EFFECTS OF RAIN-FED CROPLAND ON SORGHUM PRODUCTIVITY AMONG SMALLHOLDER FARMERS

CASE STUDY: IN OYAM AND LIRA DISTRICTS

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Master's Dissertation

Declaration

I have read the rules of Uganda Martyrs University on Plagarism and hereby state that this work is my own.

It has not been submitted to any other institution for another degree or qualification, either in full or in part.

Throughout the work I have acknowledge all sources used in its compilation.

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This work has been produced under my supervision

Name of supervisor:___________Dr. Musinguzi Simonpeter______________

Signature of Supervisor :____

Submission date:___________23/09/2024_____________________________

Submitted to: School of Postgraduate Studies and Research

DEDICATION

This book is dedicated to my Family, Friends, and In-laws

ACKNOWLEDGEMENT

I thank God, The Almighty Father through His son Jesus Christ and Mother Mary for this work. I will forever be grateful to Him for the following persons who brought me in and took me through this pursuit: First, I thank the Faculty of Agriculture for admitting me into this program and constantly supporting me. In the same respect, I thank ACALISE for accepting to contribute to my tuition while studying at Uganda Martyrs University.

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LIST OF ABBREVIATION

DAP	Diammonium Phosphate
DNA	Deoxyribonucleic Acid of Sorghum Production
FAO	United Nations Food and Agriculture Organisation
NDP	National Development Plan III(2020/2021 – 2024/2025)
SAT	Semi-Arid Tropic
SDG	Sustainable Development Goal
USA	United State Agency

ABSTRACT

Sorghum is a critical food security crop in sub-humid and semi-arid regions of Sub-Saharan Africa, Asia, and Latin America. In Uganda, it ranks second behind maize as a staple food, particularly in the north where it sustains the population. Sorghum cultivation covers roughly 491,911 hectares, yielding 268,493 metric tons. However, average yields are low (around 0.5 tons per hectare) due to dependence on rainfall patterns. Changing weather patterns and limited land availability further complicate these challenges.

This study investigated the effects of rainfed cropland on sorghum productivity in Uganda's northern Oyam and Lira Districts. The researchers sought to characterize sorghum productivity in rain-fed cropland, determine production levels, and assess productive efficiency among smallholder farmers. The descriptive research employed both quantitative and qualitative data collection methods. Data analysis using SPSS software helped characterize sorghum production and productivity efficiency. Key findings reveal that several sorghum varieties are produced at various levels as rainfed crops on small plots averaging 1-3 acres. Common practices include crop rotation and double ploughing. However, a significant portion of farmers rely on unspecified sorghum varieties. Insufficient rainfall was the primary constraint, followed by pests and diseases. Production levels and costs fluctuated between seasons, with most farmers experiencing low rainfall, pests, and some hail damage. These findings suggest opportunities to improve yields through optimized land use, improved seeds, and crop protection strategies. Land area, fertilizer application, high-quality seeds, and pesticide use all had statistically significant positive impacts on sorghum yields.

CHAPTER ONE

INTRODUCTION

1.0 Introduction

This chapter serves as the foundation for the current research investigation. It meticulously establishes the context by introducing the overarching research area and the specific problem statement. Subsequently, the chapter outlines the research objectives, clearly defining the aims that guide the study. The research questions that will drive the data collection and analysis are then presented, followed by a delineation of the study's scope to ensure a clear understanding of its boundaries. The chapter concludes by highlighting the significance and justification of the research, emphasizing its potential contributions to the existing body of knowledge. Finally, the theoretical and conceptual frameworks that underpin the research methodology are presented, providing a robust foundation for the subsequent chapters.

1.1 Background of the Study

Global Food Security and Rainfed Agriculture:

The latter half of the 20th century witnessed significant advancements in agricultural productivity due to the introduction of novel crop varieties, increased fertilizer use, and the expansion of irrigated land (Biradar et al., 2009; Cerdà et al., 2018). As a result, global food production surpassed population growth. However, pockets of food insecurity persist, particularly in Sub-Saharan Africa, where a significant portion (approximately 60%) of the world's 850 million food-insecure individuals reside (Nsubuga et al., 2014). Rainfed agriculture remains the backbone of food production for these communities, despite regional variations (Cerdà et al., 2018). In Sub-Saharan Africa, over 95% of cultivated land relies on rainfall, highlighting the critical role of this agricultural practice (Biradar et al., 2009).

Significance of Sorghum in Sub-Saharan Africa:

Sorghum (Sorghum L. Moench) has traditionally been recognized as a vital food security crop in sub-humid and semi-arid regions of Sub-Saharan Africa, Asia, and Latin America (Altieri et al., 2008; Ker, 2014; Lagemann, 1977). Its drought tolerance makes it a particularly valuable option in the face of increasing climate variability and associated impacts on rainfall patterns (Adjei and Kyerematen, 2018; Ighbareyeh et al., 2015). Climate change, characterized by rising temperatures, altered precipitation patterns, and increasing greenhouse gas concentrations, presents significant challenges for agricultural production worldwide, with varying degrees of impact across different ecological zones (Dhakal et al., 2018; Ramirez-Villegas and Thornton, 2015).

Sorghum Production in Uganda:

In Uganda, sorghum has emerged as the second most important staple food after maize, particularly in the northern regions, playing a crucial role in sustaining the population (UBOS, 2020). Sorghum cultivation occupies a dedicated cropland area of approximately 491,911 hectares, with a total production of 268,493 metric tons. However, average yields remain relatively low (around 0.5 tons per hectare), partly attributable to the dependence on rainfall patterns. Changing weather patterns and limited land availability exacerbate these challenges (Nsubuga et al., 2014).

Farming Systems and Constraints in Northern Uganda:

The dominant agricultural system in northern Uganda is subsistence farming, primarily practiced by smallholder farmers. This system is characterized by low productivity and income levels. Land productivity is heavily influenced by rainfall patterns and population pressure, resulting in low crop yields. Furthermore, limited access to capital restricts farmers' ability to adopt improved technologies (Altieri et al., 2008). The region falls within the northwest savanna agroecological zone, featuring unevenly distributed annual rainfall (ranging from 700 to 1400 mm) and sandy loam soils suitable for crops like sorghum, millet, maize, and legumes (Ssentongo et al., 2018).

Traditional Rainfed Cropping Practices:

Rainfed agriculture in this zone traditionally employs practices such as crop rotations, intercropping (planting multiple crops in the same field), and the use of diverse crop varieties within a single species (Thenkabail and Wu, 2012). Additionally, integrated pest and disease management strategies and soil and water conservation techniques are often implemented (Cerdà et al., 2018). These practices have been demonstrated to have positive effects on overall crop performance (Abate et al., 2017). Multi-cropping and cover cropping further enhance productivity and yield stability by fostering positive interactions between different plant species (García et al., 2012).

Knowledge Gap and Research Justification:

Understanding the impact of rainfed conditions on sorghum production is critical for building resilience against climate variability and ensuring long-term food security. This study aims to address the knowledge gap regarding the precise effects of rainfall patterns on sorghum yields. Furthermore, accurate information on sorghum productivity and its connection to water management practices is essential for informing sustainable agricultural strategies in the region.

1.2 Statement of the Problem

Sorghum stands as the second most important staple food in Uganda, following maize, particularly in the northern regions. It plays a vital role in ensuring food security for the population (UBOS, 2020). Cultivated on an estimated 491,911 hectares of cropland, sorghum generates a total production of 268,493 metric tons. However, a significant challenge lies in the relatively low average yields, hovering around 0.5 tons per hectare. This is partly due to the dependence on unpredictable rainfall patterns. Changing weather patterns and limited land availability further exacerbate these challenges (Nsubuga et al., 2014).

While significant research efforts have examined the influence of diverse microclimates on sorghum production within Sub-Saharan Africa, a critical knowledge gap persists regarding the optimal performance of specific sorghum varieties under rain-fed cropland conditions. This lack of knowledge presents a significant obstacle to enhancing food security, nutritional outcomes, and ultimately, alleviating poverty among smallholder farmers in northern Uganda.

Despite a reported increase in sorghum production over the past decade, overall productivity remains concerningly low. Furthermore, a comprehensive assessment of the technical efficiency of sorghum production within abundant rain-fed cropland systems has not been adequately conducted.

This study aims to address this critical knowledge gap by investigating the comparative performance of various sorghum varieties, including both hybrid and open-pollinated cultivars, within the context of rain-fed croplands in the northwest savanna grassland agro-ecological zone of northern Uganda. By evaluating the performance of different sorghum breeds under these specific environmental conditions, this research will generate valuable insights for optimizing sorghum production strategies and fostering improved food security for smallholder farmers within the region.

1.3 Objectives of the Study

1.3.1 Major Objective

To assess the effects of rainfed cropland on sorghum productivity in Oyam and Lira Districts of northern Uganda

1.3.2 Specific Objectives

a. To characterize sorghum productivity in rain-fed cropland in Oyam and Lira districts
b. To determine the level of production of sorghum among smallholder farmers in rainfed cropland in Oyam and Lira Districts
c. To determine the productive efficiency of rain-fed cropland sorghum among smallholder farmers in Oyam and Lira District.

