AN ASSESSMENT OF RAINFALL ONSET VARIABILITY FOR OPTIMIZED PLANTING DECISION MAKING IN NAKASEKE DISTRICT, UGANDA

BY

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Declaration and Approval

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

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Dedication

I dedicate this dissertation to the participants of this study and the people of Nakaseke, who despite their daily challenges took time to share their experiences with me. This dissertation is also dedicated to my beloved late grandmother, Juliet Baryomunsi Kamuhogo.

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I thank God the Almighty for the gift of knowledge that He has always blessed me with through the Holy Spirit. I am forever grateful.

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Abstract

Climate variability has enormous impact on agricultural production and the well-being of communities in Uganda and the world at large. The lack of reliable anticipative information on rainfall onsets that mark the beginning of the agricultural season has made planting decisions very difficult. Advance information on delayed onset or early cessation of the rainy seasons is extremely valuable information that is commonly requested by stakeholders. The overall objective of the study was to generate data and information, and contribute to the development of decision making support systems for adapting to rainfall onset variability in Nakaseke sub-county, Nakaseke district of Uganda.

Observed daily rainfall data for Kakoge weather station covering the period 1961 to 2015 was used to establish the trends of variability in rainfall onset. Rainfall onset dates were obtained using INSTAT program and summarised using Mean, Standard Deviation and coefficient of variation. Time-series plots were used to check patterns in onset dates and Mann-Kendall's test was used to determine significance, direction and magnitude of the trends.

In order to link the observed trends and farmers experiences, a household survey was carried out to investigate farmers' perceptions and adaptation responses of changes in planting time. Pearson chi-square test for independence (χ^2) was used to examine the relationship between farmers' perceptions / adaptation responses of changes in planting time and rainfall seasons. Statistical Package for Social Scientists (SPSS) and R programming software were used to analyze run rainfall and household data.

Preliminary findings from rainfall onset and household data analysis were corroborated through focus group discussions and thereafter logically organized to derive a model flowchart which guided the development of a Planting Decision Tool (PDT) to guide decision making for optimum planting time.

To come up with the tool, Sublime Text 3.0 software was used to write JavaScript logic and index files containing the logic for the tool, graphs and areas where the user can view outputs in the PDT.

Results show onset of rains for March, April, May (MAM) season (CV=22%) to be about four times more variable than that of September, October, November, December (SOND) season (CV=5%). False start of rains occurred once every 10 years for MAM season while no false starts were observed for SOND season over the period 1986-2015. Onsets for both

MAM and SOND were seen to be more erratic in the recent decade of 2006-2015. Effects of changes in rainfall onset differed significantly ($p<0.05$) by season.

Results from the survey show that for both MAM and SOND, the key effects of variable planting dates are reduced crop yields, and total crop loss in extreme cases. Farmers coped with the effects by practicing soil and water conservation and changing crops.

From both rainfall analysis and the survey, PDT was developed. It has a simple and basic user interface with drop down menus that require prior information on the crop type, seasonal forecast type, and season and analogue year. This tool provides profound information to guide timely planting.

In conclusion, developing such a tool will help farming communities to make informed decisions on timely planting. Further since the tool has incorporated the farmer experiences it will fit in well with their seasonal operations and thus help improve yields.

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List of Acronyms

AR4	Assessment Report 4
ASSAR	Adaptation at Scale in Semi-Arid Regions
AWS	Automatic Weather Stations
CSS	Cascading Style Sheets
ENSO	El-Nino Southern Oscillation
FAO	Food and Agricultural Organisation
HTML	Hyper Text Markup Language
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
JS	JavaScript
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MAM	March-April-May
NARO	National Agricultural Research Organization
NGO’s	Non-Governmental Organisations
PDT	Planting Decision Tool
SRES	Special Report on Emissions Scenarios
SOND	September-October-November-December
SSA	Sub-Saharan Africa
UBOS	Uganda Bureau of Statistics
UNMA	Uganda National Meteorological Authority
WWF	World Wide Fund for Nature

CHAPTER ONE

1.0 INTRODUCTION

This chapter provides the background to the study, statement of the problem, objectives, research questions and the justification of the study.

1.1 Background

Over the past decades, it has widely been accepted that the impacts of global warming and associated climate changes are inevitable and that adaptation to these changes will be essential (Mulenga & Wineman, 2014). Adaptation response actions to climate change need to consider both adaptation to longer term changes in key parameters such as rainfall and their associated impacts on food production, and on the already evident impacts of increased frequency of extreme climatic events (shocks) and greater climatic variability (Cooper et al., 2007). Climate variability has enormous impacts on agricultural production and the well-being of communities throughout the world, for example, seasonal rainfall change, higher average rainfall, high, intensity events, devastating droughts and famine (Huda & Packham, 2004). Over the next few decades, farmers will face the challenging task of increasing food production to keep up with growing population and per-capita consumption (Sacks *et al*., 2010) compounded by climatic variability.

Rainfall variability is the dominant source of livelihood risk in smallholder rain-fed agriculture systems (Hansen, 2005; Osbahr *et al*., 2011) and this is particularly pronounced in dryer environments (El-Tantawi & Saleh, 2013). This variability, expressed majorly in seasonal characteristics such as dates of onset, length of the potential growing season and dates of cessation, impacts the conditions during a crop growing season especially planting time and harvesting periods (Laux, Kunstmann, & Bardossy, 2008; Mulenga & Wineman, 2014). Projections already show that increased rainfall variability could decrease agricultural yield in Africa by 30%, this century, yet agriculture is key in providing food and employment for the majority of the ever- increasing population. Moreover, these impacts are coupled with low adaptive capacity in this region (Abid *et al*., 2015; ASSAR, 2015; Bryan *et al*., 2013; Enete & Amusa, 2010; Feng *et al*., 2013; IFAD, 2010; Mary & Majule, 2009). The impact of rainfall onset variability on crop production is expected to constitute a significant threat to food security, particularly with crops like maize in more marginal parts of Sub-Saharan Africa (SSA) (Waldman, Blekking, Attari, & Evans, 2017). Any short or long-term climate effects will therefore force farmers to adapt their management decision making to be responsive to current weather information (Ahmed et al., 2014; FAO, 2016; Iizumi & Ramankutty, 2015; Kurukulasuriya & Mendelsohn, 2008; Yohannes, 2016).

In East Africa, the climate is naturally dynamic with high temporal and spatial rainfall variability, yet its economy and the wellbeing of its people are tightly bound to climate (Hepworth & Goulden, 2008). Uganda has for many years experienced food shortages resulting from rainfall variability and with the increased manifestation of negative effects related to climate change and global warming, this challenge is becoming greater (Government of Uganda, Department of Disaster Management/Office of the Prime Minister, 2012). The current worries therefore about the fate of rain fed agriculture stem from the fact that the onset (and cessation) dates have become highly variable, thus making agricultural planning very difficult (Feleke, 2015; Morton et al., 2015; Mubiru et al., 2012; Usman & AbdulKadir, 2013). Delayed/early rains have become more frequent and/or intense and this has left most of the rural poor farmers' food insecure and their livelihoods threatened (Okonya, Syndikus, & Kroschel, 2013). For example, the 2016 March to May rainy season was three weeks late and below-average in northwestern, central, and eastern Uganda bimodal areas and this led many farmers to delay planting, causing delayed crop development especially for cereals and legumes (FEWSNET, 2016). The 2015/16 El Niño event seriously impacted the Eastern, Central, and Western regions of Uganda as a result of delayed and short lived rainfall; signaling a potential further deterioration of the affected regions' food security situation (Department of Relief Disaster Preparedness and Management Office of the Prime Minister, 2017).

The onset of the rainy season is considered to be the most important seasonal characteristic required by the farmer for the beginning of season farm operations and for planning the cropping calendar each year (Laux *et al*, 2010; Mawunya *et al*., 2011; Recha *et al*., 2012;). Onset of rains marks the beginning of the agricultural season (Moeletsi *et al*., 2011) and the timing of the occurrence can have an impact on agricultural yields. Increased variability in onsets therefore hinders effective decision making by farmers of when to plant. For example, late onset plantings have been shown to result in decreased yields, and early planting slightly before rainfall onset can improve agricultural yields due to a longer growing period (Camberlin & Okoola, 2003). Waongo, (2015) also notes that planting too early (before onset) might lead to crop failure and, in turn, planting too late might reduce valuable growing time and crop yield. Studies on rainfall variability analyze onset of rains as part of seasonal characteristics (e.g. Laux et al., 2008; Mugalavai, Kipkorir, Raes, & Rao, 2008; Usman &

AbdulKadir, 2013; Vrieling, De Leeuw, & Said, 2013). Komutunga, (2005) suggests treating the planting period as a stand-alone phenomenon in homogenous zones and recommends filtering out the planting window to precisely define the planting date. This knowledge becomes even more important if we hope to actively design strategies for adaptation, most notably, adjust planting dates (Juana *et al*., 2013; Sacks *et al*., 2010; Waongo, 2015). The ability to effectively estimate the actual start of the season therefore becomes crucial to the success of agricultural activities.

For effective adaptation to rainfall onset variability, the roles of farmers' experiences and perceptions should not be under estimated (Simelton *et al*., 2013) as they add valuable information to conventional meteorological statistics on how rainfall is changing. Research using meteorological observations is a common practice within scientific literature. However, there is still a large disconnect between this empirical information and farmers' perceptions. For example while researchers use complex statistics, farmers use simple practical approximations of available soil moisture and other indigenous signs to characterize onsets and cessations of rainfall (Mugalavai *et al*., 2008). Despite these differences, local communities are increasingly demanding for climate adaptation programs that better acknowledge local contexts (Simelton *et al*., 2013).

The tool developed in this study has incorporated farmers' experiences with rainfall onset and therefore addresses this gap. Output from the tool is a product of an analysis of scientifically identified climate dynamics and local perceptions and experiences. This can be a key possible thrust to reduce vulnerability, enhance resilience of rural farmers and increase their adaptive capacity (Jiri *et al*., 2016; Okonya *et al*., 2013).

1.2 Problem Statement.

There is limited information to guide farmers on making decisions for planting. Given the high variability in onset dates of rainfall, adjustments have be made in the way decisions are made, if Uganda is to effectively adapt to the effects of climate variability and change. Farmers lack precise information to anticipate the timing of rainfall yet they have core and important decisions to make in each season about the crops that they select and the timing of planting. The farmers wait for the actual onset of rains and weeks of valuable rainfall are wasted before they finally plant. They start tilling land after the onset of rainfall, losing a lot of moisture before planting. This leads to critical stages of crop development with high water requirements coinciding with withdrawal of rains and as a result potential crop productivity is never attained. Sometimes farmers plant immediately after the first rainfall event of the season which could be a false onset that eventually leads to dry spells after planting, risking crop failure and the need to replant.

Lack of information to deal with such puzzling mismatch of events slows down the effort and capacity of farmers to adapt, hence making them more vulnerable to the effects of rainfall variability. Further still, the traditional cropping calendars and / or cycles that farmers follow are not dynamic despite the changing nature of rainfall onset. This study therefore aimed to address some of these challenges by integrating farmers' perceptions and statistical analyses of rainfall data to derive a dynamic planting decision tool for adapting to rainfall onset variability in Nakaseke district of Uganda. Given the role that maize and beans play in diverse livelihood systems especially food and income security across Uganda, this study incorporated the two crops to be the units of reference for the decision tool.

1.3 Objectives of the study

The overall objective was to contribute to the development of decision making support systems for adapting to rainfall onset variability. The specific objectives of the study include;

i) To examine historical trends of rainfall onset to ascertain changes in planting dates over time in Nakaseke district

ii) To establish farmers' perceptions and adaptation responses of changes in planting time

iii) To derive a tool for optimizing planting time decision making

1.4 Research Questions

i) Is there evidence of increasing variability in dates of onset of rains in Nakaseke district?

ii) What is the degree and pattern of variability?

iii) What are the farmers' perceptions regarding changes in planting time?

iv) How have farmers adapted to these changes over time?

v) How can farmers' perceptions and evidence from historical rainfall data be integrated into a tool for optimizing planting time decision making?

1.5 Significance of the study

This study is expected to contribute to improved decision making processes for adaptation to climate change and variability in the semi-arid areas of Uganda.

Decisions made by farmers may have large influences beyond the farm boundary, and for this reason they are often of interest to Government and the public (Edwards-Jones, 2013). This study would therefore help decision-making bodies such as Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) to develop advisories for agricultural planning. In addition, it would help other decision-makers, government officials, donors and NGOs to prepare and allocate adequate resources to help farmers adapt to changes in planting timing.

More importantly, at the start of the agricultural season, farmers need to make critical investment decisions such as how much land to prepare and how much to spend on agricultural inputs. Although climate change will affect rainfall patterns in time and space, there is need to analyze variability in onset of rains within available historical data to capture both historical and current trend and develop the guidelines based on the historical and current trend. This would help in quantifying a planting window and a cessation window that would help in climate smart decision - making. Information obtained from this study would also help in the derivation and development of adjusted cropping calendars in the face of climate variability.

1.6 Justification of the study

Information on when rains start is vital in planning land preparation and planting. Therefore adapting the planting date is a very cost-efficient way to potentially increase crop productivity and stabilize or even increase food security in rain-fed regions which are most vulnerable to climate change. Ultimately, the ability of farmers to adapt effectively can affect regional and national economies which are highly dependent on agricultural production (Laux *et al*., 2010).

The level of knowledge on rainfall onset variability and agricultural decision systems of smallholder farmers currently being used needs to increase. The limited quantification of when farmers' plant is affecting the pace of targeting and adoption of climate change adaptation strategies. The changing circumstances for agricultural production and environmental service functions currently sustaining rural livelihoods need different approaches in the design of appropriate crop and natural resource management systems with respect to technologies.

Increasing knowledge on climate variability helps in targeting and designing relevant and targeted adaptation strategies. Incorporating observations and perceptions of the community with historical records will lead to a better interface between institutions and the communities they serve. More so, community participation in deriving this model will help in having their buy-in and adoption by other contact farmers. This will help increase uptake and adoption of the technologies and foster sustainability and also be competent guidance for livelihood responses as requirements for rural communities to use seasonal forecasts effectively.

CHAPTER TWO

2.0 LITERATURE REVIEW

This chapter provides a review of past studies on climatic change and rainfall variability, farmer perceptions and adaptation to rainfall onset variability, and optimizing decision making.

2.1 Rainfall onset variability

It is understood that climate change impacts will be felt through changes in variability rather than the long term shift in average conditions so the uncertainty around changes in variability brings some uncertainty in the extent of impacts (Hepworth & Goulden, 2008). Outputs, such as the Intergovernmental Panel on Climate Change (IPCC) reports, show that for many parts of Africa the exposure to new climatic conditions is projected to reach beyond previously experienced extreme events (Boko *et al*., 2008) with many of the impacts materializing through changes in extreme events such as drought and flooding (Herrero *et al*., 2010)

The IPCC AR4 Special Report on Emissions Scenarios (SRES) A1B emissions scenario for 2080-2099, suggests an increase in mean annual rainfall in Eastern Africa (around +7%). Regional climate model simulations by Cook & Vizy, (2013) project severe decreases in the number of growing-season days in East Africa by the mid-twenty first century because of increasing greenhouse gas concentrations.

Uganda experiences two major rainfall regimes namely bi-modal and uni-modal (Mubiru, *et al.*, 2012). The bi-modal regime is observed over majority of the country such as the southern region and areas near the equator with the first wet season occurring in March-May (MAM) (known as the "long rains" in Southern and Central Uganda) and the second wet season takes place in September-December (SOND), known as the "short rains" (Osbahr et al., 2011). The long rains contribute more than 70% to the annual rainfall and the short rains less than 20%. Much of the inter-annual variability comes from the short rains (WWF, 2006). As a result, the short rains are more predictable at seasonal scales than the long rains.

Future climate scenarios for Uganda have been developed based on the results of modelling exercises and these show that the seasonality of rainfall is likely to change in the future. The highest percentage increase in rainfall is projected for December, January and February, which is historically the driest season for many parts of Uganda. This indicates that the current wet season from March to May, may shift forwards in time or the September to November rains, may extend longer. It must be emphasized that there is already considerable variability in seasonal rainfall totals, much of which is linked to ENSO (Hepworth & Goulden, 2008).

Clarity on variability by region and specific agro-ecology is essential to support vulnerable communities to adapt their food systems to emerging climate variability realities, yet regional and national climate studies have been generalized over large scales and thus are insufficient in capturing variability at local level where management actions occur (Kansiime *et al*., 2013). Finer scale studies on rainfall onset variability are however important to understand the magnitude of this variability and impacts on important farmer decision making. Despite this, there is limited information and studies on rainfall onset variability.

Rainfall changes rarely produce the type of significant trends that temperature does. Within the general phenomena of rainfall variability, intra-seasonal factors such as the timing of the onset of first rains, which affects crop planting regimes, denote real criteria that interrupt the effectiveness and success of farming (Thomas *et al*., 2007). Recha *et al*. (2012) quantified rainfall variability for MAM and SOND seasons in Tharaka district, Kenya where they analyzed inter- annual variability of seasonal rainfall, onset and cessation using daily rainfall data in three agro-ecological zones' stations. Such results should be incorporated in implications of climate variability and vulnerability assessment.

In their study, Mubiru *et al*. (2012) analyzed historical data sets of daily rainfall and temperature to generate seasonal characteristics based on monthly and annual timescales. The results showed that variability in rainfall onset dates across Uganda is greater than the variability in withdrawal dates. They advised that it was imperative to generate agronomically relevant seasonal rainfall characteristics to guide decision- making.

In their study, Camberlin & Okoola, (2003) found large inter-annual variability of the onset in East Africa, and as a consequence, the total seasonal rainfall depends much more strongly on the onset dates than on the cessation dates. Nimusiima *et al*. (2013) found out that early rainfall onset especially in the second season seemed to prolong the length of the growing season and advised farmers to take advantage of planting most crops when an early onset is predicted for the second season.

In their study in Zimbabwe,Mupangwa, Walker, & Twomlow (2011) assessed whether there were any changes in the start, end and length of growing season. Analysis of the characteristics of the growing season demonstrated that there were insignificant changes in the start, end and length of growing season. Despite this, they identified the need to establish crop-planting windows for major crops grown.

Yengoh *et al*. (2010) assessed changes in agriculturally relevant variables using time series daily rainfall data for Tamale, Ghana. They found a forward shift (non-significant) in the timing of planting for most food crops. This situation has left farmers with a lot of uncertainty regarding planning for this activity. The risk of dry spells after planting have increased over the decades making farming for small-scale agriculturalists even more risky. The findings of the study suggest the need for the development of a comprehensive agricultural and climate policy that takes into account the mounting risks associated with agricultural production among small holder farmers. Deriving a tool for optimizing farmer decision making for adapting to planting time could be an important guide while implementing such policies.

Waongo, (2015) presented a new method to optimize crop planting dates in water-limited regions in West Africa and its benefit as an agricultural management strategy. His findings highlighted the potential of optimized planting dates as a crop management strategy and the implementation of the approach in agricultural decision support was expected to improve agricultural water-related risk management. The study further advised that optimized planting dates approach can be used in combination with seasonal climate forecasts to provide planting date information to farmers which this study intends to do. His study also further recommended the need for farmers to combine optimized planting dates with other suited farming practices to respond adequately to climate change.

2.2 Farmer perceptions and adaptation responses of changes in planting time

Farmer perceptions of weather and climate are crucial in anticipating the impacts of changing climate patterns, as only when a problem is perceived will appropriate steps be taken to adapt to it. Understanding how and why farmers have responded to past climatic change is a necessary step to informing how to support current and future adaptation and is a critical step to facilitate effective communication on science-based agrometeorological knowledge.. However, there is limited knowledge on whether farmers perceive climate change and how they are responding to the effects of a changing climate. It is also important to note that local perceptions cannot be estimated by models and the need to document how the lives of the local people are affected by the recent changes in climate (Okonya et al., 2013). In Uganda, the nature of climate variability in semi-arid areas and other areas alike is not well understood and how the communities perceive rainfall onset variability has not been well documented.

In their study, Nimusiima *et al.* (2013) characterized the nature of climate variability by analyzing variations in major climatic parameters of rainfall and temperature and how they affect local communities in the central cattle corridor districts of Nakasongola and Nakaseke. They looked at how community residents perceived climate change/variability and the trend and nature of climate variability and how it compared with people's perceptions. Results from perception compared well with trends and nature of climate variability. They however did not package this information into readily usable products that can help farmers better adapt to climate variability.

