

**EFFECTS OF CLIMATE VARIABILITY ON RAINFED RICE PRODUCTION:
A CASE STUDY OF NORTHERN FARMING SYSTEM AGROECOLOGICAL ZONE
OF UGANDA**

BY

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DECLARATION

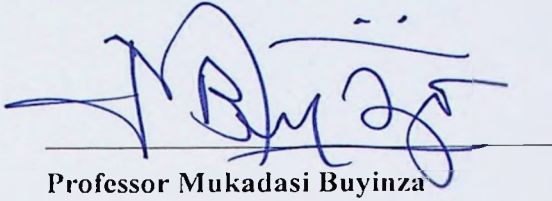
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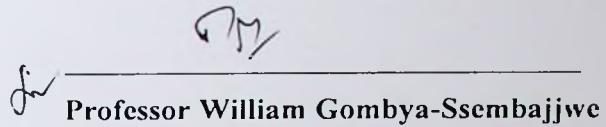
APPROVAL

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DEDICATION

The thesis is dedicated to my late father (Ben) and mother (Rosemary), my uncle (David) and my children Bray, Bram, Brad and Braylyn.

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ACRONYMS

°C	-	Degree Celsius
AIC	-	Akaike's Information Criterion
BIC	-	Bayesian Information Criterion
ECMWF-ERA5	-	5 th Generation of European Centre for Medium-Range Weather Forecasts Reanalysis
FAO	-	Food and Agricultural Organisation
GDP	-	Gross Domestic Product
GoU	-	Government of Uganda
GRiS	-	Global Rice Partnership
H ₀	-	Null Hypothesis
Ha ⁻¹	-	Per Hectare
IFPRI	-	International Food Policy Research Institute
IPCC	-	Intergovernmental Panel on Climate Change
IRRI	-	International Rice Research Institute
Kgs	-	Kilograms
LLR	-	Log Likelihood Ratio
MAAIF	-	Ministry of Agriculture Animal Industry and Fisheries
MLE	-	Maximum Likelihood Estimate
MM	-	Millilitres
MWE	-	Ministry of Water and Environment
NARO	-	National Agricultural Research Organization
NDP	-	National Development Plan
NEMA	-	National Environment Management Authority
NRDS	-	National Rice Development Strategy
OLS	-	Ordinary Least Square
PCI	-	Precipitation Concentration Index
RTS	-	Returns to scale
t	-	Tons
UBOS	-	Uganda Bureau of Statistics
Ugx	-	Uganda Currency
UNMA	-	Uganda National Meteorology Authority
VIF	-	Variable Inflation Factors

ABSTRACT

Rice (*Oryza sativa*) production is growing rapidly not only as a major source of food and nutrition to the global populace but also as a strategic crop for poverty reduction among subsistence farmers in Uganda. Despite the socio-economic and nutritional importance of rice, average yield per hectare in Uganda is only half of the potential yield under good management practice and production systems. This situation is partly attributed to its high moisture demand which makes its cultivation in rainfed system more vulnerable to climate variability. Although, literature has linked vulnerability of rainfed rice production to climate variability, there is limited empirical study in Uganda to quantitatively demonstrate impacts of climate variability on rice production (direction/magnitude) and how farmers cope. This study was motivated by the need to examine the relationships between climate variability, coping strategies and rainfed rice production in Northern farming system agroecological zone of Uganda which is comprised of 17 districts. And of these, the major four rice growing districts including Lira, Oyam, Gulu and Amuru were involved in the study. The aim of the study was to generate information which would enhance rice production for increased food and nutrition security and livelihood improvement of the rural population. The study objectives were to characterise rainfed rice production systems, determine effects of climate variability on rainfed rice production, and assess farmers' coping strategies in rainfed rice production to climate variability. The study used a four-year farm-level data on rice production and climate (2013 - 2016). Descriptive analysis was used to determine key distinguishing characteristics of the different rainfed rice production systems. The result showed a decline in rice yields from 2 t ha⁻¹ during 2013 to 1.6 t ha⁻¹ during 2016 but there was significant yield difference between lowland and upland rainfed production systems. The result also showed significant differences in production practices between the two rainfed rice production systems. To determine the extent of rice production efficiency, the stochastic frontier model was estimated. The estimation result indicated efficiency level at 76.6%. Qualitative analysis was performed to determine farmers' views of climate variability. The result showed that farmers are experiencing variability in onset, distribution and amount of rainfall and temperature conditions. To determine extent of variability and trends in rainfall and temperature, coefficient of variations, rainfall anomalies, precipitation concentration index (PCI), parametric approach (least square regression) and non-parametric tests (Mann-Kendall and Sen's slope estimator) were estimated. The results showed high coefficient of variations of monthly rainfall exceeding 30%, precipitation concentration index was

moderate at 11.3. Rainfall anomalies revealed interannual variability with eight incidences of droughts in three decades. In addition, negative trend in rainfall was detected whereas temperatures portrayed positive trends. Influence of climate variability on rainfed rice production was determined using fixed effects estimator. The result indicated reduction in yields from increasing variability in rainfall and temperature. However, an increase in mean rainfall had positive effects on yields. Subsequently, different coping strategies applied included changing rice variety, shifting rice fields along the valley area, adjusting planting dates, and regulating water. To ascertain which farmers' characteristics influence their decision to use coping strategies, binary probit regression was performed and the findings showed that exposure and effects of climate variability, soil type and gender influence decisions to cope. Finally, to determine contribution of coping strategies to yields, pooled least square regression was performed and differential contribution of coping strategies to rice yield was observed. Comparatively major contributions to yield were made by planting date, regulating water and combination of strategies. The study therefore concludes that there are differences between lowland and upland rainfed rice production systems in terms of yields and production practices used by farmers. The rice farmers are producing below the frontier and increased variability in rainfall and temperature negatively affects rice production. Coping strategies substantially improve rice yield but the type of strategies adopted are influenced by farmers' characteristics. The study recommends extension support to farmers through promotion of suitable practices for yield enhancement and cost/input minimisation. Increase awareness about climate variability to farmers and coping/adaptation measures. Government should provide water harvesting technologies to supplement rainfall. Further research to validate current temporal coping strategies for long-term sustainable measures in systems with high exposure and vulnerability. There is need to extend the current study to the broader country by including other agroecological zones of the country as well as exploring the relationship between climate variability and coping strategies.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Rice (*Oryza sativa*) is grown and consumed throughout the world as the major source of calories (GRiSP, 2013; FAO, 2017). Accordingly, the global production is estimated at 754.6 million tons from 163.1 million hectares where Asia and Africa account for 682.1 and 31.1 million tons, respectively while Uganda produces 0.215 million tons from 0.096 million hectare (FAO, 2017; UBOS, 2017). In Uganda, rice is one of the main cereal crops grown as food and cash crop and ranks 3rd after maize and sorghum. Together with other food crops, it contributes 12.1% to the Gross Domestic Product (GDP) and there are 103,570 rice growing households (GoU, 2009; UBOS, 2010).

Rice growing in Uganda dates back to 1904 but became noticeable as food crop during the 1950s mainly to feed the Second World War veterans and government institutions such as schools, prisons and hospitals (Odogola, 2006; Bua and Ojirot, 2014). However, rice production gained importance as cash crop after the establishment of Kibimba rice irrigation scheme in the 1960s followed by Doho and Olweny irrigation scheme in the 1970s (Odogola, 2006; GoU, 2009). Subsequently, rice growing spread throughout the country and the majority of the growers were smallholders found especially in eastern and Northern parts of Uganda. Much of the cultivation is rainfed lowland (53%) and rainfed upland (45%) and only 2% is irrigated compared with 11% and 53% in Africa and worldwide, respectively (Haneishi, 2014).

Historically, rice production acreage in the country has grown rapidly by 59% since 1997 (at an annual rate of 5%) while output increased by 169%. As a result, the Government of Uganda considers rice as a strategic crop with remarkable potential to contribute to increasing food and nutrition security, incomes and livelihoods of the rural population (GoU, 2010c). Consequently, the National Rice Development Strategies (NRDS) was put in place as a measure to promote rice (GoU, 2009). The on-going development strategies include (i) Research into new crop varieties through National Agricultural Research Organization (NARO) and (ii) Rehabilitation of irrigation schemes including Agoro and Olweny in the Northern agroecological zone through the Ministry of Water and Environment (MWE). These strategies are expected to ignite rapid cultivation of the crop.

Despite the socio-economic and nutritional importance of rice, climate variability is a threat which continues to affect its production (IFPRI, 2007; Rowhani *et al.*, 2011; IPCC, 2012). Like in other countries in Sub-Saharan Africa (SSA), Uganda relies heavily on rainfed weather-sensitive agriculture and as such the country is vulnerable to negative variations in climatic conditions (Mubiru *et al.*, 2012; Caffrey *et al.*, 2013; FAO, 2018). The country's average annual rainfall is 1,318 mm but it is the most sensitive climate variable that affects agricultural production. As such, the country in recent years has witnessed erratic onset and cessation of rainfall with frequent droughts year to year as well as within and between the different agroecological zones of the country (Wasige, 2009; GoU, 2010a; Mubiru *et al.*, 2012; Kansiime *et al.*, 2013). For instance, negative variation in rainfall was observed during 2010 to 2015 (between 1.6 and 8.9%) but positive variation (1.1%) during 2007 and 2016. Experts believe that variability in climate will significantly alter the country's production conditions (Kaggwa *et al.*, 2009; Kansiime *et al.*, 2013).

Rice is traditionally a wetland crop, requiring reliable amount of moisture and warmth during critical stages of growth (GRiSP, 2013; IRRI, 2015). However, early flowering and maturity of the crop has been associated with variability in onset and cessations of seasonal rains as well as high temperature (temperature as high as 32°C can cause reduction in output) (Mubiru *et al.*, 2012; GRiSP, 2013). Consequently, the global short fall in production of 4.1 million tons in 2017 was caused by dry conditions in some parts of Asia and erratic rains in East Africa (FAO, 2017). In Uganda, rice yield is considerably low (barely 2.5 t ha⁻¹) and has remained stagnant over the last two decades (from 1997) at around 2 t ha⁻¹ while only 1.7 t ha⁻¹ is exhibited in the Northern region (Northern farming system agroecological zone), the country's second largest and oldest rice producing area. This is in comparison to global average of 4.6 t ha⁻¹ and potential average of 5 to 8 t ha⁻¹ depending on variety and production system (GoU, 2009; UBOS, 2010; Luzi-Kihupi, 2011).

As a result, interpreting low trends in yield and identifying potential policy responses has proved difficult due to unclear understanding of factors affecting rice production (GoU, 2009). Firstly, biotic and abiotic factors including low use of improved crop technologies have been reported as the causes of low production (Odogola, 2006; GoU, 2009; UBOS, 2010; Kijima, 2012; Miyamoto *et al.*, 2012). Secondly, its production is dominated by rainfed cultivation which makes it highly sensitive to climate variability (Rowhani *et al.*, 2011; Caffrey *et al.*, 2013). For instance, a decline in production from 132,000 tons (2003) to

121,000 tons (2004) representing a decline of 8%, from 232,986 tons (2011) to 213,772 (2013) representing a decline of 8.2%, and from 238,000 tons (2015) to 215,000 tons (2016) representing a decline of 10% were attributed to climate variability (UBOS, 2005, 2015, 2016). These declines are of particular concern given the well documented variability in rainfall and temperature in the country (Wasige, 2009; Mubiru *et al.*, 2012; Kansiime *et al.*, 2013).

In view of the above challenges, coping measures are therefore needed to respond to the volatile climate (Wasige, 2009; Caffrey *et al.*, 2013; Okonya *et al.*, 2013; EPRC, 2016). However, the extent to which farmers in developing countries are able to adjust their practices to cope or adapt to the impacts of climate variability is also a subject of discussion. Coping strategy is an adjustment of farming activities or methods to lessen potential damage from climate variability. Strategies such as adjusting the planting date, changing crop variety and cultivating in lowland are possible options (Lansigan *et al.*, 2000; Mary and Majule, 2009; Mabe *et al.*, 2012; Oselebe *et al.*, 2016).

1.2 The research problem

Research evidence has shown that rice production in Uganda is characterized by low yield which is about half of the global average and barely a quarter of potential yield (Kijima, 2012; Miyamoto *et al.*, 2012; Haneishi *et al.*, 2013). Although production is affected by factors such as soils, pests and diseases, low use of new/improved crop technologies as well as low access to production services, evidence also point to vulnerability of its rainfed cultivation to climate variability (Rowhani *et al.*, 2011; Mubiru *et al.*, 2012). However, a review of existing literature presents knowledge gaps on the potential effects of climate variability on rice production in Uganda. Moreover, evidences linking climate variability to rice production are inconsistent (Ajetomobi *et al.*, 2011; Rowhani *et al.*, 2011; Thornton *et al.*, 2014). Secondly, there is limited empirical study in Uganda which has quantitatively demonstrated impacts of climate variability on rice production (direction/magnitude) and how farmers cope. Therefore, providing empirical evidence linking climate variability to rainfed rice production and how farmers cope could motivate appropriate policies and strategies for improving rice production, and achieving self-sufficiency and sustained development in the sector.

To date, available empirical studies on characterisation of rice production in Uganda includes (Kijima, 2012; Miyamoto *et al.*, 2012; Haneishi, 2014). Kijima (2012) analysed expansion of lowland rice production and constraints on rice green revolution. Haneishi (2014) explored rainfed rice farming based on regionality, varieties and yield. However, none of these studies gave due consideration to the differences in production embedded in the lowland and upland rainfed systems in terms of moisture requirements, input requirements and production practice.

Although Hyuha *et al.*, (2007) and Asiimwe (2009) examined profit and technical efficiency, respectively, and confirmed inefficiencies in rice production; no consideration was given to climate as an important factor in rice production. Nevertheless, Mubiru *et al.* (2012) and Kansiime *et al.* (2013) provided an account of seasonal variability in onset, amount and distribution of rainfall as well as shortening of the growing season but they did not indicate crops that are likely to be affected. On the other hand, Odogola (2006); Caffrey *et al.* (2013) and Elepu and Dalipagic (2014) reported exposure of rice farmers to climate variability but they did not point out the magnitude of exposure. Generally, all the empirical studies on coping strategies in Uganda targeted none rice crops. For example, Okonya *et al.* (2013) examined farmers' perception of and coping strategies to climate change in sweet potato from six agroecological zone of Uganda. Kansiime and Mastenbroek (2016) explored how to enhance resilience of farmer seed system to climate-induced stresses in West Nile region. Most of the literature on impact of climate variability on rice and coping strategies are reported outside Uganda (Ajetomobi *et al.*, 2011; Rowhani *et al.*, 2011; Mabe *et al.*, 2012; Shakoor *et al.*, 2015). It is therefore important to address the above gaps by investigating the nature and magnitude of impacts of climate variability in rainfed rice production and how farmers cope, specifically in the case of Uganda.

1.3 Objectives

1.3.1 General objective

The general objective of this study was to examine the relationships between climate variability, coping strategies and rainfed rice production in the Northern farming system agroecological zone of Uganda. It is hoped that information generated would enhance rice

production for increased food and nutrition security and livelihood improvement of the rural population.

1.3.2 Specific objectives

The specific objectives of the study were to:

- i) Characterise rainfed rice production systems,
- ii) Determine effects of climate variability on rainfed rice production and
- iii) Assess farmers' coping strategies in rainfed rice production to climate variability.

1.4 Research questions

The above objectives were achieved by addressing the following research questions:

Objective 1:

- 1) What are the key distinguishing characteristics of the different rainfed rice production systems of Northern farming system agroecological zone of Uganda?
- 2) What is the level of efficiency in rice production in the rainfed rice production system of Northern farming system agroecological zone?
- 3) How do farmers' characteristics influence inefficiency in rice production in rainfed production systems?

Objective 2:

- 1) What are farmers' views of climate variability in rainfed rice production systems of Northern farming agroecological zone?
- 2) How is rainfall and temperature distributed in the Northern farming system agroecological zone?
- 3) What is the influence of climate variability on rice production in rainfed rice production systems of Northern farming system agroecological zone?

Objective 3:

- 1) What are the coping strategies being used by farmers to counter effects of climate variability in rainfed rice production systems?
- 2) What farmer characteristics influence decisions to use coping strategies against climate variability in rainfed rice production systems?
- 3) To what extent does coping strategies contribute to rice yield in rainfed production systems?

1.5 Significance of the study

Rice production is growing rapidly not only for food and nutrition security but also as a strategic crop for poverty reduction among subsistence farmers in the country (GoU, 2009; Bua and Ojirot, 2014; Haneishi, 2014). However, its yield is only half and quarter, respectively, of the global and potential yield (UBOS, 2010; GRiSP, 2013; FAO, 2017). This situation is partly attributed to its high moisture demand which makes its cultivation in rainfed systems more vulnerable to climate variability (Ajetomobi *et al.*, 2011; Rowhani *et al.*, 2011; Tsuboi, 2011; IRRI, 2015; Shakoor *et al.*, 2015).

This study was, therefore, motivated by the need to first highlight the production difference between the lowland and upland rainfed rice production systems. While information is known for other parts of the world (see for example GRiSP, 2013), it is not available for Uganda. The difference, if any, will help to explain variability in impact magnitude of climate factors on rice production in the country. Secondly, understanding the magnitude and direction of effects of climate variability on rainfed rice production will guide development of appropriate strategies and policies to push production up from the current level. This will support increase in food and nutrition security and livelihood improvement of the rural population. Also, examining the current coping strategies used by farmers will support identification and validation of appropriate strategies into long-term adaptation strategies in rice production (Mabe *et al.*, 2012; Caffrey *et al.*, 2013; Elepu and Dalipagic, 2014).

This study is, therefore a pioneer effort in Uganda to use farm-level panel data and use it to examine the impact of climate variability on rice production and how farmers are coping with the effects in the Northern farming system agroecological zone of Uganda. This study refers

and considers climate variability in terms of intra-seasonal and inter-seasonal changes in mean rainfall and temperature during crop growth period.

1.6 Conceptual framework

Conceptual framework of rice production (Figure 1.1) illustrates the effect chain of climate variability on rice production. The solid lines represent direct effects (depicts the relationships of interest in this study) while the dashed lines depict relationships that exist between the variables but not within the scope of this study. Climate variability and farmers' characteristics are cross-cutting factors which affect rice production through production practices and coping strategies adopted. In line with the specific objective, objective 1 was addressed through characterisation of production and determining level of efficiency in production; objective two was determined by assessing the relationship between climate variability and production characteristics, and objective three was assessed by examining the tripartite relationship among coping strategies, rice production characteristics and farmers' characteristics.

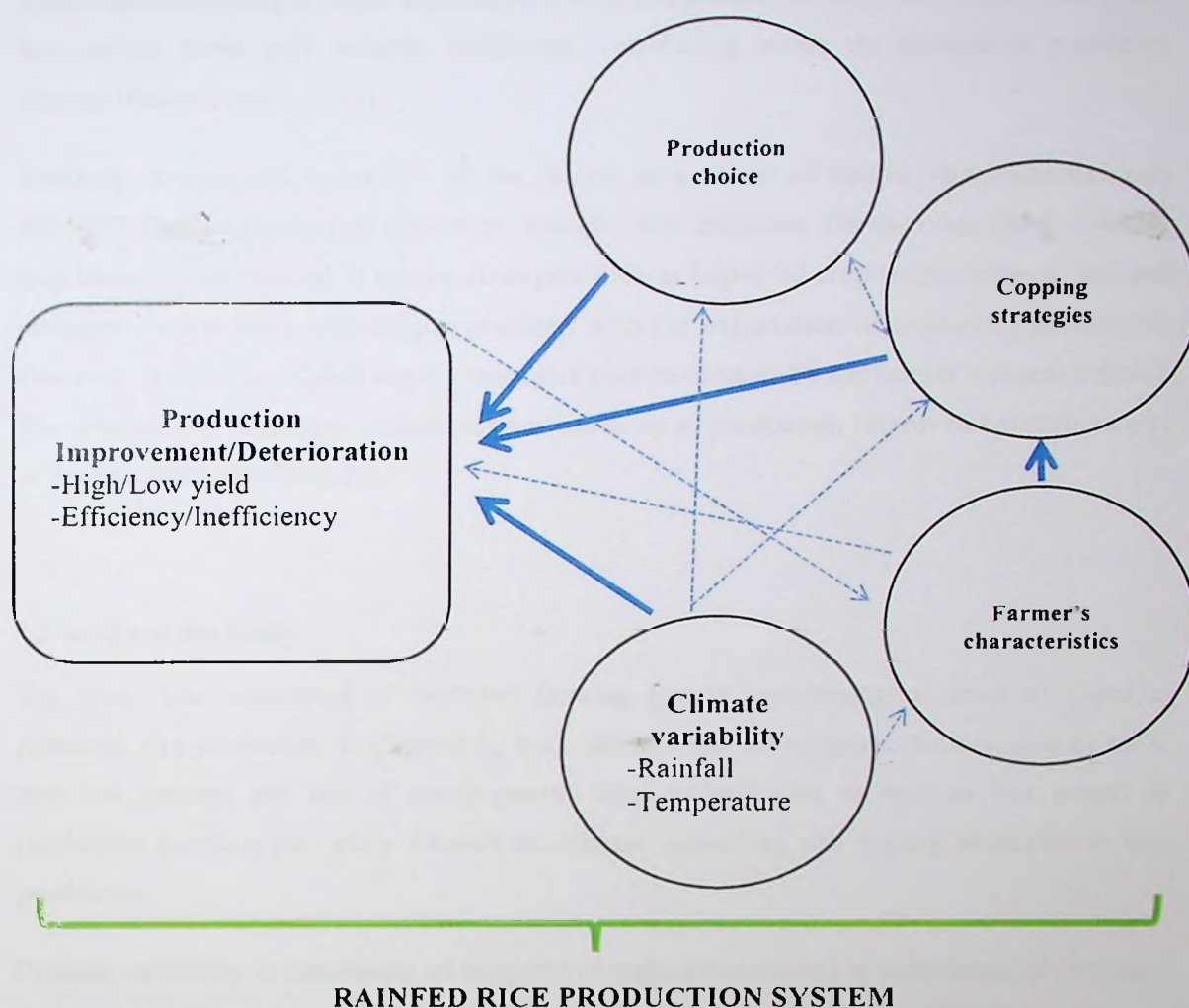


Figure 1.1: Conceptual framework of rice production system

Accordingly, rice production system is conceived as an interrelated dynamic system composed of many sub-elements including the farmers' characteristics, production characteristics (inputs and production practices), and environmental factors (climate). In production processes, observed output is often the result of a series of economic activities (transformation of inputs into outputs) such that the sub-elements must perform to their equilibrium (being efficient) in order to obtain optimal production. However, climate variability in terms of changing rainfall patterns and temperature conditions is a random external factor/a factor of the biophysical environment that interact with the natural

production system. Consequently, mismatch between the amount of rainfall and temperature conditions and timing of input application affects the production function. It is for this reason that certain farms may become inefficient / producing inside the production possibility frontier (Hughes *et al.*, 2011).

Similarly, managerial behaviour of the farmer as a result of his/her characteristics may directly influence production efficiency through their decisions. On the other hand, a farmer may choose to adopt a set of coping strategies such as improved crop technologies or soil and moisture conservation technologies/practices with the expectation of improving production. However, the choice of such coping strategies may be dictated by the farmer's characteristics. The relationship, therefore, contributes and sums up to production improvement (efficiency) or deterioration (inefficiency).

1.7 Scope of the study

The study was conducted in Northern farming system agroecological zone of Uganda. Although rice production is affected by both climatic and non-climatic factors such as soils, pest and disease, low use of new/improved crop technologies as well as low access to production services, this study focuses on climate variability and coping strategies in rice production.

Climate variability is considered as temporal changes (mean state) in intra-seasonal and inter-seasonal distribution of rainfall and temperatures during crop growth period (Climate literacy, 2009; IPCC, 2012). In this study, focus is on variability rather than change for two reasons: first, Uganda is experiencing variability in seasonal distribution patterns and onset of seasonal rainfall and temperature (GoU, 2007; Mubiru *et al.*, 2012; Caffrey *et al.*, 2013; Kansiime *et al.*, 2013). Second, climate change studies require data stretching over 30 years which is lacking in Uganda given that rice is relatively a new crop (Kansiime *et al.*, 2013). As a result, this study is limited to strategies (coping strategies) generated by the farmers themselves within the farming community and not those that have been introduced (adaptation).

Analysis was limited to the population of rice farmers. Data covered production seasons of 2013 to 2016 based on rice growing season. Season refers to the period between planting to

harvest of rice which falls in either the first rains (March/April and June) or second rains (August and October). The scope of analysis stops at production value chain.

1.8 Organization of the thesis

This thesis is organized in monograph format and is composed of seven chapters. Chapter One introduces the study and includes background information, statement of the research problem, objectives, research questions, justification of the study, conceptual framework and scope of the study. Chapter Two presents literature review of agriculture in Uganda, agroecological zones and farming systems of Uganda, rice production characteristics, effects of climate variability on crop production and coping strategies. Chapter Three consists of the research methodology which includes a description of the study area, study design and general overview of data collection and analysis. Chapters Four to Six contain the findings based on the specific objectives: Chapter Four focuses on characteristics of rainfed rice production while Chapter Five dwells on the effects of climate variability on rainfed rice production. Chapter Six examines the coping strategies to climate variability and Chapter Seven provides general discussion, conclusions and recommendations.

1.9 Papers published from this thesis

The following papers were published using data from this thesis:

- 1) Akongo, G. O., Gombya-Ssembajjwe, W.S., Buyinza, M., and Namaalwa, J.J. (2018). Characterisation of rice production systems in the Northern agro-ecological zone, Uganda. *Journal of Agricultural Science*, Vol. 10, No. 1, pp. 272-282.
- 2) Akongo, G. O., Gombya-Ssembajjwe, W.S., Buyinza, M., Elepu, G., Namaalwa, J.J., Bua, A., and Nabanoga, G. (2019). How climate variability influence rainfed rice production frontier: Northern agroecological zone of Uganda. *Journal of Economics and Sustainable Development*. Vol. 10, No.14, 2019, pp. 90-98.

CHAPTER TWO

LITERATURE REVIEW

2.1 Agriculture in Uganda

The available information shows that performance of the agriculture in Uganda has not been impressive since 1997 despite of its importance to the economy (GoU, 2010a, 2010c). As such, agricultural sector's share in total Gross Domestic Product (GDP) has declined from 42% in 2001 to only 23.5% in 2016. The decline in agricultural performance has been due to a number of factors including: weather changes (mainly drought and erratic rains); crop pests and diseases, declining soil fertility; poor extension access and changes in domestic and international commodity prices (NARO, 2018). Despite the bottleneck in the sector, agriculture remains the mainstay of the country's economy and hence the driver of economic growth, food security, income enhancement and employment especially in rural Uganda. Consequently, its importance to the economy has attracted a number of development policies and programmes which among others included: the Plan for the Modernization of Agriculture (PMA) launched in 2002 (GoU, 2004).

PMA was a multi-sectoral policy framework for agriculture and rural development consisting of seven pillars (research and technology development, national agricultural advisory services, rural finance, agro-processing and marketing, agricultural education, physical infrastructure and sustainable natural resource utilization and management) (GoU, 2004). One of the achievements under PMA was development of new rice varieties (NERICA) and promotion of upland rice cultivation throughout the country through efforts of then Uganda's Vice President Professor Gilbert Bukenya. However, PMA was characterized by implementation gaps at the ministerial and agency level. Nevertheless, the plan has been carried forward using line ministry (Agriculture, Animal Industry and Fisheries) strategies and national programs such as Operation Wealth Creation (program for input distribution), extension support, rehabilitation of irrigation schemes and rural infrastructure, among others.

The manifestation of these programmes and strategies includes increase in total share of land for rice by 10.3% of the total area under food crops, i.e., total acreage under rice cultivation increased from 80,000 hectares during 2002 to 95,515 hectares as of 2016 (UBOS, 2003, 2017). Total production also increased from 120,000 to 214,910 metric tons during the same period. However, non-linear growth in yields per hectare was observed during the same

period. For instance, yield declined from 1.5 t ha⁻¹ during 2002 to 1.4 t ha⁻¹ during 2007. However, the decline was contrary to what the country expected since improved new varieties of upland rice was being popularised. One of the reasons for this could have been poor adaptability of the new varieties to rainfed upland condition of certain agroecological zones. Negative variability in climate or were still learning and adjusting to rainfed upland rice production. A peak was reached 2008/2009 seasons (2.6 t ha⁻¹) and thereafter, a downward trend occurred until 2016 (2.3 t ha⁻¹), Appendix 1.

2.2 Characteristics of rice production

2.2.1 Rice production systems

Rice is grown in a diversity of production systems broadly classified as irrigated, lowland rainfed and upland rainfed. About 93 million hectares of irrigated rice provide 75% of the world's production (GRiSP (2013). Global lowland rainfed occupies 52 million hectares and supplies 20% of production. Upland rainfed occupies 15 million hectares and contributes about 4% of the world's total rice production. In Africa rice is grown in both irrigated and rainfed systems with irrigated areas constituting 11% of the total rice area. In East and South Africa, irrigated area constitutes 25%, lowland rainfed is 60% and upland rainfed represents 15%. Much of the production in Uganda is under rainfed lowland (53%) and upland (45%) and only 2% of rice area is irrigated (GoU (2010a).

In Uganda, rice is grown throughout the country but the production systems are determined by the agroecological characteristics of each region (Odogola, 2006, UBOS, 2010; Haneishi, 2014). Haneishi's (2014) study on rainfed rice systems in five agroecologies in the country concluded that rice production systems are dictated by the agroecological condition in which it is grown. The country's agroecological zones include: Western Rangelands, Eastern Highlands, Northern Moist Farmlands, West Nile Farmlands, South Western Highlands, Southern Rangelands, and Northern farming system (Northern agroecological zone) (NARO, 2018). Rainfed rice cultivation is spread throughout the country with lowland dominating eastern region and upland in western region (Odogola, 2006; Haneishi, 2014). Exceptional areas where rice is not cultivated include low rainfall areas of North-eastern and South-western dryland (pastoral system) as well as highland ranges which have very cold climate. Northern agroecological zone practices both lowland and upland rainfed systems which are

spread throughout the 17 districts. Lowland rainfed cultivation is concentrated in the districts of Lira, Dokolo, Alebtong, Oyam, Otuke and Kole. Upland cultivation is done majorly in the districts of Gulu, Amuru and Nwoya.

2.2.2 Rice yields

Estimated potential rice yield under good growing conditions and management practice is on average between 5 and 8 t ha⁻¹ but different studies have reported lower averages under farmers' situation and geographical areas (Tsuboi, 2011). For example, GRiSP (2013) reported an average global yield of 4.43 t ha⁻¹, in Asia it was at 5.4 t ha⁻¹ while in West Africa yields average of 3 t ha⁻¹ are observed. In Uganda, Asiimwe (2009) and UBOS (2010) puts average yield at 2.5 t ha⁻¹ but it varies throughout the country, from 0.8 t ha⁻¹ (Central) to 1.6 t ha⁻¹ (Western), 1.7 t ha⁻¹ (Northern) and 3.6 t ha⁻¹ (Eastern region). Dissimilarities in yield performance in different regions of the country imply that rice yield is influenced by growing conditions within and between agroecological zones. Specific studies have also reported varying yield performance, e.g. Haneishi (2014) reported average yield of 1.8 to 2.7 t ha⁻¹ but with variations between agroecologies which he attributed to varied growing conditions inherent in rainfed cultivation. Higher yield when other factors were controlled (rainfall, land type and variety) was observed in north-west savannah grassland (Northern farming system agroecological zone). Miyamoto *et al.* (2012) reported yield of 3 t ha⁻¹ in Central region. However, Oonyu (2011) reported lower average yield of 1.9 t ha⁻¹ which he attributed to variations between plots within the scheme (2.5 t ha⁻¹) and those outside (1.6 t ha⁻¹) as a result of declining soil fertility, inability to control water use, low yielding varieties, and poor farming practices. From this review it is clear that yield performances are dictated by growing conditions of different agroecological zones in which rice is grown, production systems, climate, and production practices.

2.2.3 Production practices

GRiSP (2013) reported an average global acreage of rice as 1 hectare per household but 3.76 hectares in Nigeria in West Africa (Ajetomobi, 2009) while in Uganda, land devoted to rice is between 0.5 and 0.6 hectares (Asiimwe, 2009; UBOS, 2010; Haneishi *et al.*, 2013). Globally recommended seed rate according to GRiSP (2013) and IRRI (2015) is 30–40 kg ha⁻¹ for transplanted rice crop, 80 kg ha⁻¹ for machine drill and 100 kg ha⁻¹ for hand broadcast.

However, literature in Uganda have reported higher seed rates above the recommended rate, e.g. Asiimwe (2009), Miyamoto *et al.* (2012) and Haneishi (2014), respectively observed 154, 110 and 96 kg ha⁻¹. This is a sign of wastage of seed inputs among Uganda rice farmers. On utilisation of labour inputs, Miyamoto *et al.* (2012) reported 466 man-days of labour ha⁻¹ in rice. Asiimwe (2009) also observed high labour intensiveness (1136 person days) where weeding was more labour demanding followed by land preparation and harvesting. The authors (Asiimwe, 2009 and Miyamoto *et al.*, 2012) also observed variation in labour usage between men (456 days) and women (586 days). Women were more involved in planting, weeding and harvesting while men took on land preparation and bird scaring. Earlier report by Odogola (2006) also showed more involvement of women than men in rice production activities. On contrary Barungi and Odokonyero (2016) pointed out dominance of men throughout the rice value chain including labour participation. They also observed that women were not taking rice as an economically viable enterprise.

There is evidence of low usage of conventional inputs especially fertilizer and pesticides in developing countries. For instance, Asiimwe (2009) reported low utilisation of conventional inputs in which application rates for fertilizer and herbicides were only 0.01 to 9.7%, respectively. Barungi and Odokonyero (2016) reported low use of fertilizer at 18% while Haneishi *et al.* (2013) observed low fertilizer usage between 14 and 17% and herbicide between 12 and 15%. According to Odogola (2006), only 11% of the farmers in the Northern agroecological zone used herbicides in weed control, 12.6% apply inorganic fertilizer while 12% and 5% of rice farmers respectively use animal traction (animal draught power) and tractor in land preparation.

IRRI (2015) documented 12 key steps in rice production as a guide for farmers. The steps include use of crop calendar, choosing suitable variety according to the biophysical growing conditions, use of quality seed, ploughing seedbed at least twice, and weeding within the first 20–50 days after crop establishment. Besides IRRI (2015) technical guideline, a number of studies have also reported production practices. For example, Odogola (2006) noted varying ploughing frequencies before planting (7% ploughed once, 61% twice, 28% thrice and 4% four times). He also noted that essential difference in numbers of times a field was ploughed before planting was largely dictated by environment in which rice was grown. For instance, 68% ploughed once or twice in the upland while 32% ploughed thrice or even four times in the lowland. Planting methods used were drill (62%), dibbled (12%), broadcasted (19%), and

transplanted (7%) rice. Weeding frequency was reportedly done twice (88%), thrice (9%) or none (3%). Elepu and Dalipagic (2014) reported use of cropping calendar in which rice is grown in two seasons in Northern agroecological zone (first season is from March to July and second season commenced from August to December). The study also noted that diversities of varieties grown were dependent on the production system. Hancishi (2014) and Barungi and Odokonyero (2016) reported two prominent rice varieties; NERICA 4 (64%) for upland and SUPA (50%) for lowland. However, both studies including (Odogola, 2006) pointed out high use of local rice varieties (74%) and recycled seeds (81 to 85%). Otherwise, the review point to one fact that production practices adopted by rice farmers will have implication on the final output from rice.

2.2.4 Efficiencies (inefficiencies) in rice production

Hasnain *et al.* (2015) examined technical efficiency of Boro rice production in Bangladesh, using a stochastic frontier model and reported mean technical efficiency of 89.6% implying inefficiency gap of 10.4%. Ajetomobi (2009) analysed productivity of rice in Economic Community of West African States (ECOWAS) using both data envelopment analysis (DEA) and stochastic frontier model (SFM) and found that farmers were producing close to the frontier at 99% implying that inefficiency gap was only 1% (this was the highest efficiency level recorded in the literature reviewed). However, the author observed negative contribution of fertilizer output (-0.052) but the rest of the inputs had positive effects. In addition, positive technical progress (at 12%) was observed between 1961 and 2005 as well as increasing returns to scale technology (RTS at 1.34).

In East Africa, Omondi and Shikuku (2013) analysed technical efficiency of rice farmers in Kenya Ahero Irrigation Scheme and observed inefficiency gap of 18% (mean technical efficiency was 82%). The highest elasticity was reported on labour but seed and cost of chemical had negative effects on rice production. They found out that gender of the farmer, experience and higher income reduces inefficiency in production while distance to the market increases inefficiency. In Uganda, Asimwe (2009) examined technical efficiency of upland rice in south western Uganda where he observed increasing RTS (1.23) but high output depended on land. Mean technical efficiency was 61% creating inefficiency gap of 39% (efficiency ranged between minimum of 12% and maximum 89%). The author also observed reduction in inefficiency as education level increases but experience and extension increase

inefficiency level in rice production. Hyuha *et al.* (2007) analysed profit inefficiency in rice production in eastern and Northern Uganda (Northern agroecological zone). The authors found negative relationship between inefficiency and education, access to extension, credit, experience and specialization. Although Miyamoto *et al.* (2012) did not use stochastic frontier approach, the researchers examined determinants of NERICA yields in central region where the yield function revealed positive contribution of inputs to productivity. A unit increase in seed, fertilizer and labour increased output, respectively, by 8, 46 and 9 kg ha⁻¹ but continuous planting in the same fields reduced yield by 130 kg ha⁻¹.