1.3 Research questions.

a. What are the characteristics of increased sorghum productivity in rain-fed cropland in Oyam and Lira Districts?
b. What are the levels of sorghum production in the two districts?
c. What are the levels of efficiency of sorghum productivity in Oyam and Lira Districts?

1.4 Scope of the Study

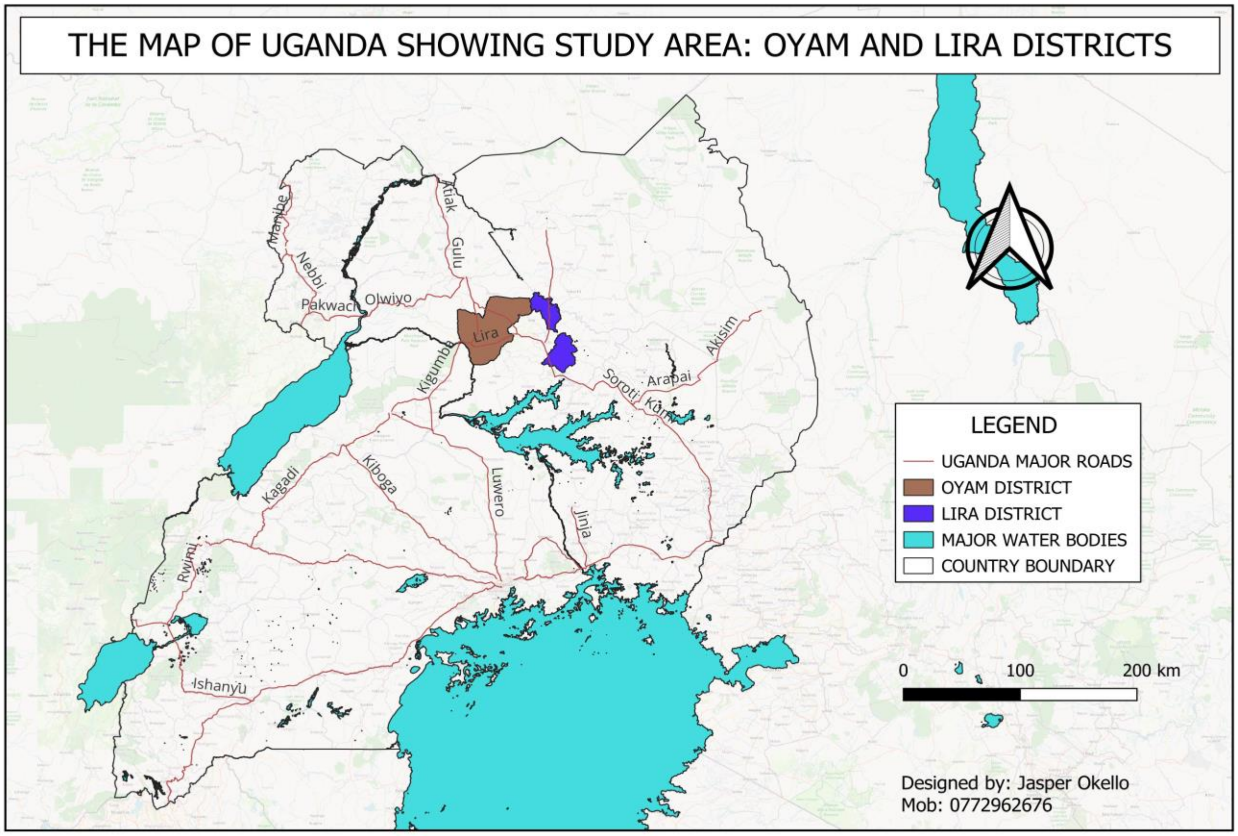


Figure 1: Map of Uganda locating Study Area

Geographical Scope: The study was geographically restricted to northern Uganda's northwest savanna grassland agroecological zone. Data collection was specifically conducted within the Oyam and Lira Districts, which are representative of this ecological zone. This region possesses a microclimate ideally suited to produce sorghum, a crucial staple food crop that underpins regional food security.

Technical Scope: This research investigates the comparative performance of various sorghum cultivars within rain-fed agroecosystems of northern Uganda's northwest savanna grasslands. The study employs a multifaceted approach encompassing the following key aspects:

Sorghum Cultivar Characterization and Production Assessment: The study identifies and characterizes distinct sorghum cultivars cultivated within the target agroecological zone. Subsequently, it assesses their production levels under rain-fed conditions, evaluating the impact of this specific cropping system on sorghum productivity across two consecutive growing seasons (Season B 2020 and Season B 2021).

Technical Efficiency Estimation: To quantify the technical efficiency of sorghum production within the two selected districts, the study utilizes Cobb-Douglas production function analysis. This established econometric technique estimates the production frontier, representing the maximum attainable output given a specific set of inputs. By incorporating data on intermediate inputs and production factors, the Cobb-Douglas analysis enables the measurement of technical efficiency, revealing potential deviations from this optimal production frontier.

1.6 Significance of the Study

This research addresses a critical knowledge gap in rainfed sorghum production within semi-arid, tropical Africa. By investigating the comparative performance of various sorghum cultivars under these specific conditions, the study directly contributes to the understanding of factors influencing food security in the region. The findings hold significant value for smallholder farmers, who primarily cultivate sorghum as their staple food and income source.

The study offers valuable insights into the impact of rainfed croplands on sorghum productivity across different production stages. This information empowers farmers to identify cost-effective production processes suited to their environment, ultimately leading to more sustainable and efficient sorghum cultivation practices.

This research contributes to existing knowledge on sorghum production by:

- **Assessing Economic Potential:** By analyzing field data, the study provides crucial evidence for stakeholders at various levels (international, regional, national, and local decision-makers). This evidence can inform policy and program development focused on improving technical efficiency in sorghum production for different cultivars.

- **Guiding Strategic Interventions:** Policymakers, ecologists, agriculturists, and development practitioners can leverage the findings to select, disseminate, and promote viable sorghum varieties best suited to the northwest savanna grassland agroecological zone. This targeted approach can significantly enhance food security in the region.

This study contributes to a deeper scientific understanding of the challenges and opportunities associated with sorghum production in rain-fed croplands. By analyzing the relationship between inputs and outputs, the research sheds light on the level of technical efficiency achievable within this specific microclimate. This knowledge base strengthens research efforts aimed at optimizing production strategies and improving food security in the long run.

1.7 Justification of the Study

Rainfed croplands constitute a vital agricultural system, underpinning food security and nutritional well-being for a substantial portion of the global population, particularly within Sub-Saharan Africa (Biradar et al., 2008). These lands are the mainstay of subsistence farmers, estimated to contribute to roughly 60% of the world's food needs (Biradar et al., 2008). However, the effectiveness of this agricultural practice is increasingly challenged by a confluence of factors, including rising human population pressure, accelerated urbanization, and industrialization (Biradar et al., 2008). These factors exacerbate climate change, manifesting as increased heat waves, erratic rainfall patterns, and soil erosion, posing a significant threat to the livelihoods of smallholder farmers.

While extensive research has explored rain-fed croplands, a critical knowledge gap persists regarding the precise effects of practices employed within these systems on sorghum productivity. This study aims to bridge this gap by investigating the relationship between rain-fed agricultural practices and their impact on sorghum yield within the context of northern Uganda.

The findings of this research make valuable contributions on both an academic and practical level. By elucidating the effects of rain-fed agricultural practices on sorghum production, the study will contribute to a deeper understanding of management strategies for optimizing sorghum output in these specific ecological zones. This knowledge base can inform the development of targeted interventions aimed at enhancing food security and improving the livelihoods of smallholder farmers within the region.

Furthermore, the research aligns with Uganda's National Development Plan III (2020/21 – 2025/26), potentially supporting objectives related to increased agricultural production and improved post-harvest practices (Government of Uganda, 2020). Additionally, the findings can contribute to achieving the Sustainable Development Goals (SDGs) 1, 2, and 3, which focus on poverty reduction, zero hunger, and ensuring healthy lives and well-being (United Nations, 2015).

In essence, this study aspires to equip ecologists, research institutions, agricultural development organizations, and policymakers with valuable insights. The data and knowledge generated can empower these stakeholders to develop effective strategies for managing rain-fed croplands and fostering increased sorghum productivity. Ultimately, this can lead to a more sustainable agricultural system, contributing to enhanced food security, poverty reduction, and improved well-being for smallholder farmers and local communities in the long run.

1.8 Key operational terms

Agro-ecological zone – refers to the geographical areas exhibiting similar climatic conditions that determine their ability to support rainfed sorghum production.

Hydroclimatic – these are varied physical factors (such as temperature, pH, density, turbidity) and often associated chemical factors (such as the concentration of certain ions) that characterize a particular soil biodiversity that supports sorghum production and productivity.

Rainfed agriculture – a farming system that relies on rainfall for water. It provides much of the sorghum consumed by poor communities in Oyam and Lira and other parts of developing countries.

Rainfed Cropland – Land used for sorghum crop growing and only relies on rainfall for water.

Sorghum production **-** the amount of sorghum produced in a given calendar year, including both the quantities of the sorghum sold in the market and the quantities of sorghum consumed or used by the producers.

Sorghum productivity - Refers to the measurement of sorghum ratio of output to a volume measure of input use.