Osbahr *et al*. (2011) conducted a study in southwest Uganda of farmers' perceptions of climate trends and variability and compared this local knowledge with the climate data to uncover how perceptions of risk and opportunity were associated with recent climate. They write that analysis of subjective observations about weather and climate requires deeper investigation of the socio-economic, cultural and environmental conditions experienced by the affected people and the ways this influences decision-making to cope with uncertainty, agricultural innovation and livelihood adaptability. The study further urges that tools to support farmers to use climate information to increase productivity and minimize risk will need to recognize these issues.

Studies by Breytenbach (2013) and Orlove *et al*. (2010) in western and southern Uganda found out that most farmers plant approximately after two to three rain events and involves farmers waiting for the soil to reach saturation before they will plant. After two to three rain events enough water will have soaked into the soil to soften and cool the ground sufficiently. The studies further note that the two or three rain events need to occur within months when rain is expected in order for farmers to plant; rains are expected to begin in February for the MAM season and between July and August for the SOND season. If the rain events occur before these expected time frames farmers will not plant.

There are also a number of relevant studies on farmer perceptions in other countries. Simelton *et al*. (2013) sought to identify southern African farmers' perceptions of rainfall, rainfall variations, and changes; examine the nature of meteorological evidence for the perceived rainfall variability and change; document farmers' responses to rainfall variability; and discuss why discrepancies may occur between farmers' perceptions and meteorological observations of rainfall. In their findings, they suggested that scientists, policymakers, and developers of climate adaptation projects need to be more in tune with farmers' and extension workers' understandings of how weather is changing in order to improve adaptation policy formulation and implementation.

Makate, Makate, & Mango, (2017) examined the role played by perceptions on the adoption of sustainable agricultural in Southern Africa. Their results indicated that farmer's perceptions significantly influence the use of sustainable agricultural practices and they highlighted the need for a serious and perhaps equal consideration of farmer perceptions regarding climate change, as important inputs to climate change adaptation policies targeted at enhancing climatic resilience in smallholder farming communities. They recommended the focus of adaptation policy in smallholder farming to include inputs from a wide array of stakeholders, including the experiences and understanding of climatic variability and change in the different sectors of the farming community, in addition to the scientific evidence and expert knowledge available.

Wiid & Ziervogel, (2012) undertook a study in South Africa to explore commercial farmers' perceptions of and responses to shifting climates in order to test the robustness of the narratives and to understand how farmers' perceptions and experiences drive their climate-related decisions. They evaluated changes in the climate experienced in the area by comparing quantitative statistical analyses of rainfall data recorded from 1967 to 2009, with qualitative historical narratives and formulated perceptions of change for the same period. The narratives revealed that the farmers perceived a gradual but dramatic shift in climate over almost four decades, including changing annual rainfall patterns mirrored by the recorded weather data that show similar results to the narratives. Their research contributes to the growing local and regional evidence of variability and change to climate systems, and documents how people have already responded to change in order to help build locally relevant climate change adaptation approaches that could potentially benefit a wider range of farmers.

Mary & Majule (2009) carried out a study in Tanzania to understand local communities' perceptions on climate and variability issues and establish its impacts and adaptation strategies within the agricultural sector. The study concluded that, the wealth of knowledge on coping and adaptation that a farmer has should form a foundation for designing agricultural innovation systems to deal with impacts of climate change and variability. They identified a combination of strategies to adapt, such as proper timing of agricultural operations, crop diversification, use of different crop varieties and changing planting dates.

Bert *et al*. (2006) and Laux *et al.* (2008) write that farmers have evolved conservative cropping strategies to cope with rainfall variability depending on site conditions because they usually do not know what climate to expect in the following growing season. Adger *et al*. (2007), Morton *et al*. (2015) and Thomas *et al*. (2007) further agree that individuals and communities have coped with and adapted to climate variability for centuries based on personal experiences and perceptions. These include planting at onset of rains (Okonya *et al*., 2013), changing planting dates, as well as changing the choice of crops (Abid *et al*., 2015). In most farming systems, local crop calendars are established that are often followed by farmers in their decision-making. Traditional agricultural calendars are based on the mean climate occurrence in a given area over many generations (Haile, 2005). Farmers have developed specific dates for planting various crops that they follow depending on the expected start of rains for each season. Of course, after the event, farmers may discover that they have made the wrong decision but, in general, over a large number of farms and many years, the local calendar will give the best results.

2.3 Tools for optimizing planting time (and related agronomic) decision making.

Across Africa and the globe, farmers need tools and technologies that will enable them to adapt to a changing climate. Uncertainties in climate change, coupled with the complexities of social-ecological systems, emphasize the need for a variety of tools in adaptation planning and decision making. Multidisciplinary efforts have been engaged to develop, assess, and communicate climate information and risk assessments across time scales; from simple agro-climatic calendars to computerized decision-support tools. However, there is limited information and studies on tools that guide farmers to make planting decisions based on their experiences and climatic data.

Steynor *et al*. (2016) note that many decision-makers operate in a highly complex decision space where decisions are always made in isolation. Climate data is being provided into this decision space largely through a science-driven process. Often though, this climate information lacks vital guidance information about how the data were generated or whether or not any evaluation process was undertaken to test the validity and robustness of the climate data product. Users are thus unable to evaluate whether or not the climate data can be appropriately applied to their decision-making context. This creates the potential for maladaptation and actions that impede efforts to respond effectively to impacts from climate change. To overcome the disconnect between climate data and application, Awuor *et al*. (2016) and Girvetz *et al*. (2012) suggest that it requires a fundamentally different kind of engagement between the science community and the various potential end users of climate information. Therefore, although a wide range of adaptations are possible with current technologies and management practices, development and diffusion of technologies with farmer experiences can expand the range of adaptation possibilities by increasing their acceptability and adoption.

Maatman, Schweigman, & Ruijs, (2002) identify sequential decision making as one of the most important ways to cope with risk due to uncertain rainfall. Various modeling methods are used to model decision stages in time and space, and some methods can be combined to represent a sequential decision-making process. A farm decision-making problem should be modeled within an integrative modeling framework that includes sequential aspects of the decision-making process and the adaptive capability and reactivity of farmers to address changes in their environment. Integration of agrometeorological products with local knowledge on weather forecasting and climate prediction may therefore improve adaptation strategies and ensure that new knowledge, products, and services are implemented at farm level.

Moeletsi *et al*. (2013) developed a decision support tool to provide agro-climatological risk information important to the production of rain-fed maize in the Free State Province of South Africa. The tool was aimed at equipping the agricultural community with knowledge of the likelihood of the first rains and cessation of frost for planning of ploughing and planting dates. The tool can be used by farmers, extension officers, policy-makers and agricultural risk advisors to climatological risk analysis and forecasting. The tool however does not incorporate experiences and perceptions of farmers and this could lead to a low buy-in from farmers as they always want to relate to something they have experienced before.

From the foregoing literature, it is clear that though some work on climate change and variability has been done in Uganda, none is strongly biased to assessing rainfall onset variability and farmer planting time decision making. These gaps provide the entry point of this study.

CHAPTER THREE

This chapter describes the study area, data, methods and tools of data collection, and data analysis that were used to address the study objectives outlined in section 1.3.

3.0 STUDY AREA AND METHODS

3.1 Study area

The study was carried out in Nakaseke Sub-county, Nakaseke District (Figure 3.1) that lies in the cattle corridor of Uganda, an area that exhibits semi-arid characteristics such as high rainfall variability and periodic late onset/droughts, The district covers an area of 3,477.3 km^2 with 197,369 people (UBOS, 2016). The district is located between 2^0 and 3^0 North of the Equator and 32^o to 32^o 23" E. It shares its borders with Wakiso and Mityana Districts in the South, Luweero District in the East, Masindi and Nakasongola Districts in the North and Kiboga and Kyankwanzi Districts in the West. The District's climate can be described as modified equatorial climate. Nakaseke District has two rainfall seasons like most parts of the country, with the main one from March to May (MAM) and the second one from mid-August to early December (SOND). The average rainfall is 1300mm, with high inter and intra-seasonal variability spatially and over time, characterized by sporadic and poor distribution and occurrence patterns (Mbolanyi, Egeru, & Mfitumukiza, 2017)

3.2 Methods and tools of data collection

3.2.1 Trends of variability in rainfall onset

3.2.1.1 Observed rainfall data

Daily rainfall observations from the Kakoge 1st order weather station, covering the period 1961-2015 were used for this study. The station was chosen for this study because it is the nearest available station that best represents conditions similar to the study area. Kakoge station is located 1.067^o North and 32.467^o East in the greater Luweero district and lies about 1189 m above sea level. Data were obtained from the Uganda National Meteorological Authority (UNMA) archives.

The lack of serially complete rainfall data poses a significant challenge to studying rainfall in Uganda, but an alternative exists in the availability of automated weather station (AWS) data and simulated rainfall estimates that can supplement the data from existing manual weather stations. Initially, daily observed rainfall dataset contained about 9% of missing records.

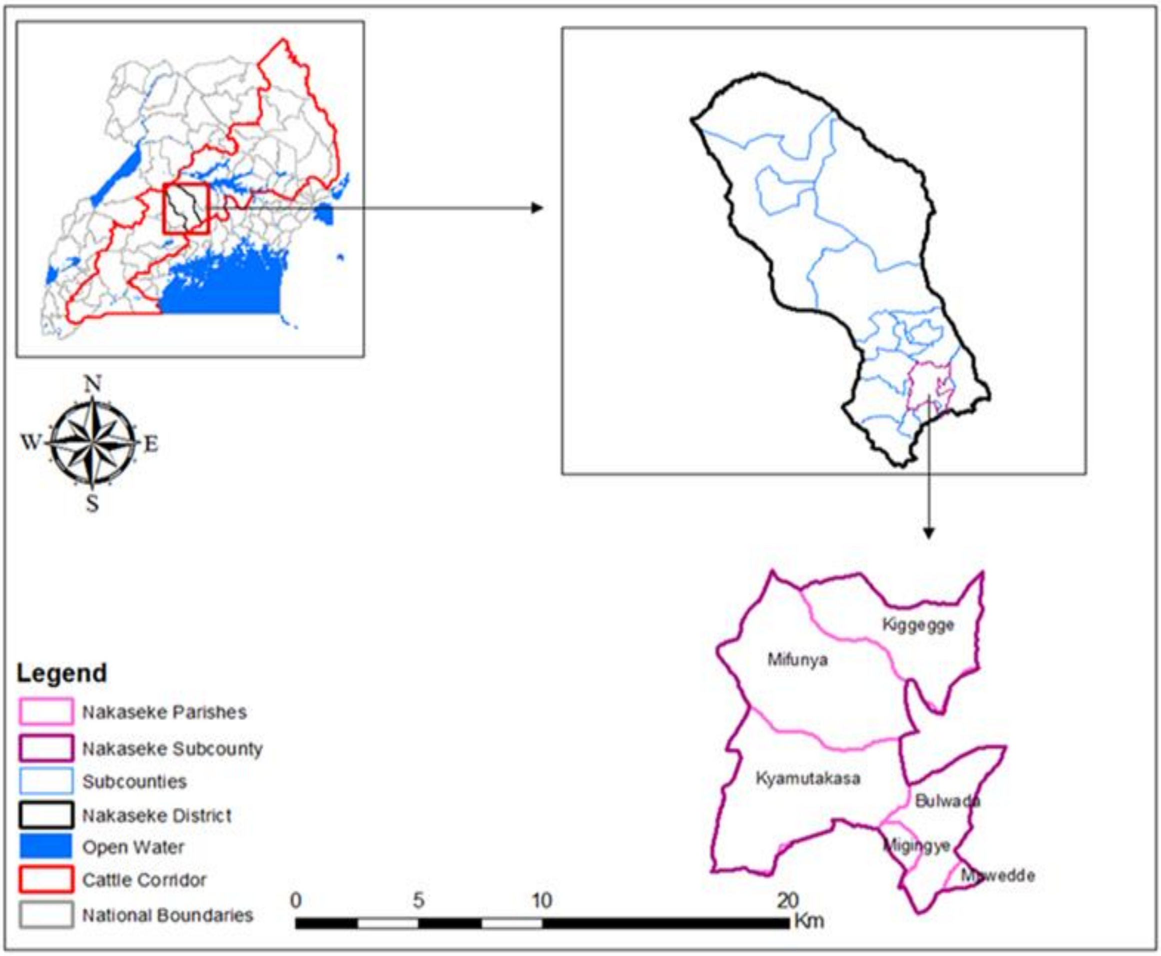

Figure 3.1: *Map showing location of study area*

3.2.1.2 Data Quality Control

These gaps were addressed using steps for harmonizing historical climate data described by Komutunga et al., (2015) where data from Weatherman correlates strongly and significantly with the observed weather data. The two datasets, one from NARO AWS and another from Weatherman simulated rainfall, were analyzed using regression analysis to simulate data for missing periods after correcting for differences in times of observation and location.

3.2.2 Farmer perceptions and adaptation responses of changes in planting time

To investigate farmers' perceptions and adaptation responses to changes in planting time, a cross sectional household survey was carried out in selected parishes as later described in the sampling design. The survey was undertaken using a semi-structured questionnaire administered by way of guided interviews to selected respondents at household level. It was designed to collect data on household socio-economic and farming characteristics, perceptions and experiences of rainfall, rainfall variations and changes in onset and planting times across growing seasons, their impacts and how the farmers were coping and adapting to these changes (See Appendix 1).

Nakaseke sub-county was purposively selected as the area of study due to its representativeness of varying rainfall gradients within the region. It is also an agro-pastoral zone that was suitable for characteristics being investigated in this study.

3.2.2.1 Sampling design and Sample size determination

The required sample size was determined using the formula for estimating a population proportion *P* (Bartlett et al., 2001) as described below.

$$n = \frac{p\,q\,z_{\alpha/2}^{2}}{e^{2}} \quad \text{………………………………………………………………………….. (1)}$$

Where n = sample size to be computed

p = proportion of target population in the study area estimated to have the characteristics being measured, that is, the proportion of farmers in Nakaseke that perceive rainfall characteristics to have changed over the recent past

$q = 1 - p$

e = acceptable margin of error

α = level of significance

z = critical value or z-score for a 100(1-α) % confidence interval

According to Nimusiima *et al.* (2013), about 42% of farmers in Nakaseke perceived rainfall characteristics to have changed in the last 5-10 years. Therefore, p was assigned the value 0.42. Setting e = 0.05 and α = 0.05 (Bartlett *et al.*, 2001) yielded the following sample size

$$n = \frac{\left(0.42 \text{ x } 0.58 \text{ x } 1.96^{2}\right)}{0.05^{2}} = 374.33 \quad \text{………………………………………………...(2)}$$

The generated sample of 374 respondents was obtained from Nakaseke sub-county (study area) using ***proportional allocation stratified random sampling*** method as stipulated below. This method was preferred as it is known to increase efficiency of estimators of overall population parameters and also makes the survey easier to administer operationally.

$$\frac{n_h}{n} = \frac{N_h}{N} \quad \text{Hence} \quad n_h = n(N_h / N) \qquad (3)$$

Where n = computed sample size

n_h = sample size of the h^{th} stratum (parish)

N_h = population size of the h^{th} stratum (parish)

N = total population size (sub-county)

Therefore, using six parishes in the study area, the sample was allocated in proportion to the size of each parish as shown in Table 3.1. Simple random sampling method was then used to draw respondents in each of the selected parishes (strata). The selected households were identified with the help of field extension workers.

Table 3.1: Proportional allocation stratified random sampling

Parish	**Population size N_h** *UBOS (2011, 2016)*	**Sample size n_h**
Bulwadda	3,582	70
Kasagga	3,085	61
Kasambya	3,282	65
Kigegge	3,607	71
Kyamutakasa	2,201	43
Mifunya	3,269	64
Total	**19,026**	**374**

3.2.2.2 Focus group discussions

To obtain data to validate the current planting decision making process, focus group discussions were conducted in the study area. The discussions also aimed at translating farmers' perceptions/experiences and climate data into adaptation action planning and decision making. This information was then used to develop a decision making model flowchart. The discussions were guided by structured questions administered to selected respondents. It was designed to collect data on maize and bean yields, management and adaptation practices to achieve desired yield and decision making options. Notes were taken during the discussions to generate in-depth information on agro-advisories to be integrated into the tool.

A total of 4 focus group discussions were carried out in four randomly selected parishes of; Kyamutakasa, Bulwadda, Kasagga and Mifunya in the study area. Each group comprised of 8-10 purposively selected respondents. The respondents were drawn from a sampling frame consisting of a list of names of beans and maize farmers in each parish generated from existing local farmer forums. The selected participants were identified with the help of field extension workers.

3.2.3 Tool for optimizing planting time decision making

This section and subsequent sub-sections detail the data that was required for derivation of the tool. Historical climate data and farmers' perceptions and adaptation responses to changes in rainfall onset dates needed to be logically organized into a model flowchart depicting an integrated decision making process. This would later help in developing a planting decision tool depicting the optimized decision making process in a way that minimizes the prevailing impacts. Secondary input data was also needed for operationalizing and making the tool responsive. This included; Seasonal forecast, Analogue years, crop yield data, planting windows and recommendations.

3.2.3.1 Seasonal forecast type data

The tool needed to let the user choose the type of season (MAM or SOND) they would want to view and also the season type that depicts the expected season rainfall performance in comparison with the location's historical rainfall performance. The seasonal rainfall performance was categorized in three types; Normal, Above Normal and Below Normal rainfall. The seasonal forecast types and thresholds (refer to 3.3.3.1) for each of these types were provided by the Uganda National Meteorological Authority.

3.2.3.2 Analogue year data

Analogue years from the historical climate data were needed in order to visualize an ideal situation of how the planting season might perform. An analogue year is derived from analogue based methods of weather predictions in which a current state of the atmosphere is compared with historical states of the atmosphere to determine the most similar year in the past (Delle Monache, Eckel, Rife, Nagarajan, & Searight, 2013). At the beginning of each rainfall season, UNMA provides the analogue year(s) for that season. In this case, the onset dates of each individual year covering the study period (1961-2015) would be a potential analogue year once selected. .

3.2.3.3 Crop yield data

Besides rainfall characteristics, maize and beans yield data was required to define season's performance. This data was obtained from farmers' perceptions during the focus group discussions, where they were asked to give threshold values for grain yield during what they perceived to be a good season and poor season. To validate farmers' attainable yield data, potential yield data for each crop were obtained from seed companies and the cereals research program of NARO. Potential yield data show how much yield can be got under optimum conditions. The comparison of potential yield and farmer attainable yield was expected to relay to the user the yield gap between the varieties. The yield gap is the difference between the potential yield and farmer attainable yield.

3.2.3.4 Planting windows

In order to reduce the error of estimation of onset dates, onset windows, thereafter referred to as planting windows were needed. These were generated from summary statistics of long term climate data (1961-2015) in objective one, by getting the differences between the calculated onset dates and their standard deviation as denoted below.

$$PW = \text{Mean} \pm SD \qquad (4)$$

Where PW is Planting Window, SD is standard deviation

3.2.3.5 Information on recommendations

Recommendations for the different planting windows and yield data were needed as an output of the tool. These were derived from the farmers' focus group discussions and some of the adaptation responses in objective two

3.2.3.6 Planting Decision Tool

To develop the planting decision tool, data from all sections in 3.2.1, 3.2.2 and 3.2.3 above needed to be coded into logic files. This necessitated the use of various computer programming languages (formal language that specifies a set of instructions that can be used to produce various kinds of output) to write the logic files. These included; Hyper Text Markup Language - 5 (HTML5) for structuring and presenting information on the webpages, Cascading Style Sheets (CSS - a scripting language used to control the style and layout of web pages all at once) for styling and positioning of the various HTML5 elements and

JavaScript (JS) to change HTML attributes, make the web pages dynamic and implement the logic in the tool.

Index files containing the graphs and areas where the user could view the expected outputs were needed to visualize the comparisons between local and improved yield. These were generated from Chart.js, an open source JavaScript charting library that helps to easily visualize data using JavaScript. These were open source software that were downloaded from the internet (https://www.chartjs.org/)

3.3 Data Analysis and presentation

Data analysis comprised of complementary qualitative and quantitative techniques as explained in the subsections below

3.3.1 Trends of variability in rainfall onset

3.3.1.1 Seasonal onset dates

Rainfall onset dates for MAM and SOND seasons were computed using INSTAT program (a climatological analysis tool) according to the formula defined by Stern *et al*. (2006). The formula, which is inbuilt in the tool describes the "start of rains" in two ways as follows:

i. The first occasion with at least 20 mm of rainfall in three consecutive days after the onset date (from long term data - 21st February for MAM season or 15th August for SOND season);

ii. The first occasion with more than 20 mm rainfall in three consecutive days after 21st February or 15th August and no dry spell of 10 days or more within the following 30 days.