2.3 Climate variability and crop production

2.3.1 Effects of climate variability on rice production

Mubiru *et al.* (2012) assessed climate risk and uncertainty in crop production in Uganda. The authors found higher variability in onset of rainfall than withdrawal. For instance, withdrawal dates are not conditioned on start dates, thus making the growing season shorter. As a result, the authors observed decrease in the number of rainy days during March to May rainy season (during critical period of crop growth) implying that crops grown in this season are prone to climatic risks. According to the authors, intra-seasonal variations revealed a decreasing trend in rainy days and amount during the months of April and May yet these are the critical months of crop growth. Their analysis further revealed an increase in temperature, with the lower limits of the ranges of daily maximums increasing faster than the upper limits.

Kansiime *et al.* (2013) used regression analysis to determine the magnitude, direction and trends in annual and seasonal rainfall in eastern Uganda. The authors reported variation in mean annual rainfall (1374-2058 mm) and seasonal rainfall (522-905 mm). Coefficients of variation for both annual and seasonal rains were less than 30%. Subjective information revealed over 90% of the farmers perceived change in rainfall pattern in the last 15 years. As such variability was reported in onset, amount and intensity of rainfall within a season as well as shifts in seasons.

Mwaura and Okoboi (2014) also showed that annual rainfall varied in cyclical pattern over the years. Between 1981-1985, 1991-1992 and 2002-2004, rainfall received was below long-term annual average of 1251 mm higher amount above long-term average was received

between 1986-1990 and 1993-2001. The study also revealed that variation in long-term mean rainfall and temperature affects crop production.

Although the relationships between conventional inputs (land, seed, labour and capital) and rice production are well emphasized in literature (Hyuha *et al.*, 2007; Assimwe, 2009; Miyamoto *et al.*, 2012), these studies did not consider moisture (rainfall) and warmth (temperature) as critical inputs in rice production. There are only a few studies which have directly included climate variables (rainfall, temperature and humidity) as inputs in production function. Hughes *et al.* (2011) estimated climate adjusted production frontiers for the Australian cropping industry. The authors found positive association between rainfall and rice production but negative association with temperatures. However, the gaps in regards to this current study arise from the fact that it was none rice focus. In Asia, Tazhibayeva and Townsend (2012) investigated impact of climate change on rice yields in Thailand. Using three climate change scenarios the authors observed yield reduction of 3.7% (mild increases in temperature and rainfall), 3.8% (neutral) and reduction by 2.8% (more extreme temperature increases and less rainfall). Shakoor *et al.* (2015) used Vector Auto Regression (VAR) model to investigate impacts of climate variability on rice production in Pakistan. The authors observed increases in rice production by 7%, 6% and 3%, respectively, due to variations in mean temperature, minimum temperature and rainfall. In contrast, variation in maximum temperature reduced rice production by 1.7 to 2%. Simulated increases in temperature from 2 to 4°C then 4 to 5°C, respectively, reduces yield by 8 and 11.5%. Conversely, simultaneous increases in rainfall from 5 to 10% then 10 to 15% would reduce yield by 0.3% by 2030. Ali *et al.* (2017) also in Pakistan observed negative effects of rainfall and minimum temperature on rice crop but rising maximum temperature improved rice production.

On the African continent, Ajetomobi *et al.* (2011) used revenue approach to estimate effects of climate change on net revenue of rice in Nigeria. They also made projection of future increase in temperature by 2°C and decline in rainfall by 5% and reported reduction in rainfed revenue, respectively, by 11.7% and 65.4%. Simultaneous increase in temperature (+2°C) and decrease in rainfall (-5%) reduces rainfed revenue by 52.4%. Within East Africa, Rowhani *et al.* (2011) examined cross-sectional and temporal attributes of climate dataset using linear mixed model in Tanzania. The study revealed that climate variability during growing season was an important factor for crop yields. A projected temperature increase by

2°C drastically reduced rice yield (6%) while increase in rainfall by 20% over the same period increased yield by 1.7%.

In Uganda empirical literature is lacking to the extent that only Hancishi *et al.* (2013) has included rainfall as an additional variable in the production function where the authors found an increase in rice yield by 1.2 kg ha⁻¹ due to a 1 mm increase in rainfall. Few other studies have also documented the effects of climate variability on rice production in Uganda (UBOS, 2010; Caffrey *et al.*, 2013; Barungi and Odokonyero, 2016; EPRC, 2016). Caffrey *et al.* (2013) observed that variations in rainfall patterns as well as increases in temperature will render growing of rice almost impossible by 2030. In fact, the year to year variations in rainfall can exceed 30% of the total annual rainfall in some locations. Similarly, onset of rainy season can shift by 15-30 days and total duration of the season can change by 20 to 40 days. Rice was labelled among the likely affected crops but the study also revealed that most of the affected population lacked adaptive capacity including rice farmers in Northern agroecological zone. UBOS (2010) reported that 30% of farmers were affected by floods, 92% had experienced drought and 54% had lost crops to droughts, 41% were affected by erratic rainfall while 47% experienced hailstorm. EPRC (2016) analysed risks and uncertainty from climate change along rice value chain and found floods due to heavy rains a constraint to yield, seed quality and delivery systems. In a related study, Barungi and Odokonyero (2016) analysed challenges along rice value chain and reported weather uncertainties (particularly heavy rains and prolonged drought) as a major challenge.

The rest of the empirical literatures in the country are on none rice crops: Wasige (2009) reported future decline in crop yield (maize) by 10-50% but irrigation may boost grain yields by 35-73%. Kikoyo and Nobe (2016) projected reduction in maize yields by 4.7% in fast warming-low rainfall climates and an increase by 3.5% in slow warming-high rainfall regions by 2050. Lazzaroni and Bedi (2014) examined impact of weather variability on food consumption in Uganda where they found negative susceptibility of consumption to rainy days and maximum temperature (a 1°C increase is associated with a 10-12% reduction in consumption). However, interaction between rainfall and maximum temperature using a 4% increase in rainy days or 8% increase in mean rainfall is enough to undo the negative effects of temperature.

2.4 Coping strategies to climate variability

2.4.1 Coping strategies

In Uganda, Odogola (2006) observed absence of viable options to mitigate drought and floods in rice production. His report revealed that 69% of the farmers did not have remedy for drought and 29% had no copying strategy for floods, 23.6% followed seasonal calendar, planted timely, respondents who made bunds, maintained drainage and regulated water constituted 31%, shifted rice fields to lowlands (0.5%) and mulched (0.2%). Among the recommendations of the study was the need to determine suitable rice growing areas in light of recurrent droughts and water stress given geographical ecology for rice growing. Separately Barungi and Odokonyero (2016) recommended the need for irrigations to sidestep the effects of drought conditions; and to put in place water control and conservation measures.

Okonya *et al.* (2013) analysed farmers' perception of climate change and coping strategies in six agroecological zones where they reported 99% of households had experienced climate change in the last 10 years. Drought and floods had the highest impact on crop production while coping strategies included diversification and digging drainage channels, planting at onset of rains, pesticide/fungicide application and improved varieties (high-yielding, early-maturing, drought-tolerant, pest and disease resistant varieties).

2.4.2 Determinants of coping strategies

Mabe *et al.* (2012) examined effects of household characteristics on farmer adaptive capacity in rice production in Ghana. The study reported that 81% of the variations in rice output were explained by the farmer adaptive capacity. The average adaptive capacity ranged between 0.66 and 1 while over 70% of the farmers had moderate to high degree of adaptive capacity. Ndamani and Watanabe (2015) also in Ghana investigated determinants of farmers' adaptation to climate change. The study revealed that 67% of farmers who adapted used crop diversification, planting date, crop varieties and irrigation, among others. Results of the logistic regression indicated that education, information, household size, credit, income, associations and market promotes adaptation while experience and being female heads of household limit adaptation.

Oselebe *et al.* (2016) assessed perceptions of climate change and climate variability, impacts and adaptation strategies among rice farmers in Nigeria. The study noted low use of coping

strategies with only 38.6 and 30.4% of the farmers using timing of planting and agrochemicals, respectively. Constraints to adopting coping strategies included lack of subsidies and credit. In East Africa, Mugula and Mkuna (2016) studied farmers' perceptions on climate change impacts in different rice production systems in Tanzania, and found that socio-economic factors such as age, education, family size and main livelihood activities affected adaptation and coping strategies of rice farmers. Shikuku *et al.* (2017) similarly investigated smallholder farmers' attitudes and determinants of adaptation to climate risks in East Africa (Uganda inclusive). The result of the study showed that farmers' attitudes favoured introduction and change to new crop varieties and change of planting date but did not favour adoption of water management practices. Associations and credit access promotes adaptation.

Bomuhangi *et al.* (2016) investigated intra household level decision-making in two rural districts in the Mt Elgon region in Uganda. The study revealed that coping and adaptation decisions within households are done either as sole or joint decisions by the head or spouse. Guloba (2014) analysed adaptation to climate change and climate variability base on gender and welfare perspective. The author reported that climate change is observed from the altered rainfall, temperatures and onset and cessation of rainfall patterns from natural expectations. However, adoption of adaptation strategies by the farmers were influenced by age, distance to markets, land tenure system, area of residence, region, and off-farm employment and agroecological zones. Similarly, Okonya *et al.* (2013) found that gender of household head and size of the household was important determinants of adaptive strategies in Uganda. Although Okonya *et al.* (2013) and Guloba (2014) both studied determinants of adoption of coping strategies in the country, both studies were none rice base. In addition, no further attempts were made in both studies to assess contribution of these strategies as mitigation measures.

2.5 Conclusion and implications

The reviews are made along the three study objectives while incorporating issues pertinent to this study, i.e., performance of agriculture in Uganda with due attention given to rice, rice production characteristics, rice production efficiency, climate variability, trends and effects on rice production and coping strategies to climate variability. In summary, the following featured:

- i) The review confirmed that persistent decline in performance of the agricultural sector is threatening its central role as the driver of the country's economic growth, food security, income enhancement and employment. Climate variability was cited as one of the key drivers of poor performance of agriculture, rice inclusive. Climate variability was viewed as untimely onset, inadequate and poorly distributed rains and raising temperature.
- ii) The review also indicated that rice growing is spread throughout agroecological zones of the country but production intensity is dictated by the agro-climatic condition which further determine production systems. Most importantly cited as part of a rice production system are climate (rainfall and temperature conditions), rice producers and rice production practices. Each of the elements of a rice production system differ or vary between the different production systems, seasons and years and therefore affect rice production differently. Therefore, their level of impact on rice production is determined by the agroecological zone and production system in which rice cultivation is taking place.
- iii) Subsequently, poor performance of rice yields below attainable average under good management conditions are reported in the literature. In addition, dissimilarities in average rice yields between agroecological zones, production systems, seasons and years are also cited, relatively lower average yields are reported in Northern agroecological zone. Furthermore, the review acknowledges the fact that Northern agroecological zone possess potential for rice production in reference to its second position in the country.
- iv) The review also acknowledges the fact that unfavourable conditions within rice growing households and unfavourable climatic conditions inherent in the rainfed cultivation are suggested causes of shortfall in outputs from its most efficient production level. Noted in the review are inadequate, erratic and unreliable rainfalls as well as unmatched temperature conditions within crop growth requirements. Over or low input application in rice production including labour, seed and agrochemicals are reported as constraints to rice production. Similarly, some of the characteristics embedded in the rice growing households such as age, experience, gender, wealth, education and access to services were suggested hindrance to rice production efficiency.
- v) Literature has also reported a number of coping strategies used by farmers in a bid to counter effects of climate variability in crop production. Most commonly cited strategies were; changing crop varieties, timely planting, shifting crop fields to lowlands, irrigations,

water control and conservation measures. While some of the strategies have proven successful in accordance with their set objectives, others have reportedly failed as cited in the literature.

- vi) The literature cited low application of some of the coping strategies and hence a number of reasons advanced were related to farmers' characteristics and institutional factors such as access to extension and credit services, wealth, age, education and gender.

Issues identified in the review have a number of implications and thus moving forward;

- i) It is important to understand the different rice production systems in order to map out dissimilarities associated with climatic conditions (rainfall and temperatures), rice growing households, production practices, rice yields and production constraints.
- ii) There is also need to investigate whether rice farmers within the agroecological zone of Uganda are producing efficiently given over or under application of inputs exhibited in the literature.
- iii) Whether variability in climatic factors cited are linked to poor yield performance and dissimilarities in yields between rice production systems and between agroecological zones as cited.
- iv) Literature has cited a number of coping strategies used in other countries; however, there is need to identify coping strategies farmers are using in the context of the different agroecological zones of Uganda, ascertain contribution of each strategy towards crop production enhancement and examine contextual factors which determine their application.

CHAPTER THREE

METHODOLOGY

3.1 Study area

3.1.1 Size and location

The study was conducted in the Northern farming system agroecological zone of Uganda. The Northern farming system AEZ lies between Latitude 03°80' N and Longitude 33°00' E (see Figure 3.1) with elevations varying between 600 and 1,200 meters above sea level (GoU, 2012). The Northern farming system AEZ is bordered by South Sudan in the north. The neighbouring agroecological zones includes West Nile farmlands and Lake Albert Crescent in the west, Lake Victoria Crescent in the south and Northern moist farmlands in the east. The agroecological zone has 17 districts including Gulu, Amuru, Nwoya, Omoro, Kitgum, Lamwo, Pader, Agago, Alebtong, Amolatar, Apac, Dokolo, Lira, Kole, Otuke, Oyam and Kwanja. Overall, it covers an area of 42,021.2 km², representing 18% of total land area of Uganda (UBOS, 2016).

This agroecological zone was chosen because it is the second major rice producing area accounting for 21% of the national production after Eastern region whose production is at 67.2% (UBOS, 2010). Secondly, Northern Uganda compared to the rest of the country is more prone to climate variability (Wasige, 2009; Caffrey *et al.*, 2013).

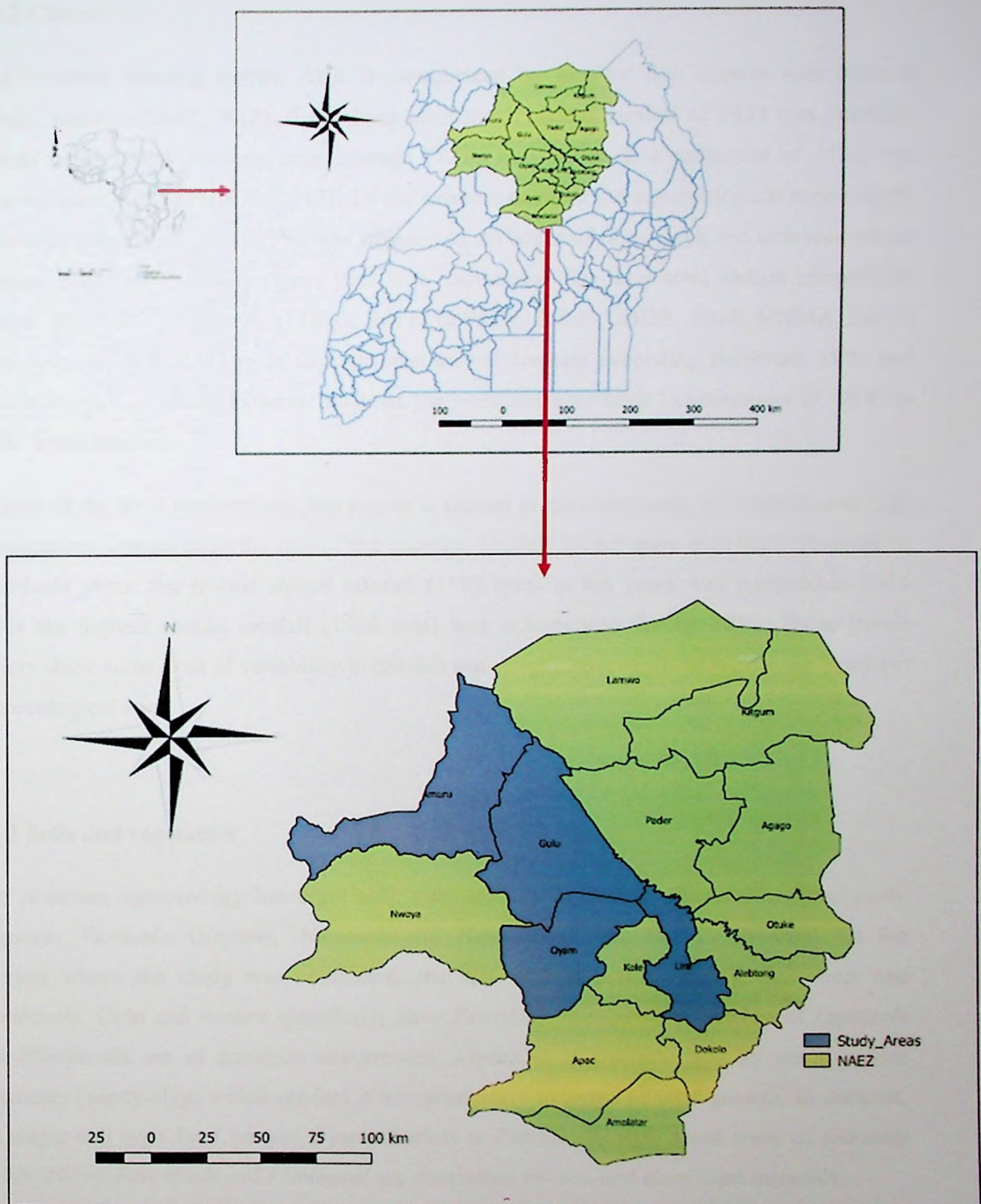


Figure 3.1: Map of Uganda showing the study area.

3.1.2 Climate

The Northern farming system AEZ is categorized by tropical dry climate with bimodal rainfall patterns (GoU, 2012). It has long-term mean annual rainfall of 1434 mm however; annual mean below its long term average (1278 mm which is a reduction of 11%) was received during 2016 (UBOS, 2017). To the extreme north of the agroecological zone slightly low mean annual rainfall of 1291 mm is received. In terms of rainy days, the area receives an average above 120 rainy days per year with variations. The long term annual temperature ranges from 17°C to 29.2°C (LDLG, 2011; GWIEA, 2013; UBOS, 2016; UNMA, 2017). However, the years 2012 to 2016 registered annual average exceeding minimum 19°C and maximum 30°C. To the extreme north of the zone extreme high temperatures of 18°C to 32°C is experienced.

In spite of the 2016 performance, the region is known to have relatively low rainfall and high temperatures compared to the rest of the country. Unclear trends have also been observed in the recent years: the lowest annual rainfall (1197 mm) in ten years was received in 2011 while the highest annual rainfall (1926 mm) was experienced during 2013. These trends clearly show some kind of variability in rainfall and temperature received within the Northern agroecological zone.

3.1.3 Soils and vegetation

The Northern agroecology has eight soil types namely *Leptosols*, *Ferralsols*, *Plinthosols*, *Regosols*, *Vertisols*, *Gleysols*, *Arenosols* and *Histosols* (IUSS, 2015). However, for the districts where the study was conducted, the soil type is predominantly *Ferralsols* and *Plinthosols*. Gulu and Amuru specifically have *Ferralsols* though some patches of *Leptosols* and *Plinthosols* are of common occurrences. *Leptosols* is characterized by many coarse fragments (sandy-clay) which renders it less productive in terms of crop growth. In contrast, the major soil type for Lira and Oyam districts is *Plinthosols* with some trace of *Gleysols* (IUSS, 2015). *Ferralsols* and *Plinthosols* are dominated by iron and aluminum minerals.

The predominant vegetation is tropical vegetation and intermediate savannah grassland with scattered trees in the eastern districts, many of which are the valuable Shea trees. The forests, wood and bush land coverage is 9,921.2 km² (23.6%), grassland is 5,437.5 km² (12.9%),

water bodies and wetland coverage is 2,014.0 km² (4.8%), mountainous and hilly areas is 37.3 km² (0.1%) while cultivatable land constitute 24,610.8 km² which is 58.6% of the total land (GoU, 2012; UBOS, 2016).

3.1.4 Demographic and socio-economic characteristics

The Northern farming system AEZ is home to the Acholi and Lango people with a total population of 3.6 million people of whom women constitute 51.5% (UBOS, 2016). Agriculture is the backbone of the economy and the major source of household income is sale of food crops. Over 81% of the population is engaged in subsistence agriculture. Agricultural households total to 533,321 while rice growing households are 230,279. Diversity of crops grown include cereals (rice, maize, millet and sorghum), root tubers (cassava and sweet potato), pulses (beans and peas), oilseed crops (simsim, groundnuts, soybean and sunflower) and cotton. Rice is rapidly becoming a major cash crop in the agroecological zone.

3.1.5 Rice production

Although rice production in the region picked-up immediately after eastern region, its production was confined in swamps around Lira and Dokolo districts. Its production only spread to upland areas years later especially after the introduction of upland varieties (Odogola, 2006). The crop is mainly grown for cash and the most common varieties grown are SUPA, KAISO and SINDANO (Odogola, 2006; Hyuha *et al.*, 2007; Hancishi, 2014). According to UBOS (2010), Northern region produced 39,022 metric tons of rice, an equivalent of about 21% of the national production.

3.2 Study design and sampling design

Both descriptive and exploratory designs were adopted since the study was intended to compare between groups and to show the relationships between variables. The research approach was both qualitative and quantitative in nature where qualitative approach encompassed descriptive analysis while quantitative approach employed econometric models.

The study population consisted of rice farmers from both lowland and upland rainfed production systems. Multiple-stage stratified sampling procedure was used to identify the farmers from the two rainfed systems as indicated in Table 3.1. From each system, two leading rice growing districts were identified based on proportion of farmers producing the crop. Upland production is commonly practised in the districts of Gulu, Amuru and Nwoya. Meanwhile lowland production characterises areas around Lira, Dokolo, Oyam and Alebtong and to a lesser extent Otuoke and Kole district. Gulu and Amuru emerged as district with high prevalence of upland production while Lira and Oyam constituted lowland districts. In each district, one major rice growing sub-county was selected based on the intensity of production. Lira had exception of two sub-counties since the swamp/lowland in which rice is grown spread across two sub-counties. From each of the sub-counties, two parishes were selected. Prior assessment of candidates to be included in the sample bases on rice production registry at the subcounties revealed that only 63% had history of continuous cultivation. Subsequently, only candidates with history of continuous cultivation were picked as potential candidate since the study was interested in capturing trends over the years. In general, 30 rice farmers per parish were randomly selected and interviewed. The final sample of 240 rice growing farmers was obtained using simple random sampling procedure.

The sample size was determined as described by CRS (2012), i.e. population at 95% confidence level and $e = 0.05$; $n = \frac{N}{1+N*(e)}$

Where:

N is population size

e is margin of error.

Table 3. 1: Sampling frame

Rain-fed system	District	Sub-county	Parish	Sample size
Upland	Amuru	Pabo	Gaya	30
			Kal	30
	Gulu	Bungatira	Atiaba	30
			Punena	30
Lowland	Oyam	Minakulu	Adel	30
			Aceno	30
	Lira	Agali Barr	Okile	30
			Alebere	30
Total	4	5	8	240

3.3 Data collection

Both primary and secondary data were collected. Primary data were collected directly at the farm level with the use of semi-structured questionnaire administered to the rice farmers between 2014 and 2016. During the first visit in December of 2014 an attempt to use farmers' recall ability to collect production data beginning 2010 proved unsuccessful due to low recall ability. The time frame was pushed to 2013 since farmers' recall ability was still high. Subsequently data were collected on production for 2013 and 2014 in that first visit. Again the second field visit was made in December of 2015 where we collected similar data from the same farmers for production seasons of 2015. Finally, the last visit was made in December of 2016. Meaning that for each of the 240 rice farmers, the same question was asked on a variable repeatedly for four production years making a total of 960 observations.

Data were collected on (1) Farmers' characteristics and access to rice production information and services. (2) Input utilisation, yields and crop production practice. (3) Farmers' views of climate variability and coping strategies. In respect to secondary data, climate variables included monthly rainfall, temperatures and heat stress days were retrieved directly from earth map (retrieved from ECMWF-ERA5 (The ERA5 global reanalysis). ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate) as opposed to data collected from weather station. ERA-5 was developed by the Copernicus Climate Change Service (C3S) and produced at the European Centre for Medium-Range Weather Forecasts (ECMWF). The data was retrieved from within the radius of 4square kilometres in order to provide the rest approximate of rainfall and temperature for each location. Subsequently, a new rainfall and temperature data were reconstructed by matching rainfall and temperature to each rice plot/household for the period between planting and harvest of the crop.

3.4 Data analysis

Data were analysed using STATA (version 15) and Excel STAT whereby descriptive and inferential statistics were performed. In the case of objective (i), descriptive statistics were used because it permits application of t-test to generate mean difference between the two production systems. In addition, the stochastic frontier model was applied to estimate efficiency. The same model was used for similar studies by Kumbhakar and Lovell (2000); Coelli *et al.* (2005); Ajetomobi *et al.* (2011); Hughes *et al.* (2011); Belotti *et al.* (2012). The

model helps to predict and estimate efficiency and also account for measurement error and other statistical noise in survey data. For objective (ii), qualitative analysis was performed to determine farmers' views of climate variability. Variability and trend analysis used coefficient of variations, rainfall anomalies, precipitation concentration index (PCI), parametric approach (least square regression) and non-parametric tests (Mann-Kendall and Sen's slope estimator). Influence of climate variability on rainfed rice production was determined using least square regression (fixed effects model). In objective (iii), descriptive statistics using frequencies and cross tabulation was used to identify coping strategies being used by farmers. Influence of farmers' characteristics on choice of coping strategies was determined using probit regression (Long and Freese, 2006). Finally, contribution of coping strategies to yields was determined through least square regression (random effects model). Detailed of analyses are described under each study objective.

CHAPTER FOUR

CHARACTERISATION OF RAINFED RICE PRODUCTION SYSTEM IN THE NORTHERN AGROECOLOGICAL ZONE

4.1 Introduction

Rice production in Uganda dates back to the 1940s but its production gained momentum in the 1970s in wetlands around eastern region of the country and it slowly spread to Northern region (Northern agroecological zone) and subsequently to the rest of the country (GoU, 2009; UBOS, 2010; Bua and Ojirot, 2014). Rice is basically produced in three systems namely: irrigated system, lowland rainfed system and upland rainfed system. Much of the cultivation is rainfed lowland (53%) and rainfed upland (45%) and only 2% is irrigated (Haneishi, 2014). However, production in the Northern farming system agroecological zone is currently done under two rainfed systems, i.e., lowland rainfed and upland rainfed.

In spite of the ever growing importance of rice cultivation as source of food and livelihood to the subsistence farmers, there is limited information on production characteristics of rainfed production systems in the country. Yet, this information is very crucial in prioritising support systems that align to different production systems and farmer characteristics. Available literature on production includes Odogola (2006), UBOS (2007, 2010), Kijima (2012) and Haneishi (2014). Odogola (2006) conducted a survey on the status of rice production, processing and marketing in Uganda. UBOS (2010) conducted detailed analysis of major crops (including rice) but the report was majorly on acreage and production by districts and regions of the country. Haneishi (2014) examined rice production structure and contribution to household income generation and stability, while Kijima (2012) conducted an analysis of constraints to expanding lowland rice production in the country and observed rapid increase in lowland cultivation and farmers are adopting good practices to maximize production. Hyuha *et al.*, 2007; Asimwe, 2009, respectively investigated profit efficiency and technical efficiency in rice production.

However, the limitation in these studies was lack of disaggregation of results by the rainfed production systems making it difficult to have comparative analysis between the lowland and upland systems. This study addressed the gap by exploring production characteristics of the different rainfed rice production systems in the Northern agroecological zone of the Uganda.

Secondly, by examining rice production in light of level of input minimisation and output maximization (technical efficiency).

4.2 Materials and methods

4.2.1 Data collection

Primary data were collected directly at the farm-level with the use of semi-structured questionnaire administered to the rice farmers. Questionnaire used is shown in Appendix 6. The questionnaire had four subsections. Subsection one asked about farmers' characteristics (gender, age and education of the household head, household size, labour and land holding, number of crops grown and income) and access to production information and services. In subsection two detailed questions were asked about input utilisation (area planted, quantity of seeds, labour usage, oxen/animal draught power, tractor and fertilizer and pesticides) and yields. Subsection three asked about crop production practice which included production calendar, activities, varieties and methods for carrying out activities. And subsection four contained open ended questions about constraints in rice production.

4.2.2 Data analysis

(a) Characteristics of rainfed rice production

To answer the research question on characteristics of rainfed rice production systems, descriptive statistics was performed. Cross tabulation for multiple comparisons and t-test for mean difference were done to establish the difference between the two rainfed production systems following procedure described by Haneishi *et al.* (2013). Variables for analysis included (1) farmers' characteristics, (2) yields, (3) production practices, and (4) production constraints.

(b) Efficiency in rainfed rice production

(i) Theoretical considerations and conceptual models

A production frontier represents the maximum output that can be produced from a given level of inputs. In practice, the 'best' farms are described as technically efficient only when they produce on the production frontier. Operationally, this study viewed production efficiency (technical efficiency) as optimum utilization of rice inputs to produce desired output. A

production possibility frontier (PPF in Figure 4.1) represents the maximum possible output that can be produced with a given level of inputs and the best available production technology at a particular point in time.

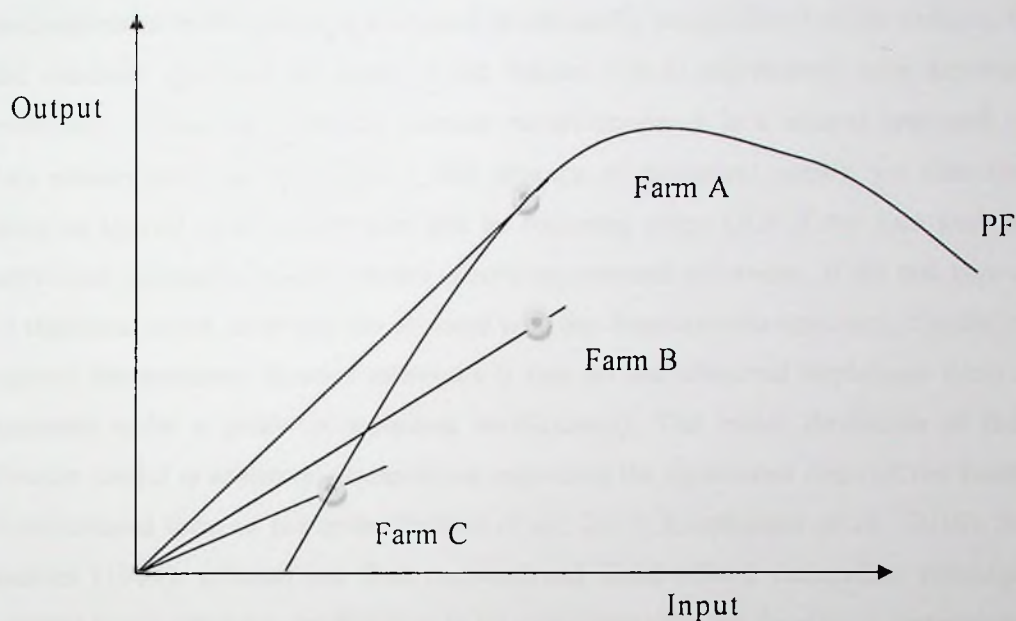


Figure 4.1: Production possibility frontier

The ratio of output to input is therefore represented by the slopes of the lines connecting individual farms with the origin. Such that each farm lying on the production possibility frontier are classified as technically efficient. For example, farms A and C are deemed to be technically efficient because they produce the maximum possible output given their input level. Contrastingly, farm B is technically inefficient because it lies below the frontier, and therefore produces less than the maximum possible output given its input level.

(ii) Stochastic frontier model and approaches to measuring efficiency

Approaches for measuring efficiency vary from non-parametric approaches (data envelopment analysis) to parametric approach (stochastic frontier analysis). The strength of stochastic frontier model is the ability to empirically test whether all decision making units are efficient

or not while taking statistical errors into account. It has the advantage of separating inefficiency effects from random effects (Coelli *et al.*, 2005). The stochastic frontier model provides a framework where production relationship is estimated also as a conditional average of outputs given inputs and other factors and any deviation from the frontier is decomposed into statistical noise and inefficiency. Importantly, the approach allows assumption of inefficiency to be tested (statistically insignificant result reduces the model to the classical approach (Ordinary Least Square (OLS) regression) with assumption of full efficiency. Thus, the stochastic frontier model approach is a natural approach which make two assumptions (no inefficiency and absence of statistical noise), yet also encompassing them as special cases, which can still be followed using OLS if the data and the statistical tests from stochastic frontier model cannot recommend otherwise. If the test supports absence of statistical noise, then one can proceed with the deterministic approach (the major criticisms against deterministic frontier estimates is that all the observed deviations from frontier are assumed to be a result of technical inefficiency). The major limitation of the stochastic frontier model is arbitrary assumptions regarding the functional form of the frontier and the distributional form of the error (Belotti *et al.*, 2012; Kumbhakar *et al.*, 2018). Schmidt and Sickles (1984), pointed out that conventional fixed-effects estimation techniques can be adapted hence allowing inefficiency to be correlated with the frontier regressors and avoiding distributional assumptions about u_i . However, the time invariant nature of the inefficiency term has been questioned, especially in presence of empirical applications based on long panel data sets.

The stochastic frontier model among others include the random-effects time-invariant inefficiency models of Pitt and Lee (1981) and Battese and Coelli (1988), the time-varying inefficiency models developed by Cornwell *et al.* (1990) and Lee and Schmidt (1993), the flexible model of Kumbhakar (1990), the inefficiency effects model of Battese and Coelli (1995) and the true fixed and random-effects models developed by Greene (2005).

This study adopted inefficiency effects model of Battese and Coelli (1995) extended to longitudinal data as follows:

$$y_{it} = f(x_{it}, \beta) + \varepsilon_{it} \quad i = 1, \dots, N, \quad t = 2, \dots, T \dots \dots \dots (4.2.1)$$

$$\varepsilon_{it} = v_{it} + u_{it},$$

$$v_{it} \sim N(0, \sigma_v^2),$$

$$u_{it} \sim F$$

Where: y_{it} denotes output of i^{th} production unit; x_{it} is a vector of input; β is the vector of technology parameters. The composed error term ε_{it} is the sum of a normally distributed disturbance (v_{it} and u_{it}). Where v_{it} , represents measurement and specification error, and a one-side disturbance and u_{it} , represents inefficiency associated with production (shortfall from maximal output dictated by the production technology), respectively (Kumbhakar and Lovell, 2000; Coelli *et al.*, 2005).

The distributional assumption on (F) is required for the identification of the inefficiency term such as Normal-Truncated Normal. Efficiency is measured as a ratio of actual output to potential output and thus from equation 4.2.2, technical efficiency can be computed as follows:

$$u_{it} = \eta_{it} u_i = \exp\{-\eta(t_{(i)} - T)\} u_i = \exp(-u_{it}) \dots \dots \dots 4.2.2$$

Where η is unknown scalar parameter and $t_{(i)}$ represents the set of (T_i) time periods involved for which observations for the i^{th} farm are obtained (Ahmad and Bravo-Ureta, 1996). Generally, inefficiency increases (efficiency reduces) over time when $\eta < 0$ and this implies production is below the maximum possible output. Whereas, production is on the best frontier/the farmer is producing maximum possible rice output for a given inputs (technically efficient) when $\eta = 0$. Efficiency increases (inefficiency reduces) when $\eta > 0$.

Three functional forms that have been used in estimation of production functions include transcendental, translog and Cobb-Douglas (Bagamba, 2007). However, translog and Cobb-Douglas are the two major functional forms widely used to examine production function relationships (Ajetomobi, 2009; Hughes *et al.*, 2011). The Cobb-Douglas functional form is popular due to its simplicity in interpretation and is frequently used (Bagamba, 2007).

(iii) Model specification

Taking the natural log of equation (4.2.1), a flexible production function was specified as (4.2.3) for quantifying output (Battese and Coelli, 1995):

$$\begin{aligned} output_{it} = & \beta_0 + \beta_1 plot_{it} + \beta_2 plot2_{it} + \beta_3 seed_{it} + \beta_4 labor_{it} + \beta_5 plotlabor_{it} \\ & + \beta_6 oxen_{it} + \beta_7 oxen2_{it} + \beta_8 plotoxen_{it} + \beta_9 tractor_{it} + \beta_{10} soil \\ & + \beta_{11} year + v_{it} + u_{it} \dots \dots \dots (4.2.3) \end{aligned}$$

Where; $\ln$ are natural logs; and β_s are unknown parameters. Plot (land), seed, labour, oxen and tractor are traditional inputs in crop production and as such they are expected to contribute to output improvement. Clay soil is associated with high productivity level as well as high water retention (good soil moisture); it is therefore expected to improve crop productivity. Although an inverse relationship is expected for high concentration of sandy to dandy loam soils because of low water retention capacity. Inclusion of soil factor was therefore, its inclusion in the model was to control for location effects. Time variable (years) was included to control for variations overtime.