Ecological zone - an area with broad yet relatively homogeneous natural vegetation formations, similar (not necessarily identical) in sorghum physiognomy

Technical efficiency - refers to identifying the share of sorghum productivity growth resulting from efficiency changes through the measurement of the distance between observed productivity and theoretical, optimal, or average productivity.

1.9 Theoretical Framework for sorghum productivity in rainfed cropland

This research explores the factors influencing sorghum productivity among smallholder farmers within the context of rain-fed croplands in northern Uganda. The theoretical framework integrates concepts from agricultural economics and production efficiency analysis to provide a robust foundation for the investigation.

Rainfed croplands constitute a vital component of agricultural systems in Sub-Saharan Africa, serving as the primary source of food security for a significant portion of the smallholder farming population (Biradar et al., 2008). However, these regions are particularly vulnerable to climate change and water scarcity, posing a significant threat to agricultural productivity and overall food security (FAO, 2017).

Sorghum, a drought-tolerant cereal, serves as a critical staple food in many developing countries, including Uganda (Altieri et al., 2008). In response to the challenges faced by rainfed agriculture, breeding programs have developed improved sorghum varieties with enhanced yield potential, particularly under drought conditions (Government of Uganda, 2020). Understanding the factors that influence the adoption of these new varieties by smallholder farmers is crucial for maximizing their impact on sorghum productivity.

Prior research in agricultural economics emphasizes the importance of understanding the characteristics of smallholder farmers that influence their adoption of new technologies (CIMMYT, 2023). This knowledge can be leveraged to develop targeted interventions and extension programs that promote the widespread adoption of improved sorghum varieties and enhance overall production efficiency (Feder & Reardon, 2011).

The production efficiency employed in stochastic frontier analysis, a well-established econometric technique, assesses the technical efficiency of sorghum production within the target population (Aigner et al., 1977; Meeusen & van den Broeck, 1977). This approach estimates a production function that explicitly incorporates a term for technical inefficiency alongside traditional factors influencing sorghum yield (Battese & Coelli, 1995). By analyzing this inefficiency component, the research can identify areas for improvement within the production system and optimize resource allocation for enhanced productivity.

By analyzing the interplay between rain-fed cropland practices, farmer characteristics, and the adoption of new sorghum varieties, this research aims to identify key determinants of sorghum productivity within the study region. The findings are anticipated to contribute to the development of targeted interventions and extension programs that promote efficient production practices and enhanced food security for smallholder farmers in northern Uganda.

1.10. Theoretical Model of the research

This section presents the theoretical model underpinning the investigation into the effects of rain-fed cropland practices on sorghum productivity among smallholder farmers within Oyam and Lira Districts, Uganda. The model serves as a visual representation of the hypothesized relationships between the key variables of interest.

Independent Variable:

Rainfed Cropland Practices: This variable encompasses the specific management strategies employed within rain-fed agricultural systems. It may include factors such as tillage techniques, planting density, water management approaches, and fertilizer application rates.

Dependent Variable:

Sorghum Productivity: This variable represents the total output of sorghum grain harvested per unit of land area cultivated under rain-fed conditions. It will be quantified in kilograms per hectare (kg/ha).

Control Variables:

The model acknowledges the potential influence of additional factors beyond rain-fed cropland practices on sorghum productivity. These factors may include, but are not limited to:

Sorghum Variety: The specific type of sorghum cultivar planted can significantly impact yield potential due to inherent genetic variations.

Farmer Characteristics: The knowledge, skills, and resource availability of smallholder farmers can influence their production decisions and ultimately, sorghum yield outcomes.

Climate Variables: Rainfall patterns and temperature fluctuations can significantly affect sorghum growth and development, potentially influencing overall productivity.

While these additional factors are not explicitly included as independent variables in the initial model, they will be recognized and potentially incorporated during the data analysis stage, particularly if the initial results suggest their relevance. This comprehensive approach ensures a robust investigation that accounts for the multifaceted nature of sorghum production in rain-fed croplands.

1.11 Conceptual frameworks of the study

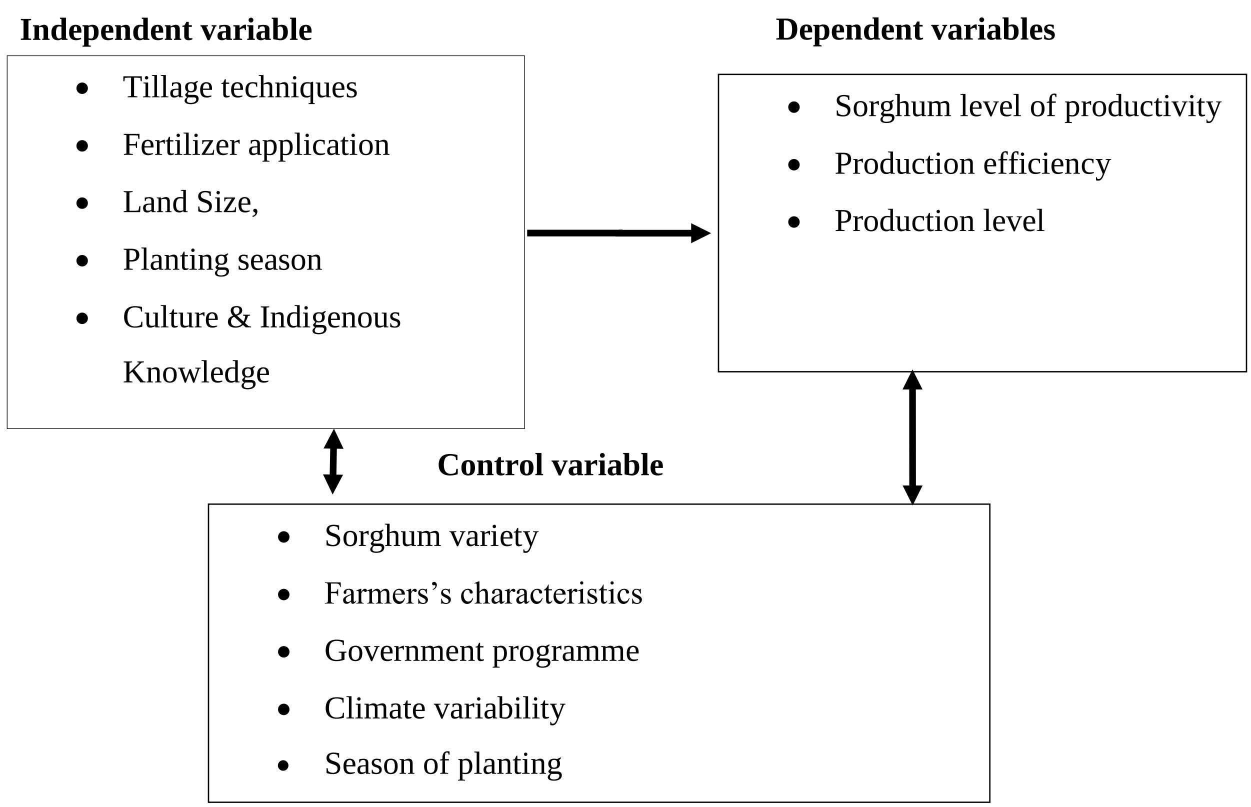


Figure 1:1 Conceptual Framework

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This critical literature review meticulously evaluates the current understanding of factors influencing sorghum productivity in these specific environments. The primary focus is on the effects of rain-fed cropland practices on sorghum yield achieved by smallholder farmers in northern Uganda. The chapter is structured as follows: Characterization and Categories of Sorghum Productivity; Production Functions for Sorghum Productivity; Measuring Technical Efficiency in Rainfed Croplands; and Conclusion. By comprehensively analyzing the existing body of knowledge, this literature review establishes a robust foundation for the investigation into the effects of rain-fed cropland practices on sorghum productivity in northern Uganda.

2.1 Characteristics of sorghum productivity in rain-fed cropland

Sorghum bicolor (L.) Moench stands out as a crucial cereal crop due to its exceptional tolerance to drought conditions(Jardim et al., 2020). Unlike many other cereals, sorghum thrives in arid and semi-arid environments with limited rainfall (400-600 mm annually) (House et al., 2003). This characteristic adaptability makes it a cornerstone food source in regions with unreliable or scarce precipitation, particularly across drought-prone areas of Africa and Asia (Kaliba et al., 2018).

Sorghum exhibits remarkable adaptability across diverse agroecological zones. Its unique physiological and phenological traits enable it to flourish in a wide range of environments, including West Nile farmlands, north-central grass-bush farmlands, and even high-altitude areas exceeding 2300 meters (Sserumaga et al., 2021). This adaptability is further bolstered by a rich genetic pool. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in

India curates a vast collection exceeding 36,000 sorghum germplasm accessions, facilitating the development of cultivars specifically tailored to distinct environmental conditions (ICRISAT, 2023).

Sorghum productivity exhibits a strong correlation with the surrounding agroecological zone. Ideally, sorghum thrives in environments with a mean annual temperature of around 20°C and annual precipitation of approximately 1200 mm, distributed either unimodally or bimodally (Cattani et al., 2018). Within the Ugandan context, sorghum production flourishes under two primary farming systems: the annual cropping and cattle northern system, characterized by bimodal rainfall patterns and annual precipitation ranging from 900 to 1200 mm (Cattani et al., 2018).