The dates obtained in the second definition were considered for this study since they have been known to produce successful planting dates. The threshold value for a rainy day to be counted as rainy was set at a value of 0.85 mm as adopted by Recha et al., (2012). The generated onset dates were summarized using descriptive statistics that included mean, standard deviation and coefficient of variation.

3.3.1.2 Variations in the onset of rains and changes in dispersion

To examine variations in the 'onset of rains' over time, the computed seasonal onset rainfall dates for the period 1986-2015 were grouped into three decades (1986-1995, 1996-2005, 2006-2015). Probability distribution plots (histograms superimposed with normal density curves) were then used to assess changes in dispersion of onset data relative to the long-term period (1961-2015).

3.3.1.3 Trends in onset dates

Time-series plots, augmented with trend lines were used to check patterns in onset dates over the period 1986-2015. Mann-Kendall's test was used for statistical analysis of observed time-series plots for rainfall onsets. Kendall's correlation coefficient (τ) was used to determine the significance, direction and magnitude of the trends. A positive value of τ indicates increasing trend while a negative value depicts a decreasing trend. At α level of significance, the trend is considered statistically significant if p-value < α.

3.3.1.4 Probability of false start of rains

Stacked line plots were used to examine the probability of false starts of seasonal rains over time by comparing onset when the probability of a dry-spell is considered to onset when the dry-spell is not taken into account. SPSS and R software programs were used to run the basic analyses.

3.3.2 Farmer perceptions and adaptation responses of changes in planting time

3.3.2.1 Household survey

The data on perceptions and adaptation responses to changes in planting time collected from the farmers' survey were captured into spreadsheets (SPSS) by first defining variables, setting labels for the values and all variables thoroughly filled out. Data was then cleaned and analyzed using descriptive statistics. Frequency tables and clustered bar graphs were used to generate summary statistics on household demographic variables and opinions about changes in rainfall onset and planting times. Pearson chi-square test for independence (χ^2) was used to examine the relationship between farmers' opinions and rainfall season. It was also used to check for association between farmer adaptation responses and demographic characteristics. At α (0.05) level of significance, the association between the variables is said to be statistically significant only if p-value < α.

3.3.2.2 Focus Group Discussions

Information obtained from focus group discussions was synthesized after multiple readings through corresponding and rearranging comments on the predetermined questions to identify and group response patterns and categories of discussion to form major themes. Themes were presented as narratives and translated into adaptation action planning and decision making from which an output on recommendations by the tool were drawn.

3.3.3 Tool for optimizing planting time decision making

A model flowchart was developed by logically organizing results from analysis of historical climate data and farmers' perceptions and adaptation responses to planting times to depict an integrated decision making process that later helped in developing the planting decision tool to optimize the decision making process in a way that minimizes the prevailing effects. The flowchart was created by first defining the process to be diagrammed, deciding on the boundaries of the process (Where or when does the process start? Where or when does it end? What level of detail to be included in the diagram)? The processes were then arranged in proper sequence and arrows drawn to show the flow of the process.

For accuracy, the flowchart needed to be reviewed/evaluated by farmers through focus group discussions and secondary input data was needed to operationalize the tool.

3.3.3.1 Seasonal forecast type

The seasonal forecast from UNMA was categorized in 3 types: Normal season, Below Normal season and Above Normal season; to let the user select the expected seasonal rainfall performance as forecasted for a particular season MAM or SOND. Normal season is when the total rainfall is in the range of 75% to 125% of the long term mean of the area. This range of rainfall is expected to adequately support the normal socio-economic activities for the various areas. Above Normal season is when the total rainfall is above 125% of the long term mean. Impact on socio-economic activities is mostly boosted especially in the modest degrees of above average. A Below Normal season is when the total rainfall is below 75% of the long term mean. Under this range there are high chances for socio-economic activities being stressed, the level of stress increasing with increasing rainfall deficiency.

The generated onset dates (section 3.3.1) for both seasons for all the years in the historical data (1961-2015) were converted into JavaScript date formats and stored in an array (An array is a special variable, which can hold more than one value at a time) and would be displayed on the tool's interface once the analogue year for the current season had been selected by the user. At the beginning of the rainy season, UNMA, on request, provides the analogue year(s) of that season.

3.3.3.2 Planting windows

Planting windows were considered as an equivalent of the onset windows generated from summary statistics, Mean ± SD, of the long term climate data (1961-2015) i.e. early start, normal start and late start. These were then classified as Early Planting, Mid Planting and Late Planting. An Early Planting window was considered as a range of dates between the difference of the average onset date and standard deviation. A Mid Planting window was considered as a range of dates between the average onset date and standard deviation. A Late Planting window was considered as any date after the normal planting window but before the end of the season.

3.3.3.3 Yield data

Yield data was classified in three categories; Good yield, Fair yield and Poor yield. These categories were derived from the probable expectations of yield performance given various scenarios of season forecast types and planting windows.

From the comparisons between potential yield and farmer attainable yield, classifications (Table 3.2) were derived. It should be noted that the yields obtained by farmers for several crop species and in many cropping systems around the world have almost always been shown to be lower than those attainable using locally optimized agricultural best practices and adapted, current cultivars (Hall, Feoli, Ingaramo, & Balzarini, 2013). Therefore the categorization of good, fair and poor attainable yield is context-dependent on environmental, economic and sociological factors.

Units of measurement of crop yield from the seed companies (tons per hectare) and farmers (bags per acre) were standardized into kilograms per acre (kg/acre).

3.3.3.4 Planting Decision Tool

To develop the planting decision tool, Sublime Text Editor Version 3.0 was used to write JavaScript logic and index files containing the logic for the application and graphs and areas where the user can view outputs as explained earlier in section 3.2.3.8

HMTL5 included detailed processing models to encourage more interoperable implementations – extends, improves and rationalizes the markup available for documents and introduces markup and application programming interfaces (API's). It uses markup tags to describe the organization of information and objects while using Hypertexts to link web pages to each other. For styling and positioning of the various HTML5 elements, CSS described how HTML elements were to be displayed on screen.

Table 3.2: Yield value classification

GOOD YIELD		**FAIR YIELD**		**POOR YIELD**	
Maize	Beans	Maize	Beans	Maize	Beans
E x A	E x A	M x N	M x N	L x B	L x B
E x N	E x N	E x B	E x B	L x N	L x N
M x A	M x A		L x A	L x A	M x B

Where *A = Above Normal season, B = Below Normal season, N = Normal season, E = Early Planting, M = Mid Planting and L = Late Planting*.

CHAPTER FOUR

4.0 RESULTS / FINDINGS

This chapter presents findings of all the objectives following the methodology in the previous section. It also gives a brief general rainfall outlook of the study area in terms of seasonal rainfall totals and their variability, pattern and distribution.

4.1 The variability in rainfall onset

General rainfall outlook

The results indicate that on average, Nakaseke receives about 1213 mm of rainfall annually. MAM and SOND seasons receive 413 mm and 478 mm of total rainfall respectively. Seasonal rainfall exhibit high variability (CV>20%) as compared to annual rainfall (See Table 4.1)

Table 4.1: Summary statistics of rainfall totals for the long-term period (1961-2015)

Statistic (unit)	Annual	Mar-May	Sep-Dec
Mean (mm)	1212.6	413.4	478.8
Std. deviation (mm)	210.4	101.0	102.5
Minimum (mm)	891.7	196.5	218.6
Maximum (mm)	1980.1	751.5	698.8
C**V (%)**	17.3	24.4	21.4

CV = coefficient of variation, Number of observations (N) = 55

A plot of long-term observed data (Figure 4.1) shows that the general pattern of rainfall for Nakaseke district is strictly bi-modal with two wet seasons occurring in a calendar year. Figure 4.1 also shows the rainfall distribution in terms of its onset, length and cessation for the major seasons in the year. The first wet season is observed to start in mid-March, reach its peak in April and end late May whereas the second season begins late August, reaches peak in October and ends in early December.

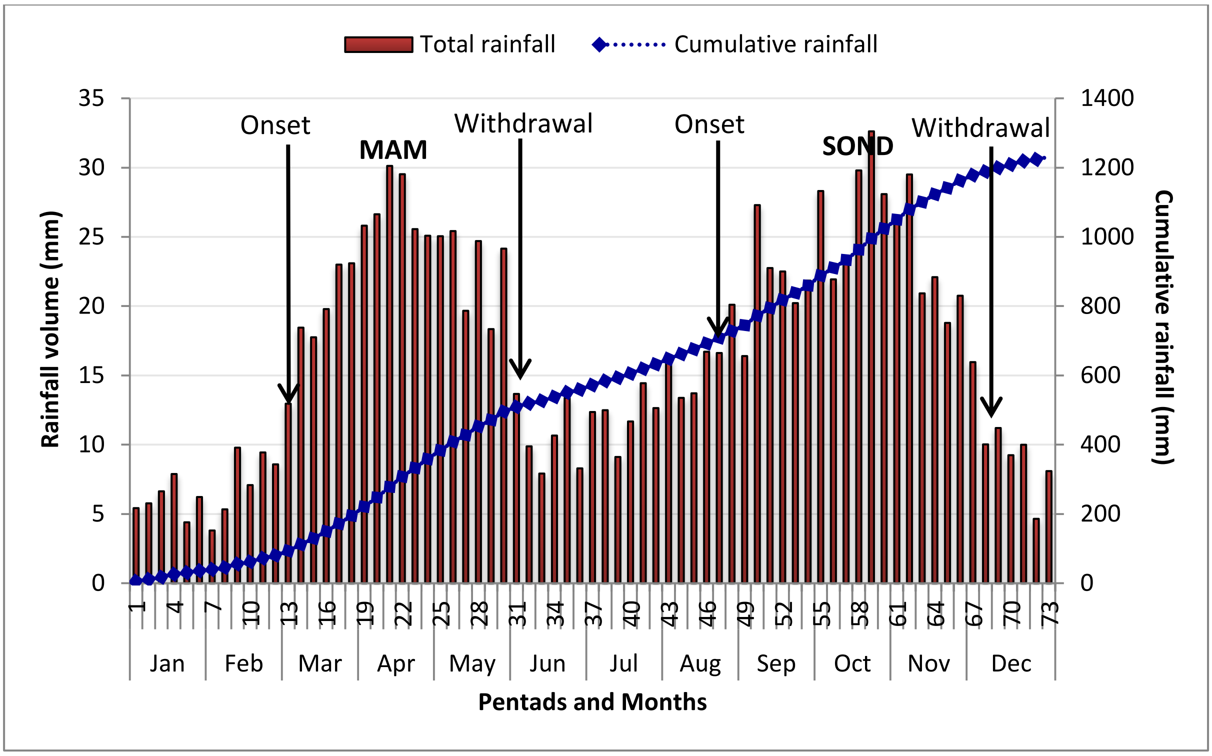

Figure 4.1: *Mass curves generated from actual rainfall (>10-mm wet pentad) showing onset and withdrawal of rain for Kakoge Station constructed from actual five-day (pentad) rainfall totals over the long-term period (1961-2015).*

4.1.1: Onset of MAM and SOND

Table 4.2: Summary statistics for seasonal rainfall onset over the long-term period 1961-2015

Statistic (units)		**Rainfall season**	
		MAM	**SOND**
Mean **onset (day of the year)** ± **Standard deviation (days)**		75.7 ± 16.3	238.1 ± 12.0
Onset window	Early start	28-Feb	13-Aug
	Mean start	16-Mar	25-Aug
	Late start	01-Apr	06-Sep
CV (%)		21.5	5.0

CV = coefficient of variation, Number of observations (N) = 55

Results in Table 4.2 above indicate that the normal start for the MAM season was mid-March (16th March) and it varied by about 16 days. SOND season on the other hand was noted to start late August (25th August) with variation of about 12 days on average. This means that the resulting onset window was longer and more variable for MAM season (4 and a half weeks) as compared to SOND season (3 weeks). More so, the start of rains was observed to be about four times more variable for MAM (CV=22%) than it is for SOND season (CV=5%).

4.1.2: Probability of false start of rains, trends in onset dates and odds of late or early onset

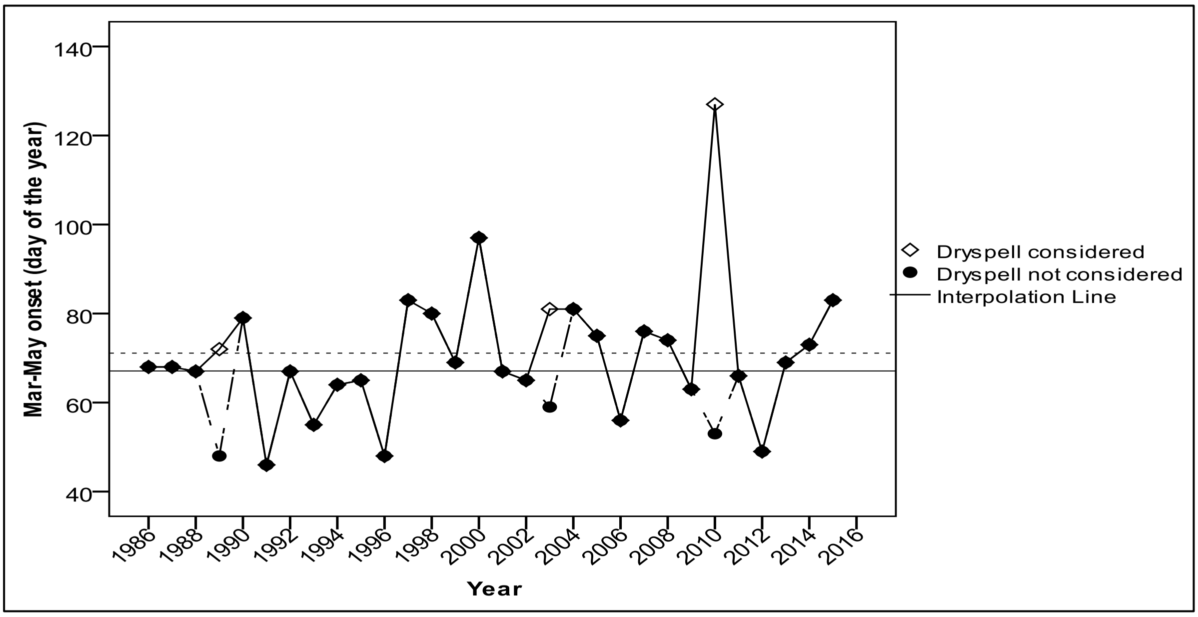

Figure 4.2: *Chance of false start of rains during MAM season for the period 1986-2015*

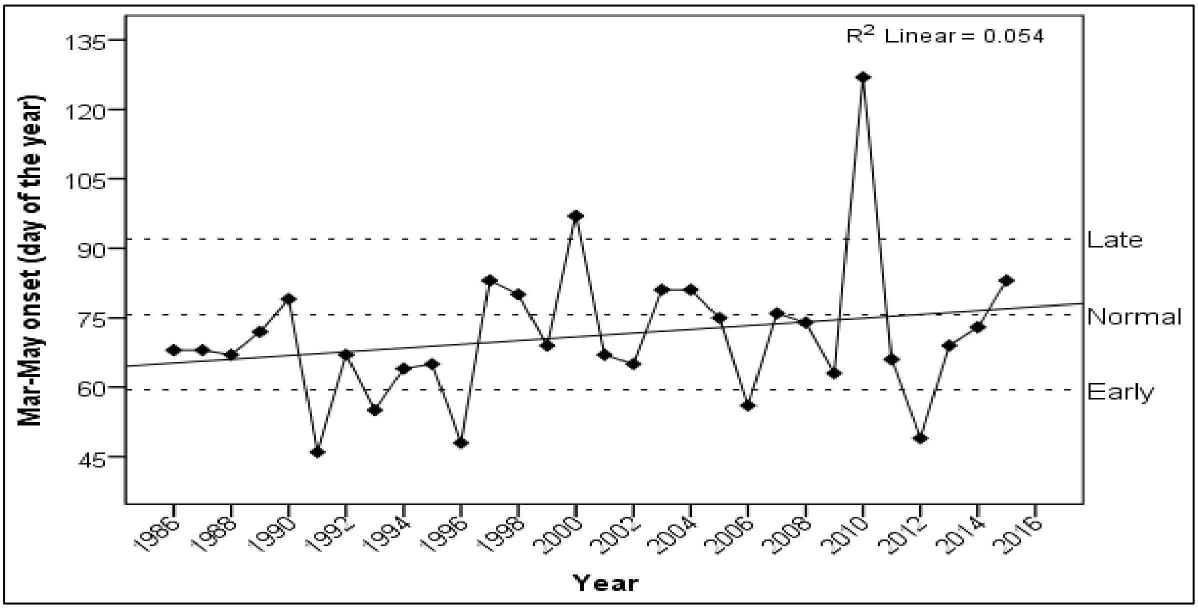

Figure 4.3: *Trend in onset of MAM season and chance of early/late start of rains for the period 1986-2015*

Findings reveal that for the March-May season, a false start of rains occurred once every 10 years for the study area and that when this happened, there was a slight delay in the actual start of rains (Figure 4.2).

Figure 4.3 shows a steady rise in rainfall onset dates for the MAM season over the period 1986-2015. This indicates that the trend is inclined to more rains starting late during this season. It was also noted that rains came earlier than expected once every six years, thus making this season highly unpredictable to farmers.

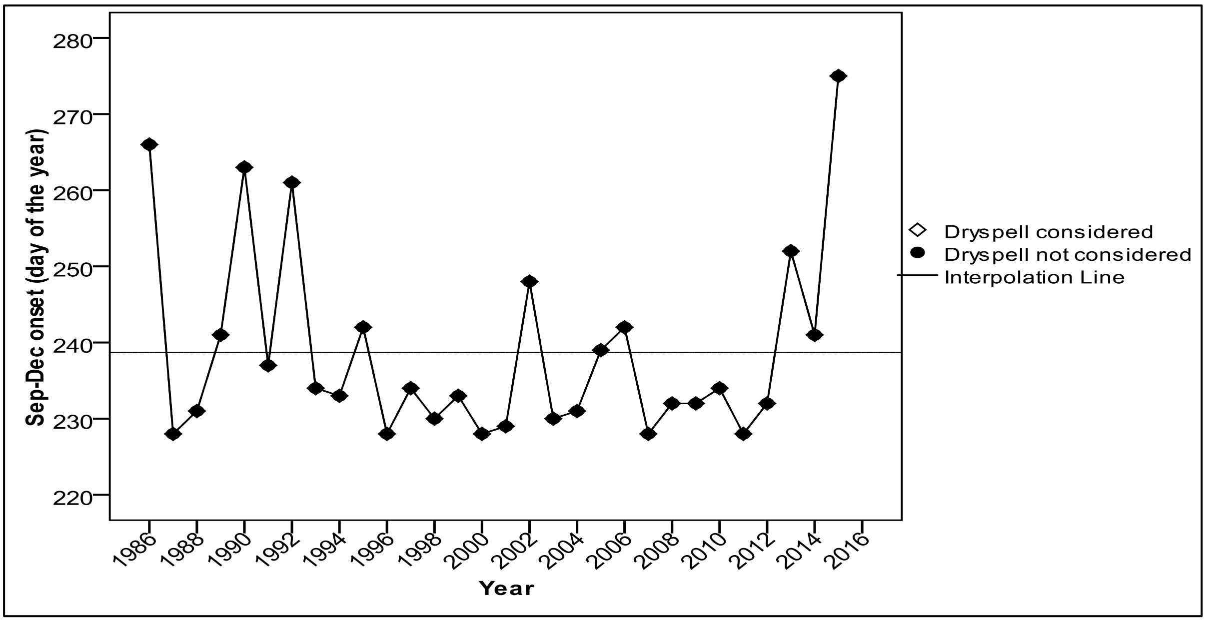

Figure 4.4: *Chance of false start of rains during SOND season for the period 1986-2015*

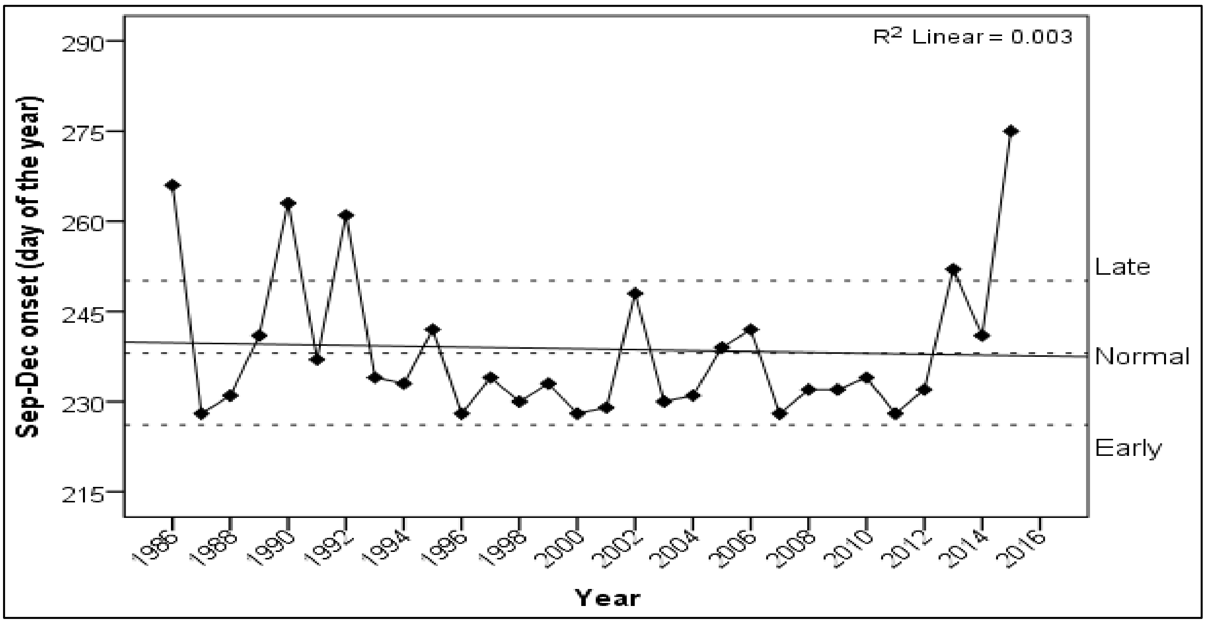

Figure 4.5: *Trend in onset of SOND season and chance of early/late start of rains for the period 1986-2015*

For the SOND season, there were no false starts observed in rainfall over the period 1986-2015 (Figure 4.4), an implication that in Nakaseke, this season produces a more reliable and stable crop growing window as compared to the first wet season.