(iv) Inefficiency model

Access to extension service and training in rice production are mechanisms for or platform for technology adoption and therefore it was expected to reduce inefficiency in production. This is because farmers gain more knowledge and skills as they learn and access better information to support production (Hyuha *et al.*, 2007; Kijima, 2012). Household income and income earned from rice production are motivations to the farmer to effectively carry out production activities in a profitable manner and is also a source of extra income to purchase productivity enhancing inputs. Diversification in terms of number of crops grown affects efficiency in production. Many crops are associated with resource allocation challenges where different crops are activities compete for the limited household resources including supervision. However, specializing fewer crops reduces inefficiency (Hyuha *et al.*, 2007). Longer growth duration is associated with high input and labour requirement to complete activities at the low end of crop growth. *Ceteris paribus*, inefficiency is expected to increase due to additional input and labour requirement. On the other hand, older farmers may offer unproductive labour due to old age.

The inefficiency effects model was thus specified as (4.2.4) to identify determinants of inefficiencies in rice production in rainfed systems (Battese and Coelli, 1995 and Greene, 2005):

$$u_{it} = \delta_0 + \delta_1 Extension_{it} + \delta_2 Training_{it} + \delta_3 HHIncome_{it} + \delta_4 Rice_income_{it} + \delta_5 Crops_{it} + \delta_6 Growth_{it} + v_{it} \dots \dots \dots (4.2.4)$$

Where;

- u_{it} represents inefficiency effects of the farmer i in time period t
- δ_1 is a dummy variable representing access to extension services by rice farmer;
- δ_2 is the dummy variable for participating in rice training;
- δ_3 is amount of income to the household;
- δ_4 represent proportion of income from rice to the total household income;
- δ_5 dummy variable representing number of crops grown access to extension services;
- δ_6 is dummy variable representing growth duration of rice crop;
- δ_s are unknown parameters to be estimated.

Two estimation procedures have been used by different studies to estimate inefficiency model, i.e., a one step and two step procedures. A two-step procedure was adopted as opposed to the one step procedure to account for determinants of inefficiency (Belotti *et al.*, 2012; Kumbhakar *et al.*, 2018). A two stage approach constructs and makes prediction of technical efficiency in the first step, and then regress inefficiency estimates on z in the second step (Jondrow *et al.*, 1982). Equation 4.2.4 was then introduced into 4.2.3 to establish influence of farmer characteristics factors on efficiency.

Table 4.1: Variables included in the production function estimates and relationships

	Parameter	Description	Relationship
Frontier model			
Output	-	Total rice output harvested (tons)	Dependent variable
Plot	β_1	Acreage under rice (Hectare)	+
Plot2	β_2	Acreage under rice (Hectare)	-/+
Seed	β_3	Quantity of rice seed planted Kilograms	+
Labour	β_4	Person days of labour used (Man-days)	+
Plot*labour	β_5	Interaction plot & labour	-/+
Oxen	β_6	Oxen days used	+
Oxen2	β_7	Oxen days used	-/+
Plot*oxen	β_8	Interaction plot & oxen	-/+
Tractor	β_9	Dummy (1=used tractor; 0=otherwise)	+
Soil type	β_{10}	Dummy (1 Proportion of area covered by clay (%age))	+
Years	β_{11}	Dummy (year 2013-2016)	-/+
Inefficiency model			
Extension access	δ_1	Dummy (1=yes; 0=otherwise)	-
Training	δ_2	Dummy (1=yes; 0=otherwise)	-
Household income	δ_3	Ugx	-
Rice income	δ_4	Proportion of rice income (%)	-
Number of crops	δ_5	Dummy (1= ≤ 4 crops; 0= ≥ 5)	-
Growth duration	δ_6	Dummy (1= ≤ 4 months; 0= ≥ 5)	-

(iv) Model implementation

Stochastic frontier analysis requires important assumptions for model selections. The likelihood ratio test ($LL = -2[\ln\{(H_0)\} - \ln\{L(H_1)\}]$) was used and the critical values are obtained from Kode and Palm (1995). The following tests were conducted: (1) Cobb-Douglas against Translog functional forms. The null was rejected in favour of flexible Translog functional form. (2) Assumption that each farm is producing on the frontier was also rejected. Otherwise, accepting the null ($H_0: \sigma_u = 0$) would reduce the stochastic frontier estimation to pooled OLS regression. (3) The assumption of time invariant efficiency (Battese and Coelli, 1988) was also rejected in favour of time decay technical efficiency (Battese and Coelli, 1992). (4) Assumption that variables included in the inefficiency effect model have no influence on the level of inefficiency ($H_0: \delta = 0$) and that technically efficient inefficiency effects were random was rejected. All statistical tests are provided in Appendix 3.

Panel data requires some diagnostic tests in order to check for reliability and validity of the data: (5) Test for normality to determine how likely it is for a random variable underlying the data set to be normally distributed using skewness and kurtosis (Sajwan and Chetty, 2018a). Skewness/Kurtosis tests for Normality both had p-value less than 0.05 indicating that the data is not normality distributes (6) Variance inflation factors (VIF) was used to check for multicollinearity had mean value of only 3.83 which is within the threshold of 10. (7) The

Breusch-Pagan/Cook-Weisberg test (Sajwan and Chetty, 2018b) revealed absence of heteroscedasticity ($\chi^2(1) = 2.67$; Prob > $\chi^2 = 0.1021$). (8) The Ramsey test for omitted variables confirmed could not be rejected.

The maximum likelihood estimation (MLE) procedure was adopted by applying *spanel* option developed to fit the model in STATA 15.0 software (Battese and Coelli, 1995; Belotti *et al.*, 2012). The programme first estimates maximum likelihood parameters of the model then make prediction of efficiency score at each data point. Prediction of efficiency was done via $\exp(-E(u|e))$ to determine whether farmers were producing efficiently. As a benchmark, a pooled cross-sectional model was estimated (Appendix 3). The likelihood function is expressed in terms of the variance parameters, $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / \sigma^2$.

4.3 Results

4.3.1 Characteristics of rainfed rice production systems in Northern farming system agroecological zone

(a) Characteristic of rice farmers

The result on characteristics of the different rainfed rice production systems in the Northern agroecological zone are summarised in Table 4.2. An average age of rice farmer was 38 years old implying that relatively youthful farmers are involved in rice production and this is a good indicator of youth empowerment. Farmers attained an average of six years of formal education. However, low level of education means that rice is mainly grown by farmers with low level of education. Yet formal education is associated with exposure and ability to access production services. Previous studies reported similar results (Hyuha *et al.*, 2007; Ajetomobi *et al.*, 2011).

The average family size was approximately six people and about three people contributed labour for rice production activities. The average land holding size was 3.4 hectares but the average holding in the lowland was 1.8 hectares while the value for upland was nearly tripled (5 hectares). This average land holding was higher than the national average of 1.1 hectare (UBOS, 2010). An average annual total income was 3.4 million Uganda Shillings while annual income from rice was 1.3 million Ugandan Shillings which is a third of the total income. Also, on average, farmers were growing approximately four crops per season. The number of crops grown could be a strategy to avoid total loss from seasonal variability in climate.

A total of 93% of the rice farmers were male headed households. Fewer female participating in the enterprise could be due to limited access to land. Secondly, women are more inclined to production of food security crops over cash crops. Low proportion of female farmers in rice confirms previous report by Barungi and Odokonyero (2016) that women are not considering rice production as an economically viable enterprise. However different views are held by gender experts, according to the scholars, women and youth have limited access to production resources and services due to power relations in a society and this probably explain low involvement of women in rice production (Okali, 2012).

A total of 45% of the farmers accessed various extension services in rice production and further analysis of frequencies of access revealed that they had 0.7 visits during the period of four years. In addition, 52% of the farmers participated in trainings and each of them attended 1.6 times during the four years. This result showed an improvement in access to training from the 12.6% Kijima (2012). It is also an indication of an improvement in knowledge of the farmers in rice production. About 40% of the farmers accessed credits up to 0.8 times during the period of four years. However, access to credit is still lagging as indicated by the decline from 44% (Hyuha *et al.*, 2007).

Table 4.2: Rice Characteristics of the respondent farmers

Variable	Pooled			Lowland			Upland		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Age	37.7667 (13.557)	18	73	37.7667 (13.5694)	10	73	37.7667 (13.5694)	10	73
Education	5.5667 (4.0599)	0	15	5.5667 (4.0637)	0	15	5.5667 (4.0637)	0	15
Household size	5.7708 (3.7472)	1	21	5.1083 (3.3967)	1	15	6.4333 (3.9617)	1	21
Land size (Ha)	3.401 (5.049)	0.125	40	1.7874 (1.4258)	0.125	10	5.0147 (6.6175)	0.4	40
Family labour	3.0458 (1.7408)	0	9	3 (1.7193)	0	8	3.0917 (1.7625)	0	9
Crops grown	3.65 (2.1841)	1	15	3.6917 (2.6097)	1	15	3.6083 (1.6565)	1	9
Total income (million)	3.3850 (3.7544)	0.1	34.02	2.8024 (3.6847)	0	34.02	3.9273 (4.0211)	0.1	34.2
Rice income (million)	1.3192 (1.3712)	0	10.8	1.0635 (0.9894)	0.015	7.29	1.8235 (2.4569)	0.045	29.4
Gender	0.9333 (0.2495)	0	1	0.9333 (0.2497)	0	1	0.9333 (0.2497)	0	1
Extension	0.4542 (0.4982)	0	1	0.45 (0.4980)	0	1	0.4583 (0.4988)	0	1
Credit*	0.4042 (0.4910)	0	1	0.4167 (0.4935)	0	1	0.3917 (0.4886)	0	1
Training*	0.5208 (0.4998)	0	1	0.5167 (0.5002)	0	1	0.525 (0.4999)	0	1

*Farmers attended training in rice production 1.6 times on average. *Number of access to extension services was 0.6 times

(b) Average rice yield per hectare

Results on yield obtained are provided for the pool data, production system, season and years in Table 4.3. For each category, the differences between the two production systems are highlighted. The average yield overall was 1.9 t ha⁻¹ but this varied significantly between the production systems. Lowland had the highest value at 2 t ha⁻¹ while the upland system showed comparatively low yield value of 1.7 t ha⁻¹. Judging from the values, the average within zone is still below the national average (2.5 t ha⁻¹), the global average (4.6 t ha⁻¹) and the potential average of 5 to 8 t ha⁻¹ (Luzi-Kihupi, 2011; FAO, 2017; UBOS, 2017). In the case of varieties, the lowland varieties (SUPA and KAISO) registered a higher average of 2.1 t ha⁻¹ while the upland varieties (NERICA and SINDANO) registered 1.6 to 1.9 t ha⁻¹. Yields from the different rice varieties are excluded from the table.

Table 4.3: Rice yield per hectare in the rainfed production systems

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
Pooled	1.8568	1.4274	0.3534	0.000	1.7664	1.9472
Lowland	2.0335	1.6235			1.8879	2.1791
Upland	1.6801	1.1752			1.5747	1.7855
Seasonal trend						
First season						
Pooled	1.8764	1.3897	0.4020	0.000	1.7804	1.9724
Lowland	2.0913	1.5984			1.9292	2.2534
Upland	1.6893	1.1478			1.5808	1.7979
Second season						
Pooled	1.7526	1.6144	0.2273	0.422	1.4939	2.0114
Lowland	1.8244	1.7025			1.4933	2.1555
Upland	1.5971	1.4089			1.1880	2.0062
Annual trend						
2013						
Pooled	2.0287	1.6968	0.5583	0.011	1.8129	2.2445
Lowland	2.3079	1.8729			1.9693	2.6464
Upland	1.7495	1.4552			1.4865	2.0126
2014						
Pooled	2.0383	1.5502	0.0134	0.947	1.8412	2.2354
Lowland	2.0450	1.5627			1.7625	2.3275
Upland	2.0316	1.5442			1.7524	2.3107
2015						
Pooled	1.7353	1.1010	-0.3198	0.024	1.5953	1.8753
Lowland	1.5754	0.9103			1.4109	1.7399
Upland	1.8952	1.2468			1.6699	2.1206
2016						
Pooled	1.6249	1.2448	0.2766	0.085	1.4666	1.7832
Lowland	1.7632	1.2996			1.5283	1.9981
Upland	1.4866	1.1766			1.2739	1.6993

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05, CI = 95%

Observations: Pooled = 960; Lowland = 480; Upland = 480; First season = 808, Second season = 152, Annually = 240

Performance of yield in respect to production seasons showed high average during the first season (1.9 t ha^{-1}). However, there was a notable yield variation between the two production systems during the first season (March to May), where lowland registered a significantly higher average of 2.1 t ha^{-1} while upland registered only 1.7 t ha^{-1} . Low yields were obtained during the second season (1.7 t ha^{-1}) but there was no significant difference between the two rainfed systems.

On annual basis, significant higher yields were obtained in 2013 (2.1 t ha^{-1}) after which a downward linear trend was observed through to 2016 (1.7 t ha^{-1}). During 2014 and 2015, farmers obtained 1.9 t ha^{-1} and 1.8 t ha^{-1} , respectively. Annual performance between the production systems also revealed variation. The lowland system exhibited higher yields than the upland system except during 2015.

(c) Rice production practices

(i) Input application

Area cultivated: An average area under rice cultivation was 0.63 hectares (Table 4.4). However, field sizes varied from 0.47 hectares in the lowland to 0.8 hectares in the upland system. Statistical test for mean differences in acreage between the two systems was significant. Variations in the plot size between two systems could be due to restriction of access to wetland by National Environment Management Authority (NEMA).

Table 4:4: Area cultivated to rice and seed planted per hectare in the rainfed systems

Group	Mean	Std. Dev	Diff	t	95% CI	
Area						
Pooled	0.6342	0.6399	-0.3326	-8.33	0.5936	0.6747
Lowland	0.4679	0.3472			0.4367	0.4990
Upland	0.8005	0.8024			0.7285	0.8724
Seed						
Pooled	105.3818	51.5206	26.6096	8.28	102.1186	108.6450
Lowland	118.6866	57.4626			113.5330	123.8402
Upland	92.0770	40.7131			88.4256	95.7284

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0.

P-value is significant at less than 0.05, CI = 95%.

Seed rate: Farmers used two methods of rice planting which include broadcast and transplanting. On average farmers planted 105 kgs ha^{-1} which exceeded recommended rate under broadcast (100 kg ha^{-1}). Recommended seed rate for line planting is $60\text{-}75 \text{ kg ha}^{-1}$ and transplanting method is $30\text{-}40 \text{ kg ha}^{-1}$ (Tsuboi, 2011; IRRI, 2015). Further analysis according to the production systems showed variation in amount of seeds planted with lowland using 119 kgs ha^{-1} and upland 92 kgs ha^{-1} . Overall test for mean difference between the two production systems was statistically significant. Consequently, low seed rate especially in the

upland system can result in low plant density while higher rate in the lowland is subject to wastage (inefficiency) and plant congestion. However, high seeds rate could also be a compensation strategy for poor germination or poor seed quality.

Labour usage in man-days per hectare: Overall, the total man-days used per hectare were 248 days. However, labour utilisation in the lowland system nearly doubled (307 man-days) the number of days observed in the upland system (192 man-days). Overall test for mean differences in labour usage between the two systems were statistically significant across all activities except weeding (Table 4.5).

Table 4.5: Labour inputs (man-days) per hectare used in rainfed rice production

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
Overall						
Pooled	248.9274	215.9486	115.6662	0.000	235.1851	262.6698
Lowland	307.3079	238.4647			285.7164	328.8993
Upland	191.6417	173.3547			176.0941	207.1892
Ploughing						
Pooled	72.2646	80.9478	26.1964	0.001	64.8559	79.6734
Lowland	82.5500	91.4412			71.7928	93.3072
Upland	56.3536	58.0169			47.8443	64.8629
Planting						
Pooled	36.1468	48.0860	11.6106	0.006	32.1007	40.1929
Lowland	40.8549	57.7611			34.5419	47.1680
Upland	29.2443	27.1796			25.6411	32.8476
Weeding						
Pooled	97.2998	103.9314	3.7713	0.584	90.5530	104.0466
Lowland	99.2597	100.9223			89.7928	108.7265
Upland	95.4884	106.7112			85.8674	105.1095
Bird scaring						
Pooled	119.7338	112.2393	69.9657	0.000	109.8119	129.6558
Lowland	145.3690	128.1722			131.1143	159.6237
Upland	75.4033	53.9381			67.4923	83.3144
Harvesting						
Pooled	59.5208	64.3773	-9.1854	0.084	54.3678	64.6737
Lowland	55.6605	54.9313			49.8773	61.4437
Upland	64.8459	75.2868			55.5241	74.1676

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05, CI = 95%.

In terms of activities, seedbed preparation (ploughing) and bird scaring took up most of the labour requirements in rice production. On average, seedbed preparation (ploughing) took 72 man-days overall. The lowland system involved 83 man-days while the upland system involved 56 man-days. The t-test for mean difference in man-days spent between the two systems was statistically significant. Planting had the least labour requirement (36 man-days) in comparison to the rest of the other activities in rice growing although this varied between the two production systems. The lowland required more man-days (41 days) for planting while the upland system used 29 man-days. Weeding required 97 man-days but statistically,

there was no significant difference in labour requirement between the two systems. Lowland system used 99 man-days while upland used 95 man-days. In contrast, bird scaring was the most labour demanding activity in rice growing (120 man-days) although this varied between the production systems. The lowland took more days (145 man-days) while the upland system took only 75 man-days. Harvesting of the crop used 59 man-days with the upland system requiring more labour (65 man-days) than the lowland system (56 man-days).

Type of labour used in rice production: Descriptive results for types of labour used during various production activities are shown in Table 4.5. Results revealed that both male and female contributed labour equally during rice growing overall although the upland system registered slightly higher percentage of the female labourers (51%). Participation of both men and women was an indication that men are taking up activities that use to be done by women (Odogola, 2006).

Source of labour: Labour for rice production was obtained from family and hired source. However, disaggregation of the two sources shows that family labour was most sourced (52%) as opposed to hired labour (48%). Comparison of sources according to the production systems indicated that up to 54% of labour used in lowland production was sourced from the family while 46% was hired. Regarding upland system, family labour was registered at 51% while hired labour was 49% in rice production.

Table 4.6: Source and gender of labour used in rice production

	Pooled		Lowland		Upland	
	Cases (n=960)	%	Cases (n=480)	%	Cases (n=480)	%
Source of labour						
Family	500	52	257	54	243	51
Hired	460	48	223	46	237	49
Gender of labour						
Female	484	50	238	50	246	51
Male	476	50	242	50	234	49

Oxen usage: On average farmers spent 10 oxen-days per hectare in land preparation for planting rice (Table 4.7). The lowland farmers used approximately 13 oxen-days while farmers in the upland used only seven oxen-days. At the activity level, 8 oxen-days were used during seedbed preparation; lowland system spent 10 days while the upland system spent only 5 days per hectare. During planting, farmers spent slightly over 4 days; lowland system needed 6 days while upland system took approximately 3 days to plant. However, variations in utilization of draught power could be due to soil types in both systems. Lowland has got heavier soils (clay-loamy) as opposed to lighter soils in the upland (sandy-loam) which

perhaps explains fewer days needed in land preparation using hand hoe. For uplands which have lighter soils, land preparation can be done easily.

Table 4.7: Oxen-days used per hectare in land preparation for rice production

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
Overall						
Pooled	10.0714	11.7373	5.1452	0.000	9.1531	10.9897
Lowland	12.5950	14.3853			11.0154	14.1747
Upland	7.4498	7.2673			6.6364	8.2633
Seed bed preparation						
Pooled	8.1753	8.9535	4.1523	0.000	7.4463	8.9042
Lowland	10.1230	10.6102			8.9353	11.3107
Upland	5.9707	5.8799			5.2701	6.6713
Planting						
Pooled	4.1250	4.9779	3.4026	0.000	3.6307	4.6193
Lowland	6.2603	7.2045			5.0818	7.4387
Upland	2.8577	2.1209			2.5914	3.1241

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05

Observations: Pooled = 960; Lowland = 480; Upland = 480

Tractor hour usage: The results showed that farmers spent approximately 3 hours in ploughing (land preparation) one hectare of rice field (Table 4.8). In the lowlands farmers spent about four hours in comparison to two hours per hectare used during seedbed in the upland system. The test statistics revealed a significant difference between the two systems.

Table 4.8: Rice Tractor hours used per hectare in land preparation for rice production

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
Pooled	2.8184	2.0050	1.6789	0.000	2.3693	3.2675
Lowland	3.9447	2.5583			2.9114	4.9781
Upland	2.2658	1.3921			1.8821	2.6495

Agrochemical utilisation: The agrochemicals used by the farmers in rice production includes fertilizer, pesticides and herbicides (Table 4.9). Overall, only 17.6% of the respondents used the different types of agrochemicals in rice production overall. Comparison by rainfed production systems revealed that 32.3% and 2.9% of the respondents reported use of agrochemicals in the lowland and upland rice production, respectively. Results by types of agrochemicals applied showed that only 4.2% of the respondents used fertilizers. Analysis at the level of production system also indicates that 7.7% of the respondents who used fertilizer were in the lowland and only 0.6% in the upland. Use of herbicide in weed control was reported by 16.8% of the respondents of which relatively higher proportion (30.6%) of the

respondents reported usage in lowland rice cultivation compared to 2.9% in the upland rice cultivation.

Table 4.9: Agrochemicals (fertilizer, herbicides/pesticides) usage in rice production

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
Agrochemicals						
Pooled	0.1760	0.3811	0.2938	0.000	0.1519	0.2002
Lowland	0.3229	0.4681			0.2809	0.3649
Upland	0.0292	0.1684			0.0141	0.0443
Herbicide/pesticide						
Pooled	0.1677	0.3738	0.2771	0.000	0.1440	0.1914
Lowland	0.3063	0.4614			0.2649	0.3476
Upland	0.0292	0.1684			0.0141	0.0443
Fertilizer						
Pooled	0.0417	0.1999	0.0708	0.000	0.029	0.0543
Lowland	0.0771	0.2670			0.0531	0.1010
Upland	0.0063	0.0789			-0.0008	0.0133

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05

Observations: Pooled = 960; Lowland = 480; Upland

(ii) Methods of seedbed preparation

The descriptive statistics for seedbed preparation are presented in Table 4.10 below. On average farmers ploughed seedbeds at least twice before planting. This practice helps to have good seedbed, reduce weeding and also good water infiltration (IRRI, 2015). Farmers in the lowland system ploughed the seedbed at least three times while those in upland system ploughed twice.

The time farmers spent between seedbed preparations and planting (sowing) of rice seed was approximately 2.5 months. Farmers in the lowlands took about three months while in the uplands they took two months before planting rice. Ideally, giving some lag period between ploughing and planting allows room for weed seed which remained in the soil to germinate and also the crop residue/weed from the previous season to decompose.

Table 4.10: Frequency and time-lag in rice seedbed preparation in rainfed systems

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
No. of ploughing						
Pooled	2.1677	0.7075	0.5979	0.000	2.1229	2.2125
Lowland	2.4667	0.6981			2.4041	2.5293
Upland	1.8688	0.5793			1.8168	1.9207
Lag to planting						
Pooled	2.2396	1.3779	0.7750	0.000	2.1523	2.3269
Lowland	2.6271	1.4990			2.4926	2.7615
Upland	1.8521	1.1197			1.7517	1.9525

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05.

Observations: Pool = 960; Lowland = 480; Upland = 480

(iii) Rice variety, months for planting and methods of planting

The rice varieties grown in the zone included NERICA, SUPA, KAISO, SINDANO and Others (including WITA9 and NAMCHE series). According to the prevalence of each variety, NERICA variety constituted 29% of the rice varieties grown, KAISO 26%, SINDANO 23%, SUPA 16% and Others 4% of the varieties grown (Table 4.11). KAISO and SUPA have high water requirement and therefore are suitable for wetland (lowland) areas while NERICA and SINDANO are suitable for dry-land area because of low water requirement. Generally, diversity in rice variety grown was mainly dictated by the production systems.

Table 4.11: Rice varieties grown in the rainfed production systems

	Pooled		Lowland		Upland	
	Cases (n=960)	%	Cases (n=480)	%	Cases (n=480)	%
Rice variety						
NERICA	279	29	48	10	232	48
KAISO	250	26	249	52		
SINDANO	221	23	19	4	202	42
SUPA	154	16	148	31		
Others	56	6	16	3	46	10

Rice was planted between March and September (Table 4.12). A total of 70% of the farmers planted between March and May. Comparison between the production systems indicated that slightly more farmers (72%) planted rice during this period in the upland in comparison to 69% in the lowlands. A total of 19% of the farmers planted rice in June. These are mainly farmers who do dry planting to wait for onset of second season rains. Again majority of farmers who planted in June were in the upland (23%) and only 14% were in the lowland system. Only 11% planted between July and September, and of this 17% were those who planted in the lowland system while only 5% were in the upland system.

Two methods (broadcast sowing and transplanting) of planting rice were practised. About 84% of the farmers planted rice by broadcasting the seeds while 16% transplanted seedlings. However, at the production system level, a total of 32% of the farmers transplanted rice while 68% did broadcast in the lowland. All the farmers in the upland system used broadcast method and none transplanted. Variations in planting methods between the two systems was due to transplanting which requires flooding the field (lowland) while upland favours direct seeding.

Table 4.12: Months and method of planting rice in the rainfed production systems

	Pooled		Lowland		Upland	
	Cases (n=960)	%	Cases (n=480)	%	Cases (n=480)	%
Month for planting						
June	180	19	69	14	111	23
March to May	674	70	330	69	344	72
July to September	106	11	81	17	25	5
Planting method						
Broadcasting	808	84	328	68	480	100
Transplanting	152	16	152	32		

(iv) Weeding

Two methods were used in weed management in rice crop are herbicide application and manual weeding (Table 4.13). Overall, 90% of the farmers used manual labour but the upland system had more cases of manual weeding (92%) than the lowland system (89%). Only 10% of the rice growers applied herbicides for weed management with slightly more farmers doing the same in the lowland system (11%).

Table 4.13: Method of weed management and frequency of weeding rice fields

Group	Mean	Std. Dev	Diff	Pr(T> t)	95% CI	
Method of weeding						
Herbicide application						
Pooled	0.1677	0.3738	0.2771	0.000	0.1440	0.1914
Lowland	0.3063	0.4614			0.2649	0.3476
Upland	0.0292	0.1684			0.0141	0.0443
Manual weeding						
Pooled	0.8323	0.3738	-0.2771	0.000	0.8086	0.8560
Lowland	0.6938	0.4614			0.6524	0.7351
Upland	0.9708	0.1684			0.9557	0.9859
Weeding frequency						
Pool	1.9167	0.7172	-0.3167	0.000	1.8712	1.9621
Lowland	1.7583	0.7339			1.6925	1.8242
Upland	2.0750	0.6642			2.0154	2.1346

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05.

Observations: Pooled = 960; Lowland = 480; Upland = 480

Weeding was done from two weeks after seed germination depending on the condition of the field. As such, the frequency of weeding ranged from once to thrice and was determined by the degree of weed infestation. On average, farmers weeded rice field approximately twice before harvest. However, there was significant difference in weeding frequencies between the systems. The lowland rice fields were weeded 1.8 times while the upland rice fields were weeded 2.1 times. The relatively high weeding frequency in the upland system could be attributed to poor methods of seedbed preparation, i.e., short time lag between seedbed preparation and planting which does not allow remaining weed seed in the soil to germinate before planting (IRRI, 2015).

(d) Seasonal calendar for rice production

Northern agroecological zone has got two cropping/rainy seasons. The first season runs from mid-March to June followed by a dry period of July which takes care of first season harvests and land preparation for second season. Second season runs from August till October. Two rice growing seasons were reported as indicated in Table 4.14. Planting during the first season starts in March and ends in May while for the second season it starts in June and ends in September. A total of 84% of the farmers planted rice in the first season of which 78% and 90% were those planting in the lowland and upland system, respectively. Only 16% of the respondents planted in the second season of which lowland constituted 22% and upland system 10%.

Table 4.14: Season for planting rice in the lowland and upland rainfed systems

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
First season						
Pooled	0.8417	0.3652	-0.1167	0.000	0.8185	0.8648
Lowland	0.7833	0.4124			0.7463	0.8203
Upland	0.9000	0.3003			0.8731	0.9269
Second season						
Pooled	0.1583	0.3652	0.1167	0.000	0.1352	0.1815
Lowland	0.2167	0.4124			0.1797	0.2537
Upland	0.1000	0.3003			0.0731	0.1269

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05.

Observations: Pooled = 960; Lowland = 480; Upland = 480

Farmers gave four reasons for choosing a particular planting season as indicated in Table 4.15. A total of 56% of the farmers indicated that their preference for a season was due to variability in climate, extent of bird damage (18%), labour constraint (17%) and limited land (9%). Farmers in the lowland considered climate and bird damage as their main reasons for selecting a planting season. Upland rice growers considered climate factor as the main reason guiding their decision on which season to plant rice.

Table 4.15: Reasons for choice of production season for rice growing

Group	Mean	Std. Dev.	Diff	Pr(T> t)	95% CI	
Weather						
Pooled	0.5551	0.4974	0.0202	0.647	0.5129	0.5974
Lowland	0.5631	0.4968			0.5089	0.6173
Upland	0.5429	0.4994			0.4749	0.6108
Labour constraint						
Pooled	0.1701	0.3761	-0.0414	0.214	0.1382	0.2020
Lowland	0.1538	0.3614			0.1144	0.1933
Upland	0.1952	0.3973			0.1412	0.2493
Bird damage						
Pooled	0.1813	0.3856	0.0319	0.350	0.1486	0.2141
Lowland	0.1938	0.3959			0.1506	0.2371
Upland	0.1619	0.3692			0.1117	0.2121
Limited land						
Pooled	0.0935	0.2913	-0.0108	0.677	0.0687	0.1182
Lowland	0.0892	0.2855			0.0581	0.1204
Upland	0.1000	0.3007			0.0591	0.1409

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0. P-value is significant at less than 0.05

Observations: Pooled = 960, Lowland = 480; Upland = 480

(e) Constraints in rainfed rice production systems

In terms of the constraints in rice production, 33.3% of the farmers mentioned variability in climate as a major challenge in rice production according to response percentage (Table 4.16). Slightly higher proportion of the farmers faced with the challenge was in upland system (35.9%). Pest and disease infestations including bird damage accounted 22.3% of the responses, whereby lowland constituted 28.9% of the responses and upland was at 14.5%. Constraint related to labour and access to various inputs had 16.3% of the responses with lowland accounting for 17% of the responses. High weed infestation had response percentage reported at 8.3% overall but lowland and upland accounted for 6.7% and 10.7%, respectively. On average 11.9% of the responses indicated low market prices as constraints in rice production. Access to quality seed and improved varieties was reported at 7% but slightly greater proportion of the responses was from upland (7.6%) in comparison to lowland (6.7%).

Table 4.16: Constraints in rainfed rice production systems

Constraints	Pooled			Lowland			Upland		
	Freq	%age of responses	%age of cases	Freq	%age of responses	%age of cases	Freq	%age of responses	%age of cases
Climate	137	33.3	65.9	80	31.6	62.0	57	35.9	72.2
Labour and inputs	67	16.3	32.2	43	17.0	33.3	24	15.1	30.4
Pest and disease	96	23.3	46.2	73	28.9	56.6	23	14.5	29.1
Weeds	34	8.3	16.4	17	6.7	13.2	17	10.7	21.5
Seed	29	7.0	13.9	17	6.7	13.2	12	7.6	15.2
Market	49	11.9	23.6	23	9.1	17.8	26	16.4	32.9
Total	412	100	198.1	253	100	196.1	159	100	201.3

4.3.2 Efficiency of rice farmers in rainfed rice production system

This result answers the second research question, i.e., to what extent are rice farmers producing efficiently. The results from stochastic frontier model demonstrated the relationship between rice yield, inputs, and climate variables. The four year balanced panel data assumed time-variant technical efficiency. The results are reported for statistical tests, frontier part of the production function and estimates of technical efficiency and its distribution.

(a) The rice production frontier for the rainfed production system

As a benchmark, a pooled OLS model and stochastic cross-sectional model were estimated to facilitate specifications and regression diagnostic tests (Appendix 3). Given the results of the statistical tests, the rest of analysis proceeded with stochastic frontier model of Translog half-normal distribution. Estimation was performed through true-fixed effects model. The results are reported concurrently for the pool model (Tables 4.17), lowland system model (Tables 4.18) and upland system model (Tables 4.19).

In pooled model, yield function revealed mixed contribution of inputs to rice output. Area cultivated had the highest elasticity and statistically significant in all the models whereas plot-square registered statistically significant negative coefficient in pooled and lowland but negative in upland. Interactions of plot and labour and oxen indicated insignificant negative relationship with rice output throughout. Seed and oxen-squared were negative in pooled model while mixed relationship was depicted in lowland and upland. Clay soil was positive

in all the models but positive coefficient was observed in the upland model. Coefficients on years were all negative and statically significant for all except 2015. Generally constant return to scale was exhibited in pooled model, lowland registered increasing returns to scale whereas decreasing return to scale was observed in upland models meaning that output is increasing by less than the proportional increase in all inputs.

(i) Area cultivated

Area cultivated had the highest response to output implying that a unit increase in hectare cultivated is more likely improve rice output by 1.0036 t ha^{-1} . Comparison according to the production system indicated that rice output is likely increase by 0.0285 and 1.4055 t ha^{-1} , respectively, in lowland and upland for a unit increase in area cultivated. However, doubling acreage above the current average *ceteris Paribas* is likely to impacts on output negatively as indicated by overall output reduction in lowland ($-0.3846 \text{ t ha}^{-1}$) and upland (-0.037 t ha^{-1}) and throughout the two rain. Increasing acreage, labour and oxen days by the same proportion is associated with reduction in output according to the negative coefficient. This is an indication of the fact that current level of labour and oxen usage given land has surpassed optimal quantity area unit area.

(ii) Seed planted

A unit increase in kilogram of seed planted is likely to result in a reduction in rice output overall by 0.0001 t ha^{-1} and in upland by 0.0005 t ha^{-1} . High output response was attained in the lowland (0.0038 t ha^{-1}) implying that a unit increase in seed-rate is associated with an improvement in output. Relatively low response in the upland system was due to high value of seeding rate (86 kg ha^{-1}) above the recommended average (62.5 kg ha^{-1}) such that further addition of seed quantity would result in plant congestion.

(iii) Labour

Additional man-day used in rice production is like to translate into an improvement in rice output by 0.0007 t ha^{-1} . The magnitude of improvement is more likely to be felt in lowland (0.001 t ha^{-1}) than in upland (0.0006 t ha^{-1}). Positive result suggests intensive labour use in land preparation and weeding.

(iv) Oxen

A unit increase in number of oxen-days is more likely to have positive improvement in rice output in pooled model (0.0484 t ha^{-1}) and lowland (0.0643 t ha^{-1}) but increasing oxen days is likely to affect rice output negatively in upland (-0.015 t ha^{-1}).

(v) Tractor

Access to tractor service is an incentive to output improvement as suggested by positive output improvement overall (0.0438 t ha^{-1}) and in lowland (0.002 t ha^{-1}). In contrast, negative association with output is suggestive upland ($-0.1367 \text{ t ha}^{-1}$).

(vi) Soil types

Plots located in area with high concentration of clay soil is more likely to have an improvement in rice output overall (1.4169), lowland (0.1302) and upland (0.0156). The result implies that clay soil has got high moisture retention and hence improves crop performance and productivity. The contrary result was observed in the upland where rice output increases (0.0166). Amount of rainfall (rain-water) available to the crop is influenced by both soil infiltrations and moisture holding capacity. For instance, clay soil is known to hold rain water for long as opposed to other soil types.

(vii) Year

The negative coefficient on year implies that rice output tended to reduce with years except 2015 where a positive effect on output was observed in upland (0.003 t ha^{-1}). The result also implies that the rice production frontier is shifting downwards.