Sorghum production can leverage either indigenous varieties or introduced species. Strategic selection and evaluation of germplasm are crucial for optimizing production within different agroecological zones (Kaliba et al., 2018). Breeding programs target various characteristics to enhance productivity and resilience, including Early maturing varieties like Dinkmash and Seredo are particularly valuable in moisture-stressed areas where a shorter growing season is advantageous (Tenywa et al., 2018). Improved varieties like SESO 1 and SESO 2 are specifically bred for high yields, making them attractive options for farmers seeking to maximize production (Andiku et al., 2020). Drought tolerance remains a key characteristic sought after in many regions. Varieties like EPU-RIPURI and SEKEDO excel in dry conditions (Singh et al., 2017). Resistance to pests like straw and diseases like midge damage is crucial for minimizing crop losses. Varieties like GA 10/010 and SRS 34708/2 are bred with such resistance in mind (Andiku et al., 2020).

Sorghum is a vigorous grass that varies between 0–6 m in height. It has deep and spread roots with a solid stem. Leaves are long (0.3-1.4 m) and wide (1-13 cm), with flat or wavy margins. The flower is a panicle, usually erect, but sometimes recurved to form a gooseneck.

Sorghum is genetically diverse. The world sorghum germplasms are deposited at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT, Patancheru) in India. ICRISAT holds about 36,000 germplasm accessions of this crop. The varieties are distinguished based on morphological traits, differences in isoenzyme patterns, and DNA polymorphism.

Sorghum productivity is best in the agroecological zone of an experienced mean annual temperature of about twenty degrees Celsius with annual precipitation of about 1200mm received unmodal and sometimes bimodal, especially in temperate zones such as France. In Uganda sorghum production is grown mainly in two farming systems in the agroecological zone, these are the annual cropping and cattle northern system which is characterized by bimodal rainfall seasonality, annual precipitation potential of 900 – 1200 mm of rain, temperature ranging between 28 – 33 degree Celsius(Cattani et al., 2018). Sorghum's unique phenology and physiology adapt and grow many agroecological zones, namely: West Nile farmland, Northwestern farmland- wooded savannah, North Moist farmlands, Northeastern-central grass-bush- farmland, Northeastern Semi-arid short grass plain, Central Wooded savannah, Southern and Eastern Lake Kyoga basin and Western Mid altitude farmland and Semiliki flats(Sserumaga et al., 2021). However, the author has not provided the existing sorghum characteristics based on either the production mode or phenotype of sorghum grown.

According to Kaliba et al., (2018), Sorghum grows well from 0 – 45-degree North and South of the Equator. It is drought resistant and a crop of far excellence for arid, semi-arid, and humid regions and areas of unreliable rainfall. It is noted as a staple food in the drier parts of Africa, Asia, India, and China with different sorghum characteristics. Sorghum production is based on either indigenous varieties or exotic species which anchor on indigenous or exotic germplasm acquisition and evaluation in different agroecological zones globally. In moisture-stressed areas sorghum growing period is short and therefore the genotype should be fast maturing but not available in most countries such as Ethiopia, India, and Burkina Faso (Adugna, 2004a) including Uganda, resulting from low levels of readily available technology.

According to Tenywa et al., (2018), Early maturing varieties such as Dinkmash, Seredo, Kobomash 76, Melkamask 79, and 76T1#23 are hybrids produced in different research stations in Ethiopia. Hybridization and population improvement of Sorghum Seed is based on the selection of parents and improvement is carried out to identify a superior genotype that tolerates various stress factors in moisture stress area (Aisen and Muts, 1987; Andiku et al., 2020; Kaliba et al., 2018). Hybridization of sorghum is hand emasculation with less information on the condition at which it operates. Other sorghum varieties (Adugna, 2004b) such as MEKO-1, Teshale, Birhan, and Yeju in Ethiopia were selected from exotic germplasm and recently released for commercial production. The commercialization of these varieties is less known under what condition commercial production would take place much as in the Ethiopian agro-ecological zone at which exotic germplasm is characterized by low levels of humid, high temperatures with an average annual rainfall of 400mm{Citation}.

In Burkina Faso, according to(Ebiyau et al., 2019) varieties of Sorghum Bicolor- L. Moench have low proanthocyanins containing sorghum. Some of these varieties had a relatively high content (>0.4% w/w) of phenolic compounds such as 3-dioxyanthocyanidins and Flavan-4-0ls which are of particular interest for food, colorant, and pharmaceutical industries. Independent of grain germination, all sorghum varieties are among the most prominent natural resources of antioxidants due essentially to their phenolic (Aisen and Muts, 1987). Sorghum varieties are highly polymorph in their expression of phenolic biosynthesizing enzymes (Goche et al., 2020). For example, phenylalanine ammonia-lyase and phenolic modifying enzymes.

In Uganda, sorghum productivity is characterized based on the level of yield, duration of maturity, and how a particular spice responds to different stresses (Ebiyau et al., 2019; Tenywa et al., 2018) and stress (Mehmood et al., 2008). Indigenous and traditional varieties such as *Abir*, *godoo*, Edeidei, and Ekirkir are considered as fast maturing but with low yield(Dicko et al., 2005) however no information is available on the level of water intake that contributes to fast maturing though with low yield. Old varieties such as EPURIPURI are SEKEDO are early maturing, drought tolerant, and high yielding with a negative trait of being highly susceptible to bird damage and high tannin levels, susceptible to midge damage (Singh et al., 2017). According to (Andiku et al., 2020) Improved varieties such as SESO 1, SESO 2, SESO 3, GA 10/010, SRS 3008/1, SRS34708/2, SRS 1108/3, GE 23/1. These varieties have high yielding, drought, and striga tolerance, mid-early maturing character and it well appreciated because of economic and commercial relevance among farmers (Ogbaga et al., 2016).

In conclusion, while this section provides a comprehensive overview of sorghum characteristics, further research endeavors are necessary to explore areas such as the specific water intake patterns of fast-maturing, low-yield varieties. The economic viability of commercial production for exotic germplasm varieties under specific conditions. By continuing to investigate these and other aspects of sorghum, researchers, and breeders can develop even more productive and resilient sorghum varieties suitable for diverse rain-fed croplands.

2.2 Production level of sorghum under rainfed cropland

Sorghum (Sorghum bicolor L. Moench) is the fifth most important cereal crop in the world after wheat (Triticum aestivum L), rice (Oryza sativa L.), maize (Zea mays L.), and barley (Hordeum vulgare L.)(Philipo et al., 2021). The center of origin of sorghum is believed to be near Lake Chad in Africa(Prasad and Staggenborg, 2010). This crop was first domesticated about 7000 BP in West Africa. Thereafter, it reached India by about 1500 BC and China by 900 AD(Reddy et al., 2010). Cultivated sorghum was first introduced to America about 100 years ago.

Worldwide, grain sorghum is produced in 43.8 million ha, with an estimated total production in 2007 of 64.6 million tons(Amelework et al., 2016). Major sorghum production areas include the great plains of North America, Sub-Saharan Africa, northeast China, and the Deccan plateau of central India (Ogeto et al., 2013). Important sorghum-producing countries in the world are India, Nigeria, Sudan, United States, Niger, and Mexico. Many of the tropical sorghums are short-day plants(Kenyatta University, P.O. Box 43844- 00100, Nairobi, Kenya et al., 2013) and their response to day length is an important adaptation. However, the selection of early-maturing varieties and hybridization helped its spread in the USA. (Mundia et al., 2019) the United States of America is the world's largest exporter of grain sorghum, and its share in world trade is about 70%. Important sorghum-producing states in the United States include Kansas, Texas, Oklahoma, Nebraska, New Mexico, and Missouri. Kansas is the largest producer of grain sorghum in the United States contributing 40% of its total production

Today, sorghum cultivation encompasses over 43.8 million hectares worldwide, with a staggering total production exceeding 64.6 million tons in 2007 (Amelework et al., 2016). Major production zones include the North American Great Plains, Sub-Saharan Africa, northeast China, and the Deccan Plateau of India (Ogeto et al., 2013). Leading producers include India, Nigeria, Sudan, the United States, Niger, and Mexico (Amelework et al., 2016).

Despite its well-established drought tolerance, sorghum production in rainfed croplands often falls short of its potential yield. Studies conducted in Sub-Saharan Africa reveal that sorghum production levels can be two to five times lower than their achievable potential (Thao et al., 2015). This yield gap contributes to a cascade of challenges, including Inefficient production practices that can exert undue pressure on natural resources such as water and soil fertility, hindering overall sustainability (Antonini & Argilés-Bosch, 2017). Low yields translate to reduced food availability, potentially exacerbating poverty and malnutrition (Woodhouse et al., 2000).

The success of sorghum cultivation in rainfed croplands is heavily influenced by climatic conditions during the growing season. Studies by Gemeyida et al. (2019) highlight the significant impact of factors like rainfall patterns, temperature, and evapotranspiration on sorghum development. Even short periods of drought can significantly affect yield (Cattani et al., 2018). While the studies don't explicitly mention production technologies, it is well-established that the adoption of appropriate tools and practices significantly influences sorghum growth, yield volume, and overall output. These considerations include planting time, sowing techniques, and proper management practices throughout the various growth stages (Rost et al., 2009).