Figure 4.5 shows an irregular/random pattern in rainfall onset times for the SOND season over the period 1986-2015. There were no occurrences of early starts of rainfall, but rather a 1 in 6 chance of a late start. The absence of a clear trend in onset dates for this season signifies no eminent shift in timeliness of rains. Nonetheless, onset remains unpredictable.

Table 4.3: Testing for monotonic trend on actual onset dates for MAM and SOND rainfall seasons (1986-2015)

	Mann-Kendall test for trend for upward or downward trend		
Season	**Number of years (*N*)**	**Kendall's coefficient (*τ*)**	**Significance (*p*)**
MAM	30	0.128	0.326
SOND	30	-0.033	0.802

From the results in Table 4.3, negative ($\tau < 0$) and positive ($\tau > 0$) trends were detected in onset dates for SOND (-0.033) and MAM rainfall (0.128) seasons respectively over the study period. However, these trends were not statistically significant ($p > 0.05$).

4.1.4 Comparison of seasonal rainfall onset patterns between long term data and recent decades

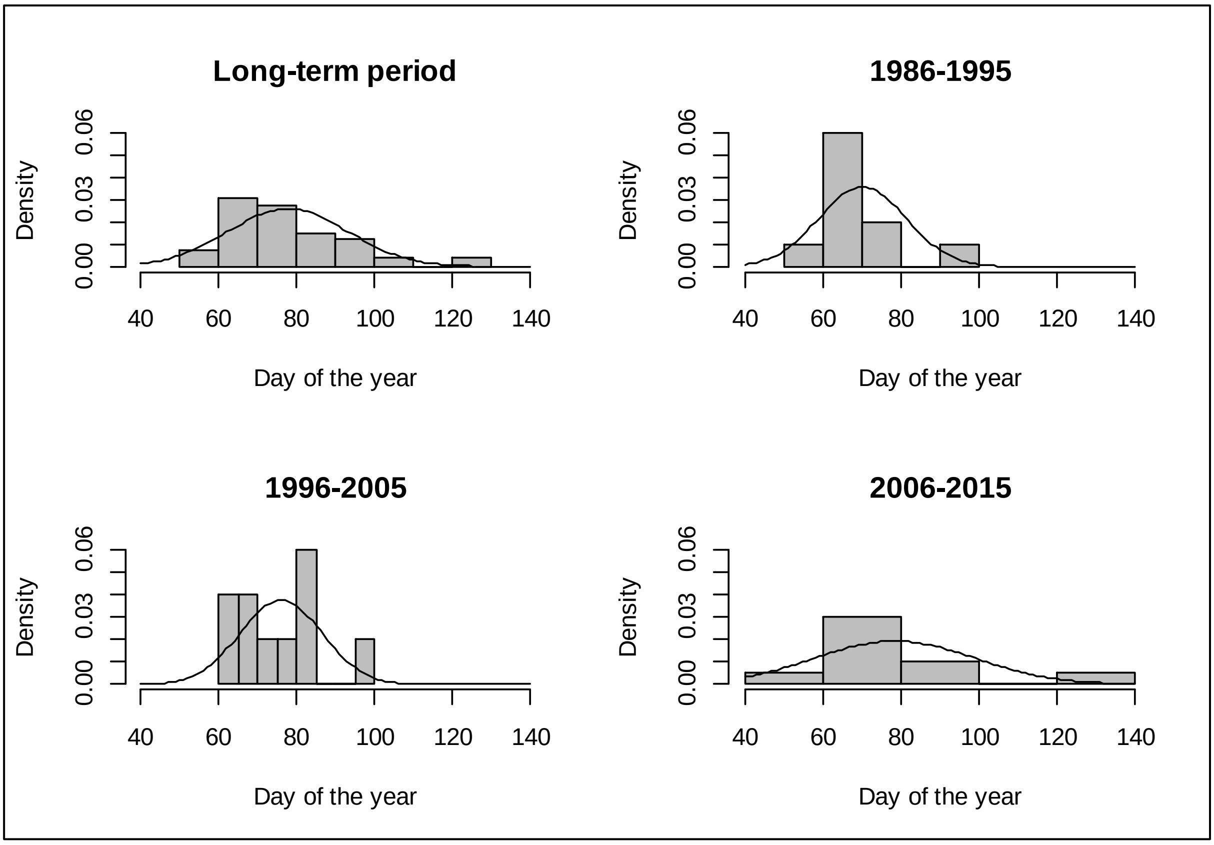

Figure 4.6: *Comparison of rainfall onset patterns for MAM season between long-term period (1961-2015) and recent decades*

Rainfall onset for the MAM season exhibited positively skewed pattern across all time periods, an indication that there were occasional delays in the start of the season. Over the long-term period, the start of rains ranged from the 60th to 120th day of the year. During the decades 1986-1995 and 1996-2005, the onset range shrunk by about 10 to 20 days with indication of a few extremes. However, onset in the subsequent decade (2006-2015) was observed to be highly variable as compared to the long-term period i.e. it ranged from the 40th to the 140th day of the year. This signified an increase in unpredictability of the start of rains for this season (Figure 4.6).

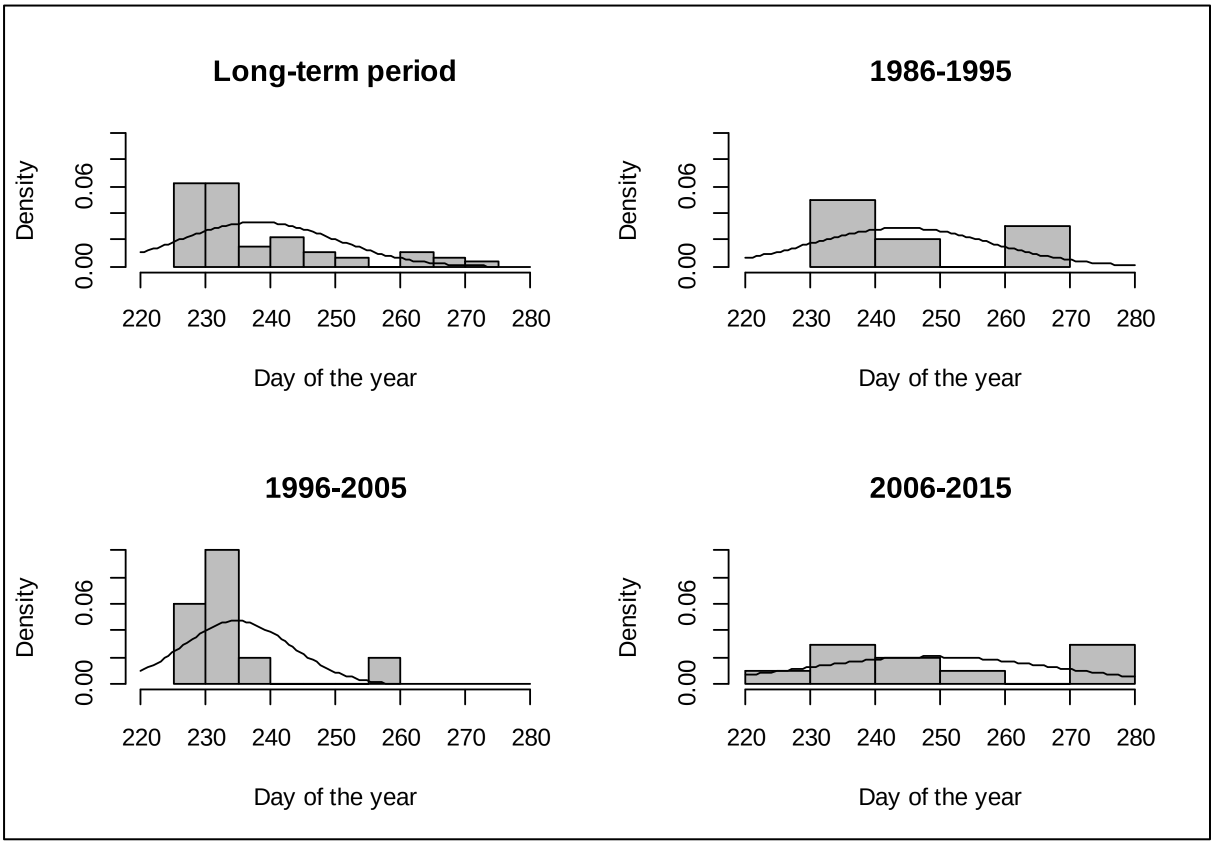

Figure 4.7: *Comparison of rainfall onset patterns for SOND season between long-term period (1961-2015) and recent decades*

Rainfall onset for the SOND season also revealed a positively skewed pattern across all time periods signifying a tendency for rains in this season to occasionally start late. For the long-term period, the start of rains ranged from the 230th to the 270th day of the year. Whereas onset during the decades 1986-1995 and 1996-2005 did not vary much from that of the long-term period, a greater dispersion was noted for the start of rains in the recent decade (2006-2015); i.e. it ranged from the 220th to the 280th day of the year (Figure 4.7).

4.2. Farmer perceptions and adaptation responses of changes in planting time

4.2.1 Demographic and farming characteristics of survey participants

Survey participants represented varied demographic characteristics. The highest proportion of respondent farmer households was headed by males (59.0%) and practiced subsistence farming (58.8%). Slightly more than half of the household heads had completed primary level of education (51.8%). On average, age of the housed head and farming experience of the households differed from each other by about 10.5 years and 12.6 years respectively. See tables 4.4 and 4.5 below.

Table 4.4: Frequency distribution of demographic and farming characteristics of households

Demographic / Farming characteristic		Count	Percent
Sex of household head	Female	152	41.0
	Male	219	59.0
	Total	371	100.0
Highest education level of household head	No formal education	66	17.8
	Primary	192	51.8
	Secondary	92	24.8
	Tertiary	21	5.7
	Total	371	100.0
Type of farming	Subsistence farming	218	58.8
	Commercial farming	151	40.7
	Other farming types	2	0.5
	Total	371	100.0

Table 4.5: Descriptive summary statistics of demographic / farming characteristics

Demographic / farming characteristic	N	Mean	Std. Dev.	Std. Error
Age of household head (years)	367	51.05	10.499	0.548
Number of years household has been in farming	366	27.14	12.622	0.660

N = number of observations, Std. Dev. = standard deviation and Std. Error = standard error.

4.2.2 Perceptions on changes in rainfall onset

Table 4.6 indicates that majority of the farmers in Nakaseke acknowledged that rainfall onset and amount had changed in the recent past (97.8%).

Table 4.6: Frequency distribution of perceptions about changes in rainfall onset

Rainfall related attribute		Count	Percent
Experiencing changes in rainfall onset	Yes	359	97.8
	No	8	2.2
	Total	367	100.0

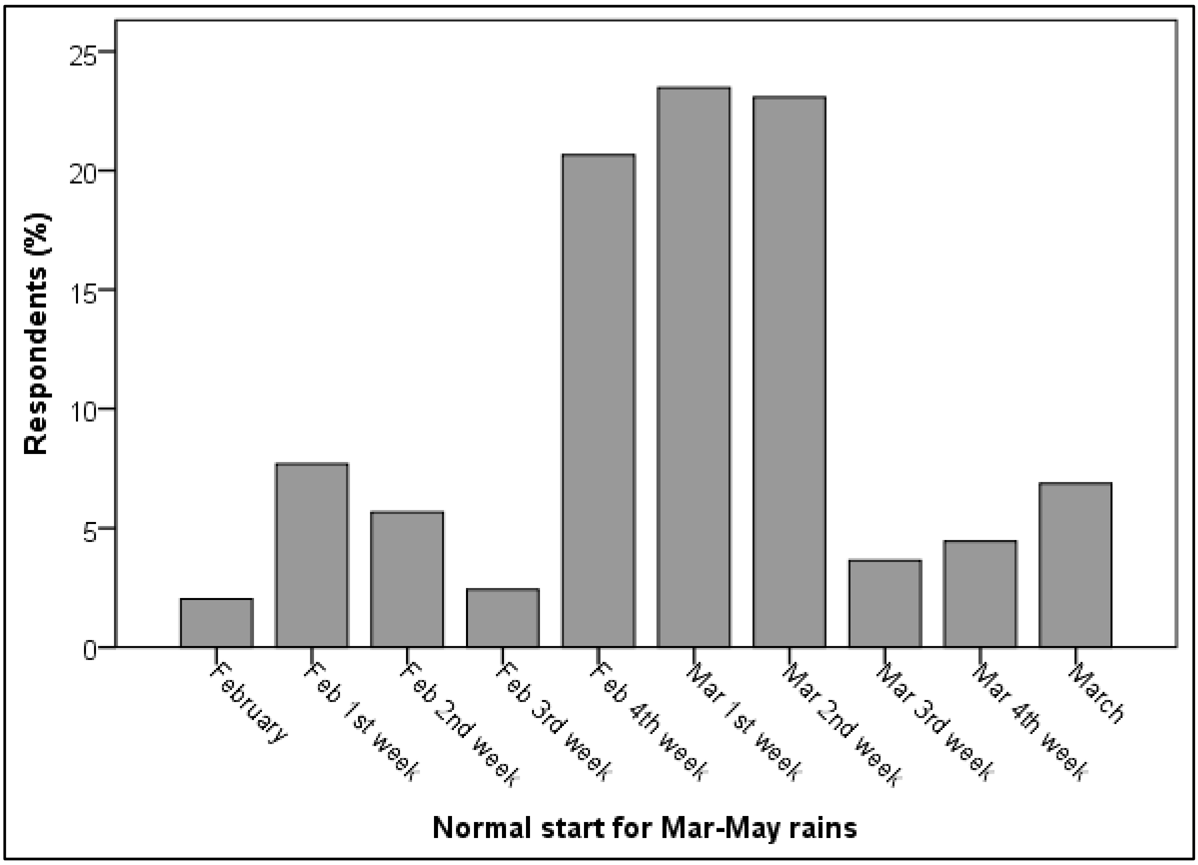

Figure 4.8: *Normal start of rains for March-May season*

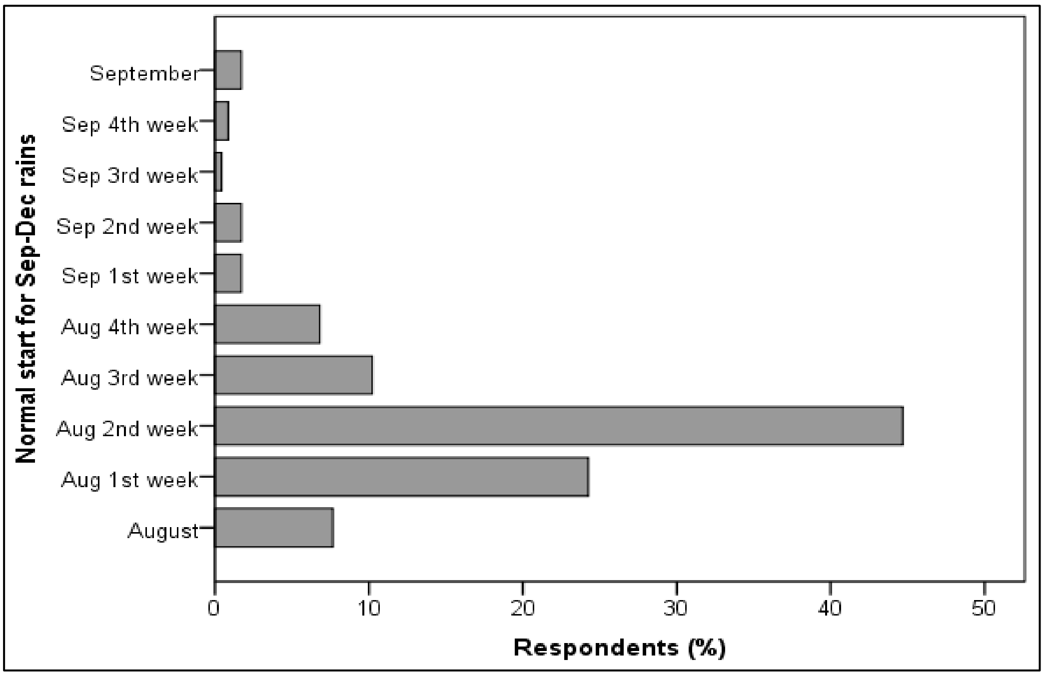

Figure 4.9: *Normal start of rains for September-December season*

For MAM season (Figure 4.8), the highest proportion of respondents reported the normal onset to be from the 4^{th} week of February to 2^{nd} week of March (67.2%). Similarly for SOND

(Figure 4.9), the normal start of rains was observed to be in the 1st two weeks of August by the highest fraction of respondents (69.0%).

Based on actual rainfall observations (long-term averages), the times reported for normal start of rainfall by farmers (Figures 4.8 & 4.9) were categorized into early, expected and late onset as shown in Figure 4.10 below.

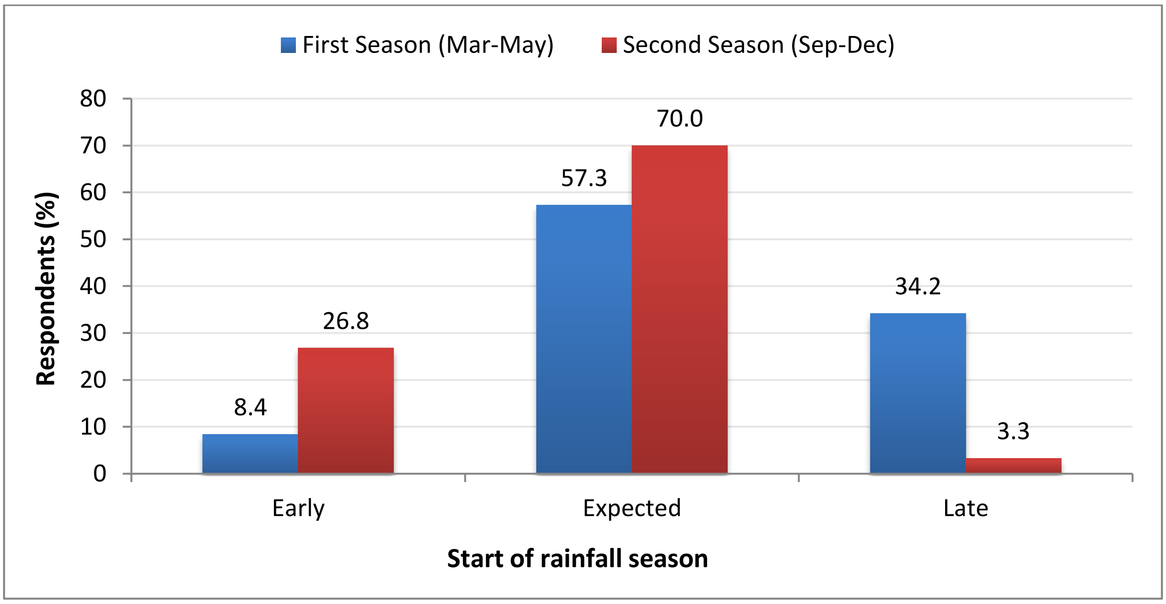

Figure 4.10: *Start of the first and second rainfall seasons as observed by farmers*

The highest proportion of respondent farmers observed that the start of rains was within the expected (regular) time range for both MAM (57.3%) and SOND (70%) seasons. However, 26.8% of respondents stated that rains in MAM season usually come early whereas only 3.3% acknowledged late start for the SOND season.