Table 4. 17: Production frontier – True fixed-effects model (half-normal) - Pooled model

Inoutput	Coef.	Std. Err.	P>z	[95% Conf. Interval]
Frontier				
Plot	1.0036	0.1315	0	0.7459 1.2614
Seed	-0.0001	0.0009	0.922	-0.0018 0.0016
Oxen	0.0484	0.0179	0.007	0.0133 0.0835
Plot*labour	-0.0003	0.0003	0.23	-0.0009 0.0002
Plot2	-0.0403	0.0102	0	-0.0602 -0.0204
Oxen2	-0.0006	0.0003	0.108	-0.0012 0.0001
Plot*oxen	-0.0158	0.0095	0.096	-0.0343 0.0028
Tractor	0.0438	0.0956	0.647	-0.1437 0.2313
Labour	0.0007	0.0005	0.199	-0.0004 0.0017
Soil type (clay)	1.4169	0.8568	0.098	-0.2623 3.0961
Year				
2014	-0.1194	0.0549	0.029	-0.2270 -0.0119
2015	-0.1140	0.0567	0.044	-0.2252 -0.0028
2016	-0.2052	0.0588	0	-0.3205 -0.0899
Return to scale	1.0395			
E(sigma_u)	0.4403			0.4088 0.4718
sigma_v	0.5327	0.0173	0	0.4999 0.5676

P-values are significant at: 0.01 (1%), 0.05 (5%), 0.1 (10%); Log likelihood = -906.749 Wald chi2(13) = 163.78; Prob > χ^2 = 0

Obs = 960; Groups 480; Obs per group 4

Table 4.18: Production frontier – True fixed-effects model (half-normal) - Lowland model

Inoutput	Coef.	Std. Err.	P>z	[95% Conf. Interval]
Frontier				
Plot	1.4055	0.4569	0.002	0.5100 2.3010
Seed	0.0038	0.0020	0.059	-0.0001 0.0078
Oxen	0.0643	0.0304	0.034	0.0047 0.1238
Plot*labour	0.0003	0.0009	0.728	-0.0015 0.0022
Plot2	-0.3846	0.2399	0.109	-0.8549 0.0856
Oxen2	-0.0008	0.0005	0.094	-0.0018 0.0001
Plot*oxen	-0.0135	0.0305	0.658	-0.0733 0.0463
Tractor	0.0020	0.1731	0.991	-0.3373 0.3414
Labour	0.0010	0.0010	0.318	-0.0010 0.0031
Soil type (clay)	0.2403	1.0149	0.813	-1.7489 2.2295
Year				
2014	-0.2000	0.0874	0.022	-0.3712 -0.0288
2015	-0.3526	0.0927	0	-0.5343 -0.1709
2016	-0.3031	0.0971	0.002	-0.4933 -0.1129
Return to scale	1.1			
E(sigma_u)	0.4783			0.4359 0.5208
sigma_v	0.5974	0.0276	0	0.5457 0.6541

P-values are significant at: 0.01 (1%), 0.05 (5%), 0.1 (10%); Log likelihood = -504.6135 Wald > χ^2 = 106.32; Prob > χ^2 = 0 (13)

Obs = 480; Groups 120; Obs per group 4

Table 4.19: Production frontier – True fixed-effects model (half-normal) - Upland model

lnoutput	Coef.	Std. Err.	P>z	[95% Conf. Interval]
Frontier				
Plot	0.8355	0.1146	0	0.6108 1.0602
Seed	-0.0005	0.0007	0.48	-0.0018 0.0009
Oxen	-0.0150	0.0279	0.591	-0.0696 0.0396
Plot*labour	-0.0002	0.0003	0.438	-0.0008 0.0003
Plot2	-0.0370	0.0077	0	-0.0521 -0.0219
Oxen2	0.0008	0.0008	0.308	-0.0007 0.0022
Plot*oxen	-0.0010	0.0086	0.908	-0.0179 0.0159
Tractor	-0.1367	0.0966	0.157	-0.3259 0.0526
Labour	0.0006	0.0006	0.336	-0.0006 0.0019
Soil type (clay)	0.0156	0.0108	0.147	-0.0055 0.0367
Year				
2014	-0.1012	0.0592	0.088	-0.2173 0.0150
2015	0.0030	0.0603	0.961	-0.1152 0.1211
2016	-0.1580	0.0575	0.006	-0.2707 -0.0453
Return to scale	0.6465			
E(sigma_u)	0.8176			0.7914 0.8439
sigma_v	0.2030	0.0351	0	0.1447 0.2848
P-values are significant at: 0.01 (1%), 0.05 (5%), 0.1 (10%); Log likelihood = -341.549 Wald > $\chi^2_{(13)} = 621.05$, Prob > $\chi^2 = 0$				
Obs = 480; Groups 120; Obs per group 4				

(c) Estimates and distribution of technical efficiency

The null hypothesis stating that each farm is operating on the most efficient production frontier ($H_0: \gamma=0$) could not be accepted. The estimated mean technical efficiency showed that farmers were producing inside and not on the frontier (Table 4.20). The figures in the table are provided in decimal but explanations are made in percentages for case of interpretation. Estimate of η using Battese and Coelli (1992) time varying decay models with truncated-normal distribution (Appendix 3) was negative indicating that technical efficiency declined at a rate of 14% over time. The mean technical efficiency level was 0.7662 overall with standard deviation of 0.227 implying that farmers are at 76.6% of the production frontier (inefficiency gap of 23.4%). Efficiency level ranged from minimum 0.016 to 1.00 meaning that some farmers were already operating on the frontier while others are far below the production frontier (inefficiency gap of 98.4%). Estimated efficiency ranged from 1 to 90% implying that the inefficiency gap stands between 99 and 6%. A substantial number of farmers constituting the majority (87% of the farmers) were operating above 50% of the frontier while only 13% of the farmers were operating below 50% of the frontier. Trend analysis of efficiency scores indicated 44.5% during 2013 but a linear decline was recorded i.e. 42.8% during 2014, 41.5% during 2015 and 41.4% in 2016. Again this confirms an inverse relationship between the frontier and time.

Analysis of distribution of efficiency revealed variation in with respect to rainfed production systems, type of rice varieties, production season and plot size. As indicated, mean technical efficiencies were 72.3 and 80.9%, respectively, in lowland and upland systems. Comparison test using t-statistics confirmed statistically significant mean difference (8.6%) in efficiency levels level between the two systems. This result confirms high input application especially labour, seed-rate and oxen days observed in the lowland system. Distribution in regards to production seasons revealed slightly higher efficiency level during second season (76.7%) over first season (76.4%) but the difference was statistically insignificant.

Farmers growing upland rice varieties registered efficiency level (81.6%) above those growing lowland varieties (70.1%). Test statistic for mean difference was statistically significant. Upland varieties have shorter growth duration and therefore require less inputs and supervision time. In regards to plot size, farmers cultivating more 0.5 hectares of rice were producing more efficiently above their counterparts with smaller acreage. The result revealed efficiency level of 79.5% in larger plots against 75.1% in smaller plots. The difference was statistically significant according to the test statistics. As already noted increasing acreage under rice production is associated with output improvement and this confirms higher efficiency in large plots.

Table 4.20: Estimates of technical efficiency level and distribution

Group	Mean	S. Err.	S. Dev.	Diff	[95% C.	Interval]
Pooled	0.7663	0.0073	0.2273		0.7519	0.7806
Lowland	0.7232	0.0105	0.2306	-0.0860*	0.7025	0.7439
Upland	0.8093	0.0098	0.2156		0.7899	0.8286
Production season						
1 st season	0.7642	0.0224	0.2295	-0.0023	0.7198	0.8086
2 nd season	0.7665	0.0078	0.2271		0.7512	0.7817
Rice varieties						
Upland varieties	0.8161	0.0087	0.2037	0.1156*	0.7990	0.8332
Lowland varieties	0.7005	0.0118	0.2399		0.6773	0.7237
Plot size						
Small (≤ 0.4 Ha)	0.7509	0.0092	0.2292	-0.0437*	0.7329	0.7690
Large (≥ 0.5 Ha)	0.7947	0.0121	0.2212		0.7709	0.8184

Obs. Pooled 960; Lowland system 480; Upland system 480; Lowland varieties 414; Upland varieties 546; First season 105; Second season

855; Small plots 624; Large plots 336.

4.3.3 Effects of farmers' characteristics on inefficiency

Rejection of the assumption of full efficiency of the decision making units led to investigation of the sources of inefficiency. This was to answer the research question, how do farmers' characteristics influence inefficiency in rice production in rainfed production systems? Subsequently, managerial factors were included in the inefficiency model to explain inefficiency. The results are reported and interpreted for pooled model (Table 4.21), lowland system (Table 4.22) and upland rainfed system (Table 4.23) concurrently. The negative relationship depicts a reduction in inefficiency while positive implies an increment. The summary of statistics in pooled model indicated that all the right hand side variables except participation in training on rice production were statistically significant which therefore justify their relevance in explaining inefficiency. Again all the variables were negatively signed in pooled model except participation in training. The results for the rest of the models are as follows:

(i) Extension access

Extension dummy was negative indicating that access to extension services reduces the possibility of operating below the frontier by 0.992. Extension supports informed decisions on resource allocation and choice as well as access to information on productivity enhancing inputs. However, access to extension was positively signed in upland suggesting that inefficiency is likely to increase by 2.7862. This could be attributed to the fact that most of the varieties grown in upland are relatively new and farmers are not fully abreast with information on production attributes and growth requirements.

(ii) Training in rice production

Participation in training on rice production had close association with reduction in inefficiencies according to the negative coefficients in lowland (-0.4228) and upland (-1.3161). However, pooled model was positively signed suggesting the likelihood of having an increase in inefficiency by 0.9464 among farmers participating in rice training. Though unexpected, there is a possibility of exclusion of information on production economics and resource allocation in rice production in training programmes given to farmers.

(iii) Household income and proportion of rice income

High household income and rice income are incentives for raising efficiency level in rice production according to the observed reduction in the level of inefficiencies. Inefficiencies

are more likely to reduce by -0.7906 and -7.7943, respectively, for farmers with high household and rice income. Reduction in inefficiency was also observed in the two production systems.

(iv) The number of crops grown

Negative coefficients reported confirms priori assumption that cultivating/specialisation tended to promote efficiency in production. As such, inefficiency is likely to reduce by -0.4273 for farmers specialising (growing less than 4 crops) than their counterparts growing many crops.

(v) Rice growth duration

Analysis of efficiency level in relation to growth duration for a rice variety showed negative association with inefficiency (-0.3187) for shorter duration varieties. In contrast, inefficiency is likely to increase in upland (0.0145) as opposed to negative reduction in lowland (-1.4983) for shorter duration varieties (4 months). Long duration varieties (above 4 months) tend to involve high inputs especially labour for remaining operational activities (weeding, pesticides and fertilizer application) before harvest.

(vi) Rice varieties

Farmers cultivating lowland rice varieties are more likely to become inefficient according to the positive coefficient (1.9056). Dimensions of inefficiencies in lowland varieties include longer growth duration which requires more inputs to sustain production as well as intensiveness of lowland cultivation which require high labour input.

(vii) Location of rice plot

Location of rice plot in Gulu, Lira and Oyam is associated with reduction in inefficiency, respectively, by -4.3374, -2.6119 and -2.0348. Higher magnitude of reduction was observed in Gulu and this can be explained by lighter sandy-loam soil which is easier to manage during cultivation as well as growing of short duration varieties.

Table 4.21: Inefficiency model – True fixed-effects model (half-normal) - Pooled model

Inefficiency	Coef.	Std. Err.	P>z	[95% Conf. Interval]
Usigma				
Extension (yes)	-0.9924	0.3617	0.006	-1.7014 -0.2835
Training (yes)	0.9464	0.4310	0.028	0.1018 1.7911
Household-income	-0.7906	0.1291	0	-1.0436 -0.5377
Rice-income (%)	-7.7943	1.2849	0	-10.3127 -5.2759
Crops (≤4crops)	-0.4273	0.3323	0.198	-1.0786 0.2240
Duration (≤4months)	-0.3187	0.3946	0.419	-1.0921 0.4547
Variety (lowland)	1.9056	0.6121	0.002	0.7060 3.1053
District				
Gulu	-4.3374	1.5437	0.005	-7.3630 -1.3119
Lira	-2.6119	0.7069	0	-3.9974 -1.2263
Oyam	-2.0348	0.6909	0.003	-3.3890 -0.6806
_cons	3.4356	0.5296	0	2.3975 4.4736
Vsigma				
_cons	-1.2597	0.0648	0	-1.3868 -1.1327

P-values are significant at: 0.01 (1%), 0.05 (5%), 0.1 (10%). Log likelihood = -906.749 Obs 960; Groups 480; Obs per group 4

Table 4.22: Inefficiency model – True fixed-effects model (half-normal) - Lowland model

Inefficiency	Coef.	Std. Err.	P>z	[95% Conf. Interval]
Usigma				
Extension (yes)	-2.0979	0.7797	0.007	-3.6260 -0.5698
Training (yes)	-0.4228	0.9311	0.65	-2.2478 1.4021
Household-income	-0.6160	0.2085	0.003	-1.0247 -0.2074
Rice-income (%)	-5.5341	1.6615	0.001	-8.7907 -2.2776
Crops (≤4crops)	-1.7667	0.4263	0	-2.6022 -0.9311
Duration (≤4months)	-1.4983	0.6835	0.028	-2.8379 -0.1587
District - Lira	-2.3695	1.0988	0.031	-4.5232 -0.2159
_cons	3.2678	1.0654	0.002	1.1797 5.3560
Vsigma				
_cons	-6.6818	0.3706	0	-7.4082 -5.9554

P-values are significant at: 0.01 (1%), 0.05 (5%), 0.1 (10%). Log likelihood = -288.4134 Obs 480; Groups 120; Obs per group 4

Table 4.23: Inefficiency model – True fixed-effects model (half-normal) - Upland model

Inefficiency	Coef.	Std. Err.	P>z	[95% Conf. Interval]
Usigma				
Extension (yes)	2.7862	0.8611	0.001	1.0984 4.4740
Training (yes)	-1.3161	0.8073	0.103	-2.8984 0.2663
Household-income	-0.9076	0.2314	0	-1.3612 -0.4540
Rice-income (%)	-4.2018	1.1437	0	-6.4433 -1.9602
Duration (≤4months)	0.0145	0.5129	0.977	-0.9907 1.0198
District - Gulu	2.4774	0.6524	0	1.1988 3.7561
_cons	0.7305	0.8277	0.377	-0.8918 2.3528
Vsigma				
_cons	-0.8814	0.3091	0.004	-1.4872 -0.2756

P-values are significant at: 0.01 (1%), 0.05 (5%), 0.1 (10%). Log likelihood = -305.1723 Obs 480; Groups 120; Obs per group 4

4.4 Discussion

The objective of this chapter was to characterise rainfed rice production systems in the Northern farming system. The research question answered was what are the characteristics of the different rainfed rice production systems? To what extent are rice farmers producing efficiently? How do farmer characteristics influence inefficiency in rice production? The discussions in this section covers rice yields under rainfed systems, production practices, challenges in rainfed rice production, rice production frontier and estimates and distribution of technical efficiency.

Research question 1: The result provided for yields showed that the average rice yield of 1.9 t ha⁻¹ realised in the study area was relatively lower than 2 t ha⁻¹ reported in the same area by Kijima (2012). The average yield was equally below the national rice yield average of 2.5 t ha⁻¹ reported during 2008/2009 (UBOS, 2010). This was also less than 5 t ha⁻¹ reported in Ahero irrigation scheme in Kenyan and potential average yield of 5 to 8 t ha⁻¹ under good management conditions (Luzi-Kihupi, 2011; Omondi and Shikuku, 2013; UBOS, 2015). Nevertheless, the average obtained in this study was within the under rainfed system in SSA between 1 and 3 t ha⁻¹ but between 2 and 6 t ha⁻¹ is got under irrigated system (van Oort *et al.*, 2015). In Kenya, irrigated average is 5 t ha⁻¹. Rainfed averages in Central and West Africa for lowland and upland are 2.3 and 1 t ha⁻¹, respectively (GRiS, 2015). Irrigated average in Asia is 5 t ha⁻¹ (ranges between 3 and 9 t ha⁻¹) but rainfed aberage in Pakistan is 1.8 t ha⁻¹ (Ali *et al.*, 2017). Generally, there were significant variations in average yield between lowland and upland rainfed cultivation, between production seasons and across the four years under study. The difference between average rice yield in the study area and elsewhere are perhaps explained by differences in the growing conditions. Eastern region of Uganda particularly has got conducive climatic conditions and availability of irrigation facilities elsewhere. Similarly, variations observed between the two rainfed systems, i.e. lowland and upland cultivation could be due to: (1) high yielding lowland varieties and moisture endowment in the lowland area; (2) Good production practice in the lowland in terms of seedbed preparation, planting and weeding; (3) High harvest in 2013/2014; and (4) Good performance in first season in the lowland system. Rahman *et al.* (2017) also found significant variations in yields between production systems in Bangladesh. Otherwise for good yields, Tsuboi (2011), GRiSP (2013), and IRRI (2015) recommend some level of moisture requirement depending on a variety and this calls for conducive climatic conditions. The annual and seasonal variations in yields were linked to annual and seasonal variability in rainfall and temperature as the trends in this study

indicate. Elepu and Dalipagic (2014) also reported variation in yields across season where higher average yield performance was observed during second than first season.

Findings were also reported for the different inputs used in rice cultivation which included land, seed, labour, oxen (animal draught power) and tractor. The result for area cultivated with rice indicated that the average plot size cultivated with rice of about of 0.6 hectares was above the national average of 0.4 hectare reported during 2008/2009 agricultural census survey (UBOS, 2010). However, variation in acreage cultivated between the lowland (0.5 hectares) and upland (0.8 hectares) system are perhaps for two reasons. First due to limited coverage of wetland area as well as restriction by National Environment Management Authority (NEMA). Overall, rice production is labour intensive. This is amplified by limited access to mechanisation equipment like tractor and animal draught power services.

The quantity of seed (105 kgs) planted per hectare was outside recommended rate per hectare under transplanting (25 kgs), line drill (65 kgs) and broadcast (100kg) (Tsuboi, 2011; IRRI, 2015). Lowland farmers used 119 kgs than recommended. Higher rate is subject to wastage (inefficiency) and low yield due to plant congestion (IRRI, 2015). However, use of high seed rate could be a coping strategy arising from the need to compensate for poor germination due to drought or flood situations and poor quality seeds. Use of seed rate outside recommended average among the Ugandan rice farmers is not limited to this study. For instance, Miyamoto *et al.* (2012), Haneishi *et al.* (2013) reported 90 and 110 kg ha⁻¹, respectively.

Different varieties of rice including SUPA, KAISO, NERICA and SINDANO are grown in the rainfed production systems. The diversity of varieties grown was majorly dictated by the production system. SUPA and KAISO are best suited for lowland rainfed cultivation while NERICA and SINDANO are suitable for upland/dry-land rainfed cultivation, hence they were the most common varieties grown in the respective systems. Elepu and Dalipagic (2014), IRRI (2015) also indicated that choice of a variety is dictated by suitability of the biophysical growing condition of a locality.

The number of man-days (249 days) spent in rice production in the study area indicates that rice production is labour intensive. High man-days (307 days) of labour spent particularly in the lowland cultivation was majorly linked to limited access to tractor services and bird scaring due to high prevalence of birds during first season. Most importantly, high number of man-days spent suggests inefficiency in rice production. The finding in this study confirmed

Haneishi *et al.* (2013), Kijima (2012), and Miyamoto *et al.* (2012) who also reported similar range between 200 and 430 man-days. Whereas, Asiiimwe (2009) reported even higher average of man-days per hectare (1136 days). In respect to source of labour, high involvement of family labour as opposed to hired labour in the lowland cultivation could be due to the nature of some lowland tasks like transplanting and weeding which require careful handling and patients. However, there was overall decline in the share of family labour from 56% in Odogola (2006) to 52% in this study signals a shift from subsistence to commercial rice production where market forces dictate labour demand and supply. In regard to gender engagement in rice production activities, more involvement of men in rice cultivation activities like weeding which used to be handled by women implies that men are increasingly taking on tasks previously considered female roles. The result also defers from earlier findings where more women than men were involved in rice production activities (Odogola, 2006; Asiiimwe, 2009).

Animal draught power (oxen) as a labour saving technology and a substitute to tractor was highly appreciated due to ease of accessibility. However, variations in utilization of draught power between the lowland and upland cultivation could be due to the nature of soils. Lowland has got heavier soils (clay-loamy) as opposed to the upland lighter soil type (sandy-loam) which can be ploughed easily (GoU, 2012). By implication, more oxen-hours are expected for lowland heavier soils than the upland lighter soil types. Hence the finding in this study indicating more oxen-days especially in the lowland in comparison to the upland when animal draught power was used is justified.

Although fertilizer helps to boost crop yields, only 4.2% of the sampled farmers used fertilizer and only in the lowland fields. Low use of soil enriching technology to enhance rice yields is not limited to this study, (Haneishi *et al.*, 2013; Barungi and Odokonyero, 2016) reported similar finding on low usage of fertilizer. In terms of pesticides and herbicide usage in pests and disease and weed control, only 16.8% of the respondents reported use. Again this was limited to lowland areas. Restricted use to only lowland cultivation could suggest high infestation of pests and diseases and weeds. Otherwise, pesticide and herbicide usage in rice cultivation in the lowland was reflected in relatively higher average yields obtained in the lowland. Otherwise, Kijima (2012) also noted low utilization of herbicide in rice in Northern region of Uganda (4%).

Results were also reported for other production practices including production seasons, methods for rice planting and weeding. Consequently, the study found out that rice cultivation was done in first and second season but most of the cultivation was done in the first season. Elepu and Dalipagic (2014) also reported that rice is grown mostly during the first season (March-April) and less during second season (August-September). High preference for first season cultivation is probably in anticipation of variability in climate whereby first season is considered to have reliable rainfall in comparison to second season. Caffrey *et al.* (2013) also reported possibility of total crop loss to variability in climate if timing of planting is not synchronised with the season.

Significant difference in ploughing frequency and duration taken before planting rice between the two rice systems were observed. The finding agrees with earlier findings that frequency and duration of ploughing is dictated by the environment rice is grown (Odogola, 2006). According to IRRI (2015) good seedbed is critical for water storage, suitable texture for sowing, germination and easy root penetration. Otherwise variations in planting methods between the two systems was because transplanting requires flooding of rice fields (lowland) while upland favours direct seeding. Relatively high weeding frequency in the upland system could be attributed to poor methods of seedbed preparation (lag period), and presence of striga weeds (Elepu and Dalipagic, 2014).

Research question 2: As far as input minimisation and output maximization was concerned, the maximum likelihood estimates for the production function confirmed that farmers were releasing less than expected level of output (inefficient). Nevertheless, land had the highest elasticity (0.64) implying that it is the most limiting factor in rice production especially in the lowland. Therefore, significant increase in yields can be attained through area expansion. Earlier studies have also reported similar finding on output dependent on land in the country with fairly comparable elasticity above 0.6 (Asiimwe, 2009; Mwaura and Okoboi, 2014). Enwerem and Ohajianya (2013) also noted similar scenario among Nigerian rice farmers. Besides area cultivated, seed was the second most limiting input in rice cultivation. This was attributed to the fact that upland farmers applied lower seed-rate than recommended average. The response of labour to output in this study was fairly comparable to 0.3 t ha^{-1} reported in ECOWAS region (Ajetomobi, 2009). However, the result in this study (0.4 t ha^{-1}) was above average of 0.01 t ha^{-1} reported elsewhere in the country by Asiimwe (2009); Miyamoto *et al.* (2012) and Haneishi *et al.* (2013).

Moreover, technological regress of 19.8% observed in time varying model of Battese and Coelli (1992), (Appendix 3) was contrary to the positive technological progress registered in Nigeria at 12% (Ajetomobi, 2009). The technological decline could be attributed to limited access and utilisation of productivity enhancing technologies such as fertilizer and improved rice varieties observed. Yet the mean technical efficiency level observed was below what has been reported among rice farmers in western Uganda at 61% and profit efficiency at 34 to 59% in Northern Uganda (Hyuha *et al.*, 2007; Asiiimwe, 2009). Omondi and Shikuku (2013) reported mean technical efficiency at 92% in Ahero irrigation scheme in Kenya while Long and Mitsuyasu (2012) reported 75% in Vietnam.

4.5 Conclusions

The section objective was to characterise rainfed rice production systems in Northern farming system. The conclusions made on this objective were drawn from the following research question: What are the characteristics of the different rainfed rice production systems? To what extent are rice farmers producing efficiently? Overall, these were the main trends/findings:

- i) Relatively youthful farmers are involved in rice cultivation and this is a good indicator for youth empowerment. Land holding of 3.4 hectare per household is a good opportunity for future expansion of rice cultivation above the current acreage (0.6 hectares). Annual income from rice being a third of the total household income places rice a strategic crop for food security, income enhancement and poverty reduction at household level. However, limited access to credit and extension services, low input application (pesticides and fertilizer), low mechanization and low level of specialisation in rice growing due to diversities of crops grown are a threat to commercialisation of rice.
- ii) The result confirmed considerably low average rice yield in the Northern farming system compared to obtain elsewhere in the country. Nevertheless, trend indicates an improvement in average yield within the agroecological zone from only 1.7 t ha⁻¹ during 2008/09 to 1.9 t ha⁻¹ during the period under study. Although the annual trend between 2013 and 2016 showed a decline in average rice yield per hectare, overall there is ample room to bridge the yield gaps. Otherwise variations in average rice yield between the lowland and upland production systems are linked to differences in production practices.

rice varieties grown, and variations in warmth (temperature) and moisture endowment (rainfall).

- iii) Production practices used in rice cultivation are generally poor; high input application particularly seed, labour, oxen and tractor hours were observed in the lowland system while the reverse were observed in the upland system. Seed bed preparation and weeding frequencies were also poorly handled in the upland system. High input application and poor production practices observed are suggested indicators of inefficiency in rice production.
- iv) All the inputs used by farmers in rice production were applied inefficiently and thus farmers are not producing optimally. However, inefficiency can be reduced through expansion of area cultivated with rice and proportionate application of the rest of inputs used in rice production given cultivated area.
- v) Based on the findings, the study recommends further investigation on the nature and magnitude of the relation between rice production and climate variability, rice being a semi-aquatic require high amount of rainfall.

CHAPTER FIVE

EFFECTS OF CLIMATE VARIABILITY ON RAINFED RICE PRODUCTION

5.1 Introduction

Climate variability is one of the most important challenges of the 21st century threatening global rice production even amidst yield enhancing crop technologies such as varieties, fertilizers and good agronomic practices (FAO, 2017). Rice production in Uganda like in other countries in Sub-Saharan Africa relies heavily on rainfed system which is vulnerable to negative variations in climatic conditions (IPCC, 2012; Caffrey *et al.*, 2013; Thornton *et al.*, 2014).

Rice is traditionally grown as a wetland crop that requires reliable amount of moisture and warmth during growth stages (GRiSP, 2013; IRRI, 2015). According to IRRI (2015), rice plant needs 2500 liters of rainfall or irrigation water to produce 1kg of grains (transpiration and evaporation accounts for 500 to 1000 and 1432 litres of this water, respectively). This makes water inputs to rice fields 2 to 3 times those of other major cereals such as (Bouman, 2009). However, variability in rainfall in terms of distribution and onsets is already threatening availability of water supply to rice crops (Mubiru *et al.*, 2012). On the other hand, increased temperature, can adversely affect rice yields (Korres *et al.*, 2017). According to Mubiru *et al.* (2012), poor distribution of rainfall and increases in maximum and minimum temperatures are shortening growing seasons for most crops. These effects cause early flowering and maturity of the crop leading to reduction in yield (Kaggwa *et al.*, 2009; Kansiime *et al.*, 2013; Nsubuga and Rautenbach, 2018).

Therefore, rice production must be viewed in light of climate variability since induced changes in rainfall patterns combined with the increasing temperature can have adverse effects on the crop production. As such, studies on climate impacts especially on the African continent are increasingly becoming major areas of scientific concern because of risks associated with climate variability on crop production (Rowhani *et al.*, 2011). Studies which have investigated effects of climate variability in rice include those of Shakoor *et al.* (2015) who reported susceptibility of rice to rising maximum temperature and increased precipitation in Pakistan. In Nigeria, differential impact of rainfall and temperature on rice revenue between irrigated and rainfed systems and between months has been reported (Ajetomobi *et al.*, 2011). In East Africa, intra-seasonal and inter-seasonal variability in

temperature and precipitation has been found to influence cereal yields, rice inclusive (Rowhani *et al.*, 2011). In Uganda rice yields are remarkably low at 2.5 t ha⁻¹ while average for the last two decades is less than 2 t ha⁻¹. The average production in the north of the country is as low as 1.7 t ha⁻¹ in spite of it being the second largest and oldest rice producing area after the eastern region (UBOS, 2010).

However, there is still limited empirical evidence that links climate variability to rice production in Uganda. This knowledge gap warrants research on impact of climate variability as pointed by Nsubuga and Rautenbach (2018). Such empirical evidence could provide useful information for farmers, scientists as well as policy makers who are interested in understanding the impacts of climate variability on rainfed rice production. It would also help to devise suitable coping options. The objective of this study was therefore to determine effects of climate variability on rainfed rice production. Effects of climate variability were examined through the following research questions: 1) what are farmers' views of climate variability in rainfed rice production systems of Northern farming system? 2) How is rainfall and temperature distributed in the Northern farming? 3) What is the influence of climate variability on rice production in rainfed rice production systems of northern farming?

5.2 Materials and methods

5.2.1 Data collection

Data was collected over a period of four years from individual farmers (households). The same sets of questions were asked and their responses repeatedly recorded. To obtain farmers' views about climate variability in rainfed rice production, open ended questions was used. A total of 240 respondents were asked if they had observed any variation in rainfall and temperature patterns with respect to onset, distribution and amount during rice growing seasons as previously described by Bomuhangi *et al.* (2016). Since the researcher relied on farmer's subjective response, predetermined attributes were provided for each response. For example, attributes for onset of rainfall were coded as "early, late or normal". For amount of rainfall, attributes were "less, excess or normal" rainfall. For temperature conditions, attributes included "high or normal". In addition, question was asked whether varying conditions of rainfall and temperature had effects on rice production.

Data requirement for variability and trend analysis as well as effects of climate variability on rainfed rice production were retrieved from beta earth map (ECMWF-ERA5 global reanalysis). ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate. Rainfall, temperature and heat stress days were extracted from with 4km² grid. The data are provided for monthly, annual and time series averages. Regarding production data (yield), the data were obtained from objective 1. Subsequently, new rainfall and temperature data were reconstructed for each farm from the time rice was planted to harvest (Hughes *et al.*, 2011; Lazzaroni and Bedi, 2014). This was intended to provide the nearest approximation of rainfall and temperature conditions since the different rice varieties have different growth requirements and duration. This was on assumption that climate variables are critical during crop growth cycle (Tsuboi, 2011; GRiSP, 2013; IRRI, 2015).

5.2.2 Data analysis

(i) Farmers' views of climate variability in rainfed rice production systems

To analyse data on farmers' views, descriptive statistic was used where frequencies and cross tabulations for multiple comparisons were done.

(ii) Rainfall and temperature variability and distribution trend

Models and methods

A number of techniques have been developed for variability and trend analysis of rainfall and temperature and these techniques fall into the category of variability and trend analysis (De Luis *et al.*, 2011; Mekonnen and Woldeamlak, 2014). Variability analysis involves computation of coefficient of variation (CV), percentage departure from the mean (Standardized precipitation anomaly), and precipitation concentration index (PCI). Trend analysis used both parametric approach (least square regression) and non-parametric tests (Mann Kendall and Sen's slope estimator) to detect extent of variability in rainfall, temperature and heat stress days (Mann, 1945; Sen, 1968; Kendall, 1975).

Coefficient of Variation (CV)

CV was calculated to evaluate variability of rainfall, temperatures and heat stress days. According to analysis (Curto and Pinto, 2009). CV is used to classify the degree of variability of rainfall events as less ($CV < 20$), moderate ($20 < CV < 30$), and high ($CV > 30$). A higher value of CV is an indicator of larger variability and a lower value implies small variability. Coefficient of variation was thus computed according to Curto and Pinto (2009) as:

$$Cv = \frac{\text{standard deviation}}{\text{mean}} * 100 \dots\dots\dots 5.2.2(i)$$

Precipitation Concentration Index (PCI)

The PCI values were computed, as given by (De Luis *et al.*, 2011) as:

$$PCI_{annual} = \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} * 100 \dots\dots\dots 5.2.2(ii)$$

where: P_i is the rainfall amount of the i^{th} month. PCI values of less than 10 indicates uniform monthly distribution of rainfall (low precipitation concentration), values between 11 and 15 denote moderate concentration, values from 16 to 20 indicates high concentration, and values of 21 and above indicate very high concentration.

Anomalies (departure from the mean)

On the other hand, standardized anomalies of rainfall were calculated to examine the nature of variability. Rainfall anomaly allows for determination of the dry and wet years for the period under observation and therefore used to assess frequency and severity of droughts (Agnew and Chappel, 1999) as:

$$z = \frac{x_i - \mu_l}{\sigma} \dots\dots\dots 5.2.2(iii)$$

where, z is standardized rainfall anomaly; x_i is the annual rainfall of a particular year; μ_i is long term mean annual rainfall over a period of 30 years being observed and σ is the standard deviation of annual rainfall over the period of observation. According to (Agnew and Chappel, 1999), the drought classes are categorised as extreme drought, severe drought, moderate drought and no drought.

Table 5. 1: Drought classes

Anomaly	Drought severity classes
Extreme drought	$Z < -1.65$
Severe drought	$-1.28 > Z > -1.65$
Moderate drought	$-0.84 > Z > -1.28$
No drought	$> Z > -0.84$

Trend analysis

Trend analysis used both parametric approach (least square regression) and non-parametric tests (Mann Kendall and Sen's slope estimator) to detect extent of variability in rainfall, temperature and heat stress days (Mann, 1945; Sen, 1968; Kendall, 1975). Unlike parametric method, Mann Kendall test explores the trend regardless of the time series linearity. Advantage over parametric test is its suitability for non-normally distributed, outlier, censored and missing data which is the case with meteorological time series (Mekonnen and Woldeamlak, 2014). In parametric tests, normality and homogeneity of variance throughout the series may be adversely affected by outliers and missing data. Prior tests for normality (skewness kurtosis test) of the climate variable was performed while Sen's slope estimator (test Pettitt's test) provided the degree of homogeneity of the data.

(iii) Influence of climate variability on rainfed rice production

Conceptual model and method

Rice production takes place within a natural environment defined by biophysical elements (climatic and soil factors) on one hand and managerial factors on the other hand. However, climatic factors (rainfall and temperature) are random external factors that interact with the natural production system to cause changes in rice production (yield). Rainfall or availability of water (moisture) is a critical input in crop production and more so in rice which is a

wetland crop. However, negative variation (too little or excess) may affect crop performance. On the other hand, too low or extreme high temperature can impair plant growth (GRiSP, 2013; IRRI, 2015). As such, strong positive and negative relationships have been demonstrated between rainfall and temperature extremes and rice production (Hughes *et al.*, 2011). Haneishi *et al.* (2013) demonstrated positive effects of rainfall on rainfed rice cultivation where an increase in annual rainfall by 1mm translated in yield increment by 1.2 kg ha⁻¹. However, mixed or indecisive results have also been reported (Ajetomobi *et al.*, 2011; Rowhani *et al.*, 2011; Shakoor *et al.*, 2015). In other studies like Long and Mitsuyasu (2012); Hasnain *et al.* (2015), irrigation has been used as proxy for moisture availability in rice production.

In this study rice yield is considered a function of climate variables and the relationship is represented by in notation form by equation;

$$y_i = (x_i\beta_i) + \varepsilon_i, \text{ where } i = 1, 2, 3 \dots, n \dots\dots\dots 5.2.2(iv)$$

y_i is the response variable (rice yield) from farmer i . x_i is the regression variables. β_i is the coefficients containing the population value of the coefficients for the k regression variables in x_i . ε_i is the error terms. The error term captures random environmental noise, choice of regression model is wrong, and omission of variables that are not measurable. On this basis, the general form of the linear regression model for farmer i can be expressed as follows:

$$y_i = x_i\beta_i + c_i + \varepsilon_i \dots\dots\dots 5.2.2(v)$$

c_i is the (theoretical) values of all the variables and effects that cannot be directly observed. c_i is the (theoretical) population values of regression coefficients for unobservable variables. The regression objective was to find a way to estimate the impact of all unobservable effects. Equation 5.2.2(v) thus suggests fixed effects or random effects model depending on whether or not the covariance term is zero, i.e. whether or not the unobservable effects are correlated with the regression variables. A fixed effect assumes the covariance is non-zero, i.e. group-

specific effects are correlated with the regression variables. Whereas random effects assume the covariance term is zero, i.e. group-specific effects are independent of the regression variables.

Following equation specified in 5.2.2(*iv*) and 5.2.2(*v*), equation for fixed effects model follows the structure;

$$y_{it} = x_{it}\beta_{it} + c_i + \varepsilon_{it} \dots\dots\dots 5.2.2(vi)$$

ε_{it} is the balance amount of error from all other sources introduced for unit *i* at time period *t*.