A study conducted in Kenya (Kenyatta University et al., 2013) underscores the suitability of sorghum for drought-prone marginal areas due to its unique characteristics: such as the extensive Root System which allows sorghum to access moisture stored deeper within the soil profile; the waxy Leaves reduces water loss through transpiration is a key adaptation to drought conditions and the drought-induced growth dormancy which is the remarkable adaptation allows the plant to survive periods of severe water scarcity.

Despite its suitability, sorghum production in these regions often remains low, with farmers facing persistent yield limitations(Jardim et al., 2020). Sorghum production faces a multitude of challenges beyond rain-fed conditions, including frequent and prolonged droughts in both local and global dry spells pose a significant threat to production (FAO, 2017). Climate Change such as the rising temperatures and increasingly erratic precipitation patterns pose a growing threat to sorghum production systems(A., et al., 2020). Population growth and economic development increase demand for food security can strain production systems(Degefa et al., 2023). Resource scarcity limits access to water, fertilizer, and other essential inputs can hinder yields(Khoddami et al., 2023).

FAO (2017) noted that Sorghum production level just like cereal crops continues to face challenges in production due to frequent and prolonged dry spells and sometimes drought both locally and internationally. Prolonged dry spells and drought are the most prevalent abiotic stresses affecting plant growth, survival, and productivity in the world. It is reported that the effect of drought is more pronounced in the Semi-Arid Tropics (SAT), where rainfall is generally low, erratic, and poorly distributed. The drastic effect of drought can be reduced by growing drought-tolerant crops such as sorghum. Sorghum is the world's fifth most important cereal, in terms of both production and areas planted. It is primarily grown in areas experiencing low rainfall. Most of these areas are unsuitable to produce other grains unless irrigation is available (Prasad and Staggenborg, 2010). Sorghum is unique in its ability to be produced under a wide array of harsh environmental conditions where other crops grow or yield poorly (Alemu, 2016). It is grown with limited water resources and usually with low fertilizer supply or other inputs by a multitude of smallholder farmers globally.

Sorghum stands out as a cornerstone for sustainable agricultural practices(Kathuli et al., 2023). This remarkable crop thrives in harsh environments(Degefa et al., 2023; Philipo et al., 2021), particularly under water-limited conditions, making it a valuable option for regions facing drought concerns. Furthermore, its cultivation alongside legumes offers a synergistic benefit. Legumes fix nitrogen in the soil, enhancing overall fertility(Kathuli et al., 2023), while co-composting sorghum with legumes creates a pathway towards the production of high-protein food sources. Beyond its environmental benefits, sorghum offers a significant health advantage. Its prolamin storage proteins differ substantially from those found in wheat and related grains, making sorghum a naturally gluten-free option for individuals with celiac disease or gluten sensitivity(A., et al., 2020). However, there is a key nutritional consideration: sorghum proteins are all deficient in the essential amino acid lysine(Pereira, 2023). Fortunately, strategies exist to improve sorghum's protein quality. Traditional lactic fermentation, a simple and well-established technology, has been demonstrated to effectively enhance protein quality(Khalid et al., 2022). Additionally, research in conventional breeding and genetic engineering holds promise for further improvement in sorghum's protein profile. While commercial production of sorghum protein as a standalone product is not yet established, a potential source already exists(Jardim et al., 2020). Spent grain, a byproduct of sorghum brewing and bioethanol production, could be repurposed as a valuable protein source for human consumption(Khoddami et al., 2023). This approach could unlock the full potential of sorghum as a sustainable and nutritious food source.

Sorghum production levels are affected by several factors in sorghum production areas globally. These factors have significant impact on sorghum production and productivity such as climate change, population growth and economic development, non-food demand, agricultural inputs, demand for other crops, agricultural resources scarcity, biodiversity, cultural influence, price, and armed conflict (Gemeyida et al., 2019; Mundia et al., 2019; Ogeto et al., 2013b, 2013b) according to revealed that multiple factors simultaneously affect sorghum production; the effect of each factor is greatly influenced by the magnitude and certainty of one or more other factors(Biradar et al., 2009); and, factors differ in relevance and degree about geography. Therefore, improved agricultural inputs, population growth/economic development, and climate change have a substantial influence on sorghum production (Ogeto et al., 2013b).

In conclusion, Sorghum's exceptional drought tolerance makes it a vital crop in rainfed croplands. However, several factors contribute to yield gaps, including climatic variability, resource limitations, and technological constraints. Addressing these challenges through research, improved practices, and targeted interventions is crucial for enhancing sorghum production and ensuring food security in vulnerable regions.

2.3 Productivity efficiency of rain-fed cropland sorghum among smallholder farmers

The technical efficiency of sorghum production and its determinants was conducted by Zalkuwi et al., (2015) using the stochastic frontier production function which incorporates a model of inefficiency effects. According to (FAO, 2017; Haile, 2018; and Lemma et al., 2020a) farm level data were collected from a sample of 100 sorghum farmers in the Hong Local Government area of Adamawa state using structured questionnaires. The empirical result shows that land, seed, and fertilizer were the major factors that influenced changes in sorghum output. However, these factors did not hang on rainfed crops but defined farm-specific variables such as education, extension contact, and household size were found to have significant effects on the technical inefficiency among the sorghum producers.

Chepng'etich et al., (2014) further in his study indicated that the likelihood estimates for parameters of the Cobb-Doughlas inefficiencies model for sorghum farmers hinged on the level of education, membership of association a farmer actively engaged with, the level of extension contacts, the size of the household and gender. These findings further show a decrease in inefficiencies with education level which is in line with Chimai and Ag, (2011) study.

According to Davila-Gomez et al., (2011), productivity efficiency is determined quality of seeds, application of chemical fertilizers such as DAP and UREA, and use of appropriate farm tools such as oxen(Jardim et al., 2020; Kazungu et al., 2023; Pereira, 2023). However author did not consider measurement error, or exogenous factors such as the amount of rain received during planting, germinating, and growing periods. Lemma et al., (2020b) use of DAP fertilizer enhances vegetative growth which is most likely to increase efficiency in the production of sorghum due to an increase in soil nutrients in the soil, which leads to improved nutrient uptake and increased photosynthesis products that in turn increases the quantitative characteristics of the crop production.

According to (FAO, 2017; the Federal College of Education and Wakili, 2012; Haile, 2018) crop production and productivity have increased in Sub Sharan Africa and Eastern and Northern Asia due to the expansion of the land. However, in rural semi-arid tropics, sub-humid agroecological zones in Sub Saharan Africa and Asia suffer setbacks in crop productivity (Zalkuwi et al., 2015b) especially yield to meet the needs of the growing population due to poverty, degradation of natural resources, and climatic variability(Chepng'etich et al., 2015). Crop yield increase is efficient and effective with the engagement of women and women in production (Chepng'etich et al., 2014). The equal participation of men and women contributes to the attainment of zero hunger, reduces malnutrition of children, promotes equal access to education, and promotes sustainable integrated management of natural resources due to the available labor force in rural semi-arid tropic and sub-humid agro-ecological zones in Sub Sharan Africa (Tadesse et al., 2013)

The question of efficient production cost is the correlation between factors of production(Lemma et al., 2020a) intermediate input and output relations (Federal College of Education and Wakili, 2012; Lemma et al., 2020a) fronted by Cobb-Douglas Stochastic frontier production. The rural growing population in Sub-Saharan Africa and all other Semi-Arid Tropics requires effective and efficient utilization of available labor force, sustainable and timely management of land, and appropriate farm inputs to produce better crop yield(Bushara and Mohammed Abuagla, 2017)without compromising the future(Lagemann, 1977). Crop yield gap analysis in rainfed agriculture in Africa, Asia, and the Middle East varies from one country to another and agroecological zone to the next(Tadesse et al., 2013). These variations are wider in

Sub-Saharan Africa where there is a relatively high production of cereal crops especially (Woodhouse et al., 2000). Variation in the region is attributed to environmental fragility, drought, and land degradation (Huang et al., 2016) caused by human activities and exacerbated by biophysical factors (Nsubuga et al., 2014; Rost et al., 2009; Ssentongo et al., 2018) related issues. For smallholder farmers cultivating sorghum in rainfed croplands, achieving optimal yields depends heavily on efficient farm management practices, a concept known as technical efficiency (Alemu, 2016; Bushara & Mohammed Abuagla, 2017).

Technical inefficiency occurs when a given set of inputs, such as land, labor, and fertilizer, produces a lower output than what's achievable with the available technology. Extensive research has explored technical efficiency in sorghum production, highlighting its dependence on specific factors like time, location, and even the crop variety itself (Thao et al., 2015). Technical efficiency is measured by the relative distance between a particular farm's sorghum production and the production frontier. This frontier represents the maximum achievable output for a given set of inputs (Chepng'Etich, 2013). Studies like Zalkuwi et al. (2015) utilize stochastic frontier production functions to assess technical efficiency and the factors influencing it within the context of sorghum production.

Research has identified various factors that influence technical efficiency among smallholder sorghum producers as farm inputs (FAO, 2017) and Lemma et al. (2020a) highlight the significant contributions of land availability, seed quality, and fertilizer application to sorghum output. In addition, farmer Characteristics especially farmer's education level, frequency of extension service contact, and household size can also influence technical efficiency (Haile, 2018; Lemma et al., 2020a). Chepng'etich et al. (2014) found a correlation between higher education levels and lower inefficiency levels. Chepng'etich et al. (2014) and

Tadesse et al. (2013) suggest that ensuring the equal participation of men and women in sorghum production processes can lead to improved efficiency and ultimately, higher yields.