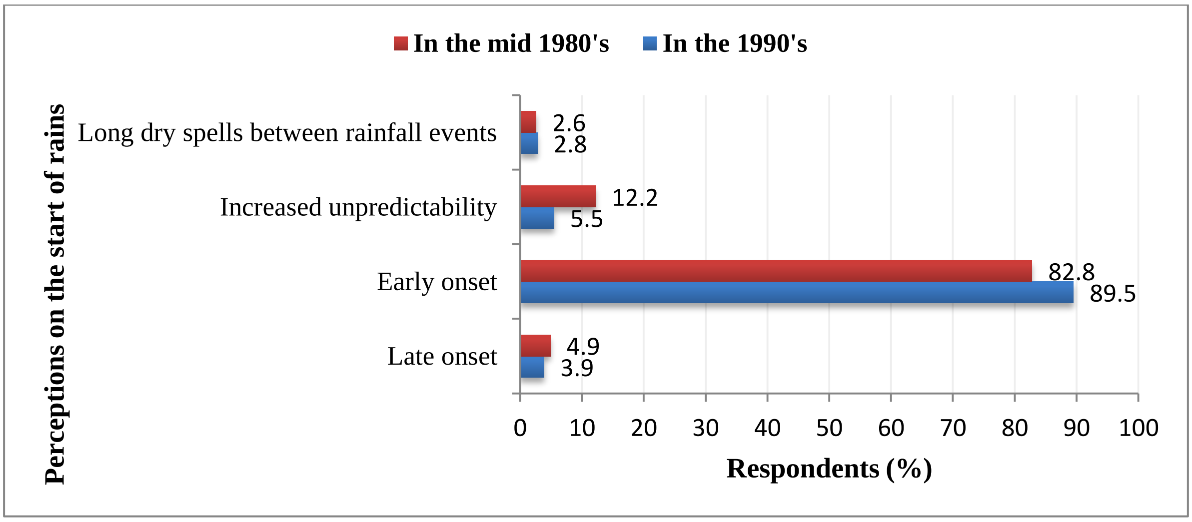

Figure 4.11: *Perceptions on the start of rains in the mid 80's and the 90's*

Findings in Figure 4.11 above, show that majority of the farmers in Nakaseke concur that rainfall during the mid-80's (82.8%) and in the 90's (89.5%) was characterized by early onset as compared to the most recent decade.

4.2.3 Association between changes in rainfall onset and rainy seasons

Results from bivariate analysis in Figure 4.12 above and Table 4.7 below indicate that there was a significant association between perceived changes in rainfall onset and the rain season ($p < 0.05$). Majority of the farmers acknowledged that the most prominent change in rainfall onset over the recent past was the delayed start of rainfall that was eminent across both wet seasons (>70%). This was followed by increased unpredictability of the start of rains and long dry spells after the first rainfall events.

Table 4.7: Relationship between changes in rainfall and cropping season

	Rainfall season *Number of responses (Percent of respondents)*		
Changes in onset characteristics	Mar-May	Sep-Dec	Both seasons
Rains come earlier than expected	8 (8.6)	11 (14.3)	34 (18.1)
Delayed start of rains	74 (79.6)	55 (71.4)	144 (76.6)
Increased unpredictability	36 (38.7)	39 (50.6)	78 (41.5)
Long dry spells between rainfall events	34 (36.6)	16 (20.8)	86 (45.7)
Other changes	6 (6.5)	2 (2.6)	13 (6.9)
Total responses	**158**	**123**	**355**
Number of respondents	*93*	*77*	*188*
Test for association: Pearson chi-square (df:38) = 108.756 p-value < 0.0001			

df =degrees of freedom

In Figure 4.12 immediately below, majority of the farmers usually prepared land before onset of rainfall (92.7%) and planted immediately after the first rains (84.9%) with only 12.1% practicing dry planting. This presents a high risk of crop failure as dry spells that occur after the first rainfall events are likely to bring about unsuccessful planting.

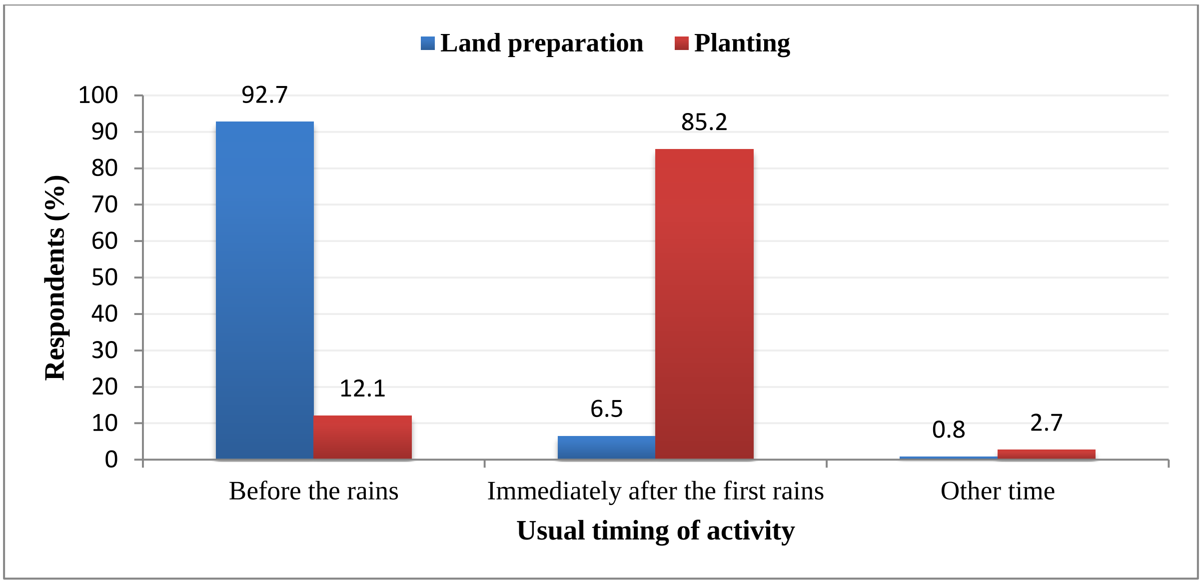

Figure 4.12: *Normal timing of land preparation and planting activities*

4.2.4 Perceived effects of changes in rainfall onset and adaptation options

Results from the chi-square test analysis (Figure 4.13) show that effects arising from changes in rainfall onset differed significantly by season ($p< 0.05$). According to farmers, reduced crop yields was the most prominent effect of onset changes observed across both planting seasons (>80.0%). This was followed by total crop loss that dominated the second season (77.2%) and irregular planting dates for both seasons (>50.0%)

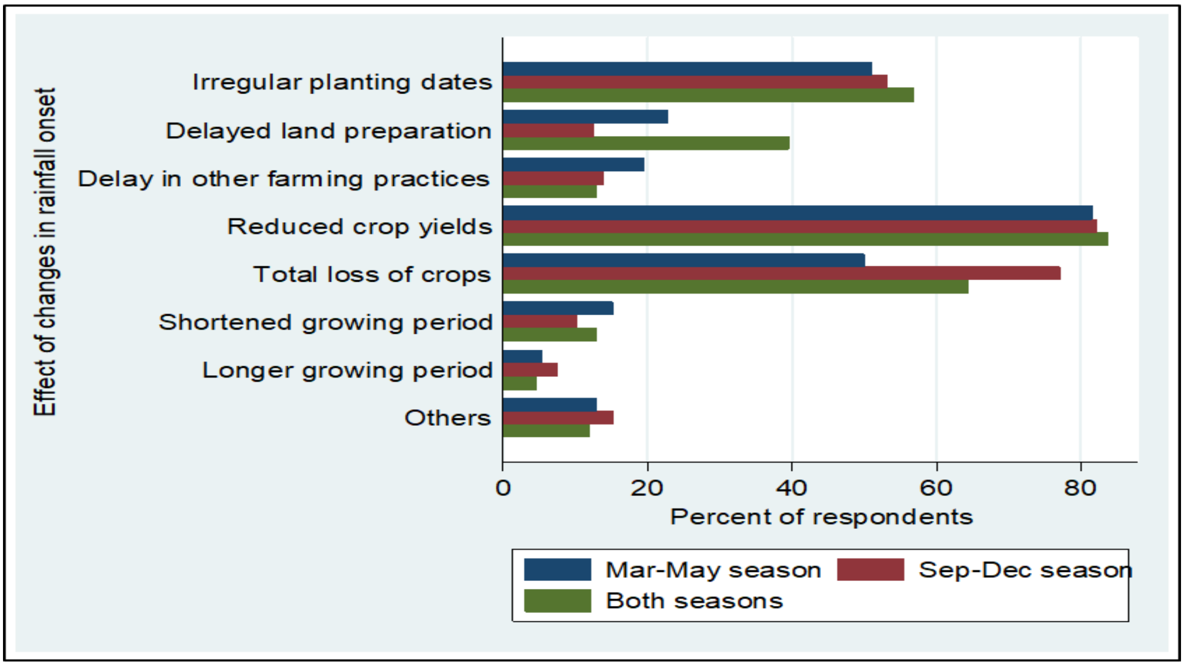

Figure 4.13: *Distribution of perceived effects of changes in rainfall onset by planting season (Pearson chi-square (124) = 188.873   p-value < 0.0001)*

Results in Table 4.8 show that the highest proportion of the farmers in Nakaseke adapted to reduced yields by practicing soil and water conservation (48.3%) and changing of crops (43.7%). For total crop loss experiences, slightly less than half of the farmers diversified livelihood from agricultural activities (49.7%) to off-farm enterprises while for irregular planting dates, about one in every three farmers planted according to the seasonal forecast (32.1%) or prepared land before rainfall onset (31.4%).

Other measures for reduced crop yields included: buying food, storage of produce, planting improved crop varieties such as early maturing and other agronomic practices like spraying with pesticides. Other measures for irregular planting dates included: planting after rains, replanting and dry planting. Other measures for total crop loss reported were planting hybrids and watering of crops.

Table 4.8: Percentage distribution of farmer adaptation options to effects of rainfall onset changes

	Effects of changes in onset ***Number of responses (Percent of cases)***						
Adaptation Measures	Irregular planting dates	Delayed land preparation	Delayed farming practices	Reduced crop yields	Total loss of crops	Shortened growing period	Longer growing periods
Plant according to the local crop calendar	45 (28.3)	5 (3.6)	1 (1.2)	13 (4.5)	3 (1.6)	3 (2.9)	1 (1.3)
Plant according to the seasonal forecast	51 (32.1)	5 (3.6)	0 (0.0)	6 (2.1)	3 (1.6)	2 (1.9)	0 (0.0)
Land preparation before onset	50 (31.4)	86 (61.4)	6 (7.1)	13 (4.5)	5 (2.6)	0 (0.0)	0 (0.0)
Plant local varieties	1 (0.6)	1 (0.7)	0 (0.0)	13 (4.5)	4 (2.1)	0 (0.0)	0 (0.0)
Plant early maturing varieties	7 (4.4)	2 (1.4)	17 (20.0)	63 (22.0)	13 (6.9)	36 (35.0)	5 (6.6)
Relay / stagger planting	3 (1.9)	2 (1.4)	4 (4.7)	73 (25.5)	56 (29.6)	3 (2.9)	0 (0.0)
Plant longer maturing crops	0 (0.0)	0 (0.0)	2 (2.4)	14 (4.9)	7 (3.7)	1 (1.0)	17 (22.4)
Changing crops	6 (3.8)	1 (0.7)	2 (2.4)	125 (43.7)	35 (18.5)	6 (5.8%)	1 (1.3)

Table 4.8 continued

Adaptation Measures	Effects of changes in onset *Number of responses (Percent of cases)*						
	Irregular planting dates	Delayed land preparation	Delayed farming practices	Reduced crop yields	Total loss of crops	Shortened growing period	Longer growing periods
Soil and water conservation practices	7 (4.4)	5 (3.6)	2 (2.4)	138 (48.3)	20 (10.6)	59 (57.3)	51 (67.1)
Small scale irrigation	5 (3.1)	1 (0.7)	2 (2.4)	60 (21.0)	19 (10.1)	6 (5.8)	0 (0.0)
Livelihood diversification from agricultural activities	10 (6.3)	39 (27.9)	49 (57.6)	41 (14.3)	94 (49.7)	1 (1.0%)	2 (2.6%)
Other measure	11 (6.9)	1 (0.7)	1 (1.2)	21 (7.3)	5 (2.6)	2 (1.9)	1 (1.3)
Total responses	**196 (100)**	**148 (100)**	**86 (100)**	**580 (100)**	**264 (100)**	**119 (100)**	**78 (100)**

4.2.5. Planning for the rainfall season and information needed

Darkening of clouds and increased night temperatures were the most selected indicators (>10.0%) for the start of the planting season (Table 4.9)

Table 4.9: What guides planting decisions among crop farmers

How do you know it is time to plant?	Count	Percent of Responses
2 to 3 days after it rains	5	1.2
After 1 rainfall event	28	6.9
After 2 rainfall events	8	2.0
After 3 rainfall events	8	2.0
After the start of rains	28	6.9
After land preparation	11	2.7
After steady rains	4	1.0
Birds and frogs make noise	32	7.9
Change in weather	10	2.5

Table 4.9 continued

How do you know it is time to plant?	**Count**	**Percent of Responses**
Increased cloud cover and movement	8	2.0
Changes in wind direction (east to west)	22	5.4
Darkening of clouds	58	14.3
Depends on the month/season	31	7.6
Fellow farmer's forecast	3	0.7
Flowering of plants	6	1.5
Follow the local cropping calendar	31	7.6
Follow the weather forecast	1	0.2
Increased temperatures especially at night	46	11.3
Moon appearance / darkening	22	5.4
Shedding of tree leaves	15	3.7
Increased soil moisture	13	3.2
Termites	2	0.5
Thunderstorms	14	3.4
Total	406	100.0

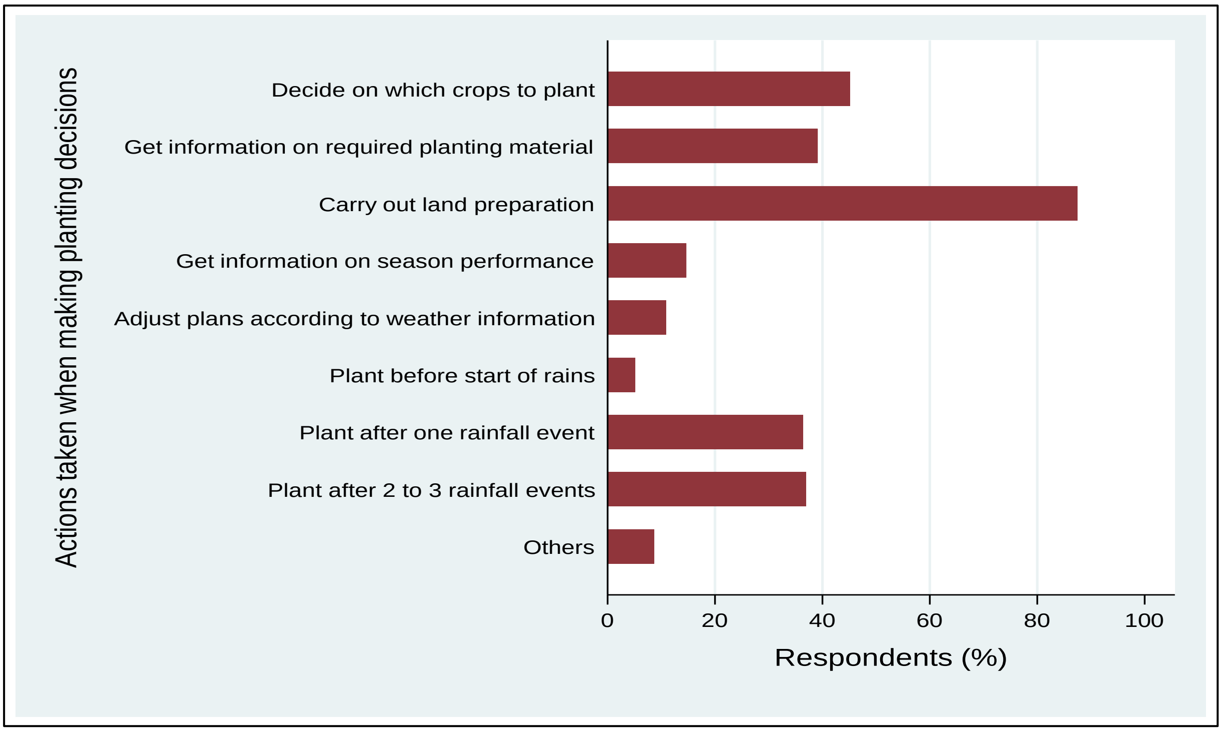

Figure 4.14: *Actions taken when planning for the planting season (existing decision making cycle)*

Majority of the farmers indicated that land preparation came on top while planning for the planting season (87%). This was followed by identifying the appropriate crops to plant (45%) and obtaining information on the required amount of planting material e.g. seed, fertilizer and where to acquire it (39%). Other actions taken when making planting decisions included: acquiring land, slashing and spraying (Fig. 4.14).

Results from the chi-square test for association in Table 4.10 below showed a significant relationship between the nature of information needed to guide the decision to plant and highest education level attained by household head ($p < 0.05$). Majority of the illiterate farmers recquired indigenous knowlegde on expected rainfall onset in order to decide when to plant (92%) as compared to only 14% that deemed scientific/forecast information on weather and climate important.

Table 4.10: Comparing kind of information used in making planting decisions by education level attained by household head

Information needed for making planting decisions	**Highest level of education in household** ***Number of responses (column percent of cases)***				
	No formal education	Primary	Secondary	Tertiary	Total
Indigenous knowledge on expected start of rains	60 (92.3)	166 (87.8)	77 (86.5)	13 (65.0)	316 (87.0)
Scientific weather & climate information	9 (13.9)	57 (30.2)	26 (29.2)	8 (40.0)	100 (27.6)
Crop and inputs information	19 (29.2)	31 (16.4)	15 (16.9)	6 (30.0)	71 (19.6)
Total	88 (135.4)	254 (134.4)	118 (132.6)	27 (135.0)	487 (134.2)
Number of farmers	**65**	**189**	**89**	**20**	**363**
Test for independence: Pearson chi-square (df:18) = 29.648 P-value = 0.041					

df = degrees of freedom

Findings in Figure 4.15 immediately below indicate that the kind of information used to make planting decisions was significantly associated with sex of the household head ($p < 0.05$). One in every four (25%) of the male headed farming households obtained their information from agricultural extension workers as compared to only 12% of the female headed ones. Similarly, about half of the male headed farming households (50%) accessed information via the radio compared to only one in every three (34%) for female headed ones. Generally, the most preferred source of information among the farmers was indigenous knowledge (>70%) followed by fellow farmers (>50%). Other ways of obtaining information listed by farmers included: Local market, phone messages, NARO and newspapers

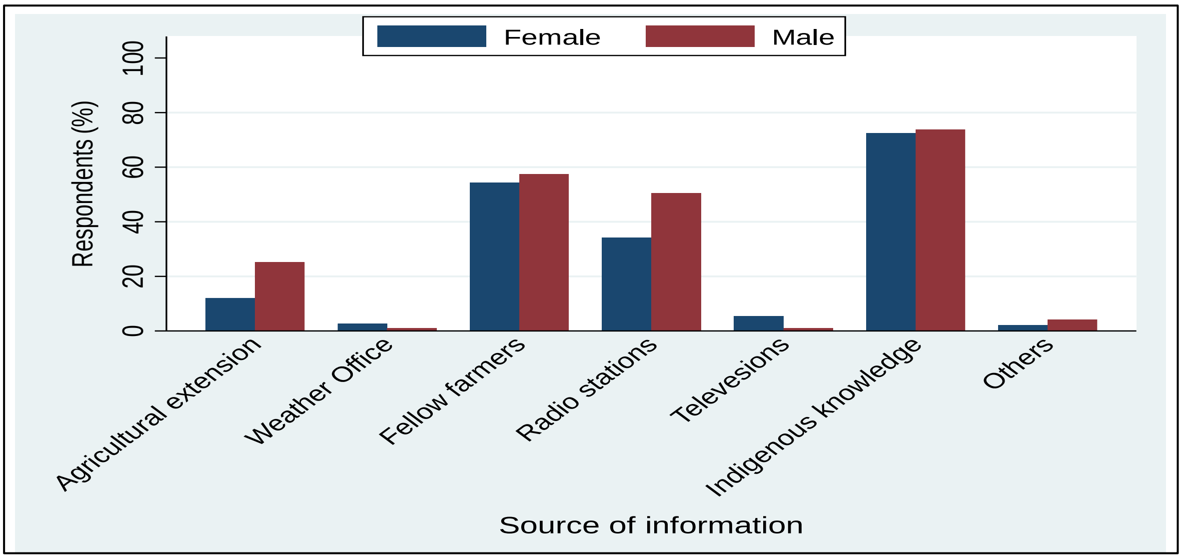

Figure 4.15: *Where and how the information to decide on planting is obtained*

Pearson chi-square (30) = 47.065   p-value = 0.025)

Results in Table 4.11 below, show that 49% of the farmers used the information in Figure 4.15 above to carry out soil and water conservation practices on their farmyards. Farmers also mentioned other ways in which information was used to make planting decisions namely; deciding which crop to plant, early planting, and determining market prices.