Matrix form:

$$y_{it} = [x_{i1t} \ x_{i2t} \ \dots x_{ikt}] \begin{bmatrix} \beta_{i1} \\ \vdots \\ \beta_{ik} \end{bmatrix} + c_i + \varepsilon_{it}$$

Least square regression is an ideal model for simple panel-data (Bascle, 2008). Other authors of climate change and variability studies have applied different approaches for analysis based on nature and objective of the study. For example, (Rowhani *et al.*, 2011) used linear mixed models while Mwaura and Okoboi (2014) used Engle’s time-varying autoregressive conditional heteroscedasticity (ARCH) model while Ali *et al.* (2017) used (FGLS) method. Therefore, taking the natural log of equation 5.2.2(*vi*), effects of climate rainfall and temperature on rice yield is modelled explicitly as;

$$\begin{aligned} \log yield_{it} = & \beta_0 + \beta_1 rf_{it} + \beta_2 cvrf_{it} + \beta_3 pci_{it} + \beta_4 mintemp_{it} + \beta_5 cvmaxtemp_{it} \\ & + \beta_6 crf_{it} + \beta_7 method_{it} + \beta_8 strategy_{it} + \beta_9 rice_{it} + \beta_{10} year \\ & + \varepsilon_{it} \dots\dots\dots 5.2.2(vii) \end{aligned}$$

$$t = 1, \dots, T; \quad i = 1, \dots, N$$

Where: ε_{it} is error for each panel and time and β is a parameter to be estimated. $\log yield_{it}$ denotes natural log of rice yield (kgs) harvested per hectare as a function of climate variables. rf , is mean rainfall amount. Water is an important input in crop production and amount of rainfall received is expected to boost production. However, variability in rainfall ($cvarf$ and pci) causes too much or too little rainfall during cropping period may affect crop production (Hughes *et al.*, 2011; Lazzaroni and Bedi, 2014). Critical crop growth stage requires regular rain to allow uniform distribution and availability of moisture. $cvmaxtemp$ and $mintemp$ temperature is important for crop growth requirements, however, temperature above 32°C or below 10°C are considered detrimental to plant growth by exerting negative effects on crop yield (Thornton *et al.*, 2014). In the face of climate variability, farmers apply set of coping mechanisms (*Strategy*) to minimize negative effects or take advantage of opportunities associated with. Production practices applied such as good method of seed-bed preparation (*method*) are hypothesized to enhance crop performance. Different rice varieties (*rice*) possess different moisture/water requirements. The lowland variety have got high water requirement whereas the upland varieties are bred for drought tolerance and hence require less water. Therefore, rainfall variability outside moisture and growth requirements for the different varieties are hypothesized to affect production performance of a variety.

Table 5. 2: Variables included in the model estimates and relationships

	Parameter	Description	Relationship
Output	-	yield (t ha ⁻¹)	Dependent variable
Rainfall amount (mm)	β_1	Millimeters	+
Coefficient of variation in rainfall	β_2	Percentage	-/+
Precipitation concentration index	β_3	Percentage	-/+
Temperature Min (°C)	β_4	Celsius	-
Coefficient of variation in maximum temperature	β_5	Percentage	-/+
Rainfall*mean temp	β_6	-	+
Method of seed-bed preparation	β_7	Dummy	+
Strategies	β_8	Dummy	+
Rice variety	β_9	Dummy	-/+
Years	γ_{10}	Dummy	-/+

Model implementation

To solve both heteroscedastic variances, yield and rainfall data was log transformed. Data reliability and validity tests were conducted to ensure robustness of the models. The

reliability and validity tests included Spearman's correlation for variable selection, information criteria for model selection, and specification and diagnostic tests for model validity. Information criteria help to determine an optimal trade-off between prediction accuracy and precision.

Variable and model selection

Variable selection method using Pearson correlation coefficient and stepwise variable selection to address the challenge of redundancy and complexity using 960 observations (Wubetie, 2019). There was a strong positive correlation between rice yields and rainfall, rainy-days, precipitation concentration index, and heat stress-days. Minimum temperature, mean temperature and effects of climate variability exhibited moderate relationships with rice yield. However, independent relation was portrayed with coefficient of variation in rainfall, coefficient of variation in minimum temperature, maximum temperature, coefficient of variation in Maximum temperature, and coefficient of variation in Mean temperature had independent relationship with rice yield. Spearman's correlation was also run to assess the strength of relationship between yield and production practices. Very strong positive relation was revealed with respect to coping strategies, method of seed bed preparation, and frequency of seedbed preparation. In regards to controlled variables (production system, soil types, production season and rice variety), a very strong positive relation exist between rice yield and variety but some very weak to no relationships were exhibited for production system, soil types and production season.

Consequently, Information criteria were used to determine the best/optimal model. Information criteria help to determine an optimal trade-off between prediction accuracy and precision (Lindsey and Sheather, 2015). The Akaike's information criterion (AIC) and Bayesian information criterion (BIC), corrected AIC and adjusted R² are popular criterion for comparing different models. The information criteria selected the following models: (i) rainfall, coefficient of variation in rainfall (%), minimum temperature (°C), coefficient of variation in maximum temperature, coping mechanism, ploughing method, ploughing frequency, and rice variety. (ii) Rainfall, coefficient of variation in rainfall (%), precipitation concentration index (%), minimum temperature (°C), and coefficient of variation in maximum temperature, coping mechanism, ploughing method, ploughing frequency, and rice variety. Years was added in the model to capture time variance while rain-days and soil types were added as instrumental variables.

Model specification and diagnostic tests

Diagnostic tests for model validity were performed using Breusch-Pagan / Cook-Weisberg test for heteroscedasticity revealed constant variance. Cameron & Trivedi's decomposition of LM-test for normality rejected normality assumption. Ramsey RESET test using powers of the fitted values for omitted variables indicted not omitted variable. And variance inflation factors for collinearity showed mean value of 7.66. The Pooled ordinary least square (OLS) regression model was used as a reference or baseline model for comparing the performance of other models which is usually the case when considering models for panel data set. The decision for the estimator to fit the data was arrived at using hausman test. The test result could not reject authenticity of fixed effects estimator ($\chi^2(11) = 15.39$; $\text{Prob} > \chi^2 = 0.1653$).

5.3 Results

The objective of this chapter was to determine effects of climate variability on rainfed rice production in northern farming. The results are therefore presented on farmers' views about climate variability, rainfall and temperature distribution trend, and influence of climate variability on rainfed rice production. The results are also reported for model specification and diagnostic tests.

5.3.1 Farmers' perception about trend in rainfall and temperature

The section sought to obtain farmers' views about climate variability in rainfed rice production systems of Northern farming system. The views are presented in terms of onset of rainfall, amount of rainfall and temperature conditions and their effects on crop production in the Northern agroecological zone.

(i) General view

The majority of the farmers interviewed agreed on the presence of variability of rainfall and temperature conditions. Slightly over 81% of the farmers reported exposure to climate variability of which only 19% were not exposed. Comparison on annual basis showed that proportion of farmers reporting exposure to climate variability was on the rise. By 2013, a total of 77% had reported exposure but increasing trend was noted as indicated by 79% (2014), 84% (2015) and 86% (2016) of the respondents, see Table 5.3.

(ii) Onset of rainfall

Attributes of onset of rainfall included early, late and timely onset. According to the farmers, late onsets and early ending of rainfall has become very common. As far as late onset of rainfall was concerned, close to 16% of the farmers reported late onset which was not in line with cropping calendar? Comparison on annual basis showed that cases reporting late onset increased between 2013 and 2016. For instance, 11% of the farmers reported late onset during 2013, 18% during 2014 and 2015 though it dropped slightly to 16% during 2016. However, 8% experienced too early onset of rainfall which did not match their planting calendar. Comparison of views on annual basis showed that cases reporting early onset increased from 6% (2013) to 11% (2015) but dropped to 7% (2016). Regarding timely onset, 77% reported timely onset of rainfall according to their cropping calendar but the proportion dropped on annual basis. For example, response on timely onset dropped from 83% in 2013 to 71% during 2015 although it rose slightly to 77% during 2016.

(iii) Amount of rainfall

A substantial proportion (59%) of the farmers reported less rains during cropping seasons. Annual response registered upward trend in views about amount of rainfall from only 45% during 2013 to 54% (2014), 65% (2015) and 71% (2016). Around 14% of them reported excessive rainfall in the entire zone. However, there was no clear trend in views on amount of rainfall. Higher proportion of farmers (28%) reported excessive rain in 2013 while lesser proportion (6%) was reported in 2016. Meanwhile, 28% of the farmers reported normal, i.e. adequate amount of rainfall. However, year by year analysis indicated a sharp drop in proportion of respondents reporting adequate rain from 38% in 2014 to only 23% in 2016.

(iv) Temperature condition

Close to 54% of the farmers indicated high temperature conditions during the production periods and 46% reported normal temperature. However, cases reporting high temperature rose from 53% in 2013 to 65% (2014), 71% (2015) and 75% (2016). However, reverse trend was observed for normal temperatures where proportion of response dropped from 47% in 2013 to 35% during 2014, 29% in 2015 then to 25% during 2016.

(v) Views on effects of climate variability on production

Regarding effects of climate variability on rice production, 70% of the farmers reported negative effects of climate variability on crop production and only 30% were not affected (Table 6.3). Of those who were affected, 64% experienced poor crop yield, 12% harvested low grain quality, 7% had delayed planting and 4% had low production due to reduced acreage. Also, a total 11% suffered from combination of delayed planted, poor yield and low grain quality.

Table 5. 3: Subjective views of farmers on rainfall and temperature trend

	Pool		2013 season		2014 season		2015 season		2016 season	
	Cases (n=960)	%	Cases (n=240)	%	Cases (n=240)	%	Cases (n=240)	%	Cases (n=240)	%
Overall										
Climate varied	780	81	184	77	188	79	200	84	208	86
Was normal	180	19	56	23	52	21	40	16	14	14
Rainfall										
Onset of rain										
Late	152	16	26	11	43	18	44	18	39	16
Early	72	8	14	6	17	7	26	11	16	7
Timely	736	76	200	83	180	75	170	71	185	77
Amount of rain										
Less	564	59	107	45	130	54	157	66	171	71
Excess	132	14	67	28	20	8	25	10	14	6
Normal	264	27	66	27	90	38	58	24	55	23
Temperature										
High	520	54	127	53	155	65	171	71	179	75
Normal	440	46	113	47	85	35	69	29	61	25

Table 5. 4: Subjective views of farmers on effects of climate variability on rainfed rice

	Cases (n=940)	%
Pooled		
Affected	848	70
Not affected	112	30
Specific effects		
Poor yield	135	64
Low grain quality	26	12
Delayed planting	14	7
Low production	8	4
Low grain quality, poor yield and delayed planting	23	11

Observations: Overall = 960; Farmers affected = 848

5.3.2 Rainfall and temperature distribution in the Northern farming system agroecological zone

The results provided in this section include variability and trends in rainfall, minimum and maximum temperatures and heat stress days. Variability is measured in terms of coefficient of variation, anomalies and precipitation concentration index. Results for trend analysis were obtained through linear regression method (parametric method) and Mann-Kendall trend (non-parametric method).

(i) Normality and homogeneity tests

Homogeneity test is important in identifying reliability as well as suitability of time series data for climate change and variability studies. The result from Pettitt's test could not reject the null hypothesis that all the climate data during the thirty years (1990-2019) except maximum temperature were homogenous (Table 5.5). Computed p-value was greater than the significance level ($p > 0.05$) and, one could not reject the null.

Similarly, skewness and kurtosis test for normality showed that the probability of skewness was 0.8078 (rainfall), 0.3715 (minimum temperature), 0.6272 (maximum temperature), and 0.2916 (heat stress days). The results imply normally distributed data (p-value of skewness > 0.05). The Pr(Kurtosis) also indicated that the kurtosis was distributed (p-value of kurtosis > 0.05) for all the climate variables. The values of chi2 were greater than 0.05 implying that the null hypothesis cannot be rejected since the residuals showed normal distribution.

Table 5. 5: Monte Carlo simulations and Skewness/Kurtosis tests for Normality

Summary	Monte Carlo simulations				Skewness/Kurtosis	
	Pettitt	SNHT test	Buishand	von Neumann	Pr (Ske)	Pr (Kurt)
Rainfall	0.056	0.030	0.038	0.146	0.808	0.800
Min temp	0.217	0.007	0.054	0.001	0.372	0.858
Max temp	0.035	0.004	0.007	0.030	0.627	0.550
Mean temp	0.107	0.008	0.036	0.009	0.199	0.477
Heat stress days	0.086	0.040	0.043	0.169	0.292	0.614

(ii) Rainfall - variability and trend

The mean annual rainfall in the Northern agroecological zone over a period of three decades was 1361.03 mm with 157.75 mm standard deviation. The minimum and maximum recorded during the period were 996.93 mm and 1676.28 mm per year, respectively (Table 5.6). It is worth noting that the average recorded in the agroecological zone was less than 1500 to 2500 mm required for successful rice production. Nevertheless, high annual (1676.28 mm) was

recorded in 1991 and this was due to high rains during the same year in the study site (1741.24 mm), i.e. Amuru and Gulu, respectively, received 1873.66 mm and 1822.81 mm. In contrast, the lowest average (996.93 mm) was received in 2016 (which falls within the period of analysis in this study). Decadal comparison revealed high mean rainfall during the first decade (1452.59 mm), then it dropped in the second decade (1283.58 mm) but rose again to 1346.9 mm (third decade).

Monthly rainfall experienced in the zone was 113.4 mm, an average lower than the national mean of 141.8 mm implying that rainfall in the zone was low. December to March registered low mean (19.38 to 88.26 mm) as expected since these are usually drier months in the zone. High monthly mean was recorded in April/May (178.43 mm/169.58 mm) which are the peak period for first season rains in the zone. Peak rainfall months for second season were August/October (164.9 mm/167.34 mm). September received very low rainfall (131.96 mm) yet it is a peak growing month. This is an indication of low rainfall during second season cropping in the zone. Low September rains total between 30 to 96 mm were registered during 1994, 1997, 2002, 2015, 2016 and 2018. June/July/November (125.96 mm/137.65 mm/111.27 mm) received relatively less rainfall. Again it was expected since these are exist months for first season and second cropping, respectively.

Coefficient of variation revealed low annual rainfall variability (11.6%). Low variability was equally recorded within the decades, although slightly higher variability (CV of 12%) was observed in third decade (2010-2019). In contrast, monthly variability was very high, i.e. coefficient of variations ranged between 21% during the month of May to 102.6% in December. April, May, July and August registered moderate degree of rainfall variability (CV ranging between 21 and 25.9%). On the contrary, November to March recorded high degree of rainfall variability (CV exceeding 30%). Generally, months falling within cropping seasons had moderate to high rainfall variability (CV ranging between 21 and 30.8%).

Table 5. 6: Coefficient of variation in rainfall (1990-2019) - Northern farming system

	Mean (mm)	Std. dev	Min	Max	CV (%)
Annual distribution					
Annual (Pooled)	1361.03	157.75	996.93	1676.28	11.6
Decadal					
1990-1999	1452.59	157.70	1151.30	1676.30	10.9
2000-2009	1283.58	113.30	1152.70	1505.00	8.8
2010-2019	1346.90	162.11	996.90	1565.90	12.0
Monthly distribution					
Jan	19.38	17.78	0.06	69.42	91.7
Feb	26.53	26.67	0.27	110.86	100.5
Mar	88.26	47.15	3.91	163.23	53.4
Apr	178.43	44.68	101.29	298.45	25.0
May	169.58	35.65	105.20	233.59	21.0
Jun	125.94	38.74	66.47	223.96	30.8
Jul	137.65	35.70	66.27	199.16	25.9
Aug	164.90	39.38	94.11	250.25	23.9
Sep	131.96	39.10	30.76	200.40	29.6
Oct	167.34	50.79	61.12	249.43	30.3
Nov	111.27	53.50	34.37	236.36	48.1
Dec	39.96	40.99	2.16	174.99	102.6

The PCI was computed to explore rainfall concentration and distribution and the result revealed presence of low to moderate concentration of rainfall (Table 5.7). Low to moderate concentration of rainfall was observed in the zone. Basically the mean PCI of 11.25) was experienced for a period of 30 years in the zone. Generally, Eastern and Northern districts of agroecological zone including the study sites had moderate concentration of rainfall. Low to moderate concentration of rainfall was observed in the zone. Low concentration was observed for only 4 years (Pooled) with mean CPI of 9.7%. Low CPI was a result of CPI less than 10 observed during 1990, 1996, 2006 and 2010) especially in district of Amolatar, Apac, Dokolo, Oyam, Kole and Nwoya. Generally, moderate concentration of rainfall (PCI of 11.25) was observed for 26 years. This was attributed to surrounding effects of Lake Kyoga, River Nile and Karuma forest reserve on the southern districts.

Table 5. 7: Precipitation concentration index (1990-2019) in Northern farming system

PCI index	Number of years			
	Pooled	1990-1999	2000-2009	2010-2019
≤ 10 (Low concentration)	4	2	1	1
11-15 (Moderate concentration)	26	8	9	9
16-20 (High concentration)	-	-	-	-
≥ 21 (Very high concentration)	-	-	-	-
Mean PCI (1990-2019)	11.25	11.04	11.06	11.70

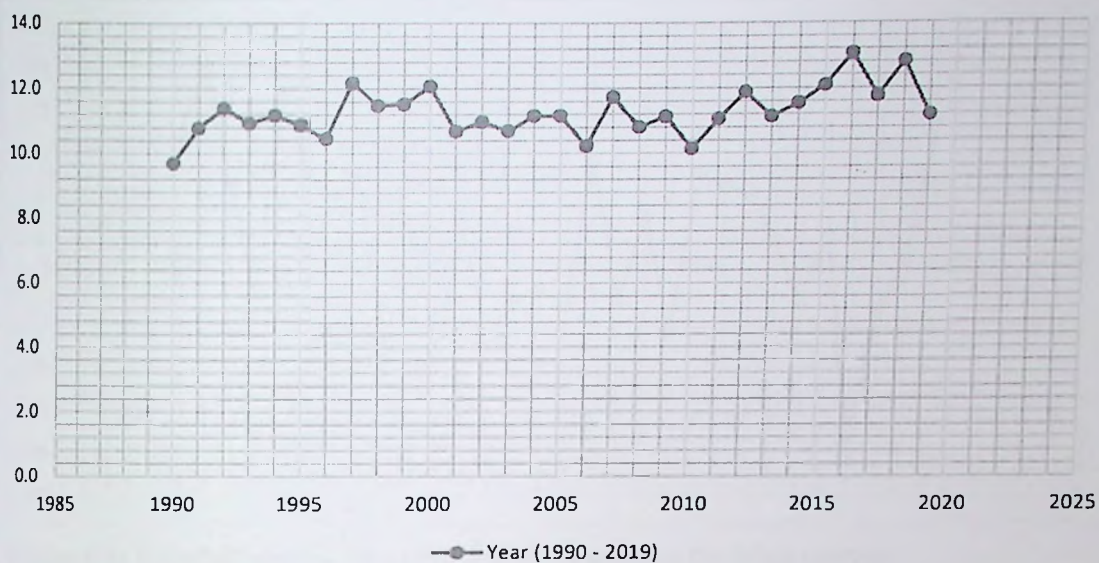


Figure 5. 3: Precipitation concentration index (1990-2019) -Northern farming system

As depicted in Table 5.8, rainfall anomaly also indicated presence of interannual variability. High rainfall above the long-term average was observed in 1991 (+2) to very low rainfall in 2016 (-2.31). In a period of three decades, eight incidence of drought was experienced in the zone. Particularly, 2016 experienced extreme drought (-2.31), severe drought was recorded during 1998 (-1.33) and 2000 (-1.32) whereas, moderate drought corresponded with the period 2002 (-1.16), 2009 (-1.05) and 2017 (-0.84). On the other hand, rainfall above the long-term average was received during 1991 (+2.0) and 1994 (+1.69), very high (severe) rainfall was recorded during 1990 (+1.23) and 2019 (+1.30) whereas moderate rainfall was received during 2006 (+0.91).

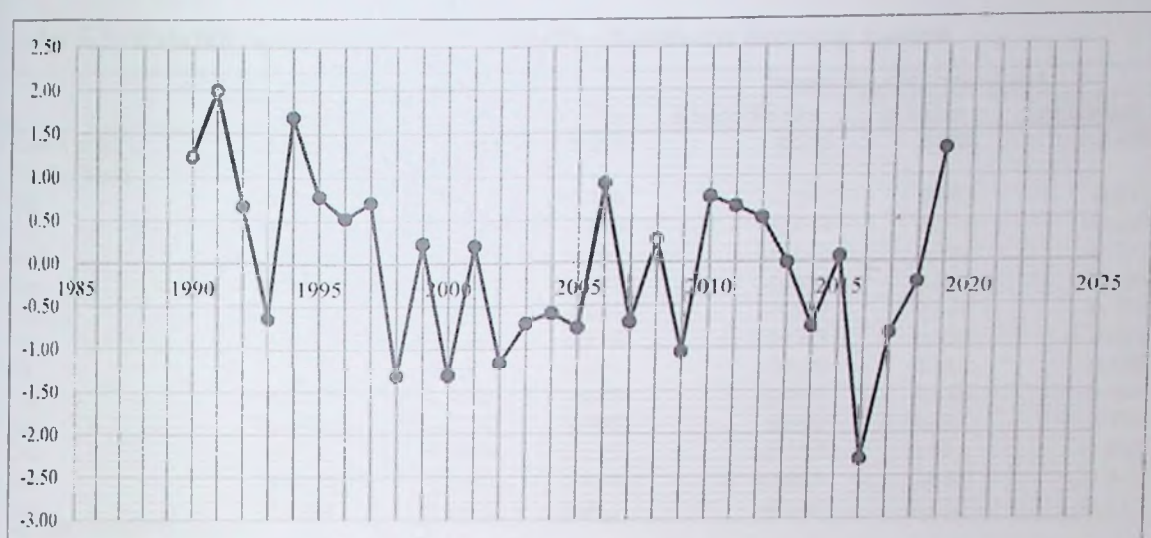


Figure 5.4: Rainfall anomalies (1990-2019) -Northern farming system

Table 5. 8: Anomalies (departure from the mean) - Northern farming system

	Drought classes	Number of years
Extreme drought	>-1.65	1
Severe drought	$>-1.28<-1.65$	2
Moderate drought	$>-0.84<-1.28$	2
No drought	<-0.84	9
Extreme excess rain	>1.28	3
Moderate drought	$>0.84<1.28$	2
Normal	<0.84	11

Trends for annual and monthly rainfall are presented in Table 5.9 and Appendix 4. The result obtained through parametric method showed statistically significant negative annual trend (-5.8897) in rainfall. Mann-Kendall trend test also detected decreasing trend (-0.255) and was statistically significant trends at 5%. Monthly trend detection using parametric method revealed a statistically significant trend for all the months except April, June, September and October and September. Statistically significant negative trends were detected for the months of January (-0.9463), February (-0.7210), March (-0.7458), May (-0.8127), November (-0.6730) and December (-0.5995). in contrast, insignificant increasing trends were observed for the months of June and September. Similar trends were also observed in non-parametric tests although statistically significant negative trend was indicated for January.

Table 5. 9: Rainfall (mm) trend (1990 – 2019) - Northern farming system

	Regression			Mann-Kendall trend test		
	Coef.	Std. Err.	P>t	Kendall's tau	p-value	Sen's slope
Annual trend	-5.8897	3.1984	0.076	-0.255	0.048	-7.480
Monthly trend						
Jan	-0.9463	0.0960	0.000	-0.292	0.023	-0.815
Feb	-0.7210	0.1519	0.000	-0.159	0.218	-0.399
Mar	-0.7458	0.2823	0.009	-0.113	0.382	-0.712
Apr	-0.2502	0.2915	0.391	-0.039	0.762	-0.594
May	-0.8127	0.2337	0.001	-0.122	0.344	-0.932
Jun	0.1381	0.2481	0.578	0.007	0.957	0.012
Jul	-0.5963	0.2572	0.021	-0.099	0.443	-0.588
Aug	-0.5838	0.2661	0.029	-0.057	0.656	-0.305
Sep	0.4490	0.2710	0.098	0.090	0.487	0.786
Oct	-0.5522	0.3634	0.129	-0.117	0.363	-1.047
Nov	-0.6730	0.3481	0.054	-0.025	0.844	-0.312
Dec	-0.5995	0.2402	0.013	-0.103	0.422	-0.437

Mann-Kendall trend test / Two-tailed test

Test interpretation: H0: There is no trend in the series. Ha: There is a trend in the series

If the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis

(iii) Minimum temperature variability and trend analysis

The summery of the results are reported in Table 5.10. The mean minimum temperature in the zone was 18.2°C. The temperature ranged from minimum 16.2°C to maximum 20.1°C with a standard deviation of 0.71°C. The high temperature reflected was attributed to high averages experienced during 2016 and 2017 with values ranging from 18.9 to 18.8°C, respectively. The mean in the study sites (18.5°C) was above the zonal mean according to the positive departure of 1.6%. Meanwhile low mean value experienced during 1990/1991 implies that minimum temperature is on the rise. However, coefficient of variation showed low annual variability (3.9%). Distribution across the decades revealed temperature range between 16.72°C and maximum 19.94°C with a mean of 18.1°C during the period 1990-1999. Insignificant rise was noted in the subsequent decade (2010-2019). Generally, low coefficient of variation of 3.7%, 3.6% and 4.3%, respectively, were observed during the first, second, third decade. Monthly distribution revealed high values during the month of February to May. March was the peak month (19.2°C) but the value of standard deviation was lower than the rest of the months (0.6°C) which suggests low temperature variability within the month. However, June and July recorded relatively lower temperature (17.5°C). The rest of the months exhibited similar temperature range (17.8 to 18.1°C). Similarly, low coefficient of variation was observed across all the months (3.1% to 4.6%) although relatively higher values were exhibited in the month of November to January.

Table 5. 10: Coefficient of variation in minimum temperature - Northern farming system

Period	Mean	Std. Dev.	Min	Max	CV (%)
Annual (Pool)	18.201	0.712	16.235	20.123	3.9
Decadal					
1990-1999	18.111	0.677	16.722	19.943	3.7
2000-2009	18.16	0.659	16.728	19.747	3.6
2010-2019	18.331	0.78	16.235	20.123	4.3
Monthly					
Jan	17.931	0.808	16.369	19.342	4.5
Feb	18.945	0.687	17.417	20.04	3.6
Mar	19.237	0.6	18.166	20.524	3.1
Apr	19.009	0.585	18.151	20.288	3.1
May	18.601	0.652	17.794	19.924	3.5
Jun	17.972	0.621	17.172	19.188	3.5
Jul	17.505	0.603	16.77	18.74	3.4
Aug	17.522	0.619	16.705	18.691	3.5
Sep	17.846	0.659	16.918	19.128	3.7
Oct	18.089	0.595	17.073	19.259	3.3
Nov	17.986	0.711	16.852	19.418	4
Dec	17.767	0.814	16.325	19.369	4.6

The result obtained through regression method showed increasing annual and monthly trends except for the months of February and April under Mann-Kendall trend (Table 5.11 and Appendix 4). Overall, positive and statistically significant trends were observed in regression (0.015) and Mann-Kendall (0.264) models. The monthly trends were statistically significant for most of the months falling within the cropping period (May to October). The positive and significant trends exhibited imply that minimum temperature during cropping period in the zone is on the rise.

Table 5. 11: Minimum Temperature (°C) trend (1990-2019) -Northern farming system

	Regression			Mann-Kendall trend test		
	Coef.	Std. Err.	P>t	Kendall's tau	p-value	Sen's slope
Annual (Pool)	0.0150	0.0062	0.022	0.264	0.040	0.015
Monthly						
Jan	0.0157	0.0167	0.357	0.140	0.276	0.019
Feb	-0.0018	0.0154	0.908	0.080	0.532	0.009
Mar	0.0056	0.0163	0.735	0.025	0.844	0.003
Apr	0.0040	0.0124	0.75	-0.011	0.929	-0.001
May	0.0224	0.0077	0.007	0.338	0.009	0.021
Jun	0.0190	0.0075	0.017	0.255	0.048	0.019
Jul	0.0186	0.0070	0.013	0.315	0.015	0.023
Aug	0.0173	0.0076	0.031	0.228	0.077	0.016
Sep	0.0205	0.0087	0.026	0.269	0.037	0.017
Oct	0.0316	0.0102	0.004	0.292	0.023	0.023
Nov	0.0171	0.0108	0.123	0.159	0.218	0.014
Dec	0.0093	0.0108	0.395	0.108	0.402	0.012

Mann-Kendall trend test / Two-tailed test

Test interpretation: H0: There is no trend in the series. Ha: There is a trend in the series

If the computed p-value is greater than the significance level $\alpha=0.05$, one cannot reject the null hypothesis

(iv) Maximum temperature variability and trend analysis

The mean maximum temperature in the Northern agroecological zone ranged from 31.9°C (minimum) to 33.63 °C (maximum) with annual average temperature of 32.71°C. High mean value exceeding national average of 30.4°C during the same period was attributed to high values recorded in Amuru district (34°C) and the rest of Eastern and Northern districts of the zone (above 33°C). The low mean value of 32.4°C was recorded during the first decade but a slight rise (32.9°C) was observed during the second decade. This slight increase was contributed by high averages above 33°C recorded during 2002, 2003 and 2009. Coefficient of variation also indicated low variability between 1.4 and 0.9%. Monthly mean values revealed high temperature during the month of November to April (between 32.2 and 36.45°C). Relatively lower averages were registered during the months of May to October (ranging between 29.92 and 31.99°C). Cropping months with the exception of March and April tended to have mean value within the threshold of 32°C for rice production. Generally, coefficient of variation revealed low annual (1.3%), decadal (0.9 to 1.4%) and monthly (1.5 to 3.5%) variability in mean values.

Table 5. 12: Coefficient of variation in maximum temperature - Northern farming system

Period	Mean	Std. Dev.	Min	Max	CV (%)
Annual (pooled)	32.714	0.439	31.899	33.625	1.3
Decadal					
1990-1999	32.381	0.451	31.899	33.159	1.4
2000-2009	32.918	0.381	32.285	33.625	1.2
2010-2019	32.843	0.291	32.458	33.276	0.9
Monthly					
Jan	35.304	0.970	32.745	36.987	2.7
Feb	36.452	0.973	33.893	38.217	2.7
Mar	36.064	1.051	33.280	37.740	2.9
Apr	33.454	1.162	30.733	34.968	3.5
May	31.208	0.833	29.472	32.562	2.7
Jun	30.444	0.650	29.059	31.584	2.1
Jul	29.917	0.524	28.869	30.908	1.8
Aug	30.315	0.462	29.248	31.055	1.5
Sep	31.543	0.698	29.954	32.408	2.2
Oct	31.985	0.759	30.226	32.827	2.4
Nov	32.166	0.910	29.906	33.287	2.8
Dec	33.714	0.975	31.208	35.311	2.9

Trend analysis

The trend for annual mean maximum temperature showed statistically significant rising trends for parametric (0.0245) and Mann-Kendall trend (0.306). As demonstrated in Table 5.13 and Appendix 4, increasing trends were observed across all the months (Mann-Kendall trend) although decreasing trends were observed for November and December (parametric method). The trends were statistically significant for January, February and May only.

Table 5. 13: Maximum Temperature (°C) trend - Northern farming system

	Regression			Mann-Kendall trend test		
	Coef.	Std. Err.	P>t	Kendall's tau	p-value	Sen's slope
Annual (pool)	0.0245	0.0082	0.006	0.306	0.018	0.025
Monthly						
Jan	0.0472	0.0204	0.028	0.283	0.028	0.052
Feb	0.0546	0.0199	0.01	0.338	0.009	0.047
Mar	0.0425	0.0318	0.192	0.205	0.112	0.054
Apr	0.0363	0.0344	0.3	0.149	0.246	0.026
May	0.0334	0.0150	0.035	0.301	0.019	0.036
Jun	0.0194	0.0143	0.187	0.131	0.309	0.018
Jul	0.0211	0.0142	0.15	0.214	0.097	0.018
Aug	0.0185	0.0151	0.23	0.218	0.090	0.020
Sep	0.0177	0.0209	0.404	0.030	0.817	0.004
Oct	0.0068	0.0192	0.728	0.071	0.580	0.009
Nov	-0.0026	0.0240	0.915	0.062	0.630	0.016
Dec	-0.0012	0.0247	0.96	0.011	0.929	0.001

Mann-Kendall trend test / Two-tailed test

Test interpretation: H0: There is no trend in the series. H1: There is a trend in the series

If the computed p-value is greater than the significance level $\alpha=0.05$, one cannot reject the null hypothesis

(v) Heat stress days above 32°C variability and trend analysis

The average number of heat stress days in the zone was 62.5 days with a standard deviation of 17.5 days (Table 5.14). It ranged from minimum 37.3 to maximum 98.7 days. The zonal average was attributed to high number of heat stress days in the districts of Amuru (89.4), Lamwo (91.6), Otuke (91.1) and Pader (83.9). Coefficient of variations of heat stress days showed moderate annual variability (28.1%). Inter-decadal revealed an average of 57 days during 2000-2009 with range of 37.4 days in comparison to 67.9 days during 2010-2019. Coefficient of variation with the decades was also moderate at 24.8 and 28.8 days, respective, for first and second decade. Monthly observation indicated high heat stress days (8.3 to 16.4 days) outside the cropping calendar for Northern agroecological zone (December to March) which ranged from. This result implies that heat stress days may not be challenge to crop production in the zone. However, variability analysis reported very high coefficient of variations exceeding 30% (CV ranged between 31.4 and 74%) in number of days.

Table 5. 14: Coefficient of variation in heat stress days - Northern farming system

Variable	Obs	Mean	Std.Dev.	Min	Max	CV (%)
Annual (pooled)	20	62.4482	17.5170	37.2628	98.7089	28.05
Decadal						
2000-2009	10	57.0023	14.1294	37.2628	84.5367	24.79
2010-2019	10	67.8941	19.5510	40.0844	98.7089	28.80
Monthly						
Jan	20	14.7047	6.6540	1.5835	26.1470	45.25
Feb	20	16.3570	7.4506	1.4860	25.5795	45.55
Mar	20	14.4246	7.1007	3.8858	25.9529	49.23
Apr	20	4.3222	2.7273	1.2263	12.3713	63.10
May	19	1.9332	0.8295	1	4.2732	42.91
Jun	10	1.7480	0.5977	1	2.6200	34.19
Jul	12	2.2025	0.9775	1	4	44.38
Aug	10	1.5792	0.4957	1	2.6296	31.39
Sep	18	2.0422	1.1893	1	5.9776	58.24
Oct	18	2.8926	1.6101	1.2193	7.2920	55.66
Nov	20	3.4822	2.2782	1	9.4591	65.42
Dec	20	8.3497	6.1761	1.3432	22.2620	73.97

Positive and statistically significant ($p < 0.05$) annual trend was detected in the number of heat stress days in the zone (Table 15 and Appendix 4). In linear regression, the number of heat stress days increased annually at a rate of 0.0925. Notable positive trend was also detected in Mann-Kendall trend at an annual rate of 0.347. Monthly trend was statistically significant for January in parametric method (0.487) and Mann-Kendall trend (0.389). The month of May reported rising trend in the number of heat stress days but the coefficient (-0.0622) was only significant in parametric method. Otherwise, the rest of the months had weak trends:

December to June had increasing trends whereas July to October presented declining trends in the number of heat stress days.

Table 5. 15: Heat stress days trend – (2000 – 2019) - Northern farming system

	Regression			Mann-Kendall trend test		
	Coef.	Std. Err.	P>t	Kendall's tau	p-value	Sen's slope
Annual (pooled)	0.0925	0.0406	0.024	0.347	0.032	1.578
Monthly						
Jan	0.4870	0.1821	0.015	0.389	0.016	0.548
Feb	0.2729	0.1756	0.138	0.253	0.119	0.267
Mar	0.3742	0.2696	0.182	0.221	0.173	0.474
Apr	0.1042	0.1139	0.372	0.000	1.000	0.000
May	-0.0622	0.0306	0.057	-0.165	0.326	-0.024
Jun	0.0014	0.0393	0.973	0.090	0.719	0.014
Jul	-0.0690	0.0502	0.186	-0.303	0.170	-0.043
Aug	-0.0316	0.0318	0.333	-0.315	0.209	-0.031
Sep	-0.0523	0.0507	0.316	-0.066	0.705	-0.002
Oct	-0.0170	0.0702	0.812	0.007	0.970	0.000
Nov	0.0265	0.0890	0.769	-0.016	0.922	-0.005
Dec	0.0760	0.2385	0.754	0.011	0.948	0.013

Number of observations = 20, Mann-Kendall trend test / Two-tailed test, Test interpretation: H0: There is no trend in the series. Ha: There is a trend in the series

5.3.3 Effects of climate variability on rainfed rice production

The concern addressed in this result section was, what is the influence of climate variability on rice production in rainfed rice production systems of northern farming system? Descriptive statistics of variables used in the estimation are provided in Table 16. The variables included rice yield per hectare, coefficient of variations in rainfall, lowland and upland rice varieties, coefficient of variations in minimum temperature, maximum temperature, and mean temperature. The regression results are presented in Table 5.17 to 5.19.

Table 5. 16: Descriptive statistics for variables used in analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
Rainfall	960	674.918	113.761	255.308	1019.628
Minimum temp	960	18.584	0.741	17.045	20.572
Maximum temp	960	31.588	1.026	29.876	34.342
Mean temp	960	24.023	0.834	22.610	26.195
CV (%) - Rainfall	960	35.799	12.316	10.811	112.384
CV (%) – Minimum temp	960	3.071	1.077	0.216	7.209
CV (%) – Maximum temp	960	4.515	2.663	0.823	12.229
CV (%) – Mean temp	960	3.318	1.835	0.762	10.055
Variety	960	0.4313	0.4955	0	1

Mean rainfall, minimum and maximum temperature registered positive relationship with rice yield. Measures of variability in terms of precipitation concentration index, coefficient of variations in rainfall and temperature were all negative implying that variability in climate affects rice yield negatively.