Productivity efficiency encompasses the optimal utilization of all resources to achieve desired outputs. Davila-Gomez et al. (2011) highlight factors like seed quality, fertilizer application, and the use of appropriate farm tools as crucial for achieving productivity efficiency. Lemma et al. (2020b) emphasize the role of DAP fertilizer in enhancing vegetative growth and nutrient uptake, ultimately leading to increased yield.

The studies acknowledge limitations inherent in efficiency studies, including measurement error which is the accuracy of data collection methods can influence the final results. The exogenous factors which are unforeseen factors like rainfall patterns during critical growth stages can significantly impact yield. However, analysis of crop yield gaps reveals significant variations across different regions and agroecological zones (Tadesse et al., 2013). Sub-Saharan Africa, a region with high sorghum production, experiences wider yield gaps compared to other regions (Woodhouse et al., 2000). These variations are often attributed to environmental factors like drought, land degradation, and inherent biophysical limitations (Huang et al., 2016; Nsubuga et al., 2014).

In conclusion, optimizing both technical and overall productivity efficiency is crucial for smallholder farmers to achieve sustainable sorghum production in rainfed croplands. By addressing factors like resource management, farmer education, and gender equity, significant strides can be made towards closing yield gaps and ensuring food security in vulnerable regions.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

This chapter presents a robust framework for investigating the effects of rainfed cropland management on sorghum productivity in Uganda's Oyam and Lira districts. It meticulously outlines the research design, encompassing the specific areas of inquiry, technical considerations, and the geographical scope. Subsequently, the chapter details a comprehensive data collection methodology, including sample size determination, rigorous techniques to ensure data quality, and data processing and management procedures. Establishing a clear research framework, a robust data collection methodology, and well-defined objectives, lays the foundation for a rigorous analysis of the relationship between rainfed croplands and sorghum productivity in the target regions.

3.1 Research Design

This study employs a descriptive research design to comprehensively investigate the characteristics of sorghum productivity and the technical efficiency achieved by smallholder farmers utilizing rainfed croplands. This approach aims to illuminate the current state of sorghum production within this context and describe the existing relationship between rainfed croplands and sorghum yields.

Data Collection Strategy

A mixed-methods approach was utilized to gather data pertinent to the research objectives. This strategy incorporates both quantitative and qualitative data collection techniques.

- **Quantitative Data Collection:** Quantitative data was collected from a representative sample of smallholder farmers, selected through a rigorous sampling method was detailed later. The farmers were asked to estimate and record their sorghum production over two planting and harvesting seasons. This data was collected alongside information on the inputs utilized in their production practices. Subsequent analysis focuses on assessing the technical and economic efficiency of these practices.
- **Qualitative Data Collection:** Qualitative data collection methods were employed to delve into the farmers' perspectives on agroclimatic conditions, particularly regarding precipitation and dry spells they have observed over time. To complement this experiential data, scientific precipitation data spanning the past three years was obtained from Makerere University. This combined approach establishes a robust factual baseline alongside valuable insights into the farmers' lived experiences and perceptions of these climatic factors.

By employing a mixed-methods approach, the study seeks to create a comprehensive understanding of the relationship between rainfed croplands and sorghum productivity in the target region. This comprehensive approach not only provides a quantitative picture of production efficiency but also illuminates the qualitative factors influencing sorghum production from the farmers' perspective.

3.2 Area of Study

Refer to the Figure 1 in Chapter 1., this investigation explores sorghum production within two districts situated in northern Uganda: Lira and Oyam. These districts reside within the northwest savanna grassland agroecological zone and were purposefully selected due to their established reputation for sorghum cultivation. Sorghum constitutes a critical agricultural crop in the region, serving as a cornerstone for food security, nutritional well-being, and household income generation for the local populace.

- **Geographical Context:** Lira and Oyam Districts, Northern Uganda
- **Proximity to Kampala:** Approximately 300km to 370km via Masindi-Karuma Road
- **Agroecological Zone:** Northwest savanna grassland
- **Selection Rationale:**
    - Prominence of sorghum production
    - Significance for regional food security, nutrition, and income generation
- **District Profiles:**
    - **Lira District:**
        - Total Area: 1330 square kilometers
        - Households: 89,170 (with 64% classified as smallholder farmers)
        - Administrative Divisions: 9 sub-counties and 4 divisions
    - **Oyam District:**
        - Total Area: 2,196 square kilometers
        - Households: 76,615 (with 91% classified as smallholder farmers)
        - Administrative Divisions: 12 sub-counties

3.3 Study Population

To ensure the generalizability of the research findings to the wider population of smallholder sorghum farmers, a multi-stage sampling approach will be employed within the northwest savanna grassland agroecological zone of Uganda's Lira and Oyam Districts. This methodology aligns perfectly with the study's descriptive and empirical nature, fostering the collection of data that accurately reflects the broader population characteristics.

Sampling Framework:

The sampling process was meticulously implemented in a series of well-defined stages:

1. **District Selection:** Lira and Oyam Districts were purposefully chosen due to their established reputation as prominent sorghum production centers.
2. **Sub-county Selection:** To achieve a representative sample of sorghum production within each district, two sub-counties were strategically selected based on verifiable data on sorghum production levels. This targeted approach ensures a focus on areas with demonstrably high sorghum production activity.
3. **Parish Selection:** Within each chosen sub-county, a random selection of four parishes was conducted. This randomization process guarantees an unbiased and representative sample of the farming communities residing within each sub-county.
4. **Smallholder Farmer Selection:** From each selected parish, a sample of smallholder farmers actively engaged in sorghum production was recruited. The systematic sampling method was employed to determine based on the availability of a comprehensive sampling frame for farmers within each parish. This ensures a statistically robust selection process, minimizing selection bias.

To further strengthen the data collection process and facilitate triangulation of findings, a purposive sample of 20 extension staff members was included in the study. These extension personnel possess invaluable technical expertise regarding sorghum production efficiency, offering crucial insights that complement the data gathered from smallholder farmers. Their inclusion fosters a more nuanced and comprehensive understanding of the factors influencing productivity within the target region.

By implementing this multi-stage sampling approach alongside data collection from extension staff, the study secures a representative sample and gathers a diversity of perspectives. This combined approach sheds light on the effects of rainfed cropland management practices on sorghum productivity in Lira and Oyam Districts, Uganda, with a level of robustness that strengthens the generalizability of the findings.

3.4 Sampling Procedures

This study adopts a probability-based sampling approach to select sub-counties, parishes, and ultimately, smallholder farmer participants within Lira and Oyam Districts, Uganda. This methodology ensures each element within the target population possesses a known and non-zero probability of being included in the final sample.

Balancing Randomness with Strategic Selection: While the overarching objective is to achieve a random sample, the study acknowledges the need for some strategic considerations to optimize representativeness and data collection efficiency.

District Selection: As outlined in Section 3.2 above, Lira and Oyam Districts were deliberately chosen due to their well-established reputation as leading sorghum producers. This targeted selection strengthens the study's focus on the most relevant geographical areas within the northwest savanna grassland agroecological zone.

Leveraging Established Local Networks: To facilitate the selection process and enhance its effectiveness, the study team collaborated with established local organizations:

- **District Farmer Associations and Cooperatives:** These organizations within each district were instrumental in providing comprehensive sample lists of parishes and smallholder farmers actively engaged in sorghum production.

- **Sample Frame Development:** The acquired list was meticulously consolidated into a single, robust sampling frame. This framework was the foundation for calculating the appropriate sample size for each study district, ensuring a statistically sound selection process.
- **Prioritizing Representativeness:**It is important to acknowledge that while all sub-counties within Lira and Oyam Districts exhibit high levels of sorghum production, the purposive selection of these districts underscores the significance of geographical location within the target agroecological zone. This strategic selection ensures the study focuses on a region demonstrably well-suited for sorghum cultivation, fostering the collection of data that accurately reflects the experiences and practices of relevant smallholder farmers.

By implementing a probability-based sampling approach with strategic adaptations, the study prioritizes the selection of a representative sample from the target population. This methodological rigor strengthens the generalizability of the research findings and allows for the confident drawing of conclusions applicable to the broader context of sorghum production within the northwest savanna grassland agroecological zone.

3.5 Sample Size Determination

This study employs a mixed-methods approach, incorporating both quantitative and qualitative data collection methods. Quantitative data was gathered from a representative sample of smallholder farmers in Lira and Oyam Districts, Uganda. To ensure the generalizability of the findings derived from this quantitative data, a statistically robust sample size was used to determine.

3.5.1 Quantitative Sample Size Calculation

A formula-based approach is utilized to calculate the appropriate sample size for the quantitative data collection component. This formula incorporates the following factors:

- **Confidence Level:** The desired confidence level, typically set at 95%, was established. This threshold reflects the probability that the sample results accurately represent the characteristics of the larger target population.

- **Margin of Error:** A tolerable margin of error was predefined. This value represents the maximum deviation from the population parameter that can be tolerated while ensuring the validity of the findings.

