Do you receive farmer-to-farmer extension? 1. Yes   2. No

38. Do you have access to credit? 1. Yes 2. No

39. If yes, what is the source of your credit? 1. Formal institution, 2. Farmers' group, 3. Farmer in the village, 4. Relative 5. Others (specify) ……………………………………

40. What were the constraints in changing your farming ways? 1. Shortage of land 2. Lack of access to Credit/money 3. Lack of information about climate change and appropriate adaptation responses 4. Lack of market access 5. Insecure property rights 6. Lack of access to water for irrigation 7. Shortage of labor. 8. None 9. Others (specify) ……………………………………………………..

41. Do you, or any other household member, belong to any social group? *(Yes/No)*
If yes, mention the groups and their activities

Group name	Group activity

42. How do you think government can improve your coping mechanism to climate change?
……
……
……

43. Are there any institutions in your area dealing with climate change? 1. Yes 2. No

If yes, mention them and the practices that they have introduced in your area?

Institution	Strategy introduced	Have farmers complied with the strategy?	If no, why?

44. Are there any regulations that were put in place in your area in response to climate change?

If yes, mention them;

Regulation	Who declared the regulation?	Have farmers complied with the regulation?	If no, why?

SECTION E: INFORMATION FLOW AND UPTAKE

45. Have you received any weather information during the last 12 months ? 1. Yes 2. No

Type of information	2.From whom or how did you receive the information? *(List up to three*	4. Did it include advice on how to use the information in your farming? *(Yes/No)*	How did you use the information
Forecast of drought, flood, frost, cyclone, tidal surge or other extreme event	----- ----- -----	-----	

Type of information	2.From whom or how did you receive the information? *(List up to three*	4. Did it include advice on how to use the information in your farming? *(Yes/No)*	How did you use the information
Forecast of pest or disease outbreak	----- ----- -----	-----	
Forecast of the start of the rains	----- ----- -----	-----	
Forecast of the weather for the following 2-3 months	----- ----- -----	-----	
Forecast of the weather for today, 24 hours and/or next 2-3 days	----- ----- -----	-----	

SECTION F: FOOD SECURITY IN RELATION TO CLIMATE CHANGE

46. For each month say whether the food you consume is mainly from your own farm or from other sources. In addition, which months if any you tend to find you do not have enough food to eat for your family.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. Source of food	---	---	---	---	---	---	---	---	---	---	---	---

Codes for 2.1: 1=Mainly from own farm, 2=Mainly from off farm (purchase/aid/other)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2. Shortage / struggle to feed the family	---	---	---	---	---	---	---	---	---	---	---	---

Codes for 2.2: 1=Shortage, 0=No shortage

47. Which of the following structures/utilities does your household have? *(Yes/No)*

a. Improved storage facility for crops (food or feed) -----
b. Water storage tank (for domestic water, > 500 litres) -----
c. Well/borehole (for household water) -----
d. Running/tap water in the dwelling -----
e. Electricity from a grid -----
f. Improved housing (e.g. concrete, bricks, etc.) -----
g. Improved roofing (e.g. tin, tiles, etc.) -----
h. Separate housing for farm animals -----
i. Others (specify) -----

48. How many gardens do you have?

Garden	Distance from household
1.	
2.	
3.	
4.	

49. In which market do you sell your agricultural products and how far is it from your home?
……………………………………………………………………………………………….

50. Where do you buy Agro-inputs from, and how far is it from your home?
…………………………………………………………………………………………………..

SECTION G: INFORMATION ABOUT FISH FARMING

51. Are you involved in fish farming? 1. Yes 2.No

52. How many people in your village are involved in fish farming? ………………….

53. Who introduced fish farming in your village? ....

54. For what purpose was fish farming introduced in your village?
……
…….

END

THANK YOU.