(i) Rainfall

Overall, increased mean rainfall is associated with an improvement in rice yield according to the positive coefficient (2.0468). The reduction was observed in the lowland varieties (SUPA and KAISO) as indicated by the negative coefficient (-0.0025). Inverse relationship between yield and rainfall was a reflection of negative variability in rainfall as observed in variability and trend analysis (section 5.3.2 (ii)). In contrast, upland varieties registered a positive relationship (0.003). Variability in rainfall as measured by coefficient of variation in rainfall and precipitation concentration index had a decreasing effects on rice yield. Rice yield is likely to decline by -0.012 and -0.007, respectively, for increases in coefficient of variation in rainfall and precipitation concentration index.

(ii) Temperature

Mean minimum and maximum temperature during growth period had significant positive impacts on rice yield. The results suggest the likely improvement in yield by 1.29 and 0.0019, respectively, for minimum and maximum temperatures. However, negative association between minimum temperature and rice yield was felt in the lowland varieties according to the observed yield (-2.8628). Coefficient of variation minimum and maximum temperature had reduction effects on yields across all the models. As such, yield is likely to decline in pooled model (-0.1624). The magnitude of declines in yield is likely to be higher in lowland varieties (-0.0592) as opposed to the upland varieties (-0.0251). The slow impact in upland varieties was probably due resilience of the varieties to heat stress. Similarly, interaction effects between the current level of mean rainfall and temperature revealed negative association between yield and climate variable. There is a likelihood of reduction in yield significantly by -0.0002.

(iii) Production practices and coping strategies

Analysis of the relationship between rice yield and production practices reflected increasing relationships. Rice yield increased (0.1027) for farmers who applied coping mechanism to climate variability. However, use of rudimentary tools like hand-hoe in seedbed preparation impact on yield negative. Poorly prepared seedbed does not facilitate good water infiltration

as well as moisture retention. Analysis in terms of rice varieties indicated negative effects of lowland varieties on rice yield (-0.0784).

Table 5. 17: Effects of climate variability on rice yield – pooled model

	Coef.	Std. Err.	P>t	[95% Conf. Interval]	
lnyield					
Rainfall (mm)	2.0468	0.7580	0.007	0.5586	3.5350
CV in rainfall	-0.0121	0.0077	0.118	-0.0273	0.0031
Precipitation concentration index	-0.0070	0.0052	0.175	-0.0172	0.0031
Minimum temperature (°C)	1.2900	0.5390	0.017	0.2317	2.3484
CV in minimum temp	-0.1624	1.6114	0.92	-3.3261	3.0012
Maximum temperature	0.0019	0.0479	0.968	-0.0920	0.0959
Rainfall*mean temperature	-0.0002	0.0000	0.002	-0.0002	-0.0001
Coping strategies	0.1027	0.0950	0.28	-0.0839	0.2893
Seed bed preparation method	-0.0068	0.1182	0.954	-0.2389	0.2253
Rice variety (lowland)	-0.0784	0.1815	0.666	-0.4348	0.2780
year					
2014	-0.5499	0.2128	0.01	-0.9676	-0.1321
2015	-1.0701	0.4233	0.012	-1.9011	-0.2391
2016	-1.5611	0.6071	0.01	-2.7531	-0.3691
cons	-33.1496	11.5848	0.004	-55.8942	-10.4050
sigma_u	1.1090				
sigma_e	0.7908				
rho	0.6629				
R-Sq: within	0.0559				
between	0.0005				
overall	0.0021				
F test that all u_i=0: F(239, 707) = 2.11 Prob > F = 0.0000 F(13, 707) Prob > F = 0.0001 corr(u_1, Xb) = -0.8340 Obs = 960					

Table 5. 18: Effects of climate variability on rice yield – Lowland varieties

yield	Coef.	Std. Err.	z	P>z	[95% C.I.]	
Rainfall (mm)	-0.0025	0.0020	-1.29	0.195	-0.0064	0.0013
CV in rainfall	-0.0072	0.0105	-0.68	0.497	-0.0278	0.0135
Precipitation concentration index	-0.0095	0.0187	-0.51	0.611	-0.0461	0.0271
Minimum temperature (°C)	-0.0592	0.0736	-0.8	0.421	-0.2035	0.0851
CV in maximum temperature	-2.8628	1.4878	-1.92	0.054	-5.7788	0.0533
Coping mechanism	0.4909	0.1846	2.66	0.008	0.1291	0.8528
Practices						
Ploughing method	0.3551	0.2183	1.63	0.104	-0.0728	0.7829
Ploughing freq	0.1527	0.1353	1.13	0.259	-0.1124	0.4179
year						
2014	-0.2787	0.2420	-1.15	0.249	-0.7529	0.1955
2015	-0.5650	0.4141	-1.36	0.172	-1.3765	0.2466
2016	-0.7403	0.4581	-1.62	0.106	-1.6382	0.1576
cons	8.7153	3.7377	2.33	0.02	1.3896	16.0410
sigma_u	0.8531					
sigma_e	1.4479					
rho	0.2577					
RSq: within	0.0690					
between	0.0224					
overall	0.0517					
Wald chi2(11)	27.28	Prob > chi2	0.004			
Group variable: hhno; Number of obs = 414; Obs per group = 113						

Table 5. 19: Effects of climate variability on rice yield – Upland varieties

yield	Coef.	Std. Err.	z	[95% C.I.]	
Rainfall (mm)	0.0003	0.0013	0.25	-0.0022	0.0029
CV in rainfall	-0.0025	0.0022	-1.12	-0.0068	0.0019
Precipitation concentration index	-0.0122	0.0107	-1.14	-0.0333	0.0088
Minimum temperature (°C)	-0.0251	0.0428	-0.59	-0.1090	0.0589
CV in maximum temperature	0.0987	0.7011	0.14	-1.2754	1.4728
Coping mechanism	0.2054	0.1383	1.49	-0.0657	0.4766
Practices					
Ploughing method	0.1834	0.1422	1.29	-0.0953	0.4620
Ploughing freq	0.0777	0.1179	0.66	-0.1534	0.3088
year					
2014	-0.1611	0.1208	-1.33	-0.3979	0.0757
2015	-0.0427	0.1174	-0.36	-0.2729	0.1874
2016	-0.3033	0.1521	-1.99	-0.6014	-0.0052
cons	2.0921	2.0989	1	-2.0216	6.2059
sigma_u	1.0131				
sigma_e	0.9163				
rho	0.5501				
R-sq:					
within	0.0463				
between	0.1036				
overall	0.0669				
Wald chi2(11)	29.22	Prob > chi2	0.002		

Group variable: hhno; Number of obs =546; Obs per group: = 153

5.4 Discussion

The objective of this chapter was to determine effects of climate variability on rainfed rice production. Research questions discussed are: What are farmers' views of climate variability in rainfed rice production systems? How is rainfall and temperature distributed in the Northern agroecological zone? What is the influence of climate variability on rice production in rainfed rice production systems of northern agroecological zone?

Research question 1: The result obtained from variability and trend analysis agrees with the views held by farmers about climate variability. The finding indicated that farmers are exposed to climate variability and the proportion of those exposed is incremental. The dimension of variability in climate included variations in onset of rainfall and amount of rainfall received. However, greater proportions of farmers were concerned with variations in amount of rainfall received than its onset. Low concern over onset of rainfall could be attributed to the fact that farmers can easily adjust planting dates to match onset of rains.

Views of farmers about climate variability is not limited to this study, In related studies, Odogola (2006) reported that 69% of rice farmers were prone to drought. GoU (2007); Caffrey *et al.* (2013); Okonya *et al.* (2013); Mwaura and Okoboi (2014); Kansime and

Mastenbroek (2016) also confirmed late onset, poor distribution within a season and early cessation of rains. Mwaura and Okoboi (2014) observed that farmers perceived decline and unexpected timing of rainfall as major causes of decreased food production. Elepu and Dalipagic (2014) noted that drought and flooding can have a devastating impact on harvest and post-harvest handling. FAO (2018) noted delayed season in Kenya by 55-85% while Oselebe *et al.* (2016) reported that 86.2% of rice farmers in south-east Nigeria have experienced yield reduction. Lansigan *et al.* (2000) observed that rainfed cultivation in Philippines is determined by the onset of rainy season. Naylor *et al.* (2007) reported that delayed rains into the cropping calendar affect timing of planting, acreage and yield in Indonesian. The observations made within the zone and elsewhere reaffirm that farmers are experiencing different dimension of climate variability to include variations in onset, intensity and amount of rainfall and temperature conditions.

Research question2: Views on variability in rainfall reported herein are in tandem with meteorological data: An average rainfall received in the zone was less than optimal range (1500 to 2500 mm) required for successful rice production. Variations are felt in terms of distribution within the months (21 to 102.6%) as opposed to annual and decadal variability (8.8 to 12%). Specifically, moderate rainfall variations are observed across growing months except June (30.8%) and October (30.3%). Coefficient of variation for June was high at 30.8% (first season) as well as October (30.3%) implying that farmers are receiving very high/very low rainfall in some years. On the other hand, very high coefficient of variation for March (53.4%) and November (48.1%) was an indication of rain returning earlier than expected (March) or withdrawing earlier/late (November). Although moderate concentration of rainfall (mean PCI of 11.3) was indicated, rainfall anomalies revealed excess rain in some years (a total of 16 years of excess rain was experienced in three decades) which farmers should take advantage of since rice require a lot of water (1500 to 2500 mm). However, eight drought incidence experienced implies regular drought and therefore, the need to plan for irrigation. Negative trends are indicated for all the months except June and September. This implies that rainfall will continue to decline in zone. However, positive trend in June and September is an indication that more rains are being received during the months.

Regarding temperature, positive and significant trends exhibited implies that both minimum and maximum temperature during cropping period in the zone is on the rise. According to the trend, magnitude of increase in maximum temperature tended to be high for months falling

within first season suggesting faster increase than second season. With regards to heat stress days, variability in annual heat stress days may not be challenge to crop production in the zone. This was also confirmed by results obtained from trend analysis indicating reduction in the number of heat stress days during cropping months (April to October). However, the concern is with very high variability (ranging between 31.4 and 65%) within the cropping months which may trigger increase in heat stress days and hence poor performance.

Research question 3: Subjective views regarding effects of climate variability on crop production were also at par with quantitative results in section 5.3.2. Mean rainfall had increasing effects on yield as expected. Suggested reason for the inverse relationship observed with regards to precipitation index could be due to flooding from upstream creating more water than expected or wash away of the seedlings before they are fully established. Secondly, rice plant requires 1500 to 2500 mm but only 702.76 mm of rain water was available to production of which transpiration and evaporation accounts for 500 to 1432 mm of this rain water). Otherwise, result from Pooled and upland varieties agrees with (Yoshida, 1973; IRRI, 2015) that rainfall amount between 1500-2500 mm is adequate for rice production. Haneishi *et al.* (2013) also reported increase in rice yield by 1.2 kg ha^{-1} for a 1 mm increase in rainfall under rainfed cultivation in Uganda. Similar mixed results was reported by Ajetomobi *et al.* (2011) where revenue reduction by 62,911 and 52,421 Naira ha^{-1} , respectively, were observed for a 1 mm increase in January and annual rains but revenue increases for April and July rains.

Coefficient of variation of rainfall and precipitation concentration index were negative meaning that the variability in rainfall was negatively skewed and this confirms effects of declining trend in rainfall observed in the zone. However, positive impact on upland varieties is attributed to low water requirement associated with the varieties. Generally, reduction in yield due to variations in rainfall variability during growth period agrees with other studies in the country that rainfall extremity (erratic rains) affects rice crops (Odogola, 2006; UBOS, 2010; Barungi and Odokonyero, 2016). Elsewhere, Rowhani *et al.* (2011) found out that increased variability in rainfall between months has negative effects on rice yields and also an increase in the coefficient of variation of rainfall by 20% by the year 2050 reduces rice yields by $7.6 \pm 2.7\%$. Lansigan *et al.* (2000) also observed that prolonged increases or decreases in rainfall during initial and critical growth period aborts crop or lead to rice yield reduction in Philippines. Shakoob *et al.* (2015) reported rice yield decrease by 0.3% for a 5 to 10%

increase in rainfall scenario and by 0.59% decrease for a 10 to 15% increase in rainfall scenario by 2030 in Pakistan.

In regards to temperature, yield reduction observed with respect to coefficient of variation in maximum temperature and minimum temperature ($^{\circ}\text{C}$) was a reflection of increasing trend in minimum temperature as well as high maximum temperature (32°C which was above the optimal range of 20 to 30°C or 17 to 30°C), (Yoshida, 1973; Lamo *et al.*, 2021). This result indicates that temperature exceeding 30°C is not conducive for rice production in Northern agroecological zone especially lowland varieties. Negative impacts of temperature on rice yield have been reported elsewhere on account of increasing temperature (Ajetomobi *et al.*, 2011; Shakoor *et al.*, 2015; Ali *et al.*, 2017). Ali *et al.* (2017) also observed reductions in rice yield by 3.92 and 0.70 due to rising maximum and minimum temperatures, respectively, in Pakistan. Shakoor *et al.* (2015) confirmed negative effects of rising temperatures on rice yields where by a unit increase in minimum temperature reduces yield by 6%, yield reduce by 1.7% for a unit increase in maximum temperature. In addition, a scenario increase in temperature from 2°C to 4°C decreases rice yield by 8% and a further increase from 4°C to 5°C decreases rice yield by 11.5% by year 2030. IRRI (2015) recommended that temperatures for fruitful production should not exceed 10°C (minimum) and 32°C (maximum). In Nigeria, Ajetomobi *et al.* (2011) observed a reduction in revenue among Nigerian rainfed farmers by 11.7% as a result of a 2°C increase in temperature and further reduction by 52.4% from a simultaneous increase in temperature (2°C) and decrease in rainfall (5%).

On the other hand, positive effects of variability in maximum temperature (coefficient of variation) on yield. Positive response could have arisen from reduction in coefficient of variation in maximum temperature between 2013 and 2016 (from 5.4 to 3.8%). This range was too small to have physiological effects of extreme variability in temperature on yield. In addition, an average of only 5 heat-stressed days (maximum temperature exceeding 32°C) during crop growth period was registered. Other studies have also documented positive impact of temperature variability on rice yield. Rowhani *et al.* (2011) reported increasing yields by $5.4 \pm 1.3\%$ for 20% increase in coefficient of variation in temperature in Tanzania.

5.5 Conclusions

Objective of this chapter was to determine effects of climate variability on rainfed rice production. To address the study objective, three research questions were addressed: What

are farmers' views of climate variability in rainfed rice production systems of Northern agroecological zone? How is rainfall and temperature distributed in the Northern agroecological zone? And how does climate variability influence rice production in the rainfed systems of Northern agroecological zone? Subsequently, this section draws the following conclusions from the findings:

- i) It was found that farmers are exposed to climate variability and the level of exposure is on the increase and varies between the two production systems. The dimension of variability in climate included variations in onset of rainfall and the amount of rainfall received but farmers are more concern with variations in amount of rainfall received than with onset of rainfall and temperature conditions. Majority of the rice farmers are negatively affected by climate variability in terms of poor crop yield, low grain quality, delayed planting and reduction in area cultivated.
- ii) Subjective views held by the farmers about variability in climate are in tandem with quantitative information on variability and trend in rainfall and temperature. Both annual and monthly rainfall is observed to be decreasing as indicated by significant decreasing trends. High variability in rainfall exceeding 30% has been observed across rice growing months. A total of eight drought incidents have also occurred in a period of thirty years which confirms rainfall variability. Minimum and maximum temperatures are increasing as indicated by rising trends.
- iii) Negative effects of rainfall on yields especially in lowland varieties implies that lowland varieties are less tolerant to the current stress caused rainfall variability as measured by high coefficient of variation and precipitation concentration index. Mean rainfall (mm) during crop growth period was only 702.76 mm (below optimal range of 1500 to 2500 mm) but the inverse relationship in lowland varieties was triggered by mismatch between cropping activities and critical growth stages on one hand and poorly distributed rains and water supply (field flooding) from upstream.
- iv) The negative effects of minimum temperature and coefficient of variation in maximum temperature are indicators suggesting that variability in temperatures are exceeding optimal range and therefore affecting rice production negatively.
- v) Therefore, the inverse relationship between climate variables and rice production as indicated by yield reductions suggests that lowland production/varieties are becoming less suitable in the face of climate variability.

- vi) The study therefore recommends timing of production activities when rainfall or water supplies are adequate. Farmers should take note of high rainfall during the growing months of April/May/June for first season (increases in June rains being observed is good for rice production) and September for second season (rainfall tended to increase in September which is an ideal growing month for second season according to the positive trend).
- vii) Declining rainfall is observed in August/October according to the negative trend (although both months appeared to have high rainfall). It is recommendable for farmers to adjust planting date so that flowering can coincide with September rains as well as growing drought/short maturing varieties to match August/October high but declining rains.
- viii) Extremely very low rainfall is received which cannot fully sustain rice crop production, inconsistent onset (March) and withdrawals (November) of rainfall, increasing temperatures as well as increased drought incidence. The need for irrigation facilities as well as adjusting planting dates is highly recommended for the farmers.
- ix) Finally, the study recommends the need to identify and explore coping strategies farmers are using to mitigate effects of rainfall variability.

CHAPTER SIX

COPING STRATEGIES TO CLIMATE VARIABILITY

6.1 Introduction

Vulnerability of the Ugandan agriculture to climate variability is worsening as the country continues to experience increased floods and droughts due to increased temperature and reduced rainfall. This has in turn affected soil moisture, crop resilience, timing and length of growing seasons, emergence of new weeds, cropping activities and yields (Mubiru *et al.*, 2012; Kansiime *et al.*, 2013). The situation is made worst due to over dependence on rainfed agriculture, limited access to weather focus information and production technologies (GoU, 2009, 2010a). As far as rice is concerned, effects of climate variability is being observed as reflected in production decline during the period 2004, 2014 and 2016 (UBOS, 2017).

Subsequently, there has been growing need to understand how farmers cope with the likely impacts of climate variability on rice production (Bouman, 2009; Korres *et al.*, 2017). However, there has been limited attention on how farmers cope with vulnerability of rice production to changing and extreme climate conditions given the fact that rice is a wetland crop requiring a lot of moisture (Mabe *et al.*, 2012; GRiSP, 2013). Coping strategies encompasses changing or adjusting farming practices to reduce the negative effects of climate variability or exploit the positive ones (Akinagbe and Irohibe, 2014). The common coping strategies used in agriculture by farmers include use of drought tolerant or water efficient crop varieties, moisture utilisation strategies and changing cropping calendar, among others. A number of drought-tolerant varieties have been developed ranging from the NERICA to the NAMCHE series (NARO, undated). For example, lowland varieties require significant amount of moisture compared to varieties bred for dry/upland production. For instance in Tanzania, to avoid crop production risks due to rainfall variability and drought, most farmers plant crops before rain onset (dry planting) and others plant immediately after rain so as to maximize use of moisture (Mary and Majule, 2009).

Therefore, it is imperative to understand coping strategies to climate variability in rainfed rice production systems in Uganda. The objective of the study reported herein was therefore to assess farmers' coping strategies to climate variability in rainfed rice production. Specifically, farmers' views on climate variability and coping strategies were obtained. Contribution of coping strategies to rice yield was subsequently determined. Also influence

of farmers' characteristics on choice of coping strategies used to counter negative effects of climate variability in the Northern farming system zone was investigated.

6.2 Methods and materials

6.2.1 Data collection

To obtain farmers' views about climate variability in rainfed rice production and how they are coping, open ended questions was used. Production data (output) were collected earlier under objective one was used in the analysis. The questionnaire had two subsections: subsection one contains questions regarding variations in climate in rice production. A total of 240 respondents were asked if they had observed any variation in rainfall and temperature patterns with respect to onset, distribution and amount during rice growing seasons as previously described by Bomuhangi *et al.* (2016). Since the researcher relied on farmer's subjective response, predetermined attributes were provided for each response. For example, attributes for onset of rainfall were coded as "early, late or normal". For amount of rainfall, attributes were "less, excess or normal" rainfall. For temperature conditions, attributes included "high or normal". In addition, question was asked whether varying conditions of rainfall and temperature had effects on rice production. Farmers were given the liberty to enumerate effects they have felt on rice production. Lastly subsection two questions dwelt on coping strategies farmers used to respond to effects of climate variability in production, again as previously described by Bomuhangi *et al.* (2016). Farmers were given the privilege to enumerate strategies used.

6.2.2 Data analysis

(a) Farmers view and coping strategies

To analyse data on farmers' views and coping strategies, descriptive statistic was used where frequencies and cross tabulations for multiple comparisons were done.

(b) Effects of farmers' characteristics on choice of coping strategies

Conceptual model and methods

Binary probit regression model was used to investigate factors that influence the decision to adopt or not to adopt a given coping strategy. A strong linkage between binary choice models and the theory of utility has been reported in literature. The common estimation approaches used include random utility approach, latent variable approach and non-linear or pure probability approach. Linking the random utility approach to the consumer theory, the approach suggests that individuals are rational, and if faced with the decision to choose between two alternatives, will prefer the option that provides the maximum level of utility. Therefore, a choice to adopt or not to adopt a given coping strategy by the rice farmers when faced with climate variability is considered a utility maximization problem. Therefore, choice of a given coping strategy is a function of the expected utility derived from using that strategy and the utility function is stated as follows:

$$cs_{ia} = v_{ia} + \varepsilon_{ia} \dots \dots \dots 6.2.1$$

cs_{ik} denotes utility of i^{th} rice farmer for adopting a coping strategy a , v_{ia} is the systematic (or deterministic) component of utility for farmer i associated with adopting the strategy, and ε_{ia} is the error associated with adoption (Ndamani and Watanabe, 2015; Mugula and Mkuna, 2016; Shikuku *et al.*, 2017), which captures factors that influence utility but are unobserved. The random utility model assumes that rice farmer i will choose a coping measure if the perceived utility from using exceeds non-use:

$$cs_{ia} > y_{ik} \forall a \neq k \dots \dots \dots 6.2.2$$

However, utility levels of adopting a coping strategy by the rice farmer cannot be measured due to dynamic human behaviour but the probability of making a specific choice to adopt or not to adopt is quantifiable. In this case, the complexity in human behaviour is associated with the natural environmental factors (climate variability) and managerial decisions concerning rice production. This is depicted mathematically as:

$$\begin{aligned}
p(cs_{ia} = 1) &= p(y_{ia} > y_{ik}) \dots\dots\dots 6.2.3 \\
&= p(cs_{ia} + \varepsilon_{ia} > v_{ik} + \varepsilon_{ik}) \\
&= p(cs_{ia} + \varepsilon_{ia} > p(\varepsilon_{ik} - \varepsilon_{ia} < p(\varepsilon_{ia} - \varepsilon_{ik})
\end{aligned}$$

Considering a panel standard binary probit model with exogenous explanatory variable x (Hosmer and Lemeshow, 2000; Treiman, 2009; Greene, 2012):

$$E(cs_{it}|x_{it}, c_i) = \Phi(x_{it}, \beta + c_i), t = 1 \dots, T \dots\dots\dots (6.2.3)$$

The variable (cs_{it}) is a random dependent variable representing adoption of a coping strategy by rice farmer if $(cs_{it}) = 1$. The dependent variable, coping strategies (cs_{it}) is hypothesized as being influenced by a set of independent variables: $x_1... x_n$ specific to rice farmers (Kumbhakar and Lovell, 2000; Ndamani and Watanabe, 2015; Mugula and Mkuna, 2016; Shikuku *et al.*, 2017). Each rice farmer is faced with the decision to adopt or not adopt a given coping measure. The choice of each measure is assumed to depend on a number of managerial factors and factors in the natural environment, x_{it} . The model is used to predict the probabilities of the possible outcomes of dependent variable (Hosmer and Lemeshow, 2000; Treiman, 2009; Greene, 2012). It assumes strict exogeneity (conditional on c_i). In binary response case under serial independence, all parameters are identified and MLE can be used. Adding the time averages $\bar{x}_i$: $c_i = \psi + \bar{x}_i\xi + a_i, a_i|x_i \sim Normal(0, \sigma_a^2)$.

The empirical model is specified as:

$$\begin{aligned}
cs_{it} = &\beta_0 + \beta_1exp_{it} + \beta_2effec_{it} + \beta_3yield_{it} + \beta_4soil_i + \beta_5loc_i + \beta_6crop_{it} + \beta_7ext_{it} \\
&+ \beta_8gen_i + \beta_9cred_{it} + \varepsilon_i \dots\dots\dots (6.2.4)
\end{aligned}$$

Where;

cs_{it} indexes coping strategy adopted by farmer i , in time t . Strategies used by rice farmers including rice varieties, planting, shifting to the valley regulating water and a combination of two or more coping measures (dependent variables). exp_{it} , dummy variable representing exposure to climate variability by rice farmers. It is expected to influence use of coping strategies positively. $effec_{it}$, dummy variable for effects of climate variability. Rice farmers being affected by climate variability are expected to adopt a set of coping strategies. $yield_{it}$, dummy variable representing rice yield above 2 t ha⁻¹. Higher yield is a motivation factor for adoption of coping strategies to improve crop performance and yield. $soil_i$, soil type (dummy) where rice is grow. Some coping strategies are dictated by soil type. loc_i , location of rice plot (dummy). $crop_{it}$, number of crops grown. Crop diversification was hypothesized to have a negative influence on coping strategies. ext_{it} , access to extension services in rice production is associated with knowledge in rice production and it enhances access to rice production information and services. gen_i , gender of rice farmer, $cred_{it}$, access to credit for rice production. β is unknown parameters to be estimate; and ε_{it} is error term.

Table 6. 1: Variables used in the analysis of coping strategies

Variable	Parameter	Description	Relationship
Coping strategy	-	Dependent variable	
Exposure to variability	β_1	1=Yes; 0=Otherwise	+
Effects of variability	β_2	1=Yes; 0=Otherwise	+
Yield>2t Ha ⁻¹	β_3	1= > 2 t ha ⁻¹ ; 0 = 2 t ha ⁻¹	+
Soil type	β_4	1=Clay, 0-Otherwise	+/-
Location of rice plot	β_5	1=Upland; 0=Otherwise	+/-
Number of crops	β_6	Number of crops grown	+/-
No. of extension visit	β_7	Number of visits/training	+
Gender-Male	β_8	1= male, 0=Female	+/-
Accessed credit	β_9	1=Yes; 0=Otherwise	+

The model was estimated through random effects estimated and the estimates are reporting as marginal effects. Coefficients obtained through probit regression model shows only the direction of change in the dependent variable given a change in the independent variable(s) and the associated significance level. What it doesn't indicate is the magnitude of change. The magnitude of the effect of change (marginal changes) is a derivate of probit function given as:

$$\frac{dc_{it}}{dx_{it}} = f(x_i\beta)\beta, \quad i = 1, 2, \dots, N; \quad t = 1, 2, \dots, K \dots \dots \dots 6.2.5$$

Marginal effect is the slope of the curve relating x_{it} to cs_{it} and also the probability of success or failure.

(b) Contribution of coping strategies to yield

Conceptual models and methods

Pooled least square regression was used as a suitable for panel data sets. In many panel data sets, it serves as the reference or baseline model for comparing the performance of other models. The regression model expresses rice yield as a function $f(.)$ of coping strategies used by farmer i . In a notation form;

$$y_i = (x_i\beta_i) + \varepsilon_i, \text{ where } i = 1, 2, 3 \dots, n \dots \dots \dots (6.2.3)$$

y_i is the response variable (rice yield) from farmer i . x_i is the regression variables. β_i is the coefficients containing the population value of the coefficients for the k regression variables in x_i . ε_i is the error terms. The error term captures random environmental noise, choice of regression model is wrong, and omission of variables that are not measurable. On this basis, the general form of the linear regression model for farmer i can be expressed as follows:

$$y_i = x_i\beta_i + z_i\gamma_i + \varepsilon_i \dots \dots \dots (6.2.4)$$

z_i is the (theoretical) values of all the variables and effects that cannot be directly observed. γ_i is the (theoretical) population values of regression coefficients for unobservable variables. The regression objective is to find a way to estimate the impact of all unobservable effects contained in z_i on y . Equation (6.2.4) can also be estimated using fixed effects or random effects model by introducing term element depending on whether or not the covariance term is

zero, i.e. whether or not the unobservable effects z_i are correlated with the regression variables. A fixed effect assumes the covariance is non-zero, i.e. group-specific effects are correlated with the regression variables. Whereas random effects assume the covariance term is zero, i.e. group-specific effects are independent of the regression variables.

The goal was to precisely assesse the relationship between coping strategies and rice yield. Equation (6.2.6) to model effects of coping strategies on rice yield was thus specified empirically as:

$$y_i = \beta_0 + \beta_1cs_i + \beta_2cv_effect_i + \beta_3age_i + \beta_4cred_i + \beta_5train_i + \beta_6loc_i + \beta_7time_i + \varepsilon_i \dots \dots \dots (6.2.6)$$

Where:

y_i is yield of rice (t ha⁻¹) of the ith rice household;

cs_i represents dummy variable for coping strategies (combination of strategies; changing rice varieties; adjusting planting date; shifting cultivation along the valley areas; constructing drainage to regulate water; and no strategy). Control variables accounting for socioeconomic, location and time effects are follows:

cv_effect_i represents dummy variable for effects of climate variability;

age_i is age of rice farmer in years;

$cred_i$ denotes dummy variable for participation in training on rice production;

$train_i$ denotes dummy variable for access to credit for rice production;

loc_i is a dummy for districts where rice farming household/plot is location;

$time_i$ represents time dimension dummies;

β_s are unknown parameters to be estimated and ε_i is error term.

Model implementation

To proceed with analysis, the data was structured in linear format (flatten) by placing households (panel) and year (time) as two columns. Variable and model selection tests were then performed using information criterion and pairwise selections to determine an optimal trade-off between prediction accuracy and precision (Lindsey and Sheather, 2010). The Akaike’s information criterion (AIC) and Bayesian information criterion (BIC), corrected AIC and adjusted R-sq are popular criterion for comparing different models. Reduced model (model with only coping strategies was evaluated against full model (model with additional

variable to control for time, location and socio-economic effects). Comparably, adjusted R-sq (0.4775) was larger in full model and also both AIC (2514.661) and BIC (2558.231) were smaller in full model. The F-test for regression produced a test statistic of 7.01 with a p-value <0.001 implying that the model's coefficient estimates are jointly significant.

As a starting point, model robustness check was performed and the results were as follow: The variable inflation factor for the independent variables was below 10 (mean VIF=1.41). Breusch-Pagan / Cook-Weisberg test for heteroskedasticity could not rejected the null hypothesis of constant variance at Prob > 0.05 (chi2(1) = 0.12; Prob > chi2 = 0.7246). The Ramsey RESET test confirmed that the model had no omitted variables at Prob > 0.05 (F (3, 951) = 1.24; Prob > F = 0.2933). The Q-Q plot of the residuals test of normality showed that residuals of the fitted model are normally distributed.

Hausman specification test revealed that results obtained through Pooled OLS estimator was robust than random effects estimator. The P-value of 0.9998 was larger than rejection level of 0.05. On this basis, the rest of the analysis was performed through Pooled OLS estimator. Summary of the diagnostic tests are provided in Appendix 5. The rest of the results pertaining to effects of coping strategies on rice yields are presented below.

6.3 Results

6.3.1 Coping strategies to climate variability in rainfed rice production systems

Results presented include subjective information by the farmers on climate variability and its effects on rice production and coping strategies being used.

(b) Farmers' coping strategies to climate variability in rainfed rice production

Descriptive statistics on response of the farmers towards climate variability and types of coping strategies used are presented in Table 6.2 and 6.3. Response to climate variability was based on actual experience and expectation of a climate variability event such as onset and amount of rainfall and temperature conditions.

Overall, a total of 44.1% of the farmers used mitigation strategies during production but the majority (56%) did not use any strategy. However, analysis according to the production system revealed significant difference between the proportion of farmers using coping strategies in the lowland and upland rain-fed systems. In the lowland, 60% of the farmers and 28.1% for upland system used coping strategies.

Analysis of response according to exposure to climate variability showed that 52% of the farmers who were exposed applied coping strategies for mitigation. In contrast 48% did not use any coping strategy despite the fact that they were exposed. Farmers who were not exposed at all to climate variability also undertook proactive measure as indicated by 25% who applied coping strategies against 75% who did not.

In regards to those who were affected by effects of climate variability, a total of 49% of those who were affected resorted to coping measures but 51% did not cope. Also some 33% of those who were not affected by climate variability undertook coping measure although the majority (67%) declined to undertake coping measures.

Table 6. 2: Response of farmers to climate variability in rainfed rice production

Responses	Pooled		Lowland		Upland	
	Freq.	%age	Freq.	%age	Freq.	%age
Used coping strategy	423	44	288	60	135	28
Did not coping strategy	537	56	192	40	345	72
Exposed and used coping strategy	354	52	187	42	99	41
Exposed but did not use coping strategy	330	48	255	58	143	59
Not exposed but used strategy (proactive)	69	25	33	87	36	15
Not exposed and did not use coping strategy	204	75	5	13	199	85
Affected and used coping strategy	315	49	216	54	99	42
Affected but did not use coping strategy	322	51	183	46	139	58
Not affected but used strategy (proactive)	108	33	72	89	36	15
Not affected and did not use coping strategy	215	67	9	11	206	85

(i) Combination of strategies

About 12% of the farmers used combination of two or more different coping strategies to minimize effects of climate variability. However, more farmers in the lowland system (16.3%) used combination of strategies than farmers in the upland system (9%).

(ii) Changing rice varieties

Most commonly used varieties were drought tolerant varieties (short maturing, drought tolerant or variety with high water requirement). According to specific coping strategy, 196% of the sampled farmers switched to different rice varieties. Comparison of response by production system revealed difference between the systems whereby 27.9% in the lowland and only 10% in the upland systems changed varieties.

(iii) Adjusting planting dates

Result showed that 13.2% of the sampled farmers adjusted planting dates according to the climate variability event. However, the majority were in the lowland system (17.1%) against

only 9.4% in the upland system. The strategy was applied when farmers were able to predict onset of rain based on their past experience.

(iv) Constructed drainage to regulated water

Only 11.7% of the sample constructed drainage/canal to regulate supply of water in the field. However, significant variation in utilisation of the coping strategy was observed between the two systems. All the farmers who regulated water supply were in the lowland system (23.3%) and none in the upland system. This was because farmers in the upland system did not have water supply.

(v) Shifting cultivation to the valley areas

Those who shifted cultivation along the valley area were 8.8% of the total sample in the study area. Comparison of result according to the production systems indicated that all the farmers (17.5%) who shifted to the valley were in the upland system.

Table 6. 3: Farmers' coping strategies to climate variability in rainfed rice production

Strategies	Pooled data		Lowland		Upland	
	Cases	%age	Cases	%age	Cases	%age
Used at least one strategy	423	44.06	288	60	135	28.13
Combination	121	12.6	78	16.25	43	8.96
Specific coping strategy						
Changed rice variety	182	18.96	134	27.92	48	10
Changed planting date	127	13.23	82	17.08	45	9.38
Regulated water	112	11.67	112	23.33		
Shifted to the valley	84	8.75			84	17.5

6.3.2 Effects of farmers' characteristics on choice of coping strategies

Model selection was done using log-likelihood ratio test. Pooled probit regression (mixed-effects probit regression) was specified by the null hypothesis as being more appropriate for the data against random-effects probit regression. The result defined by $LL = -2\{\log [\text{Likelihood (H0)}] - \log [\text{Likelihood (H1)}]\}$ was strongly rejected. The computed value (188.857) was greater than critical value (16.919). However, the test failed to reject mixed-effects probit regression over complementary log-log regression (alternative regression). The computed value (10.892) was less than the critical value (16.919). The critical values got from Kode and Palm (1986). Therefore, the results for random-effects regression are displayed and those obtained from mixed-effects and complementary log-log regressions are in Appendix 5.

Results estimated through probit random effects models are provided in Tables 6.4 and 6.5 below. Estimates are reported in term or marginal effects (Table 6.5). The model had binary dependent variables, i.e., adoption of coping strategies and no strategy. Results are displayed for exposure to climate variability, being affected by climate variability, yield of rice, soil type, location in the lowland rainfed system, number of crops, number of extension visits, gender of the farmer and access to credit.

(i) Exposure to climate variability

Being exposure to climate variability increases the likelihood of using coping strategies against climate variability. The value of marginal effects showed that the likelihood of using a coping strategy increased by 0.1875 above non-exposed farmers. This is driven by the fact that experienced farmers have good knowledge of climate variability trend and therefore response accordingly.

(ii) Effects of climate variability

Being affected by effects of climate variability presented an inverse relationship with coping strategies. Farmers who are affected would choose not to develop coping mechanism. As such, the probability of using a coping strategy reduces by -0.2514 for the affected farmers. Although this was unexpected, continue loose of rice crop to variability in climate is a demotivating factor which can move concentration of the farmer to none rice enterprises.