The following formula was used to determine the sample size of the study population:

$$n = \frac{1.96^2 \alpha^2}{E^2}$$

Where n is the population size, 1.96^2 is the level of confidence which is always 95%, α^2 is the standard deviation = 25, and E^2 is the Error Rate = 3.

Therefore, the population size considered in this study was 2,400 farmers growing sorghum, and the sample population was 266 respondents.

3.5.2 Qualitative Sample Size Justification

For the qualitative data collection component, a purposive sampling approach was employed. This approach strategically selects participants with characteristics relevant to the research objectives. Data saturation will guide the determination of the final sample size. Data saturation is achieved when no new significant information emerges from further interviews or focus groups. This iterative process ensures that the collected qualitative data comprehensively captures the relevant perspectives and experiences of the participants.

By implementing a statistically sound sampling approach for quantitative data collection and a data saturation-driven approach for qualitative data collection, the study strengthens the representativeness and informativeness of the sample drawn from the target population. This methodological rigor allows for the collection of high-quality data that can generate robust and generalizable findings.

3.6 Sampling Techniques

This section details the specific sampling techniques employed to select participants for both quantitative and qualitative data collection phases of the study.

3.6.1 Quantitative Data Collection: Systematic Random Sampling

To achieve a representative sample of smallholder farmers from the established sampling frame (Section 3.4), a systematic random sampling technique was implemented. This approach offers distinct advantages when dealing with large populations, as anticipated with smallholder farmers in Lira and Oyam Districts.

The systematic random sampling process was executed in the following steps:

1. **Numbering the Sampling Frame:** Each entry within the sampling frame (i.e., list of smallholder farmers) was assigned a unique identifier.
2. **Calculating the Sampling Interval:** The sampling interval was determined by dividing the total number of farmers in the frame by the desired sample size. This calculation establishes the frequency at which farmers were selected from the list.

3. **Selecting a Random Starting Point:** A random number generator was utilized to select a random starting point within the sampling frame. This ensures an unbiased selection process, free from preconceived notions.
4. **Systematic Selection:** Commencing from the randomly chosen starting point, every nth farmer on the list was included in the sample, where n represents the sampling interval. This systematic approach minimizes the potential for bias and guarantees a representative selection across the entire sampling frame.

3.6.2 Qualitative Data Collection: Purposive Sampling

For the selection of 20 extension staff, a purposive sampling technique was strategically employed. This targeted approach allows for the deliberate selection of participants possessing specific characteristics highly relevant to the research objectives. In this case, extension staff members with demonstrably strong technical expertise in sorghum and maize production within the northwest savanna grassland agroecological zone were purposefully recruited to participate in the qualitative data collection phase.

3.6.3 Justification for Purposive Sampling

The selection of extension staff leverages the following:

- **Technical Expertise:** Their in-depth knowledge of sorghum production practices specific to the target region provided valuable insights into the factors influencing productivity within the study area

- **Extension Service Experience:** Their understanding of the challenges and opportunities faced by smallholder farmers in the context of rainfed croplands enriched the qualitative data collection process by capturing the lived experiences and perspectives of the farming community.

By combining a systematic random sampling technique for quantitative data collection with purposive sampling for qualitative data collection, the study ensures a representative sample of smallholder farmers while also capturing the valuable perspectives of extension staff with specialized knowledge. This methodological approach fosters a comprehensive and nuanced understanding of the research topic, encompassing both the broader experiences of the farming community and the targeted expertise of extension personnel.

3.7 Data Collection Methods and Instruments

This section details the instruments and methodologies employed for data collection within this study. A multifaceted approach was utilized to gather both quantitative and qualitative data from various sources, ensuring a comprehensive understanding of the research topic.

3.7.1 Quantitative Data Collection

Instrument Development: A standardized survey tool with a closed-ended questionnaire specifically designed for smallholder farmer surveys serves as the primary tool for quantitative data collection. This instrument is meticulously crafted to assess the effects of rainfed cropland management practices on sorghum productivity among smallholder farmers within the target region.

Language Considerations: While English was the primary language used in the questionnaire to guarantee clarity and accurate representation of scientific terminology, the research team acknowledges potential limitations due to language barriers. To mitigate this, strategies were implemented to ensure clear communication with participants, potentially including translated versions of key terminology or the recruitment of bilingual research assistants.

Data Collector Training: A team of five research assistants per district was recruited and rigorously trained to ensure the quality and consistency of data collection. This training program encompasses the following key elements:

- In-depth familiarization with the designed questionnaire and its functionalities
- Development of effective communication and interviewing skills to optimize data collection.
- Strategies for overcoming potential language barriers and fostering clear participant understanding.

Pilot Testing: To ensure the effectiveness and robustness of the data collection instruments, a pilot test was conducted before commencing data collection within the study area. This pre-testing phase involves administering the questionnaire to a sample of 15 smallholder farmers from a location outside the target districts. The data gathered during this pilot test was instrumental in:

- Evaluating the clarity, comprehensiveness, and user-friendliness of the questionnaire
- Identifying any ambiguities or areas for improvement in the question wording
- Refining the data collection process to enhance efficiency and participant comprehension.

3.7.2 Qualitative Data Collection

Structured Interviews: structured interviews were conducted with a purposive sample of 20 extension staff members. This approach allows for in-depth exploration of the technical aspects of sorghum production practices specific to the northwest savanna grassland agroecological zone.

Interview Guide Development: A semi-structured interview guide was meticulously developed to ensure consistent coverage of key thematic areas while simultaneously allowing for flexibility to explore emerging themes or insights organically shared by the participants. This interview guide serves as a roadmap to guide the interview process while fostering a space for rich and nuanced discussion.

Focus Group Discussions: 10 smallholder farmer groups of an average population of 6 – 8 participations involve bringing together a small, purposefully selected group of individuals engaged in sorghum growing at least for the last 6 planting seasons to discuss characteristics, level of production, and production efficiency. This approach facilitates the exploration of smallholder farmers' dynamics and shared perspectives, offering valuable insights beyond those obtainable from individual interviews.

3.7.3 Data Management and Quality Control

Supervision and Monitoring: Data collection activities were undertaken by the research assistants under direct supervision and with the active participation of the researcher. This close oversight ensures consistent application of data collection protocols, timely identification of any potential issues, and the maintenance of data integrity throughout the process.

Data Cross-checking: A meticulous data cross-checking process was implemented throughout the data collection period. Collected data was systematically reviewed daily to guarantee accuracy, completeness, and consistency. This ongoing process minimizes the risk of errors and ensures the reliability of the final dataset.

By implementing a multifaceted data collection approach that integrates standardized quantitative instruments with in-depth qualitative methods, coupled with rigorous training, pre-testing, and data management procedures, the study strives to gather high-quality data that comprehensively address the research objectives. This methodological approach fosters a well-rounded understanding of the effects of rainfed croplands on sorghum productivity in the target region, encompassing both the quantitative realities experienced by smallholder farmers and the qualitative insights gleaned from the expertise of extension staff members.

3.8 Quality Control Methods

This section elaborates on the meticulous measures undertaken to guarantee the quality of the data collected throughout the study.

Instrument Development and Refinement: Before data collection, the research instruments (questionnaire and interview guide) underwent a rigorous development and refinement process. This process involved:

- **Content Validity:** Experts in the field of sorghum production and survey methodology were consulted to ensure the instruments comprehensively capture the intended information.
- **Internal Consistency:** The instruments were evaluated to ensure the various components align seamlessly and the questions effectively measure the target constructs.

Data Collection Planning and Management: A comprehensive data collection plan was established, outlining a realistic timeframe for data-gathering activities. This plan considered:

- **Logistical Considerations:** The plan addressed logistical factors such as transportation, participant recruitment strategies, and scheduling to minimize disruptions and optimize data collection efficiency.
- **Seasonal Variations:** The potential influence of seasonal variations on participant responses was acknowledged and addressed within the data collection timeframe. By adhering to this well-defined plan, the study aims to minimize disruptions and safeguard the reliability of the collected information.
- **Data Entry and Management:** A robust data entry and management strategy was implemented to ensure data accuracy and integrity. This strategy encompassed the following elements:

- **Data Entry Software:** Data collected from the quantitative instruments (questionnaires) was meticulously entered into a reputable statistical software SPSS. This software offers functionalities to minimize data entry errors and streamline data organization.
- **Double-Entry Verification:** To further enhance data accuracy, a double-entry verification process was implemented. This involves having two separate researchers independently enter a subset of the collected data. Any discrepancies could then be identified and addressed promptly, minimizing the risk of errors persisting within the final dataset.
- **Data Cleaning and Coding:** Once the data entry process was complete, the data underwent a thorough cleaning and coding phase. This stage involves meticulously reviewing the data for inconsistencies, missing values, and outliers. Any identified issues were systematically addressed using established data-cleaning techniques to ensure the data completeness, accuracy, and appropriate coding for subsequent analysis.

By implementing these rigorous data quality control measures, the study strives to minimize errors and inconsistencies within the collected data. This meticulous approach fosters a high level of confidence in the validity and reliability of the findings, ultimately strengthening the overall research endeavor.

3.9 Data Management and Processing

Following the data collection phase, the meticulously compiled data underwent a comprehensive processing and analysis stage to extract meaningful insights and illuminate the relationships between variables of interest.