Table 4.11: Ways in which information obtained by farmers is used to adapt/cope to expected changes in onset

Ways how information is used	***Number of responses (Percent of cases)***
Plant according to the local crop calendar	123 (35.8%)
Plant according to the seasonal forecast	80 (23.3%)
Land preparation before onset	146 (42.4%)
Plant local varieties	0 (0.0%)
Plant early maturing varieties	84 (24.4%)
Relay / stagger planting	29 (8.4%)
Planting longer maturing crops	44 (12.8%)
Changing crop cycles	86 (25.0%)
Soil and water conservation practices	168 (48.8%)
Small scale irrigation	48 (14.0%)
Livelihood diversification from agricultural activities	59 (17.2%)
Others	26 (7.6%)
Total responses	**893 (259.6%)**

4.2.6 Findings from Focus Group Discussions

Information from focus group discussions was translated into adaptation action planning and decision making, specifically, recommendations in the tool.

4.2.6.1 Current planting decision making options

During the household survey, farmers had been asked about the actions they took when planning for the season (Figure 4.14). These actions were also evaluated in the focus groups. From the discussions, it was seen that farmers had good traditional understanding of weather and climate of their communities and acknowledged that variability in onset was increasing. Despite the increasing variability, farmers still depended on their traditional understanding to make seasonal cropping decisions (Figure 4.16) and also use cropping guidelines based on past experiences and perceptions. For MAM season land clearing was usually done in the month of February. Planting then starts in 1^{st} week of March (early planting) and goes on up to April (which can be considered late planting). For SOND season, they start planting from the 2^{nd} week of August up to 15^{th} October and any planting after that can be considered late planting and there is always a high risk of crop failure. Some farmers who prepare land earlier practice dry seeding. Maize seeds can stay in the soil and when it rains, they will germinate. Decisions for the next seasons are always determined by what happens in the current season. Most farmers perceive that if the current season is bad, they expect the following season to be good. Some of the identified reasons for late planting included; Farmers having multiple cropping; Less land where they have to first wait for farmers with a lot of land to first plant and see if they remain with some land for renting out**;** False starts and short rains that lead to germination failure**;** Relay cropping for food security and acute labour shortage during planting season.

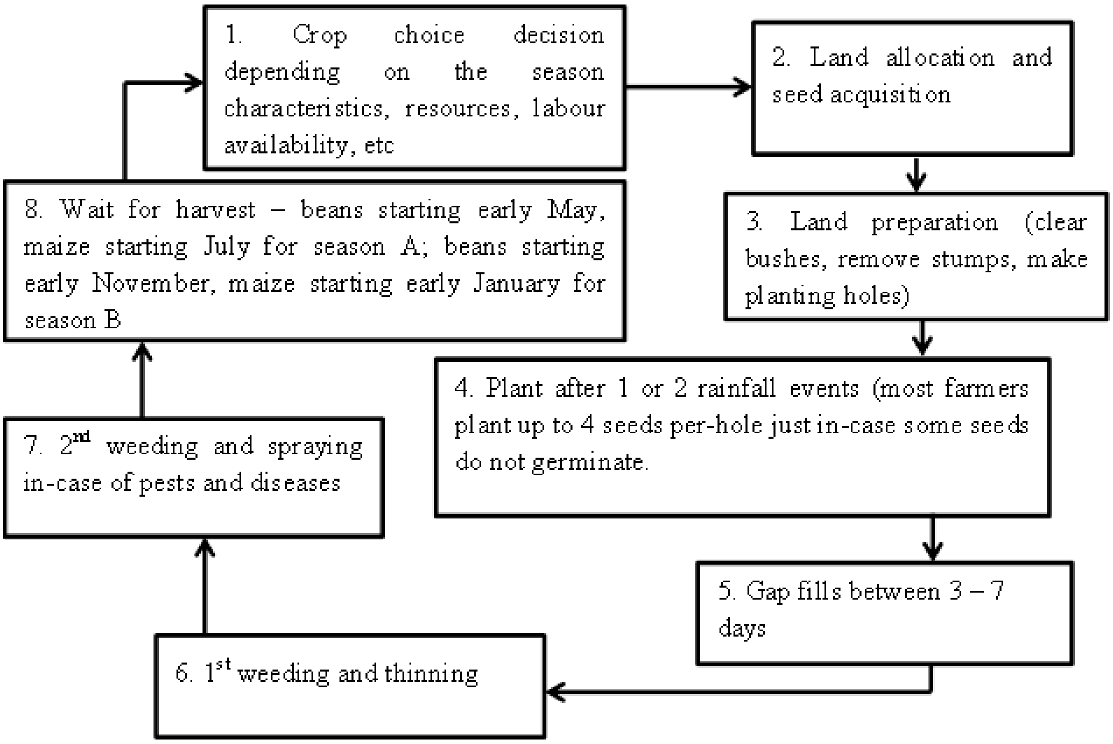

Figure 4.16: *Current seasonal planting decision making cycle*

4.2.6.2 Perception on yield

The common or preferred maize varieties were *Longe 5,* (open pollinated improved variety), *Longe 7H, Longe 10H* (hybrids) and indigenous varieties. Yields in a good season for both MAM and SOND seasons were quantified at 1400 kilograms per acre (kg/acre) and above as a good yield. A good season was considered to be one where there was Normal or Above Normal rains, planting was done early and recommended agronomic practices were used such as regular weeding, early harvesting, good drying and storage and pest control were used. In usual conditions, yield was between 1000 to 1400 kg/acre. Anything below 1000 kg/acre was considered to be a poor yield. Respondents also noted that yield depends on the location and characteristics of planted land.

………"If the land has many anthills and tree stumps, you cannot get the same yield as clear land. Average yields would go as low as 360 kg/acre in a season with below normal rains, late onset or poor distribution"……

The common or preferred bean varieties were identified as NABE 16 (improved variety) locally known as "*Nambaale short"* because of expected higher yields. A good yield in a good season was quantified at 1400 kg/acre and above. Normal yield was quantified to be between 500 and 1000 kg/acre. Anything below 500 kg/acre was considered a poor yield.

Table 4.12: Summary of yield value classification

Crop	**Good yield (kg/acre)**	**Normal yield (kg/acre)**	**Poor yield (kg/acre)**
Maize	1400 and above	1000 - 1400	Below 1000
Beans	1000 and above	500 - 1000	Below 500

4.3 Tool for optimizing planting time decision making

The proceeding subsections detail the development of the Planting Decision Tool (PDT)

4.3.1 Model flowchart for the development of the PDT

Information from farmer perceptions on changes in planting time and historical climate data were logically and systematically arranged to derive a planting decision tool. The existing planting decision making options in Figures 4.14 and 4.16 and analysis of rainfall data were optimized into a framework that guided the development of the planting decision tool. (Figure 4.17)

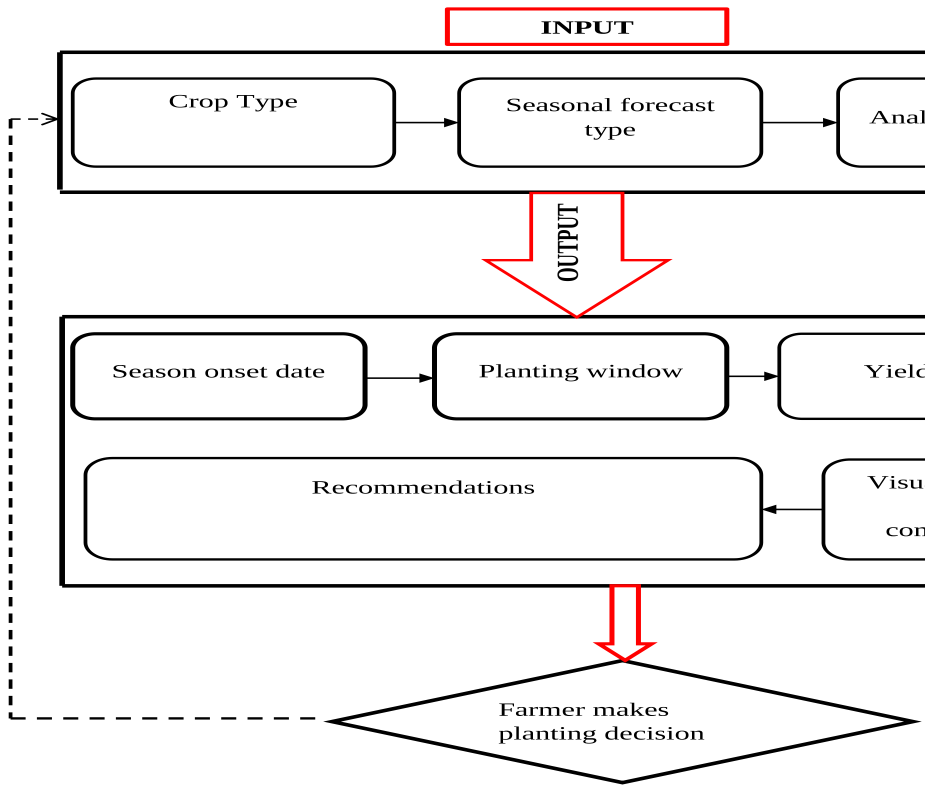

Figure 4.17: *Model flowchart showing an optimized planting decision making process*

4.3.2 The Planting Decision Tool

A Planting Decision Tool (PDT) was developed following criteria set out in the methodology.

The PDT has a simple and basic user interface with drop down menus that require prior information on the crop type, seasonal forecast type, and season and analogue year. This information can be obtained from the nearest UNMA representatives or agricultural extension staff and agents. The tool lets the user choose the crop type (maize or beans), the season type (Normal, Above Normal or Below Normal), rainfall season (MAM or SOND) and the most suitable analogue year for the season being forecasted. The tool then returns results on the calculated onset date for the analogue year and the planting window in which that date falls. It will also calculate the expected yield for that season and provide recommendations for each yield value classification based on farmer experiences and generally acceptable agronomic practices for the selected crops. The tool also visualizes the yield comparisons of the local and improved varieties and this can inform the user on which variety they can decide to use. Based on these, the farmer can then make the final decision on planting *(*Figure 4.18*).* The tool is currently hosted on a free domain and can be accessed on http://cagaba.000webhostapp.com/

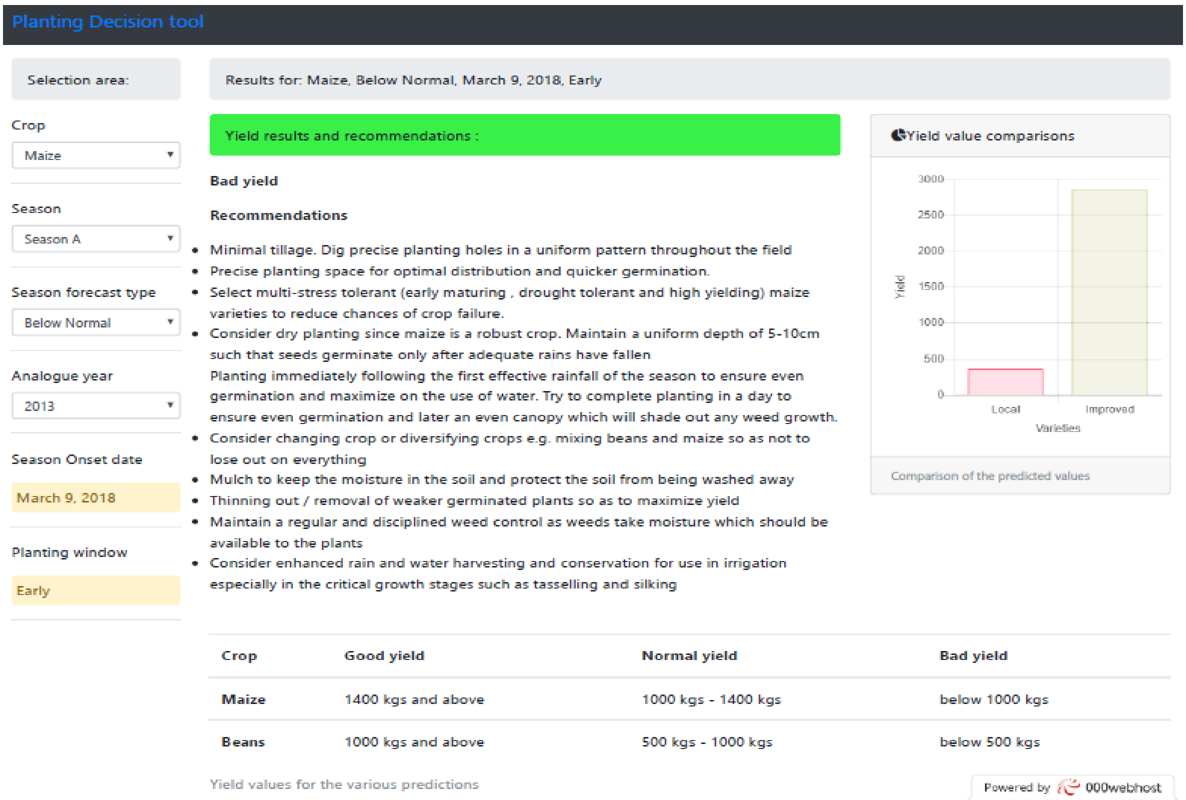

Figure 4.18: *Screen shot showing the Planting Decision Tool user interface*

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

5.1 Historical trends and patterns of variability in rainfall onset

From analysis of long term rainfall data, the study shows that the resulting onset (and thus onset windows) of Nakaseke was more variable for MAM than SOND. The onset of MAM is highly unpredictable thus making it more difficult for farmers to determine when to plant their crops. This therefore makes the MAM season less suitable for planting longer-maturing crops such as cereals (Dodd & Jolliffe, 2001; Waongo, 2015). This result corroborates with findings by Breytenbach (2013), Komutunga (2005), Mubiru et al. (2012), Nimusiima et al. (2013) and Osbahr et al. (2011) who observed MAM rainfall patterns to be more variable than SOND in Nakaseke and other parts of Uganda.

The study reveals false start of rains to have occurred once every 10 years for the MAM season over the period 1986-2015, and that when this happened, there was a slight delay in the start of rains. The false rainfall starts can be misleading to farmers who tend to plant upon receiving first rains and thus risk poor or no germination of crops. No false starts were observed for the SOND season, implying that this season has had a more reliable and stable crop growing window as compared to MAM season. Osbahr *et al.* (2011) had a similar result, with the risk of a dry spell exceeding seven days during the 30 days after first planting to be much less for the SOND season at 13% (or one year in eight) than for the first season at 35%.

There were no substantial changes in occurrences of early/late onset during the MAM season over the period 1986-2015, nonetheless the season remains highly variable. There was a slight tendency for the rains to start late during this season and rains came earlier than expected once every six years. For the SOND season, there were no occurrences of early onset of rains. These results imply that the start of rains for SOND has been relatively more stable over time compared to that of MAM, thus giving more reliable planting dates. In their study in Nakaseke and Nakasongola districts, Nimusiima *et al*., (2013) reported that early rainfall onset especially in the second season prolongs the length of the growing season and recommended farmers to take advantage of planting most crops when an early onset is predicted for the second season.

The lack of statistically significant trends as seen in Table 4.3 shows no evidence of a shift in the start of seasonal rains over the area. However, limited moisture during the critical stage of germination, though not significant, can affect crop canopy establishment or no germination at all leading to eventual lead to crop failure (Limantol et al. 2016). Studies by Ngongondo et al. (2014); Msongaleli et al. (2017); Mugalavai et al. (2008); Mupangwa, Walker, & Twomlow (2011); and Yengoh et al. (2010) revealed non-significant trends in shift of rainfall onset for seasons in semi-arid Tanzania, Kenya, Zimbabwe, Malawi and Ghana respectively

A comparison of rainfall onset patterns between the long-term period and the past three decades indicated the onset of rains for both MAM (Fig. 4.6) and SOND (Fig. 4.7) seasons to have become more erratic in recent times. Still, MAM season had a much more varying onset as compared to the SOND season across the entire study period. For the first time, this study also found out onset of rains to be more erratic in the recent decade than previous decades evidenced by the high dispersion in onset between 2006 and 2015. The finding is in agreement with farmers' perceptions of increased unpredictability of rainfall onset in Nakaseke in recent decades. Majority of the farmers concurred that rainfall during the mid-1980's and in the 1990's was characterized by early onset as compared to increased delayed onset in the most recent decade.

5.2 Farmer perceptions and adaptation responses of changes in planting time

The majority of farmers perceived the region to receive inadequate rainfall and rainfall onset to have changed in the recent years. Majority respondents also perceived rainy seasons to be more variable than they were in the past (10 or more years ago). The most agreement existed regarding variability associated with the MAM season, and a perceived decrease in the length of the MAM season. Respondents had a better recollection of weather patterns of the recent past, than weather patterns from long ago. Majority also indicated that the normal start of rains was within the regular time range for both seasons. This is in agreement with the empirical climatic data findings of non-significant trends in onset variability for both seasons. Farmers also acknowledged that rains in MAM normally come late compared to SOND which further agrees with climatic data analysis findings that SOND rainfall onset had been more stable and predictable over time. This is a common finding from studies on perceptions and experiences on climate change in Uganda where farmers perceive increased variability of rainfall, shifts in the growing seasons and extreme unpredictability (Breytenbach 2013; Kansiime *et al*., 2013; Nimusiima *et al*., 2013; Orlove *et al*., 2010; Osbahr *et al*., 2011).

Other studies on farmers' perception in other semi-arid regions such as in Kenya (Huho *et al*., 2012), Nile basin of Ethiopia (Deressa *et al*., 2009), Malawi (Coulibaly *et al*., 2015) and Sahel (Mertz *et al*., 2009), also reveal similar findings.

The majority of farmers usually prepared land before onset of rainfall and planted immediately after the first rains. This may however present a high risk of crop failure in case there are dry spells between the rainfall events which are likely to bring about unsuccessful planting dates. Seasonal planning is rather cyclical and farmers have always followed the same planting calendar despite the variability in onset. They always start with land preparation, identify the type of crop to plant and get required information on planting materials especially from fellow farmers and then plant immediately after one to three rain events. Hella, Vah Huylenbroeck, Haese, & Mlambiti (2000) also found a similar pattern of sequential decision making at the beginning and during the crop growing season in Tanzania. In their study, they found out that at the beginning of each growing season farmers had subjective expectations developed from the past experience concerning the probable onset of rains and they sequentially adjusted their cropping patterns and cultivation practices as the season progressed. They reported a number of decisions made as risk management strategies depending on the production cycle; time and methods of land preparation, planting time, decision on plant population, and variety.