(iii) Rice yield

Farmers getting higher yield above 2 t ha⁻¹ are more likely to invest in coping strategies to counter effects of climate variability. This is because higher yield is a positive driving factor for improved income and food security of the households. The value of marginal effects revealed that higher yield will improve the chance of using a coping strategy by 0.0238 above lower yields.

(iv) Soil type

In terms of soil type, clay soil type was a positive driver of choosing to use a coping strategy. Positive marginal effect suggests that the likelihood of using a coping strategy increases (0.0035). This is because clay soil has got high water retention capacity which allows the farmer to carryout moisture related strategies like constructing water channel/drainage to regulate water supply.

(v) Location of rice plot

Farmers located in the upland are less likely to use coping strategy over no strategy. Probability to use reduces in the upland system by -0.0957 and this is driven by the fact that there are limited options of strategies currently used by the farmers cultivating in the upland.

(vi) The number of crops grown

Increased number of crops grown by the farmer reduces the possibility of using coping strategies. The likelihood reduces by -0.0006 for those growing many crops (diversification). The negative result is linked to intensity of rice cultivation especially in the lowland which does not permit growing of many crops at the same timeless.

(vii) Access to extension services in rice production

Farmers with access to extension support in rice production are less inclined to use coping strategy. Probability of using coping strategy reduces by -0.0038 for farmers accessing extension services in rice production. Ideally extension support is expected to equip the farmers with knowledge on how to cope with climate variability. However, the negative result could be attributed to some specialized services in rice which are none climate related.

(viii) Gender of rice farmer

Gender of rice farmers had negative effects on coping strategy suggesting that being a male rice farmer does not support use of coping strategies. Accordingly, probability of using strategies reduces by -0.1546 for male farmers.

(ix) Access to credit

Access to credit registered negative value (-0.0466) indicating that farmers with access to credit are less inclined to use coping strategies.

Table 6. 4: Effects of farmers characteristics on decision to use coping strategies

Strategies	Coef.	Std. Err.	P>z	[95% Conf. Interval]	
Exposure to variability	1.8805	0.9030	0.037	0.1107	3.6504
Effects of variability	-2.5216	0.8692	0.004	-4.2252	-0.8181
Yield>2t Ha ⁻¹	0.2391	0.1905	0.209	-0.1342	0.6124
Soil type	0.0353	0.0186	0.058	-0.0012	0.0718
Lowland system	-0.9603	0.6720	0.153	-2.2775	0.3568
Number of crops	-0.0055	0.0813	0.946	-0.1649	0.1539
No. of extension visit	-0.0381	0.1685	0.821	-0.3683	0.2921
Gender-Male	-1.5512	0.7691	0.044	-3.0587	-0.0437
Accessed credit	-0.4674	0.4001	0.243	-1.2516	0.3167
cons	-0.7026	3.3224	0.833	-7.2144	5.8091
/lnsig2u	1.5949	0.2416		1.1213	2.0685
sigma_u	2.2199	0.2682		1.7518	2.8130
rho	0.8313	0.0339		0.7542	0.8878

LR test of rho=0: chibar2(01) = 188.86 Prob >= chibar2 = 0.000

Log likelihood = -286.5896; Wald chi2(9) = 39.43

Group variable: entity; Number of obs = 960 Number of groups = 240 Prob > chi2 = 0.000

P-values are significant at less than 0.05 (5%)

Table 6. 5: Marginal effects of farmers' characteristics on coping strategy

	Delta-method		z	P>z	[95% Conf. Interval]	
	dy/dx	Std.Err.				
Exposure to variability	0.1875	0.0904	2.07	0.038	0.0103	0.3646
Effects of variability	-0.2514	0.0868	-2.9	0.004	-0.4214	-0.0813
Yield>2t Ha ⁻¹	0.0238	0.0189	1.26	0.209	-0.0133	0.0610
Soil type	0.0035	0.0018	1.91	0.056	-0.0001	0.0071
Lowland system	-0.0957	0.0667	-1.43	0.151	-0.2265	0.0351
Number of crops	-0.0006	0.0081	-0.07	0.946	-0.0164	0.0153
No. of extension visit	-0.0038	0.0168	-0.23	0.821	-0.0367	0.0291
Gender-Male	-0.1546	0.0751	-2.06	0.04	-0.3019	-0.0074
Accessed credit	-0.0466	0.0397	-1.17	0.241	-0.1245	0.0313

P-values are significant at less than 0.05 (5%)

6.3.3 Extent of contribution of coping strategies to rice yield in rainfed production systems

The section result responded to the research question. "To what extent does coping strategies contribute to rice yield in rainfed production system?" Estimated results through fixed effect model are presented in Table 6.6 below. All the coping variables were positively signed as expected although significance levels varied. Controlled variables submitted mixed signs on coefficients: age, education level, extension access, upland production system, number of crops grown and time dimension were all negatively signed. However, male farmer, rice income, access to credit and participation in rice training registered positive influence.

(i) Changing rice varieties

Changing rice variety as a mitigation measure against climate variability is associated with an improvement in yield according to the positive coefficient (0.1953). In terms of averages, yield realised by those who changed rice varieties was 2.06 t ha^{-1} and this was relatively higher than those who did not use the strategy (1.8 t ha^{-1}).

(ii) Adjusting planting dates

Adjusting planting dates to match the season's variability in rainfall and temperature is more likely to lead to yield improvement by 0.5482. On average, a farmer using the strategy is likely to obtain 2.34 t ha^{-1} of rice yield from his/her plot.

(iii) Regulating water

Constructing drainage to regulating water ensures adequate and balanced supply during cropping cycle and is an ideal strategy in less or excessive rains. Using the strategy had positive contribution to yield according (0.9586). In regards to average total yield per hectare, farmers using the strategy get about 2.6127 tons against 1.757 tons for none adopters.

(iv) Shifting to the valley area

Shifting cultivation along the valley is likely to improve rice yield by 0.3188. the strategy is particularly important where moisture/water may not be adequate to sustain crop growth in the dryland fields. However, an average yield of 1.75 t ha^{-1} was suggested and this was an equivalent of amount obtained by farmers who did not use the strategy.

(v) Combination of strategies

Likelihood of yield improvement is associated with using combination of coping strategies according to the positive coefficient (0.4124). In regards to per hectare average, 2.7 t ha^{-1} of rice yield is suggested for farmers using combination of strategies.

Table 6. 6: Rice yield response to coping strategies in rainfed production systems

Yield	Coef.	Std. Err.	P>t	[95% C. Interval]	
Strategies					
Combination of strategies	0.4124	0.1458	0.005	0.1263	0.6985
Changing planting date	0.5482	0.3033	0.071	-0.0470	1.1434
Shifting to valley area valley	0.3188	0.2142	0.137	-0.1016	0.7391
Changing rice variety	0.1631	0.1682	0.333	-0.1671	0.4933
Regulating water supply	0.9586	0.2338	0	0.4999	1.4173
Affected by variability (yes)	-0.3493	0.1125	0.002	-0.5702	-0.1285
Age	-0.0052	0.0038	0.181	-0.0127	0.0024
Gender (male)	0.4128	0.1984	0.038	0.0234	0.8022
Rice income	0.0978	0.0325	0.003	0.0341	0.1615
Credit (yes)	0.2579	0.0945	0.006	0.0724	0.4434
Education	-0.0197	0.0115	0.087	-0.0423	0.0028
Extension access (yes)	-0.1858	0.1070	0.083	-0.3957	0.0242
Training (yes)	0.1971	0.1058	0.063	-0.0106	0.4049
Prod system (upland)	-0.4084	0.1067	0	-0.6178	-0.1990
Number of crops grown	-0.0220	0.0209	0.293	-0.0630	0.0190
Year					
2014	-0.2943	0.1286	0.022	-0.5467	-0.0418
2015	-0.3990	0.1288	0.002	-0.6518	-0.1463
2016	-0.4505	0.1260	0	-0.6977	-0.2032
cons	1.7164	0.3798	0	0.9711	2.4617
Number of obs = 960 Number of groups = 240 F(18, 941) = 5.41; R-sq = 0.0937					

Overall, an average rice yield measuring 2.09 t ha⁻¹ was obtained from plots which used at least a coping strategy. In contract, plots where farmers did not use any coping strategy as a response to climate variability recorded 1.67 t ha⁻¹ only.

Table 6. 7: Average rice yield per hectare with and without coping strategy

Strategies	With coping strategy	Without coping strategy	Difference		
	Mean	Mean	Diff	t	Pr(T > t)
Pooled	2.0911 (1.584)	1.6722 (1.260)	0.4189 (0.092)	4.56	0.000
Combination of strategies	2.1658 (1.684)	1.8122 (1.382)	0.3535 (0.138)	2.55	0.005
Changing rice variety	2.0557 (1.538)	1.8103 (1.397)	0.2455 (0.117)	2.09	0.018
Changing planting date	2.3399 (1.750)	1.7831 (1.358)	0.5567 (0.135)	4.13	0.000
Regulating water	2.6127 (1.795)	1.7570 (1.341)	0.8558 (0.141)	6.07	0.000
Shifting to the valley area	1.7528 (1.306)	1.8668 (1.439)	-0.1140 (0.163)	-0.70	0.7577

Null hypothesis (H₀): difference = 0 against the alternative (H_a): difference > 0.

Figures in parenthesis are Std.Dev for mean and Std.Err. for mean difference, respectively.

6.4 Discussion

Research question 1: Farmers have adopted a range of coping strategies as mitigating measures to counter effects of climate variability on rice production. The result of the descriptive statistics indicated those changing rice varieties, shifting cultivation to the valley areas, and adjusting planting dates as the commonly used strategies. However, the result indicated that a small proportion (44%) of rice farmers who experienced climate variability actually used coping strategies, most which were in the lowland system. The probable reason for variations in application could be that most of the mitigating strategies at the disposal of the farmers are best suited for lowland production system. Low use of coping strategies observed herein is consistent with the report by Guloba (2014) that farmers in developed countries readily response to climate variability but those in developing countries are less responsive to climate variability. In regard to the type of coping strategies used by the farmers, similar strategies were reported among rice farmers in Philippines and Nigeria (Lansigan *et al.*, 2000; Oselebe *et al.*, 2016). Earlier studies also indicated limited access to moisture utilisation strategies (at only 5%) moreover transplanting rice was done by only 6% of the farmers in Lira against 59% in the entire country (Kijima, 2012). Odogola (2006) recommended the need to determine suitable rice growing areas in light of recurrent droughts and water stress given geographical ecology for rice growing. According to previous studies, there are only a few rice varieties such as NERICA and WITA9 at the disposal of the farmers (Elepu and Dalipagic, 2014; Barungi and Odokonyero, 2016). The finding on low utilisation of fertilizer is in agreement with similar earlier report on low utilization of fertilizer (Haneishi *et al.*, 2013). Elsewhere, Oselebe *et al.* (2016) also reported low use of fertilizer and other agro-chemicals (30%) and planting dates (39%) as coping strategies among Nigerian rice farmers. Otherwise, low application of some coping strategies in the study area could probably be linked to observation made by Omach (2002) that the agricultural households in the region are still struggling to regain their livelihood means after the two decades of civil war. The above observations present convergence of findings between the past and the present study and therefore confirm that farmers are affected by variability in climate but their ability to cope is limited.

Research question 2: Further inquiry into the drivers of coping strategy as a mitigation measure using probit random effect regression model confirmed that location of a rice plot in the lowland was found to favours use of coping strategies. Decision to use coping strategies by the lowland cultivators is probably driven by the fact that a range of strategies can be

applied. The result was consistent with the report by Guloba (2014) that location of resident of farmers is key in influencing choice of coping strategies.

Farmers with access to extension support in rice production declined to use coping strategies. Ideally extension support is expected to equip the farmers with knowledge on how to cope with climate variability. However, declining to choose the combination suggests that farmers are accessing services that are not related to climate. In addition, farmers could be using other strategies not listed among the findings. On the other hand, knowledge capacity of the farmers in using a strategy is perhaps limited given low level of formal education (6 years), limited extension access (45%), and low participation in training (1.6 times) in four years. Otherwise, the result contrasts previous reports in which extension and formal education were found to be important factors for effective utilization of technologies and information (Hyuha *et al.*, 2007; Mugula and Mkuna, 2016).

Inverse relationship between access to credit for rice production and coping strategies could be due to indiscipline nature of some farmers where credit is diverted to none rice activities. Or limited access to credit, only 40% of the farmer had access to credit and on average only 0.8 times during the period of four years. Hyuha *et al.* (2007) also reported that access to credit is still lagging at only 44%. Negative effects of credit on choice of coping strategy is also consistent with the findings by Oselebe *et al.* (2016) who found negative effects of credit on adoption of coping strategy.

Growing many crops reduces the possibility of using coping strategies. The negative result in the lowland system could be linked to intensiveness of rice cultivation which does not permit growing of many crops at the same time (rice households grow up to four crops on average). Many crops competing for the same limited resource as similarly observed by Hyuha *et al.* (2007).

Research question 3: Analysis of rice yield response to coping strategies confirmed that application of coping strategies as mitigation measures to climate variability improves rice yields. Interestingly, all coping strategies correlated positively with rice yield except combination of strategies which appeared to arise from unobservable covariance which model was unable to explain. Otherwise, test statistics for mean difference (with and without scenario) clearly showed statistically significant positive yield difference (p-value of 0.0054). The Pearson's correlation test also confirmed statically significant positive relationship with

yield (p-value of 0.0108). Low response of varieties to yields was attributed to the fact that farmers have limited options of varieties bred for drought tolerance. At the time of the study, only Nerica series (an improved upland variety) was at the disposal of the farmers. All the lowland varieties were traditional varieties (Supa and Kaiso) with very high water requirement. Low yield improvement from shifting to the valley areas could have arisen from low moisture endowment or high temperature. As noted already in section 5.3.3 that increasing variability in rainfall and maximum temperature impact on yield negatively.

Similarly results has been reported in other studies, Okonya *et al.* (2013) and Barungi and Odokonyero (2016) also suggested that adjusting planting date, water control and shifting rice fields to lowlands can boost yield. Elsewhere, Mabe *et al.* (2012) attributed 81% of variations in rice output to types of coping strategies used by rice farmers in Ghana. The result of adjusting planting date confirms recommendation by IRRI (2015) that planting on time facilitates fast-growing and higher yields. Karim *et al.* (2012) also reported significant change in average rice yield under different planting dates in Bangladesh. Similarly, Oselebe *et al.* (2016) found adjusting planting dates timing and fertilizer was indeed effective in reducing effects of climate on rice in Nigeria. Positive contribution of rice variety to yield as observed in this study was also reported by Rahman *et al.* (2017) who found use of modern rice varieties along with additional farming technologies such as agrochemicals and irrigation to improve crop output.

6.5 Conclusion and recommendation

The objective was to assess farmers' coping strategies in rain-fed rice production to climate variability and the following questions were investigated: Which farmers' characteristics influence choice of coping strategies to climate variability in rainfed rice production systems? And to what extent does coping strategies contribute to rice production in rainfed production systems?

- i) It was found that farmers in the Northern agroecological have adopted a number of mitigating measures including changing rice varieties, shifting cultivation to the valley areas, and adjusting planting dates as the commonly used strategies to counter effects of climate variability. However, only a small proportion of rice farmers, most whom are in

the lowland system have adopted coping strategies as mitigating measure against climate variability as most of the strategies are best suited for lowland.

- ii) While the drivers of choice coping strategies identified includes, earlier exposure to or experience of climate variability, soil types, location of rice plot in the lowland system and higher yields.
- iii) All coping strategies adopted by the farmers enhance rice yield but constructing drainage to regulate water and adjusting planting dates are highly beneficial in yield enhancement.
- iv) As such, this study recommends validating the current temporary coping mechanisms and transforming them into long term sustainable adaptation measures in smallholder farming communities with high exposure and vulnerability.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1 General discussion

The study was built around the fact that rainfed rice cultivation is vulnerable to climate variability (Rowhani *et al.*, 2011; Mubiru *et al.*, 2012). However, knowledge gap exists on the potential effects of climate variability on rice production and how rice farmers are coping with variability in the country. In addition, evidences linking climate variability to rice production are inconsistent (Ajetomobi *et al.*, 2011; Rowhani *et al.*, 2011; Thornton *et al.*, 2014). The aim of this study was therefore to examine the relationships between climate variability, coping strategies and rainfed rice production in the Northern agroecological zone of Uganda.

Moving forward, literature review was made in order to identify salient issues that would aide validation of facts in this study. Generally, the review covered performance of agriculture in Uganda with due attention given to rice, rice production characteristics, effects of climate variability on rice production, and coping strategies to climate variability.

A review of agriculture in Uganda shows that the sector still remains a primary contributor to the Ugandan economy. However, its contribution to the country's GDP has been declining over the years partly due to climate variability among other factors (GoU, 2010a; UBOS, 2010). The review also noted that performance of agriculture in Ugandan and rice in particular is determined by agroecological and climatic conditions. That rice production is done under irrigated, rainfed lowland and rainfed upland system. As such production practices, production performance and constraints vary according to how each system response to prevailing climatic conditions (rainfall and temperature), (Odogola, 2006; Rowhani *et al.*, 2011; Mubiru *et al.*, 2012; GRiSP, 2013; Kansiime *et al.*, 2013;).

Subsequent review of performance of rice production revealed that some farmers are producing inefficiently while others are efficient (Hyuha *et al.*, 2007; Ajetomobi, 2009; Asiiimwe 2009; Enwerem and Ohajianya, 2013; Omondi and Shikuku, 2013). Variations in inefficiencies in the literature were due to different dynamics within the rice production systems (Odogola, 2006; GRiSP, 2013).

Literature also suggests that coping strategies could reduce potential damage arising from negative climate variability; however, choice and utilization of strategies can also be enhanced or downplayed by farmers' specific factors (Mabe *et al.*, 2012; Guloba, 2014; Bomuhangi *et al.*, 2016; Kansiime and Mastenbrock, 2016; Oselebe *et al.*, 2016).

Subsequently, empirical review on methodologies and approach used in related studies was made. Both descriptive and econometric methods were adopted in the literature. Specifically, descriptive statistics involved computation of means, frequencies and percentages supplemented with t-tests to characterize production systems (Haneishi *et al.*, 2013). Econometric methods included stochastic frontier model (Battese and Coelli, 1995; Ahmad and Bravo-Ureta, 1996; Kumbhakar and Lovell, 2000; Schmidt, 2011; Belotti *et al.*, 2012), ordinary least square and multinomial, regression (Hosmer and Lemeshow, 2000; Treiman, 2009; Greene, 2012).

The following were thus evident from the review: (1) There were dissimilarities in climatic conditions and production systems and hence rice production performance. (2) Performance of the rice production do vary and this is determined by the physical environment/climatic factor (rainfall, temperature), conditions within the rice growing households, and policy environment. And (3) farmers have adopted a range of coping strategies as mitigation measures to counter shortcomings in rice production.

Key issues arising from the literature review that are of interest to this study were validated through study objectives. Hence the following findings obtained from the objectives of this study: The first objective was to characterise rice production systems. This objective was achieved by answering the research question, i.e., what are the characteristics of the different rainfed rice production systems in the Northern agroecological zone of Uganda? Descriptive statistics was performed (Haneishi, 2014) and the findings confirmed significant difference in production characteristics between lowland and upland rainfed production systems. This was in agreement with the literature (Odogola, 2006; GRiSP, 2013; Haneishi, 2014). The findings also revealed that rice yield was generally low in comparison to those reported by UBOS (2010), Luzi-Kihupi (2011), Hasnain *et al.* (2015), FAO (2017) and UBOS (2017). In regard to input application, there were evidence of high application in relation to seed and labour and the literature within the country clearly agrees with this result (Asiimwe, 2009; Kijima, 2012; Miyamoto *et al.*, 2012). This perhaps could be due to limited knowledge on production economics or low commercialisation. Rice production was found to be labour intensive

probably due to limited access to mechanised equipment. The second research question under objective one sought to find out whether rice farmers were producing efficiently. The results indicated that farmers were producing inefficiently as efficiency level reported in this study was below average reported elsewhere in the literature (Hyuha et al., 2007; Ajetomobi, 2009; Asimwe, 2009; Enwerem and Ohajianya, 2013; Omondi and Shikuku, 2013). The study reported efficiency level of 41% which puts inefficiency gap at 59%.

In the second objective that follows, i.e., to determine effects of climate variability on rainfed rice production, the study set out to answer two research questions. First, it sought to farmers' views of climate variability in rainfed rice production systems of Northern agroecological zone. The result obtained from subjective views confirmed that rice farmers are exposed to different dimensions of climate variability including delayed onset, early session, too little or too much rainfall (climate variability). The second research question explored rainfall and temperature distribution and trend in the Northern agroecological zone. The result confirmed increasing variability in temperature and rainfall. Coefficient of variations (exceeding 30%), rainfall anomalies and precipitation concentration index as forms of variability confirmed variability in rainfall. Whereas negative trends were detected in rainfall, positive trends were detected in temperature implying that rainfall is decreasing while temperature is on the rise. Again these observations strongly agree with different studies which examined climate variability (Kansiime et al., 2013; Mubiru et al., 2012; Mwaura and Okoboi, 2014; Bomuhangi et al., 2016). Research question three dwelt on influence of climate variability on rainfed rice production. As hypothesised climate variability was found to influence rice production and this was also previously reported by Lansigan *et al.*, 2000; Ajetomobi *et al.* (2011), Hughes *et al.* (2011), Rowhani *et al.* (2011), Caffrey *et al.* (2013), Shakoob *et al.* (2015), Ali *et al.* (2017) Rahman *et al.* (2017). The mean rainfall received as well as coefficient of variations in rainfall had negative effects on rice production whereas means temperature recorded and coefficient of variations in temperature improved production.

In the subsequent objective, the study set out to assess farmers coping strategies. Three research questions were addressed. First, the study wanted to know how they were coping. Secondly, the study aimed to establish influence of farmers' characteristics on choice of coping strategies. Lastly, the study determined the extent of contribution of coping strategies to rice yield. Response from analysis revealed that farmers use diverse coping strategies which include use of improved crop varieties, adjusting planting date, drainage management

and shifting along the valley areas. This was consistent with earlier report by Mabe *et al.* (2012) and Barungi and Odokonyero (2016). But effectiveness of the coping strategies was determined using further analysis. The report confirmed that coping strategies especially adjusting planting date, drainage management and changing rice varieties contributed to rice output substantially by 0.5 to 1.8 t ha⁻¹. This current result therefore supports earlier findings of Karim *et al.* (2012), Mabe *et al.*, (2012), Selvaraj (2014), Oselebe *et al.* (2016) and Rahman *et al.* (2017). However, choice of these strategies was highly influenced by farmers' characteristics (Ndamani and Watanabe, 2015; Bomuhangi *et al.*, 2016; Mugula and Mkuna, 2016; Shikuku *et al.*, 2017). In this current study, exposure to climate variability, being affected by climate variability, yield of rice, soil type, location in the lowland rainfed system, number of crops, education of the farmer, number of extension visits and access to credit were found to influence decisions over choice of coping strategies.

7.2 General conclusions and recommendations

Based on the above findings, this study therefore concluded that:

- i) There is significant difference between lowland and upland rainfed production systems as highlighted in the production challenges, production practices, input application and usage, yields, technical efficiency level as well as effects and coping strategies. These key distinguishing features implies that the two systems should not be treated as one.
- ii) Overall, the average rice yield realised in the study area was relatively low (1.9 t ha⁻¹) in comparison to the national average (2.5 t ha⁻¹) and potential average (5 to 8 t ha⁻¹). Low yields are attributed to natural factors including climate variability, poor agronomic practices by the farmers as well as institutional challenges. Subsequently, farmers are producing below the frontier level according to the estimated level of inefficiency gap.
- iii) The Northern farming system is facing variability in climate and this was confirmed by information obtained from meteorology which showed variability in distribution of rainfall and temperature conditions. Coefficient of variation in rainfall is exceeding 30% and 8 incidence of drought has occurred within a period of three decades. This confirms subjective views from the farmers where 81% of the farmers have experienced climate variability in form of erratic onset and poor distribution rains and increasing temperature.

- iv) Increasing variability in rainfall and temperature are having negative effects on rice yield. The lowland varieties were found to be more sensitive to low rainfall, high temperatures as well as increasing variability in rainfall and temperatures.
- v) Farmers are using a range of coping strategies to counter effects of climate variability on rice production, i.e. changing rice varieties, constructing drainage to regulate water supply, shifting cultivation along the valley areas to take advantage of moisture from within, and adjusting planting dates to match variations in rainfall and temperature. Adjusting planting date, regulating water supply in rice field, and applying combination of were found to be effective in yield enhancement.
- vi) However, choice of coping strategy is influenced by farmers' characteristics. Exposure to variability, effects of variability, soil type, and gender of rice farmers are important determinants of decision on whether or not to use coping strategies.

Based on the above findings, the study recommends the need to foster resilience of rice production to climate variability which can be achieved by initiating, strengthening and enforcing the following:

- i) Establishing smallholder farmer support systems that align to difference in key characteristics of lowland and upland rainfed production systems and farmers' characteristics. Support can include provision of system based rice technologies (e.g. development and provision of rice varieties suitable for the different production systems), innovations and information to farmers to enhance production and productivity.
- ii) Development and provision of appropriate water harvesting technologies/simple irrigation equipment for rice production will supplement low and varying amount of rainfall. Water harvesting will also encourage farmers to expand cultivation to upland system given restriction on use of wetlands by the government.
- iii) Extension support to farmers through increasing awareness about climate variability and response options, training on climate smart agriculture, suitable agronomic practices as well as enhancing participatory and consultative approach that involves all stakeholders in rice at all levels.
- iv) Further research to validate the current temporal coping strategies for long-term sustainable measures in systems with high exposure and vulnerability. Extend the current

study to the broader country by including other agroecological zones of the country as well as exploring the relationship between climate variability and coping strategies.

7.3 Contribution to knowledge

This study has therefore contributed to the body of knowledge as follows:

It contributes to the on-going debate about the impact of climate variability in rice production and agriculture as a whole. In terms of adaptation to climate variability and climate change, the study contributes to the on-going policy debate on ways to improve adaptation among farmers in Uganda and beyond. With regards to policy, the results of the study provide an input into the development strategy that emphasizes inherent difference in agricultural systems and amongst smallholder farmers as the central focus for agricultural development in the country.

7.4 Limitations

Limitations in the study include:

- i) Sampling: rice is not grown uniformly throughout the zone, i.e., there is variation between districts, subcounties and parishes and this could not allow for random sampling. To address this limitation, stratified and purpose sampling procedure based on prevalence of the crop growing at each stratum was adopted.
- ii) Data challenge: first the challenge of farmer recall ability could not allow data to be captured earlier than 2013 for reliability purpose. The study therefore captured farm level data for only four years (starting 2013 to 2016). Secondly, there was no plot-level data on rainfall and temperature. To address this limitation, rainfall and temperature data were retrieved from within 4km² grid. Subsequently, a new rainfall and temperature data for each rice plot based on growth duration (planting to harvest time) were reconstructed.

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APPENDICES

Appendix 1: Rice production and yields in Uganda (1997 – 2016)

	Total rice production				Rice yield per hectare	
	Area (Ha)	Δ in Acreage	Output (t)	Δ in output	Yield (t/Ha)	Δ in yield
1997	60,000	-	80,000	-	1.333	-
1998	64,000	4,000	90,000	10,000	1.406	0.073
1999	68,000	4,000	95,000	5,000	1.397	-0.009
2000	72,000	4,000	109,000	14,000	1.514	0.117
2001	76,000	4,000	114,000	5,000	1.500	-0.014
2002	80,000	4,000	120,000	6,000	1.500	0.000
2003	86,000	6,000	132,000	12,000	1.535	0.035
2004	93,000	7,000	121,000	-11,000	1.301	-0.234
2005	102,000	9,000	153,000	32,000	1.500	0.199
2006	113,000	11,000	154,000	1,000	1.363	-0.137
2007	119,000	6,000	162,000	8,000	1.361	-0.001
2008	68,000	-51,000	178,000	16,000	2.618	1.256
2008/09	75,086		183,000		2.437	
2009	86,000	18,000	206,000	28,000	2.395	-0.222
2010	87,000	1,000	218,000	12,000	2.506	0.110
2011	90,000	3,000	232,986	14,986	2.589	0.083
2012	92,298	2,298	212,286	-20,700	2.300	-0.289
2013	92,944	646	213,772	1,486	2.300	0.000
2014	94,803	1,859	237,008	23,236	2.500	0.200
2015	95,277	474	238,193	1,185	2.500	0.000
2016	95,515	238	214,910	-23,283	2.250	-0.250

Authors' computation based on UBOS data (1997-2016)

Appendix 2: Locations and distribution of agroecological zones of Uganda



KEY

- | | | | | |
|--|---|--------------------------|---|-------------------------|
| NARO Secretariat |  | West Nile farmlands |  | Eastern Highlands |
| NARIs - Conduct Research of National Mandate |  | Northern farming system |  | Lake Victoria Crescent |
| ZARDIs - Conduct Research for specific Agro Ecological Zones |  | Northern Moist farmlands |  | Western Range lands |
| |  | Lake Albert crescent |  | South Western Highlands |

Source: NARO (2018)

Appendix 3: Characteristics of lowland and upland rainfed rice systems

(i) Model specifications and regression diagnostic

Variable inflation factor (VIF)

Variable	VIF	1/VIF
plot	8.65	0.1155
seed	4.71	0.2123
oxen	4.53	0.2209
plotlabor	8.82	0.1133
plot2	4.47	0.2238
oxen2	2.9	0.3445
plotoxen	5.82	0.1718
Tractor	1.07	0.9315
labor	3.03	0.3297
clay-loam	1.21	0.8283
year		
2014	1.51	0.6642
2015	1.54	0.6502
2016	1.54	0.6490
Mean VIF	3.83	

Ramsey RESET test using powers of the fitted values of lnoutput

Ho: model has no omitted variables

$F(3, 943) = 9.83$

Prob > F = 0.0000

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of lnoutput

$\chi^2(1) = 2.67$

Prob > $\chi^2 = 0.1021$

Skewness/Kurtosis tests for Normality

		----- joint -----			
Variable	Obs	Pr(Skewness)	Pr(Kurtosis)	adj $\chi^2(2)$	Prob> χ^2
resid5	960	0	0.0035	65.73	0

Shapiro Wilk W test for normal data

Variable	Obs	W	V	z	Prob>z
lnOutput	960	0.9695	18.565	7.222	0.000
lnPlot	960	0.9832	10.226	5.748	0.000
lnSeed	960	0.9904	5.857	4.37	0.000
lnLabor	960	0.9722	16.89	6.988	0.000
lnOxen	960	0.9543	27.757	8.217	0.000
Tractor	960	0.9771	13.893	6.505	0.000
clay soil	960	0.7839	131.299	12.059	0.000
year	960	0.9972	1.682	1.285	0.099

Likelihood-ratio tests

Assumptions	Restricted	Unrestricted	DF	Computed value	Critical value	Decision (p<0.05)
Cobb-Douglas is an adequate representation of production frontier function (H_0)	-514.84	-502.88	3	23.9058	7.815	Reject
Each farm is producing on technical efficient frontier ($H_0 \eta = 0$)	-1204.93		1	120	3.841	Reject
Technical efficiency is time-invariant ($H_0 \sigma_u = 0$)	-1232.84	-1228.89	2	7.9	5.991	Reject
Variables included in the inefficiency effect model have no influence on the level of inefficiency ($H_0 \delta = 0$)	-705.42	-944.18	8	385.56	15.507	Reject

Note: All the tests are two tailed. Probability of exceeding critical value was decided at $p=0.05$

(ii) Stochastic frontier models

OLS model

Source	SS	Df	MS	Number of obs	=	960
				F(9, 950)	=	57.55
Model	407.8208	9	45.3134	Prob > F	=	0.000
Residual	748.0149	950	0.7874	R-squared	=	0.3528
				Adj R-squared	=	0.3467
Total	1155.8357	959	1.2053	Root MSE	=	0.8874

lnOutput	Coef.	Std. Err.	t	P>t	[95% Conf. Interval]	
lnPlot	0.6844	0.0710	9.64	0.000	0.5451	0.8238
lnSeed	0.0856	0.0693	1.23	0.217	-0.0505	0.2216
lnLabor	0.0715	0.0324	2.21	0.027	0.0079	0.1350
lnOxen	0.1677	0.0351	4.78	0.000	0.0988	0.2365
Tractor	0.3361	0.1100	3.05	0.002	0.1202	0.5521
Clay soil	-0.0010	0.0017	-0.58	0.564	-0.0042	0.0023
year						
2014	-0.1435	0.0812	-1.77	0.077	-0.3028	0.0158
2015	-0.2282	0.0819	-2.79	0.005	-0.3890	-0.0674
2016	-0.3050	0.0821	-3.71	0.000	-0.4661	-0.1438
cons	-0.8333	0.3542	-2.35	0.019	-1.5285	-0.1381

Stoc. frontier normal/half-normal model)

Inoutput	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
plot	1.3723	0.1180	11.63	0	1.1411	1.6036
seed	0.0012	0.0008	1.48	0.14	-0.0004	0.0029
oxen	0.0566	0.0123	4.6	0	0.0325	0.0808
plotlabor	-0.0010	0.0003	-3.72	0	-0.0016	-0.0005
plot2	-0.0501	0.0093	-5.38	0	-0.0684	-0.0319
oxen2	-0.0007	0.0003	-2.65	0.008	-0.0013	-0.0002
plotoxen	-0.0253	0.0064	-3.95	0	-0.0379	-0.0128
Tractor	0.0601	0.0887	0.68	0.498	-0.1138	0.2339
labor	0.0015	0.0004	3.83	0	0.0007	0.0023
Clay-loam	0.0002	0.0016	0.13	0.896	-0.0029	0.0033
year						
2014	-0.0716	0.0660	-1.08	0.279	-0.2010	0.0579
2015	-0.0950	0.0681	-1.39	0.163	-0.2286	0.0385
2016	-0.1714	0.0673	-2.55	0.011	-0.3033	-0.0394
_cons	-0.3851	0.1307	-2.95	0.003	-0.6412	-0.1290
/lnsig2v	-2.2289	0.2019	-11.04	0	-2.6246	-1.8331
/lnsig2u	0.6790	0.0718	9.46	0	0.5383	0.8196
sigma_v	0.3281	0.0331			0.2692	0.3999
sigma_u	1.4042	0.0504			1.3088	1.5066
sigma2	2.0795	0.1300			1.8246	2.3343
lambda	4.2798	0.0748			4.1332	4.4264

LR test of sigma_u=0: chibar2(01) = 1.2e+02

Prob >= chibar2 = 0.000

Number of obs = 960 Number of groups = 240

Log likelihood = -1204.9319

Wald chi2(13) = 477.40 Prob > chi2 = 0.000

Battese and Coelli, 1988 – Time-invariant model

Inoutput	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
Frontier						
plot	1.3056	0.1388	9.41	0	1.0336	1.5777
seed	0.0009	0.0010	0.92	0.358	-0.0010	0.0029
oxen	0.0824	0.0165	4.99	0	0.0500	0.1147
plotlabor	-0.0010	0.0003	-3.06	0.002	-0.0016	-0.0003
plot2	-0.0430	0.0123	-3.5	0	-0.0671	-0.0189
oxen2	-0.0008	0.0004	-2.2	0.028	-0.0016	-0.0001
plotoxen	-0.0295	0.0097	-3.04	0.002	-0.0485	-0.0105
Tractor	0.1280	0.1083	1.18	0.237	-0.0842	0.3402
labor	0.0017	0.0005	3.48	0.001	0.0008	0.0027
Clay-loam	0.0028	0.0024	1.17	0.244	-0.0019	0.0074
year						
2014	-0.0969	0.0725	-1.34	0.181	-0.2389	0.0452
2015	-0.1670	0.0736	-2.27	0.023	-0.3113	-0.0228
2016	-0.2406	0.0738	-3.26	0.001	-0.3852	-0.0961
cons	-1.0162	0.1644	-6.18	0	-1.3385	-0.6939
/lnsigma2	0.1971	0.0869	2.27	0.023	0.0268	0.3673
/ilgtgamma	-0.0606	0.2048	-0.3	0.767	-0.4620	0.3409
/mu	-0.0339					
sigma2	1.2178	0.1058			1.0272	1.4438
gamma	0.4849	0.0512			0.3865	0.5844
sigma u2	0.5905	0.1093			0.3763	0.8046
sigma v2	0.6273	0.0330			0.5627	0.6920

Number of obs = 960 Number of groups = 240

Log likelihood = -1232.8367

Wald chi2(13) = 335.76 Prob > chi2 = 0.000

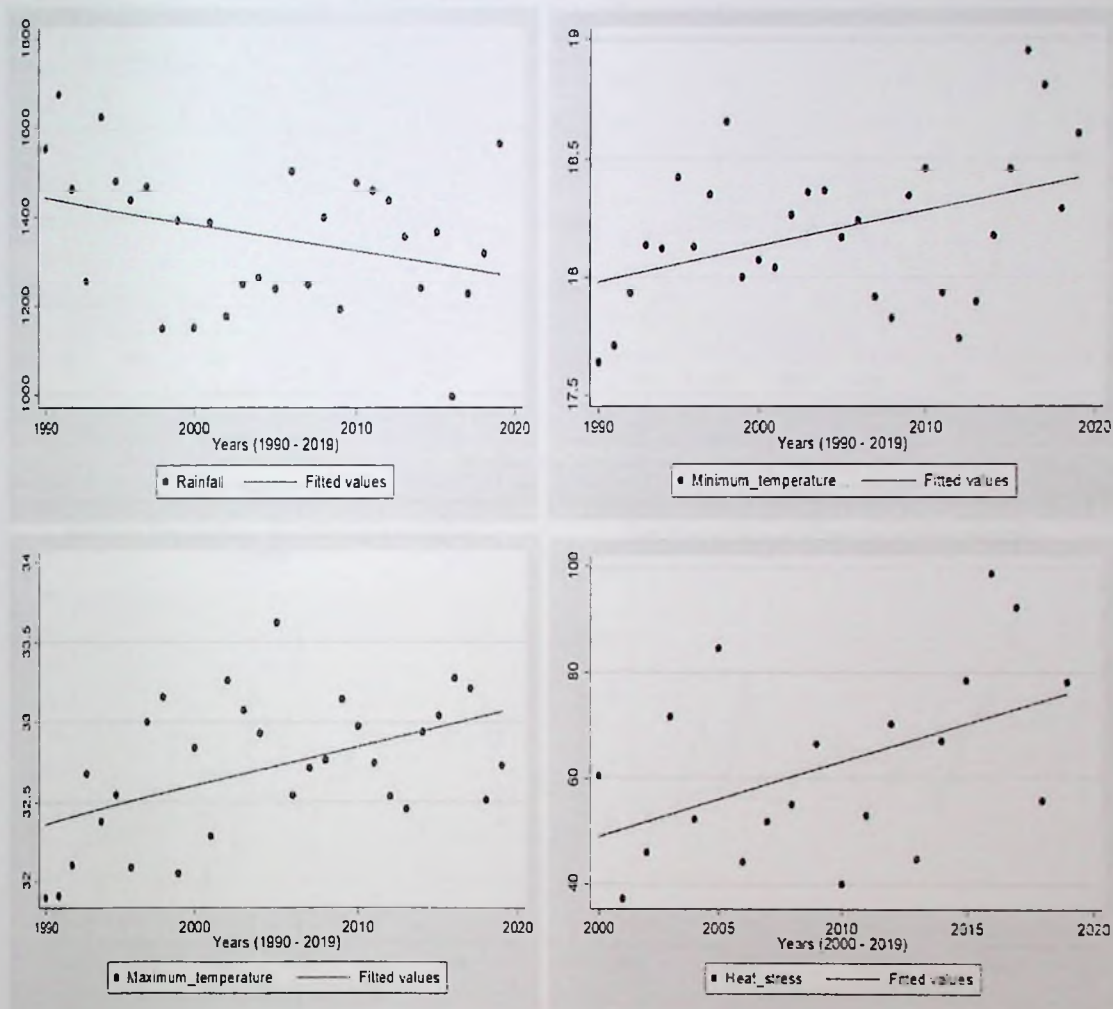
Battese & Coelli, 1992 – time varying model

lnoutput	Coef.	Std. Err.	z	P>z	[95% Conf.Interval]	
Frontier						
plot	1.2554	0.1403	8.95	0	0.9803	1.5304
seed	0.0010	0.0010	1.03	0.302	-0.0009	0.0030
oxen	0.0759	0.0166	4.58	0	0.0435	0.1084
plotlabor	-0.0009	0.0003	-3.01	0.003	-0.0016	-0.0003
plot2	-0.0417	0.0123	-3.4	0.001	-0.0657	-0.0177
oxen2	-0.0008	0.0004	-2.05	0.04	-0.0015	0.0000
plotoxen	-0.0256	0.0097	-2.64	0.008	-0.0445	-0.0066
Tractor	0.1069	0.1074	1	0.32	-0.1036	0.3173
labor	0.0018	0.0005	3.49	0	0.0008	0.0028
Clay-loam	0.0037	0.0024	1.53	0.125	-0.0010	0.0085
year						
2014	-0.0177	0.1002	-0.18	0.86	-0.2140	0.1786
2015	-0.0026	0.1682	-0.02	0.988	-0.3323	0.3271
2016	0.0209	0.2574	0.08	0.935	-0.4836	0.5254
cons	-0.6293	0.3768	-1.67	0.095	-1.3678	0.1093
/lnsigma2	-0.1153	0.0932	-1.24	0.216	-0.2979	0.0674
/ilgtgamma	-0.7810	0.3010	-2.6	0.009	-1.3709	-0.1912
/mu	1.2074	0.4773	2.53	0.011	0.2720	2.1428
/eta	-0.0809	0.0714	-1.13	0.257	-0.2208	0.0589
sigma2	0.8911	0.0831			0.7423	1.0697
gamma	0.3141	0.0648			0.2025	0.4523
sigma_u2	0.2799	0.0810			0.1212	0.4386
sigma_v2	0.6112	0.0323			0.5479	0.6745
Number of obs = 960 Number of groups = 240 Log likelihood = -1228.8879 Wald chi2(13) = 330.18 Prob>chi2= 0.000						

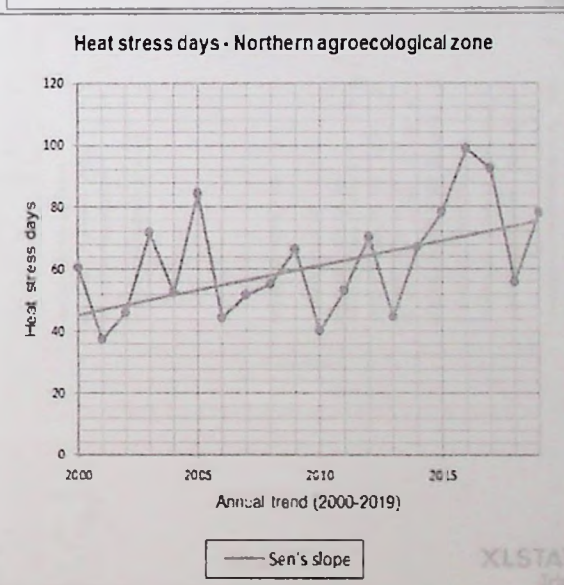
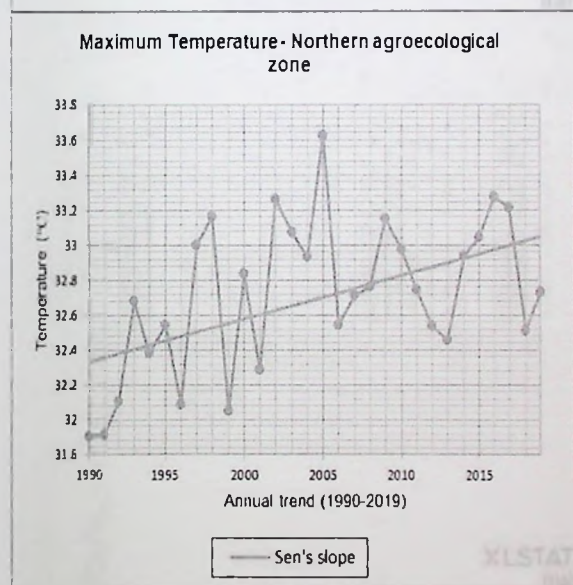
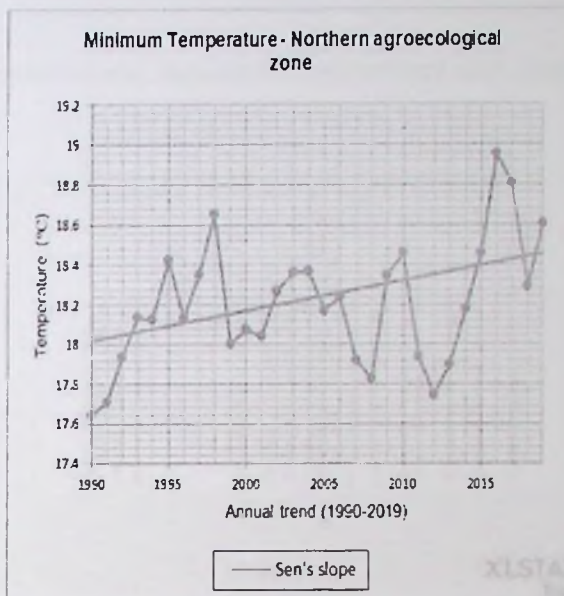
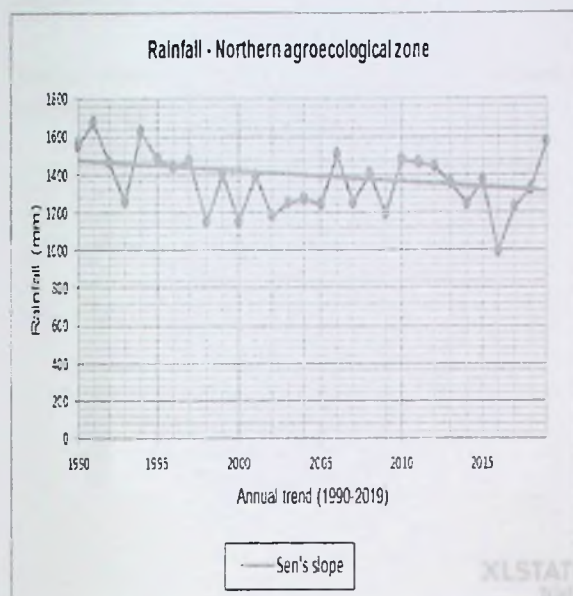
Appendix 4: Effects of climate variability on rainfed rice production

(i) Rainfall and temperature distribution and diagnostic regression

Scatterplots for rainfall, minimum temperature, maximum temperature and heat stress days

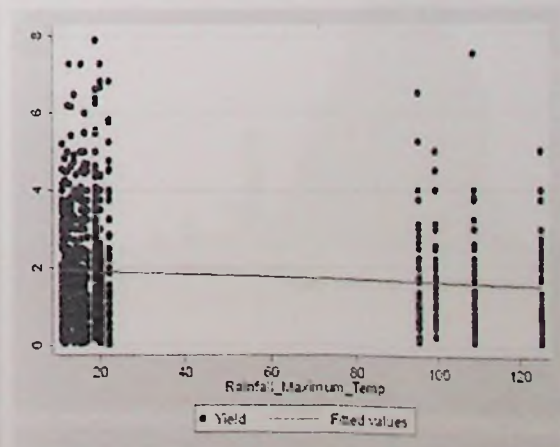
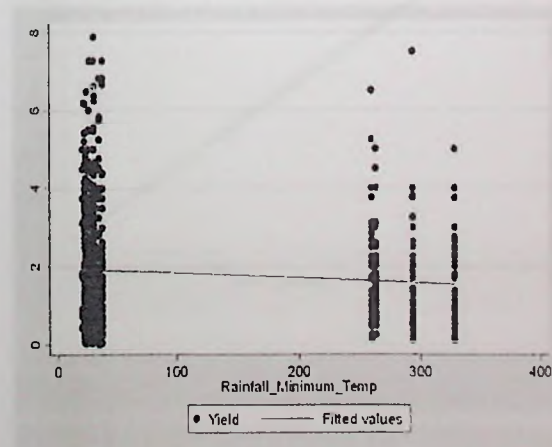
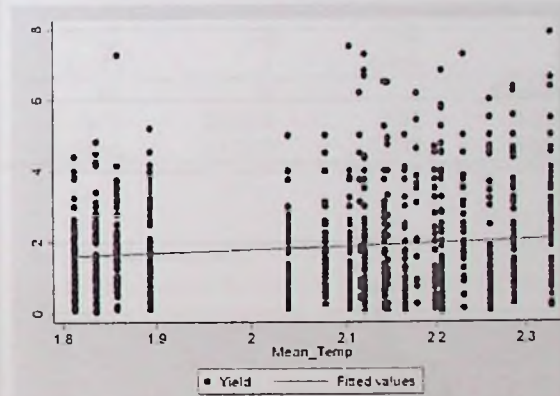
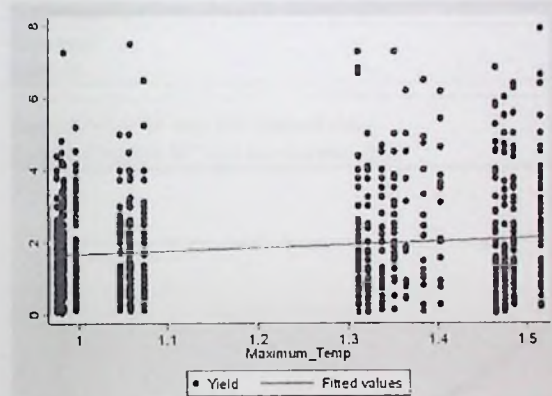
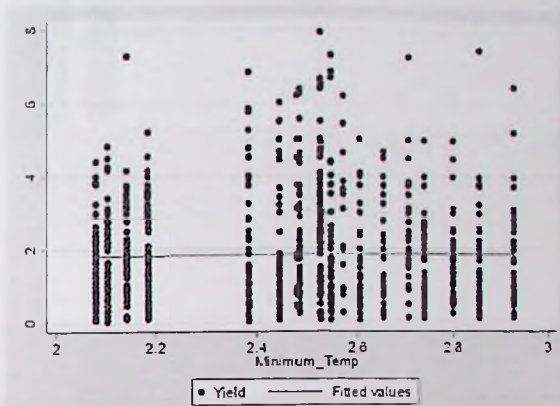
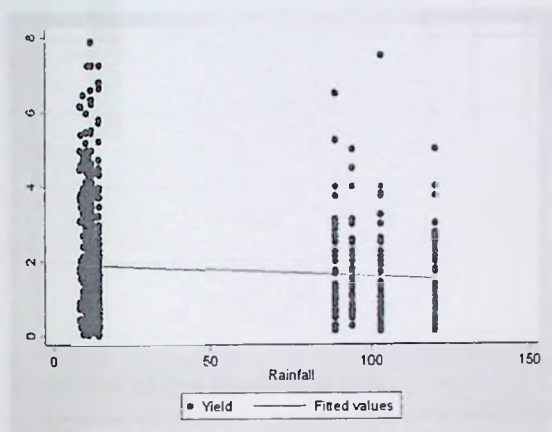


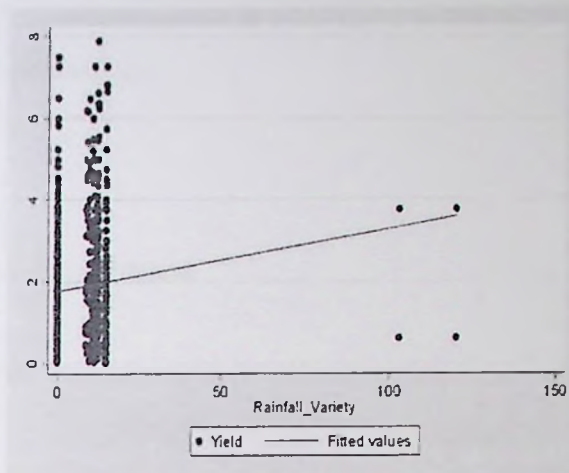
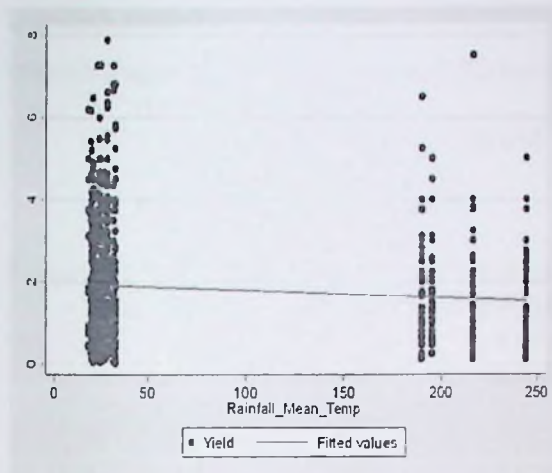
Trend analysis - rainfall, temperature and heat stress



(ii) Influence of climate variability on rice production – model specification and regression diagnostics

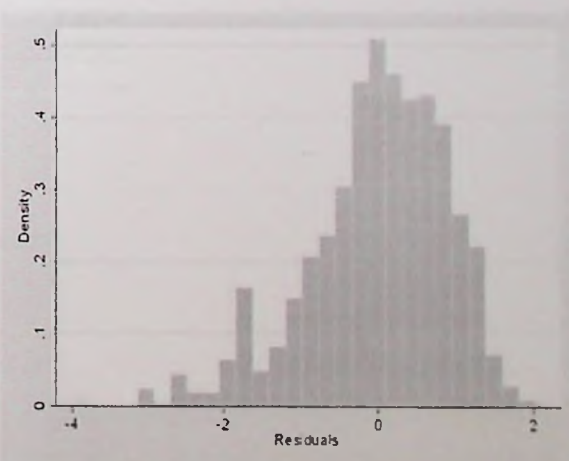
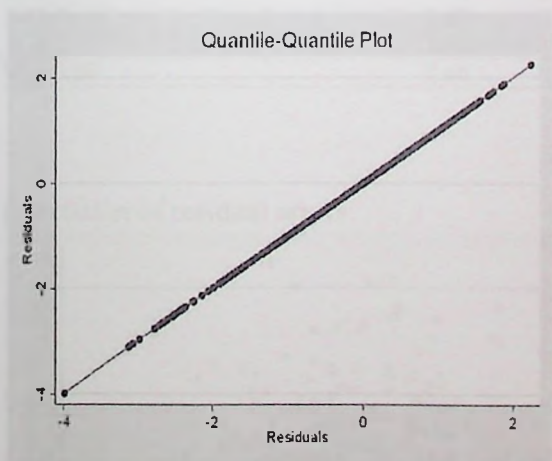
Scatter plots for yield and rainfall, minimum temperature, maximum temperature and mean temperature





Normality of the residual errors

Source	Chi2	Df	p	
Skewness/Kurtosis tests for Normality				
Skewness	71.03	10	0.000	
Kurtosis	12.95	1	0.000	
	W	V	z	Prob>z
Shapiro-Wilk W test for normal data	0.9637	22.071	7.65	0.000
Shapiro-Francia W' test for normal data	0.9636	23.529	7.222	0.000



Heteroscedasticity

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of lnyield

chi2(1) = 1.89

Prob > chi2 = 0.1692

Ramsey RESET test using powers of the fitted values of Yield

Ho: model has no omitted variables

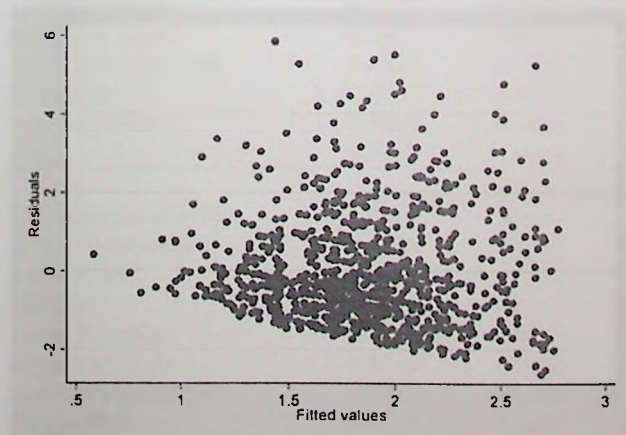
F (3, 943) = 0.94

Prob > F = 0.04226

Variance inflation factors

Variable	VIF	1/VIF
Rainfall	22.51	0.0444
Coefficient of variation in rainfall	7.04	0.1419
Precipitation concentration index	1.71	0.5838
Minimum temperature	15.33	0.0652
CV in minimum temperature	14.49	0.0690
Maximum temperature	1.83	0.5478
Rainfall-mean temperature	19.83	0.0504
Strategies	1.28	0.7791
Production method	1.11	0.9023
Rice-variety	3.92	0.2554
year		
2014	1.9	0.5261
2015	3.32	0.3014
2016	5.31	0.1884
Mean VIF	7.66	

Correlation of residual errors



Appendix 5: Farmers' coping strategies, estimation models and regression diagnostic

(i) Influence of farmer characteristics on choice of coping strategy, estimation models and regression diagnostic

Mixed-effects probit regression

Variety	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Exposure to variability	1.7267	0.2769	6.24	0.000	1.1841	2.2694
Effects of variability	-1.9971	0.2504	-7.98	0.000	-2.4878	-1.5064
Yield>2t Ha ⁻¹	0.1080	0.1031	1.05	0.295	-0.0940	0.3100
Soil type	0.0242	0.0055	4.37	0.000	0.0133	0.0350
Lowland system	0.0040	0.1862	0.02	0.983	-0.3609	0.3689
Number of crops	-0.0041	0.0220	-0.19	0.851	-0.0472	0.0389
No. of extension visit	-0.0065	0.0489	-0.13	0.894	-0.1024	0.0894
Gender-Male	-0.5070	0.1961	-2.58	0.01	-0.8914	-0.1226
Accessed credit	-0.3008	0.1146	-2.62	0.009	-0.5253	-0.0762
cons	-2.7129	0.9864	-2.75	0.006	-4.6462	-0.7796
Average marginal effects (Delta-method) dy/dx						
Exposure to variability	0.3820	0.0573	6.67	0.000	0.2697	0.4942
Effects of variability	-0.4418	0.0504	-8.76	0.000	-0.5406	-0.3430
Yield>2t Ha ⁻¹	0.0239	0.0228	1.05	0.294	-0.0207	0.0685
Soil type	0.0053	0.0012	4.39	0.000	0.0030	0.0077
Lowland system	0.0009	0.0412	0.02	0.983	-0.0798	0.0816
Number of crops	-0.0009	0.0049	-0.19	0.851	-0.0104	0.0086
No. of extension visit	-0.0014	0.0108	-0.13	0.894	-0.0227	0.0198
Gender-Male	-0.1122	0.0430	-2.61	0.009	-0.1964	-0.0279
Accessed credit	-0.0665	0.0252	-2.64	0.008	-0.1159	-0.0171
Number of obs = 960 Log likelihood = -381.01801 Wald chi2(9) = 127.2 Prob > chi2 = 0.000						

Complementary log-log regression

variety	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Exposure to variability	1.8872	0.3401	5.55	0.000	1.2205	2.5538
Effects of variability	-2.5587	0.2754	-9.29	0.000	-3.0984	-2.0190
Yield>2t Ha ⁻¹	0.1207	0.1589	0.76	0.447	-0.1907	0.4321
Soil type	0.0493	0.0105	4.69	0.000	0.0287	0.0700
Lowland system	0.1122	0.3101	0.36	0.717	-0.4956	0.7200
Number of crops	-0.0313	0.0327	-0.96	0.339	-0.0955	0.0328
No. of extension visit	0.0225	0.0747	0.3	0.763	-0.1238	0.1688
Gender-Male	-0.6007	0.2833	-2.12	0.034	-1.1560	-0.0453
Accessed credit	-0.5068	0.1886	-2.69	0.007	-0.8764	-0.1371
cons	-4.6169	1.6355	-2.82	0.005	-7.8224	-1.4115
Average marginal effects (Delta-method) dy/dx						
Exposure to variability	0.2640	0.0436	6.06	0.000	0.1786	0.3495
Effects of variability	-0.3580	0.0313	-11.42	0.000	-0.4194	-0.2966
Yield>2t Ha ⁻¹	0.0169	0.0222	0.76	0.447	-0.0267	0.0605
Soil type	0.0069	0.0015	4.65	0.000	0.0040	0.0098
Lowland system	0.0157	0.0434	0.36	0.718	-0.0694	0.1008
Number of crops	-0.0044	0.0046	-0.96	0.336	-0.0133	0.0045
No. of extension visit	0.0031	0.0104	0.3	0.763	-0.0173	0.0236
Gender-Male	-0.0840	0.0395	-2.13	0.033	-0.1615	-0.0066
Accessed credit	-0.0709	0.0263	-2.7	0.007	-0.1224	-0.0194
Number of obs = 960 Log likelihood = -375.5722 Wald chi2(9) = 153.81 Prob > chi2 = 0.000						

(ii) Contribution coping strategies on yield, estimation models and regression diagnostic

Pearson's correlation, r

	yield	Combination of varieties	Changing variety	Changing planting date	Regulating water	Shift to valley area
yield	1					
Combination of varieties	0.0822 (0.011)	1				
Changing variety	0.0674 (0.037)	0.641 (0.000)	1			
Changing planting date	0.1322 (0.000)	0.8151 (0.000)	0.4857 (0.000)	1		
Regulating water	0.1926 (0.000)	0.5561 (0.000)	0.3954 (0.000)	0.4902 (0.000)	1	
Shift to valley area	-0.0226 (0.485)	0.2823 (0.000)	0.0383 (0.236)	0.1402 (0.000)	-0.1125 (0.001)	1

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity

Ho: Constant variance

Variables: fitted values of lnyield

chi2(1) = 0.12

Prob > chi2 = 0.7246

Ramsey RESET test using powers of the fitted values of lnyield

Ho: model has no omitted variables

F (3, 951) = 1.24

Prob > F = 0.2933

Variance inflation factors

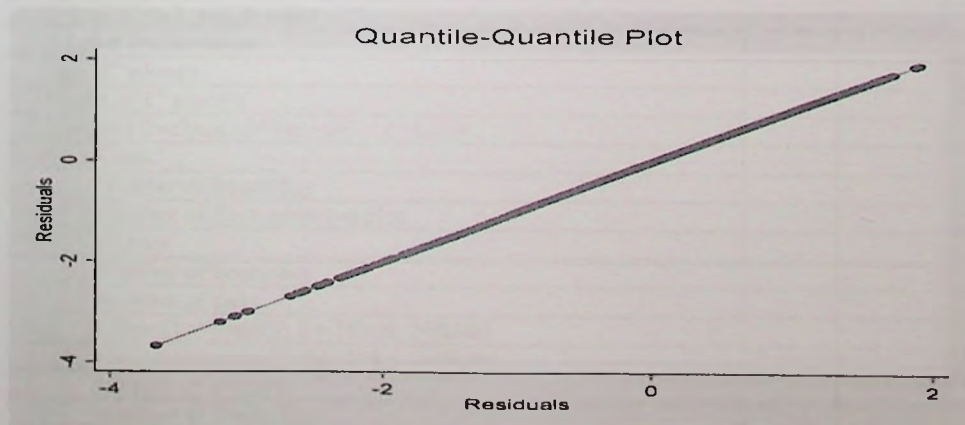
Variable	VIF	1/VIF
Strategies		
Combination of strategies	1.32	0.7569
Changing planting date	1.08	0.9254
Changing variety	1.15	0.8699
Regulating water	1.08	0.9280
Shifting to valley area	1.13	0.8813
Affected by variability	1.58	0.6332
age	1.06	0.9431
Credit	1.1	0.9127
Rice income	1.02	0.9805
Training	1.4	0.7131
District		
Gulu	1.78	0.5626
Lira	2.08	0.4818
Oyam	2.15	0.4644
Year		
2014	1.59	0.6295
2015	1.59	0.6289
2016	1.52	0.6587
Mean VIF	1.41	

Variable and model selection using Information criterion

Optimal models:						
#Preds	R2ADJ	C	AIC	AICC	BIC	
1	0.020097	47.55054	3390.12	3390.145	3399.854	
2	0.032255	36.06412	3379.131	3379.173	3393.732	
3	0.041779	27.29636	3370.633	3370.696	3390.101	
4	0.048799	21.1053	3364.57	3364.658	3388.904	
5	0.054972	15.79305	3359.314	3359.431	3388.515	
6	0.06026	11.39526	3354.92	3355.071	3388.988	
7	0.061213	11.42027	3354.937	3355.127	3393.873	
8	0.062048	11.56849	3355.075	3355.307	3398.877	
9	0.064133	10.44803	3353.928	3354.207	3402.598	
10	0.063661	11.92641	3355.401	3355.731	3408.938	
11	0.065052	11.51546	3354.962	3355.347	3413.365	
12	0.066084	11.47142	3354.889	3355.333	3418.159	
13	0.067187	11.35759	3354.74	3355.248	3422.877	
14	0.066435	13.12015	3356.498	3357.075	3429.502	
15	0.065535	15.02999	3358.406	3359.056	3436.277	
16	0.064574	17	3360.376	3361.103	3443.114	

predictors for each model:

- 1 : Strategies
- 2 : Strategies year
- 3 : Strategies year System
- 4 : Strategies year Affected_cv System
- 5 : Strategies year Affected_cv riceincome System
- 6 : Strategies year Affected_cv riceincome Credit System
- 7 : Strategies year Affected_cv riceincome Credit System Gender
- 8 : Strategies year Affected_cv riceincome Credit System Exten Train
- 9 : Strategies year Affected_cv riceincome Credit System Exten Gender Train
- 10 : Strategies year Affected_cv riceincome Credit System Gender Train crops education
- 11 : Strategies year Affected_cv riceincome Credit System Exten Gender Train Train crops
- 12 : Strategies year Affected_cv riceincome Credit System Exten Gender Train Train crops education
- 13 : Strategies year Affected_cv riceincome Credit System Exten Gender Train Train age crops education
- 14 : Strategies year Affected_cv riceincome Credit System Exten Gender Train Train age crops education Members
- 15 : Strategies year Affected_cv riceincome Credit System Exten Gender Train Train age crops education Members District
- 16 : Strategies year Affected_cv riceincome Credit System Exten Gender Train Train age crops education Members District soil d



Appendix 6: Questionnaire on rainfed rice production in Northern agroecology

1. CLASSIFYING INFORMATION –

Name of enumerator Telephone contact

1.1 Date	1.2 District	1.3 Sub-county	1.4 Parish	1.5 Village
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2. FARMERS' CHARACTERISTICS AND ACCESS TO PRODUCTION SERVICES

2.1 Name of respondent	Telephone contact
2.2 Sex of the farmer [1=M; 2=F]	2.3 Marital status [1=Married; 2=Single; 3=Widow]
2.4 Age	2.5 Education (years)
2.6 Household size?	2.7 Number of Labour for rice activities
2.8 Household land (acre)?	2.9 Total Land available for rice
2.10 Extension visit [1=Yes; 2=No]	2.11 Number of extension visits
2.12 Membership in rice group? [1=Yes; 2=No]	2.13 Which year did you join rice group
2.14 Credit access for rice? [1=Yes; 2=No]	2.15 Number of times credit was accessed
2.16 Training in rice? [1=Yes; 2=No]	2.17 Number of training attended
2.18 Number of crops grown per season	2.19 Number of crops grown/year
2.20 Total Annual Income from crop production	2.21 Total Annual income from Off-farm

2.22 Please mention the main crops you have been growing from 2013 to 2016 and its purpose

2.22.1 Crops	2.22.2 Rank	2.22.3 Purpose of the crop [(1) Food; (2) Income; (3) Both]
1.		
2.		
3.		
4.		

3. PRODUCTION AND INPUT UTILIZATION

3.1. Provide information rice production and input use in the table below for 2013 to 2016

Activity	2013	2014	2015	2016
3.1.1 Rice Season [1= 1 st season; 2=2 nd season]				
3.1.2 Reason for sowing in the season [1=Climate; 2=Labor; 3=Land; 4=Bird]				
3.1.3 Rice Variety [1=SUPA; 2=KAISO; 3=NERICA; 3=SINDANO; 5=Others (specify).....]				
3.1.4 System [1=Lowland; 2=Upland]				
3.1.5 Size of each plot in acres				
3.1.6 Land preparation				
(a) 1 st plough				
(1) Month of 1 st plough				
(2) Method [1=Oxen; 2=Tractor; 3=Labor]				
(2.1) Oxen				
(i) Number of hours/day				
(ii) Number of days spent per plot				
(2.2) Tractor				
(i) Number of hours/day				
(ii) Number of days				
(2.3) Labor [1 = Family; 2 = Hired; 2=Both]				
(i) Gender involved [1=M; 2=F; 3=Both]				
(ii) Number of persons				
(iii) Number of hours/day				
(iv) Number of days				
(b) 2 nd plough				

Activity	2013	2014	2015	2016
(1) Month of 2 nd plough				
(2) Method [1=Oxen; 2=Tractor; 3=Labor]				
(2.1) Oxen				
(i) Number of hours/day				
(ii) Number of days spent per plot				
(2.2) Tractor				
(i) Number of hours/day				
(ii) Number of days				
(2.3) Labor (1 = Family; 2 = Hired; 2=Both)				
(i) Gender involved [1=M; 2=F; 3=Both]				
(ii) Number of persons				
(iii) Number of hours/day				
(iv) Number of days				
© 3 rd plough				
(1) Month of 3 rd plough				
(2) Method [1=Oxen; 2=Tractor; 3=Labor]				
(2.1) Oxen				
(i) Number of hours/day				
(ii) Number of days spent per plot				
(2.2) Tractor				
(i) Number of hours/day				
(ii) Number of days				
(2.3) Labor [1 = Family; 2 = Hired; 2=Both]				
(i) Gender involved [1=M; 2=F; 3=Both]				
(ii) Number of persons				
(iii) Number of hours/day				
(iv) Number of days				
3.1.7 Planting				
(1) Month of planting				
(2) Method [1=Broadcast; 2=Transplant; 3=Dibble]				
(3) Planting using [1=Oxen; 2=Tractor; 3=Labor]				
(a) Oxen				
(i) Number of hours/day				
(ii) Number of days spent per plot				
(b) Tractor				
(i) Number of hours/day				
(ii) Number of days				
(c) Labor [1 = Family; 2 = Hired; 2=Both]				
(i) Gender involved (1=M; 2=F; 3=Both)				
(ii) Number of persons				
(iii) Number of hours/day				
(iv) Number of days				
3.1.8 Seeds				
(1) Type of seeds used [1 = Local, 2 = Improved]				
(2) Source [1=Own; 2=Market; 3=Research; 4=NGOs; 5=Extension; 6=Agro-dealers; 7=Friends; 8=Gov't]				
(3) Quantity of seed used in kg				
(4) Price per kg				
3.1.9 Weeding				
(a) 1 st Weeding				
(1) Month of 1 st weeding				
(2) Labour [1 = Family; 2 = Hired; 2=Both]				
(3) Gender involved [1= M; 2= F; 3= Both]				
(4) Number of persons				
(5) Number of hours/day				
(6) Number of days				
(b) 2 nd Weeding				

Activity	2013	2014	2015	2016
(1) Month of 2 nd weeding				
(2) Labour [1 = Family; 2 = Hired; 2=Both]				
(3) Gender involved [1= M; 2= F; 3= Both]				
(4) Number of persons				
(5) Number of hours/day				
(6) Number of days				
© 3 rd Weeding				
(1) Month of 3 rd weeding				
(2) Labour [1 = Family; 2 = Hired; 2=Both]				
(3) Gender involved [1= M; 2= F; 3= Both]				
(4) Number of persons				
(5) Number of hours/day				
(6) Number of days				
3.1.10 Fertility [1=Fertilizer; 2= Manure]				
(1) Source				
(2) Quantity per plot in kg/litres				
(3) Price per kg/litre				
3.1.11 Use of Herbicides[1=Yes; 2=No]				
(1) Source [1= Market; 2=Friends; 3=Organ]				
(2) Quantity used in liters or Kgs				
(3) Price per liter or Kgs				
3.1.12 Bird scaring				
(1) Month for bird scaring				
(2) Labor [1 = Family; 2 = Hired; 2=Both]				
(3) Gender involved [1=M; 2=F; 3=Both]				
(4) Number of persons				
(5) Number of hours/day				
(6) Number of days				
3.1.13 Pre, post-harvest handling activities				
(1) Month the crop was harvested				
(2) Methods for harvesting [1=Manual, 2=Mechanical]				
<i>Mechanical</i>				
(i) Number of hours per plot				
(ii) Number of days spent per plot				
<i>Labour</i>				
(a) Source of labour [1 = Family; 2 = Hired; 2=Both]				
(b) Sex of labour involved [1= M; 2= F; 3= Both]				
(i) Number of persons				
(ii) Number of hours/day				
(iii) Number of days				
3.1.14 Yield				
(1) Quantity harvested in kg				
(2) Price per kg [not milled]				
(3) Price per kg [milled]				

4. VARIATION IN WEATHER AND COPPING MECHANISMS PRODUCTION

4.1 Have you experienced any variation in climate in the recent years? /1=Yes; 2=No/

4.2 When did you begin seeing these variations in climate?

4.3 Has these changes affected your rice production in any way? /1=Yes; 2=No/

4.4 Please explain how these variations in climate have affected rice production and livelihood?

(a) Production

(b) Livelihood

4.5 Is there a year you did not grow rice at all due to poor climate condition? /1=Yes; 2=No/

4.6 If yes, which year was that

4.7 Provide information on climate and coping strategies during production of 2013 -2016

Year	4.7.1 Rain "	4.6.2 Temp "	4.7.4 Coping strategy
2013			
2014			
2015			
2016			

**(1) Early; (2) Late; (3) Little; (4) Much; (5) Short; (6) Drought; (7) Normal; (8) Dry/hot*

5 CHALLENGES IN RICE PRODUCTION

5.1 Please provide challenges faced in rice production and recommendations for solution

5.1.1 Challenge faced	5.1.2 Suggest recommendation for solution
1	
2	
3	
4	

5.2 Is there any question you want to ask?

.....