The effects arising from changes in rainfall onset differed significantly by season. Reduced crop yields, irregular planting dates and total crop loss were identified as key effects in both MAM and SOND seasons. Farmers responded to these effects by practicing soil and water conservation and/or changing crop cycles. This is similar to findings by Limantol *et al*. (2016) where majority of farmers in semi-arid Ghana (97%) perceived that they were extremely vulnerable to changes of onset of planting season. The study further assessed the outlined conditions to have had the potential to affect the growth of the crops, their maturity and consequently could lead to reduced yields and food insecurity. In the same study, it is indicated that farmers adapted to rainfall shifts through crop diversification. Yamauchi *et al*. (2012), also reported farmers' making of sequential decisions; adjusting planting timing in response to delays in the onset of rainy season. The results also corroborate a study by Mary & Majule (2009) in semi-arid Tanzania, that was undertaken to understand local communities' perceptions on climate and variability issues and establish its impacts and adaptation strategies within the agricultural sector. They identified a combination of strategies to adapt, such as proper timing of agricultural operations, crop diversification, use of different crop varieties and changing planting dates. Therefore, the wealth of knowledge and experience on coping and adaptation that farmers have, should be integral in designing sustainable agricultural innovation systems to deal with impacts of climate change and variability.

Results revealed a significant relationship between the natures of information needed and used to make planting decisions with the sex and highest education level of the household head. Male headed households obtain information from extension workers more easily than female headed ones. Women access to information and extension services is still very low and this could be attributed to the stereotyped defined gender roles in Sub-Saharan Africa and other developing countries as documented by Mbo'o-Tchouawou & Colverson, (2014). Farmers with greater access to weather information are more likely to make better informed decisions to respond to onset variability such as changes in their farming practice (Wood, Jina, Jain, Kristjanson, & DeFries, 2014), leaving the less educated and female headed households more vulnerable to the effects of rainfall onset variability.

Indigenous knowledge was shown to be important in determining whether the rainfall season had started and farmers with low or no education mainly refer to this to make planting decisions. Similarly, Nimusiima *et al.* (2013), found darkening of clouds and increased cloud cover to be the main indicator used by the communities in Nakaseke and Nakasongola for predicting the onset of rainy season. The reason why farmers are still dependent on the traditional forecasting system could be attributed to the findings by Jiri *et al.,* (2016) who show that farmers have a natural inclination towards indigenous forecasts as opposed to scientific forecasts as they value their experiences over the years. Wood *et al.,* (2014) also suggests that communities may have already become accustomed to highly variable weather, in which case weather forecasts may not provide actionable information to farmers. Moreover, there is limited availability of and access to accurate and precise weather information tailored for agricultural practice as noted by Singh *et al.,* (2017). From the results, it can also be seen that there is demand for seasonal climate forecasts to support farmers in decision making, reflected by 32% of farmers adapting to irregular planting dates by planting according to the seasonal forecast. This amplifies findings by Jiri *et al.,* (2016) who showed that farmers tend to use a combination of meteorological information and indigenous knowledge in their seasonal forecasting. They primarily rely on indigenous knowledge but are also open to receiving scientific forecasts.

Forecasting the timing of the onset of the rains and distribution has implications for local knowledge. Farmers are anxious to know when rains are going to start because they are unsure if one or two rainfall events means that the rainy season has started and that they need to plant as early as possible. Bert *et al*., (2006) and Laux *et al.*, (2008) show that farmers have evolved conservative cropping strategies to cope with rainfall variability depending on site conditions because they usually did not know what weather conditions to expect in the following growing season. Adger *et al*. (2007), Morton *et al*. (2015) and Thomas *et al*. (2007) further show that individuals and communities have coped with and adapted to climate variability for centuries based on personal experiences and perceptions. These include planting at onset of rains (Okonya *et al*., 2013), changing planting dates, as well as changing the choice of crops (Abid *et al*., 2015).

5.3 Tool for optimizing planting time decision making

The PDT tool provides yield averages and recommendations based on the planting scenarios and seasonal characteristics information used by the user. This guides the user to make the most suitable decision regarding planting. It has a basic user interface and can freely be accessed by anyone with a computer or smart phone with stable internet connection at http://cagaba.000webhostapp.com/

The dependence of the PDT on the analogue year and seasonal rainfall forecast implies that its performance is dependent on the accuracy of the seasonal rainfall forecast provided by UNMA. The determination of the correct analogue year, suitable for the expected spatial and temporal characteristics of rainfall is still a significant challenge. The weather world 2010 project (WW2010) find the analogue method difficult to use because it is virtually impossible to find a perfect analog. Various weather features rarely align themselves in the same locations they were in the previous time. Even small differences between the current time and the analog can lead to very different results. However, as more weather data is archived, the chances of finding a "good match" analogue for the current weather situation should improve, and so should analogue forecasts (http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/fcst/mth/oth.rxml).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

This study has drawn upon both qualitative and quantitative approaches to assess rainfall onset variability based on farmers' perception of onset variability and historical meteorological data to derive a Planting Decision Tool (PDT) to guide farmers in making informed planting decisions. Primarily, the study established the evidence of rainfall onset variability in the study area through analysis of meteorological data, over the past 55 years. The study further obtained farmers' perceptions of recent variability/change in the onset of rainfall. Scientific knowledge systems from meteorological data analysis were used in conjunction with farmers' perception of rainfall onset variability and effective adaptation methods and local knowledge to develop the PDT.

From the analysis, MAM season rainfall onset was found to be highly variable making it difficult for farmers to make planting decisions. SOND season rainfall onset is not as variable as MAM making this season to have a reliable onset and this makes it easy for farmers to make planting decisions.

Although the trend is not significant, data shows slightly increased delay of rains for MAM, whereas onset for SOND season is steadily normal. False rainfall onsets have been occurring once in every 10 years for the MAM season, whereas SOND recorded no false onsets.

For the first time the analysis has quantified the delay in onset dates in the last 3 decades (in comparison with the long term means), and shows that in the recent decade (2006 – 2015) start of rains have been more erratic than previous decades as evidenced by the high dispersion in onset between 2006 and 2015. Onset in the 2006 – 2015 decade delayed by 21 days for MAM season and 19 days for SOND season.

Analysis of farmers' perceptions and adaptation responses of changes in planting time revealed that majority of farmers were experiencing changes in rainfall onset in the recent years and this had effects such as declining crop yields and total loss of crops. Farmers adapted to these effects by practicing soil and water conservation and/or changing crops and diversifying livelihoods from agricultural activities.

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Relying on rainfall data alone makes it difficult to guide farmers make planting decisions. For the first time therefore, results of statistical analysis of onset were combined with farmers' perceptions and adaptation responses to changes in planting time to develop a planting decision tool. The PDT output is a planting date derived from analogue years and a quantification of the planting window which farmers can use to plant to maximize maize and beans crop yield. It further gives a yield gap visualisation. The PDT will help farming communities to make informed decisions on timely planting and since the tool has incorporated the farmer experiences it will fit in well with their seasonal operations and thus help improve yields.

6.2 Recommendations

Further studies need to be carried out on why there was greater dispersion in onset in the recent decade of 2006-2015.

There is need to enhance Nakaseke farmers' capacity to adapt to the unreliable onset patterns especially in the MAM season by promoting soil and water conservation practices, providing alternative crop seeds and advising on alternative sustainable livelihoods

The Planting Decision Tool needs to be developed further especially algorithms that will enable analogue years primarily determine the seasonal rainfall forecast categories; whether normal, below normal or above normal. Advisories in the tool can also be configured to originate from the analogue years. This will augment the wider use and effectiveness of the tool.

REFERENCES

Abid, M., Scheffran, J., Schneider, U. A., & Ashfaq, M. (2015). Farmers' perceptions of and adaptation strategies to climate change and their determinants: The case of Punjab province, Pakistan. *Earth System Dynamics*, *6*(1), 225–243. https://doi.org/10.5194/esd-6-225-2015

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pulhin, J., … Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. Climate Change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 717–743). Cambridge, UK: Cambridge University Press.

Ahmed, S., Stepp, J. R., Orians, C., Griffin, T., Matyas, C., Robbat, A., … Kennelly, E. (2014). Effects of Extreme Climate Events on Tea (Camellia sinensis) Functional Quality Validate Indigenous Farmer Knowledge and Sensory Preferences in Tropical China. *PLOS ONE*, *9*(10). https://doi.org/10.1371/journal.pone.0109126

ASSAR. (2015). *Use and Communication of Climate Information to Support Uptake of Adaptation Action in the Semi-Arid Regions of Africa and Asia*.

Awuor, F., Raburu, G., Onditi, A., & Rambim, D. (2016). Building E-Agriculture Framework in Kenya. *Journal of Agricultural Informatics*, *7*(1), 75–93. https://doi.org/10.17700/jai.2016.7.1.244

Bartlett, J. E., Kotrlik, J. W., & Higgins, C. C. (2001). Organizational Research : Determining Appropriate Sample Size in Survey Research. *Information Technology, Learning, and Performance Journal*, *19*(1), 43–50.

Bert, F. E., Satorre, E. H., Toranzo, F. R., & Podesta, G. P. (2006). Climatic information and decision-making in maize crop production systems of the Argentinean Pampas. *Agricultural Systems*, *88*(2–3), 180–204. https://doi.org/10.1016/j.agsy.2005.03.007

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., … Yanda, P. (2008). Africa. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,. In M. . Parry, O. . Canziani, J. . Palutikof, P. . van der Linden, & C. .

Hanson (Eds.) (pp. 433–467). Cambridge University Press. https://doi.org/10.2134/jeq2008.0015br

Breytenbach, E. (2013). *Following the Rains : Evidence and Perceptions Relating to Rainfall Variability in Western Uganda*. Georgia State University. Retrieved from http://scholarworks.gsu.edu/geosciences_theses/63

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., & Herrero, M. (2013). Adapting agriculture to climate change in Kenya: Household strategies and determinants. *Journal of Environmental Management*, *114*, 26–35. https://doi.org/10.1016/j.jenvman.2012.10.036

Camberlin, P., & Okoola, R. E. (2003). The onset and cessation of the '" long rains "' in eastern Africa and their interannual variability. *Theoretical and Applied Climatology*, *75*, 43–54. https://doi.org/10.1007/s00704-002-0721-5

Cook, K. H., & Vizy, E. K. (2013). Projected Changes in East African Rainy Seasons. *Journal of Climate*, 5931–5948. https://doi.org/10.1175/JCLI-D-12-00455.1

Cooper, P., Dimes, J., Rao, K., Shapiro, B., Shiferaw, B., & Twomlow, S. (2007). Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: A dress rehearsal for adapting to future climate change? *SAT EJournal (ICRISAT)*, *3*(1).

Coulibaly, J. Y., Gbetibouo, G. A., Kundhlande, G., Sileshi, G. W., & Beedy, T. L. (2015). Responding to Crop Failure: Understanding Farmers' Coping Strategies in Southern Malawi. *Sustainability*, *7*, 1620–1636. https://doi.org/10.3390/su7021620

Delle Monache, L., Eckel, F. A., Rife, D. L., Nagarajan, B., & Searight, K. (2013). Probabilistic Weather Prediction with an Analog Ensemble. *American Meteorological Society*, *141*(1974), 3498–3516. https://doi.org/10.1175/MWR-D-12-00281.1

Department of Relief Disaster Preparedness and Management Office of the Prime Minister. (2017). *National Food Security Assessment*.

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Dodd, D. E. S., & Jolliffe, I. T. (2001). Early detection of the start of the wet season in semiarid tropical climates of western Africa. *International Journal of Climatology*, *21*(10), 1251–1262. https://doi.org/10.1002/joc.640

Edwards-Jones, G. (2013). Modelling farmer decision - making : concepts , progress and challenges. *Animal Science*, *82*(06), 783–790. https://doi.org/10.1017/ASC2006112

El-Tantawi, A. M. M., & Saleh, H. (2013). Impacts of Rainfall and Growing Season Changes on Food Crops Yield in Katsina , Northern Nigeria. *Katsina Journal of Natural and Applied Sciences*, *3*(2), 128–143.

Enete, A., & Amusa, T. (2010). Challenges of Agricultural Adaptation to Climate Change in Nigeria: a Synthesis from the Literature. *Field Actions Scientific Reports*, *4*(8), 0–8. Retrieved from http://factsreports.revues.org/678

FAO. (2016). *Climate change and food security: risks and responses*. Rome: FAO.

Feleke, H. G. (2015). Assessing Weather Forecasting Needs of Smallholder Farmers for Climate Change Adaptation in the Central Rift Valley of Ethiopia. *Journal of Earth Science & Climatic Change*, *6*(10). https://doi.org/10.4172/2157-7617.1000312

Feng, X., Porporato, A., & Rodriguez-Iturbe, I. (2013). Changes in rainfall seasonality in the tropics. *Nature Climate Change*, *3*(9), 811–815. https://doi.org/10.1038/nclimate1907

FEWSNET. (2016). *UGANDA Food Security Outlook June 2016 to January 2017*.

Girvetz, E. H., Duffy, P., Maurer, E., Ruesch, A., Thrasher, B., & Zganjar, C. (2012). Making Climate Data Relevant to Decision Making : The important details of Spatial and Temporal Downscaling.

Government of Uganda Department of Disaster Management/Office of the Prime Minister. (2012). *The 2010–2011 Integrated Rainfall Variability Impacts, Needs Assessment and Drought Risk Management Strategy*.

Haile, M. (2005). Weather patterns, food security and humanitarian response in sub-Saharan Africa. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1463), 2169–2182. https://doi.org/10.1098/rstb.2005.1746

Hall, A. J., Feoli, C., Ingaramo, J., & Balzarini, M. (2013). Gaps between farmer and attainable yields across rainfed sunflower growing regions of Argentina. *Field Crops Research*, *143*, 119–129. https://doi.org/10.1016/j.fcr.2012.05.003

Hansen, J. W. (2005). Integrating seasonal climate prediction and agricultural models for insights into agricultural practice. *Philosophical Transactions of the Royal Society B*, *360*(October), 2037–2047. https://doi.org/10.1098/rstb.2005.1747

Hella, J. P., Vah Huylenbroeck, G., Haese, L. D., & Mlambiti, M. E. (2000). Linking rainfall variability and production decisions in semi-arid tanzania. In *The 1st University Wide Scientific Conference* (Vol. 2, pp. 211–224).

Hepworth, N., & Goulden, M. (2008). *Climate Change in Uganda: Understanding the implications and appraising the response* (Vol. 161). Edinburgh. https://doi.org/10.1680/ener.2008.161.2.87

Herrero, M., Ringler, C., Steeg, J. Van De, Koo, J., & Notenbaert, A. (2010). Climate variability and climate change and their impacts on Kenya's agricultural sector. Nairobi, Kenya: ILRI.

Huda, A. K. S., & Packham, R. G. (2004). *Using seasonal climate forecasting in agriculture : a participatory decision-making approach*. *ACIAR Technical Reports* (Vol. 59).

Huho, J. M., Ngaira, J. K. W., Ogindo, H. O., & Masayi, N. (2012). The changing rainfall pattern and the associated impacts on subsistence agriculture in Laikipia East District, Kenya. *Journal of Geography and Regional Planning*, *5*(7), 198–206. https://doi.org/10.5897/JGRP12.018

IFAD. (2010). *IFAD ' s response to climate change through support to adaptation and related actions*. Retrieved from http://www.ifad.org/climate/resources/adaptation.pdf

Iizumi, T., & Ramankutty, N. (2015). How do weather and climate influence cropping area and intensity ? *Global Food Security*, *4*, 46–50. https://doi.org/10.1016/j.gfs.2014.11.003

Jiri, O., Mafongoya, P. L., Mubaya, C., Mafongoya, O., Africa, S., & Pleasant, M. (2016). Seasonal Climate Prediction and Adaptation Using Indigenous Knowledge Systems in Agriculture Systems in Southern Africa : *Journal of Agricultural Science*, *8*(5), 156–172. https://doi.org/10.5539/jas.v8n5p156

Juana, J. S., Kahaka, Z., & Okurut, F. N. (2013). Farmers ' Perceptions and Adaptations to Climate Change in Sub-Sahara Africa : A Synthesis of Empirical Studies and Implications for Public Policy in African Agriculture. *Journal of Agricultural Science*, *5*(4), 121–135. https://doi.org/10.5539/jas.v5n4p121

Kansiime, M. K., Wambugu, S. K., & Shisanya, C. A. (2013). Perceived and Actual Rainfall

Trends and Variability in Eastern Uganda : Implications for Community Preparedness and Response. *Journal of Natural Sciences Research*, *3*(8).

Komutunga, E., Oratungye, K. J., Ahumuza, E., Akodi, D., & Agaba, C. (2015). New procedure in developing adjustment algorithm for harmonizing historical climate data sets. *Journal of Dynamics in Agricultural Research*, *2*(June), 21–30.

Komutunga, E. T. (2005). *Optimum cropping calendars derived for rain-fed agriculture of Uganda from rainfall data*. University of Nairobi.

Kurukulasuriya, P., & Mendelsohn, R. (2008). a Ricardian Analysis of the Impact of Climate Change on African. *AfJARE*, *2*(1), 1–62. Retrieved from http://www.researchgate.net/profile/Pradeep_Kurukulasuriya/publication/23550305_A_ricardian_analysis_of_the_impact_of_climate_change_on_African_cropland/links/0912f5084b3098b1c3000000.pdf

Laux, P., Jackel, G., Tingem, R. M., & Kunstmann, H. (2010). Impact of climate change on agricultural productivity under rainfed conditions in Cameroon-A method to improve attainable crop yields by planting date adaptations. *Agricultural and Forest Meteorology*, *150*(9), 1258–1271. https://doi.org/10.1016/j.agrformet.2010.05.008

Laux, P., Kunstmann, H., & Bardossy, A. (2008). Predicting the regional onset of the rainy season in West Africa. *International Journal of Climatology*, *28*, 329–342. https://doi.org/10.1002/joc

Limantol, A. M., Keith, B. E., Azabre, B. A., & Lennartz, B. (2016). *Farmers ' perception and adaptation practice to climate variability and change : a case study of the Vea catchment in Ghana*. *SpringerPlus*. Springer International Publishing. https://doi.org/10.1186/s40064-016-2433-9

Maatman, A., Schweigman, C., & Ruijs, A. (2002). Modeling Farmers' Response to Uncertain Rainfall in Burkina Faso: A Stochastic Programming Approach. *Operations Research*, *50*(3), 399–414. https://doi.org/0030-364X/02/5003-0399 $05.00

Makate, C., Makate, M., & Mango, N. (2017). Smallholder Farmers ' Perceptions on Climate Change and the Use of Sustainable Agricultural Practices in the Chinyanja Triangle, Southern Africa. *Social Sciences*, *6*(30), 1–14. https://doi.org/10.3390/socsci6010030

Mary, A. L., & Majule, A. E. (2009). Impacts of climate change , variability and adaptation strategies on agriculture in semi arid areas of Tanzania : The case of Manyoni District in

Singida Region , Tanzania. *African Journal of Environmental Science and Technology*, *3*(8), 206–218. Retrieved from http://www.academicjournals.org/AJEST

Mawunya, F. D., Adiku, S. G. K., Laryea, K. B., Yangyuoru, M., & Atika, E. (2011). Characterisation of Seasonal Rainfall for Cropping Schedules. *West African Journal of Applied Ecology*, *19*, 107–118.

Mbo 'o-Tchouawou, M., & Colverson, K. (2014). Increasing access to agricultural extension and advisory services: How effective are new approaches in reaching women farmers in rural areas? Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/35495/PR_extension services.pdf?sequence=5

Mbolanyi, B., Egeru, A., & Mfitumukiza, D. (2017). Choice Options to Meet Household Food Security in the Cattle Corridor of Uganda. *Environment and Natural Resources Journal*, *15*(1), 19–29. https://doi.org/10.14456/ennrj.2017.2

Mertz, O., Mbow, C., Reenberg, A., & Diouf, A. (2009). Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental Management*, *43*(5), 804–816. https://doi.org/10.1007/s00267-008-9197-0

Moeletsi, M. E., Moopisa, S. G., Walker, S., & Tsubo, M. (2013). Development of an agroclimatological risk tool for dryland maize production in the Free State Province of South Africa. *Computers and Electronics in Agriculture*, *95*(April 2016), 108–121. https://doi.org/10.1016/j.compag.2013.04.006

Moeletsi, M. E., Walker, S., & Landman, W. A. (2011). ENSO and implications on rainfall characteristics with reference to maize production in the Free State Province of South Africa. *Physics and Chemistry of the Earth*, *36*(14–15), 715–726. https://doi.org/10.1016/j.pce.2011.07.043

Morton, L. W., Hobbs, J., Arbuckle, J. G., & Loy, A. (2015). Upper Midwest Climate Variations: Farmer Responses to Excess Water Risks. *Journal of Environmental Quality*, *44*(3), 810–822. https://doi.org/10.2134/jeq2014.08.0352

Msongaleli, B. M., Tumbo, S. D., Kihupi, N. I., & Rwehumbiza, F. B. (2017). Performance of Sorghum Varieties under Variable Rainfall in Central Tanzania. *International Scholarly Research Notices*, *2017*, 10. https://doi.org/10.1155/2017/2506946

Mubiru, D. ., Komutunga, E., Agona, A., & Ngara, T. (2012). Characterising agrometeorological climate risks and uncertainties : Crop production in Uganda. *South African Journal of Science*, *103*(3–4), 108–118. https://doi.org/10.4102/sajs.v108i3/4.470

Mubiru, D. N., Komutunga, E., Agona, A., Apok, A., & Ngara, T. (2012). Characterising agrometeorological climate risks and uncertainties: Crop production in Uganda. *South African Journal of Science*, *108*(3–4). https://doi.org/10.4102/sajs.v108i3/4.470

Mugalavai, E. M., Kipkorir, E. C., Raes, D., & Rao, M. S. (2008). Analysis of rainfall onset , cessation and length of growing season for western Kenya. *Agricultural and Forest Meteorology*, *148*, 1123–1135. https://doi.org/10.1016/j.agrformet.2008.02.013

Mulenga, B. P., & Wineman, A. (2014). *Climate Trends and Farmers ' Perceptions of Climate Change in Zambia*. Lusaka, Zambia. Retrieved from http://www.aec.msu.edu/fs2/zambia/index.htm

Mupangwa, W., Walker, S., & Twomlow, S. (2011). Start, end and dry spells of the growing season in semi-arid southern Zimbabwe. *Journal of Arid Environments*, *75*(11), 1097–1104. https://doi.org/10.1016/j.jaridenv.2011.05.011

Ngongondo, C., Tallaksen, L. M., & Xu, C. (2014). Growing season length and rainfall extremes analysis in Malawi. In *FRIEND-Water 2014; Hydrology in a Changing World: Environmental and Human Dimensions* (Vol. 363, pp. 361–366). Montpellier, france: IAHS.

Nimusiima, A., Basalirwa, C. P. K., & Majaliwa, J. G. M. (2013). Nature and dynamics of climate variability in the uganda cattle corridor. *African Journal of Environmental Science and Technology*, *7*(8), 770–782. https://doi.org/10.5897/AJEST2013.1435

Okonya, J. S., Syndikus, K., & Kroschel, J. (2013). Farmers' Perception of and Coping Strategies to Climate Change: Evidence From Six Agro-Ecological Zones of Uganda. *Journal of Agricultural Science*, *5*(8), 252–263. https://doi.org/10.5539/jas.v5n8p252

Orlove, B., Roncoli, C., Kabugo, M., & Majugu, A. (2010). Indigenous climate knowledge in southern Uganda: The multiple components of a dynamic regional system. *Climatic Change*, *100*(2), 243–265. https://doi.org/10.1007/s10584-009-9586-2

Osbahr, H., Dorward, P., Stern, R., & Cooper, S. (2011). Supporting Agricultural Innovation in Uganda to Respond to Climate Risk: Linking Climate Change and Variability with Farmer Perceptions. *Expl Agric.*, *47*(2), 293–316.

https://doi.org/10.1017/S0014479710000785

Recha, C. ., Makokha, G. ., Traore, P. ., Shisanya, C., Lodoun, T., & Sako, A. (2012). Determination of seasonal rainfall variability , onset and cessation in semi-arid Tharaka district , Kenya. *Theoretical and Applied Climatology*, *108*, 479–494. https://doi.org/10.1007/s00704-011-0544-3

Sacks, W. J., Deryng, D., Foley, J. A., & Ramankutty, N. (2010). Crop planting dates : an analysis of global patterns. *Global Ecology and Biogeography*, *19*, 607–620. https://doi.org/10.1111/j.1466-8238.2010.00551.x

Simelton, E., Quinn, C. H., Batisani, N., Dougill, A. J., Dyer, J. C., Fraser, E. D. G., … Stringer, L. C. (2013). Is rainfall really changing? Farmers' perceptions, meteorological data, and policy implications. *Climate and Development*, *5*(2), 123–138. https://doi.org/10.1080/17565529.2012.751893

Singh, C., Daron, J., Bazaz, A., Ziervogel, G., Spear, D., Krishnaswamy, J., … Kituyi, E. (2017). The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India. *Climate and Development*, *0*(0), 1–17. https://doi.org/10.1080/17565529.2017.1318744

Stern, R., Rijks, D., Dale, I., & Knock, J. (2006). Instat Climatic Guide, (January).

Steynor, A., Padgham, J., Jack, C., Hewitson, B., & Lennard, C. (2016). Climate Risk Management Co-exploratory climate risk workshops : Experiences from urban Africa. *Climate Risk Management*, 1–8. https://doi.org/10.1016/j.crm.2016.03.001

Thomas, D. S. G., Twyman, C., Osbahr, H., & Hewiston, B. (2007). Adaptation to climate change and variability : farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change*, *83*, 301–322. https://doi.org/10.1007/s10584-006-9205-4

UBOS. (2011). Subcounty Development Programme: Implementation of the Community Information System (CIS), Nakaseke Local Government Report.

UBOS. (2016). National Population and Housing Census 2014 - Main Report. Kampala, Uganda: Uganda Bureau of Statistics.

Usman, M. T., & AbdulKadir, A. (2013). On determining the "real" onset date of seasonal rains in the semi-arid and sub-humid areas of West Africa. *Natural Hazards*, *66*(2), 749–758. https://doi.org/10.1007/s11069-012-0514-9

Vrieling, A., De Leeuw, J., & Said, M. Y. (2013). Length of growing period over africa: Variability and trends from 30 years of NDVI time series. *Remote Sensing*, *5*(2), 982–1000. https://doi.org/10.3390/rs5020982

Waldman, K. B., Blekking, J. P., Attari, S. Z., & Evans, T. P. (2017). Maize seed choice and perceptions of climate variability among smallholder farmers. *Global Environmental Change*, *47*(April), 51–63. https://doi.org/10.1016/j.gloenvcha.2017.09.007

Waongo, M. (2015). *Optimizing Planting Dates for Agricultural Decision-Making under Climate Change over Burkina Faso / West Africa*.

Wiid, N., & Ziervogel, G. (2012). Adapting to climate change in South Africa : commercial farmers ' perception of and response to changing climate. *South African Geographical Journal*, *94*(2), 152–173. https://doi.org/10.1080/03736245.2012.742783

Wood, S. A., Jina, A. S., Jain, M., Kristjanson, P., & DeFries, R. S. (2014). Smallholder farmer cropping decisions related to climate variability across multiple regions. *Global Environmental Change*, *25*(1), 163–172. https://doi.org/10.1016/j.gloenvcha.2013.12.011

WWF. (2006). Climate Change Impacts on East Africa. *World Wide Fund for Nature*. Gland, Switzerland: World Wide Fund for Nature.

Yamauchi, F., Takeshima, H., Sumaryanto, S., Dewina, R., & Haruna, A. (2012). Climate Change, Perceptions and the Heterogeneity of Adaptation and Rice Productivity: Evidence from Indonesian Villages. In *International Association of Agricultural Economists (IAAE) Triennial Conference* (pp. 1–38). Foz do Iguaçu, Brazil.

Yengoh, G. T., Armah, F. A., Onumah, E. E., & Odoi, J. O. (2010). Trends in Agriculturally-Relevant Rainfall Characteristics for Small-Scale Agriculture in Northern Ghana. *Journal of Agricultural Science*, *2*(3), 3–16.

Yohannes, H. (2016). A review on relationship between climate change and agriculture. *Journal of Earth Science and Climate Change*, *7*(2), 335. https://doi.org/10.4172/2157-

APPENDICES

Appendix 1: Household questionnaire

Confidential

Optimum planting decision tool derived from rainfall onset and farmer experiences for the Central Uganda Cattle Corridor

I am Choice Agaba, a second year Student at Makerere University pursuing a Master of Science degree in Environment and Natural Resource. As part of fulfilling the requirements for this degree, I am obliged to carry out research with an aim of writing my thesis. I am investigating farmers' experiences and perceptions regarding changes in planting time, how they have adapted to these changes over time. This research is being done in Nakaseke sub-county in Nakaseke district. The information generated from this study will be used to derive an optimum planting time decision tool for beans and maize crops. I kindly request for your participation on the subject matter by responding to the questions indicated herein. This will take 20 to 30 minutes; and your responses will be treated with utmost confidentiality.

Study Instrument No. 1:	Questionnaire for Household Survey

Section 1: Identifying information

(a) Questionnaire ID (b) Date of interview

100. Name of enumerator	
101. Parish	
102. Village	
103. Name of Household head	
104. Is the respondent the household head?	
105. Relationship to household head *1=wife 2=husband 3= Adult son 4=Adult daughter 5=Other (please specify)*	

Section 2: Household Demographic Information

Household characteristic	**Response**	**Codes**
200. Age of Household Head		Years
202. Highest level of education in household		*1=No formal education 2= Adult education 3=Some primary education 4=Completed primary education 5=Some vocational training 6=Completed vocational training 7=Some secondary education 8=Completed secondary education 9= Advanced level 10=College education 11=University education*
203. Type of farming		*1= Subsistence 2= Commercial 3= Other*
204. Number of years household has been farming		Years

Section 3: Perceptions on rainfall onset variability

	Response	**Code**
300. Does your area receive adequate rainfall?		*1 = Yes 0= No*
301. When do the long rains normally start in your area? (State the week and the month)		
302. When do the short rains normally start in your area? (State the week and the month)		
303. From your own experience, is the amount and patterns of rainfall onset changing?		*1 = Yes 0= No*
304. If yes, how is it changing?		*1= Rains come earlier than expected 2=Delay in start of rains 3= Increased unpredictability 4=Long*

		dry spells between rainfall events 5= Others…………………………
305. In which rainfall season have these changes been prominent?		1= Long-rains 2= Short-rains 3= Both seasons
306. What was your experience with the start of rains in the 90's?		*1= Late onset 2= Early onset 3= Increased unpredictability 4= Long dry spells between rainfall events*
307. What was your experience with the start of rains in the mid 80's?		*1= Late onset 2= Early onset 3= Increased unpredictability 4= Long dry spells between rainfall events*
308.When do you usually do land preparation		*1= Before the rains 2= Immediately after the first rains 3=Other………………………*
309. From your experience, how do you know it is time to plant?		
310. When do you usually plant?		*1= Before the rains 2= Immediately after the first rains 3=Other………………………*
311. What effects have the changes in rainfall onset had on planting seasons?		*1= Irregular planting dates 2= Delayed land preparation 3= Delayed time in other farming practices (weeding, spraying, harvesting) 4= Reduced crop yields 5= Total loss of crops 6= Shortened growing period 7= Longer growing periods 8= Others…………………………………*

Section 4: Adaptation responses and/or coping mechanisms

400. What measures have you put in place to respond to the effects of changes in rainfall onset? (write multiple codes if they apply)

1= Plant according to the local crop calendar 2= Plant according to the seasonal forecast 3= Land preparation before onset 4= Plant local varieities 5= Plant early maturing varieties 6= Relay / stagger planting 7= Planting longer maturing crops 8= Changing crop cycles 9= Soil and water conservation practices 10= Small scale irrigation 11= Livelihood diversification from agricultural activities 12= Others

Effect	**Response (write code)**
a) Irregular planting dates	
b) Delayed land preparation	
c) Delayed time in other farming practices (weeding, spraying, harvesting)	
d) Reduced crop yields	
e) Total loss of crops	
f) Shortened growing period	
g) Longer growing periods	

401. Which of the above measures have been effective and why?

Measure	Has it dealt with the effect? 1= Yes 2= No	Why has it been effective? (How does it lead to reducing the impact?)
Plant according to local calendar		*1= Reliabilty across growing zones and seasons 2= Easy to follow 3= Others*
Plant according to the seasonal forecast		*1= Maximise benefits from anticipated potential benefits 2= Intensification of cropping systems 3 = Others*
Land preparation before onset		*1= Benefit from the early rains 2= Multiple plantings 3= Nitrogen flush from early rains*

Planting local varieties		*1= Readily available 2= Higher yields 3= More drought tolerant 4= Others*
Planting early maturing varieties		*1= Availability of seed 2= Cost of the seed 3= Drought tolerant 4= Pest and disease tolerant 5= Higher yielding 6 = Others*
Relay / stagger planting		*1= Higher yields, 2= crop diversification 3= Others*
Planting longer maturing crops		*1= Availability of seed 2= Cost of the seed 3= Drought tolerant 4= Pest and disease tolerant 5= Higher yielding 6 = Others*
Changing cropping regimes		*1= Increased crop yields 2= Others*
Soil and Water conservation		*1= Reduces soil erosion 2= Allow dry seeding 3= Increased soil porosity 4= Improved infiltration 5= Reduces soil temperature 6= Affordability 7= Others*
Small scale irrigation		*1= Allow earlier planting 1= Continued plant growth during dry periods 3= Increase availabilty of soluble plant nutrients 2= Increased yields 3=*
Livelihood diversification		*1= Increased income from off-farm activities 2= Surplus to invest in agriculture 3= Others*
Others		

	Code	Response (Multiple answers)
402. What do you do when planning for the planting season? (Steps involved to decide when to plant?)		*1 = Type of crops to plant depending on the season 2= Information on the amount of seed depending on the land and where to acquire the seed, fertiliser 3= Land prepration 4= Weather information on the season performance 5= Adjust planting plans according to the weather information received 6= Plant before start of rains 7= Plant after one rainfall event 8= Plant*

		after 2 to 3 rainfall events 9= Others
403. What kind of information do you use to make planting decisions?		*1= Local knowledge on expected start of rains 2= Weather and climate information 3= Crop and inputs information*
404. Where and how do you obtain information to decide on when to plant?		*1= Agricultural extension 2= Weather Office 3= Fellow farmers 4= Radio stations 5= TV's 6= Indigenous knowledge and perceptions 7= Others*
405. How do you use the information to make planting decisions?		*1= Plant according to the local crop calendar 2= Plant according to the seasonal forecast 3= Land preparation before onset 4= Plant early maturing varieties 5= Relay / stagger planting 6= Planting longer maturing crops 7= Changing crop cycles 8= Soil and water conservation practices 9= Small scale irrigation 10= Livelihood diversification from agricultural activities 11= Others*
406. What do you do in your planning to deal with the anticipated / ongoing changes in onset of rainfall?		*1= Plant according to the local crop calendar 2= Plant according to the seasonal forecast 3= Land preparation before onset 4= Plant local varieities 5= Plant early maturing varieties 6= Relay / stagger planting 7= Planting longer maturing crops 8= Changing crop cycles 9= Soil and water conservation practices 10= Small scale irrigation 11= Livelihood diversification from agricultural activities 12= Others*
407. What do you expect to occur in the future in relation to ongoing changes in onset of rainfall?		*1= Increased earlier onset than expected 2=Increased delay in start of rains 3= Increased unpredictability 4= Normal rainfall onset like in the past 5=Longer dry spells*

		between rainfall events 6= Longer growing periods 7= Shorter growing periods 8= Others…………………………
408. Does this perception of future events affect your plans for the future?		*1= Yes 2= No*
409. If yes, how does this perception of future events affect your plans for the future?		*1= Continue planting according to the local crop calendar 2= Continue planting according to the seasonal forecast 3= Land preparation before onset 4= Continue planting early maturing varieties 5= Relay / stagger planting 6= Continue planting longer maturing crops 7= Changing crop cycles 8= Soil and water conservation practices 9= Small scale irrigation 10= Livelihood diversification from agricultural activities 11= Others*

THANK YOU FOR YOUR COOPERATION

Appendix 2: Focus Group Discussion guide

Study Instrument No. 2: **Guide for Focus Group Discussions**

Translating farmers' perceptions & experiences and climate data into adaptation actions

Name of Parish ________________________

1. **Cropping system**

Maize

- Common varieties / preferred varieties – which one yields higher?
- Planting time
- Yields in a good season (or when planted on time / early) – Season A and Season B
- Yield in a bad season - Season A and Season B

Beans

- Common / preferred varieties – which one yields higher?
- Planting time
- Yields in a good season (or when planted on time / early) – Season A and Season B
- Yield in a bad season - Season A and Season B

2. **Management practices**

- Management and adaptation practices to achieve desired yield – what can be done?
- **Decision to plant maize or beans**

  A) Why decision to plant beans

  B) Why decision to plant maize

- **Decision making cycle up to the time of final sowing**

3. **Weather information access**

- When and how obtained

ANNEXES

Annex 1: Relevant Analyses

Table A: Usual start of rainfall/wet seasons

Season	Rainfall onset	Count [N]	Percent of respondents
MAM	Early start (Feb: Week I – Week IV)	90	36.4
	Mid/average start (Mar: Week I – Week IV)	135	54.7
	Late start (Apr: Week I onwards)	0	0.0
	Not sure (did not mention week)	22	8.9
	Total number of respondents	247	100.0
SOND	Early start (Aug: Week I)	57	24.3
	Mid/average start (Aug, Week II – Sep Week I)	149	63.4
	Late start (Sep: Week II onwards)	7	3.0
	Not sure (did not mention week)	22	9.4
	Total number of respondents	235	100.0

Table B: Experience with the start of rains in the mid 80's and the 90's

Period	Rainfall experience	Number of responses	Percent of respondents
In the 90's	Late onset	14	3.9
	Early onset	324	89.5
	Increased unpredictability	20	5.5
	Long dry spells between rainfall events	10	2.8
	Total number of respondents = 362		
In the mid 80's	Late onset	17	4.9
	Early onset	285	82.8
	Increased unpredictability	42	12.2
	Long dry spells between rainfall events	9	2.6
	Total number of respondents = 344		

Table C: Usual timing of land preparation and planting activities

Activity	Usual timing	Count [N]	Percent of respondents
Land preparation	Before the rains	342	92.7
	Immediately after the first rains	24	6.5
	Other time	3	0.8
	Total number of respondents	369	100.0
Planting	Before the rains	45	12.1
	Immediately after the first rains	315	84.9

	Other time	11	3.0
	Total number of respondents	371	100.0

Table D: Distribution of perceived effects of changes in rainfall onset by planting season

Perceived effect	Rainfall/planting season		
	Season A	**Season B**	**Both seasons**
Irregular planting dates	42 (53.2)	47 (51.1)	109 (56.8)
Delayed land preparation	10 (12.7)	21 (22.8)	76 (39.6)
Delayed time in other farming practices	11 (13.9)	18 (19.6)	25 (13.0)
Reduced crop yields	65 (82.3)	75 (81.5)	161 (83.9)
Total loss of crops	61 (77.2)	46 (50.0)	124 (64.6)
Shortened growing period	8 (10.1)	14 (15.2)	25 (13.0)
Longer growing period	6 (7.6)	5 (5.4)	9 (4.7)
Others	11 (13.9)	12 (13.0)	23 (12.0)
Total number of respondents	**79**	**92**	**192**
Test for association: *Pearson chi-square (df:124) = 188.873 p-value < 0.0001*			

Percentages are based on respondents.

Table E: Actions taken while planning for the planting season (what guides farmers' decisions to plant)

Actions in planting decisions	Number of Responses	Percent of Respondents
Type of crops to plant depending on the season	166	45.1
Information on the amount of seed depending on the land and where to acquire the seed, fertilizer	144	39.1
Land preparation	322	87.5
Weather information on the season performance	54	14.7
Adjust plans according to the weather information received	40	10.9
Plant before start of rains	19	5.2
Plant after one rainfall event	133	36.1
Plant after 2 to 3 rainfall events	136	37.0
Others	32	8.7

Total number of respondents (N) = 368

Table F: Where and how the information to decide on planting is obtained

Source of information to guide planting	Sex of household head	
	Female	**Male**
Agricultural extension	18 (12.1)	54 (25.2)
Weather office	4 (2.7)	2 (0.9)
Fellow farmers	81 (54.4)	123 (57.5)
Radio stations	51 (34.2)	108 (50.5)
Televisions	8 (5.4)	2 (0.9)
Indigenous knowledge and perceptions	108 (72.5)	158 (73.8)
Others	3 (2.0)	9 (4.2)
Total number of respondents	**149**	**214**
Test for association: Pearson chi-square (df:30) = 47.065 p-value = 0.025		

Percentages are based on respondents.

Table G: Testing for equality of variances in rainfall onset dates across the study period

Season	Decade	N	Std. Deviation	Variance	Test for Homogeneity of Variances	
					Levene Statistic	Significance (p)
Mar-May	1986-1995	10	11.183	125.067	1.533	0.234
	1996-2005	10	10.562	111.556		
	2006-2015	10	20.555	422.500		
Sep-Dec	1986-1995	10	13.782	189.956	5.749	0.008
	1996-2005	10	8.430	71.067		
	2006-2015	10	19.338	373.956		

Degrees of freedom (df1, df2) = (2, 27)