- **Data Organization and Exploration:** Utilizing the functionalities of the SPSS statistical software, the data was systematically organized and categorized into a logical format that aligns with the research objectives. This structured organization facilitates efficient data exploration and analysis. Descriptive statistics were employed to provide a foundational understanding of the data's central tendencies, variability, and distribution.

- **Data Cleaning and Coding (Continued):** During this phase, any remaining data inconsistencies, missing values, or outliers were addressed using established data cleaning techniques. The data was also re-coded, to transform categorical variables into numerical representations suitable for statistical analysis.

- **Data Analysis:** A diverse range of statistical analysis techniques examined the processed data. The specific methods chosen was contingent upon the nature of the data, the research objectives, and the results of the initial exploratory analysis. Potential techniques may include:

    - **Correlation Analysis:** To identify potential relationships between variables.
    - **Regression Analysis:** To quantify the strength and direction of these relationships, particularly focusing on the effects of rainfed cropland management practices on sorghum productivity.

- **Data Visualization:** To effectively communicate the research findings and illuminate patterns within the data, compelling data visualization techniques were employed. Charts, graphs, and other visual representations were strategically incorporated to present complex data in a readily understandable format, fostering clear communication of the research outcomes.

By meticulously processing and analyzing the collected data, the study aims to transform raw information into valuable knowledge. This comprehensive approach allows for the identification of trends, relationships, and significant effects influencing sorghum productivity within the context of rainfed croplands in Lira and Oyam.

3.10 Data Analysis

This section details the comprehensive data analysis strategies that was implemented to extract meaningful insights from the collected data and address the research objectives.

Statistical Software and Techniques: A reputable statistical software program, such as SPSS, was utilized to facilitate data analysis. The specific techniques employed meticulously chosen based on the nature of the data, the research questions, and the initial exploratory analysis.

Descriptive Statistics: Descriptive statistics serve as the foundation for data analysis. These techniques provided a clear understanding of the central tendencies, variability, and distribution of the data collected from both quantitative and qualitative sources. This initial analysis will establish a baseline understanding of the characteristics of the study population, sorghum production practices, and efficiency levels of the smallholder farmers within the target region.

Hypothesis Testing and Regression Analysis: Building upon the initial descriptive analysis, hypothesis testing, and regression analysis were employed to examine the relationships between variables of interest. This may involve:

- **Linear Regression:** To quantify the strength and direction of the relationships between rainfed cropland management practices (independent variables) and sorghum productivity (dependent variable). This analysis will illuminate how changes in input utilization influence sorghum yields within the context of smallholder farming practices

- **Cobb-Douglas Production Function:** If the research objectives warrant, the Cobb-Douglas production function may be utilized to model the relationship between various inputs and sorghum output at the individual farm level. This approach allows for an in-depth exploration of how specific factors influence production efficiency within the study area.

- **Data Visualization:** To effectively communicate the research findings and illuminate patterns within the data, compelling data visualization techniques will be employed. Charts, graphs, and other visual representations will be strategically incorporated to present complex data in a readily understandable format, fostering clear communication of the research outcomes.

By applying a diverse range of statistical and econometric techniques, the study aims to extract valuable insights from the collected data. This comprehensive data analysis approach addresses the research objectives by identifying the relationships between rainfed cropland management, sorghum productivity, and efficiency levels experienced by smallholder farmers in Lira and Oyam Districts, Uganda.

3.11. Ethical Considerations

This research was firmly committed to upholding the highest ethical standards throughout the research process. The well-being and dignity of all participants, including research assistants, respondents, and supervisors, were prioritized at every stage.

Informed Consent: Before their involvement in the study, all participants were provided with a clear and comprehensive informed consent document. This document details the research objectives, data collection procedures, potential risks and benefits of participation, and the participants' rights to withdraw from the study at any time. Only after providing their voluntary consent, individuals were included in the study.

Minimizing Harm: The research design, data collection tools, and data analysis procedures were meticulously developed to minimize any potential for physical, psychological, or emotional harm to participants. Sensitivity was exercised throughout the research process to ensure a safe and respectful environment for all involved.

Confidentiality and Anonymity: The anonymity and confidentiality of all research participants will be safeguarded. Data was anonymized whenever possible, and any identifiable information will be securely stored using password protection and encryption. Participant data will only be used for this research study and will not be shared with any third parties without explicit consent.

Respectful Communication: All interactions with research participants will be conducted with respect and courtesy. Offensive, discriminatory, or other inappropriate language will be strictly avoided throughout the research process. Researchers will be trained in culturally sensitive communication practices to ensure a comfortable and inclusive environment for all participants.

Responsible Authorship: The intellectual contributions of all individuals who have played a role in the research are acknowledged. Any sources or references utilized within the research are meticulously documented using a recognized academic referencing style guide, such as the Harvard referencing system.

Objectivity and Transparency: The research was conducted with the utmost objectivity, striving to present unbiased findings based on the collected data. Transparent reporting methods were employed to ensure the research findings were accurately and comprehensively communicated. A detailed research protocol was developed outlining the methodology and data analysis plan to enhance the transparency and replicability of the research.

By adhering to these ethical principles, the study aims to conduct responsible research that contributes valuable knowledge while safeguarding the well-being and rights of all participants.

3.12 Limitations of the Study

This research acknowledges inherent limitations that shape its scope and generalizability.

Focus on Sorghum Characteristics and Adoption: The study primarily focuses on the characteristics of sorghum varieties and the level of adoption by smallholder farmers within the northwest savanna grassland agroecological zone. While maize production is also considered, sorghum remains the primary focus. This focus provides a deeper understanding of sorghum production practices within the target region, but it is important to acknowledge that other crops cultivated by smallholder farmers may not be addressed in this study.

Productivity Measures: The study operationalizes productivity using measures consistent with economic theory. This approach focuses on the total output of the sorghum production process, combining intermediate inputs and factors of production. It is important to acknowledge that this definition may not capture all aspects of productivity relevant to smallholder farmers, such as resource efficiency or sustainability. Future research endeavors may explore alternative productivity measures that encompass a broader range of considerations.

Production Frontier Analysis: The study utilizes production frontier analysis to estimate technical efficiency for sorghum production in the two target districts. While this technique provides valuable insights, it is crucial to recognize that it relies on certain assumptions about the production process. The generalizability of the efficiency estimates may be limited by these assumptions. Researcher acknowledges these limitations and future studies may explore alternative methods for assessing efficiency that account for a wider range of factors influencing production outcomes.

By acknowledging these limitations, the study fosters a nuanced understanding of its findings and encourages further research that may explore other aspects of rainfed cropland management, sorghum productivity, and efficiency in the target region.

CHAPTER FOUR

PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

4.0 Introduction

This chapter is divided into four sections. The first section presents the descriptive analysis of the demographic profile of respondents. This is followed by the analysis of the characteristics of sorghum productivity in rain-fed cropland. Subsequently, the findings on the level of production of sorghum among smallholder farmers in rain-fed cropland. The chapter ends with an analysis and discussion of the productive efficiency of rain-fed cropland sorghum among smallholder farmers in the Oyam and Lira Districts. This chapter presents the study findings, interprets the results, and discusses them in comparison to past studies.

4.1 Demographic Profile of the Respondents

This section presents a descriptive analysis of the demographic characteristics of the smallholder farmers who participated in the study. Understanding these characteristics provides a crucial foundation for interpreting subsequent findings on production practices and efficiency levels.

4.1.1 Sex of the Respondents

Table 3: Sex distribution of the respondents in Lira and Oyam District.

Sex of the respondent * District Crosstabulation					
			District		Total
			Lira	Oyam	
Sex of the respondent	Male	Frequency	54	75	129
		% of Total	23.2%	32.2%	55.4%
	Female	Frequency	55	49	104
		% of Total	23.6%	21.0%	44.6%
Total		Frequency	109	124	233
		% of Total	46.8%	53.2%	100.0%

Source: Primary data

The data analysis revealed a gender disparity in sorghum production activities within the study area. As shown in Table 1, a higher proportion of respondents identified as male (55.4%) compared to female (44.6%). This finding suggests and is confirmed by key informants that male farmers constitute many participants engaged in sorghum production within the target region. Further research endeavors could delve deeper into the factors contributing to this gender disparity.

4.1.2 Age group of the respondents

Table 4: Age group crosstabulation.

Age Group	*Lira District*	*Oyam District*	*Total*
Youth (18-34)	11.6%	11.6%	23.2%
Adult (35-54)	25.8%	32.6%	58.4%
Elderly (55+)	9.4%	9.0%	18.5%
Total	46.8%	53.2%	100.0%

Source: Primary data

The study encompassed a representative sample of smallholder farmers across various age and gender demographics, including young males and females, middle-aged adults, and senior citizens. As illustrated in the table, many respondents (58.4%) fell within the adult age group. Youths comprised 23.2% of the sample, while the elderly demographic accounted for the remaining 18.4%.

A further breakdown by district is presented in Table 2 (age group crosstabulation) above. Oyam district exhibited a participation rate of 53.2%, with the distribution across age groups being 32.6% for adults, 11.6% for youths, and 9.0% for elderly individuals. In the Lira district, the participation rate was 46.8%, with a similar age distribution: 25.8% adults, 11.6% youths, and 9.4% elderly.

4.1.3 Education Levels of the Respondents

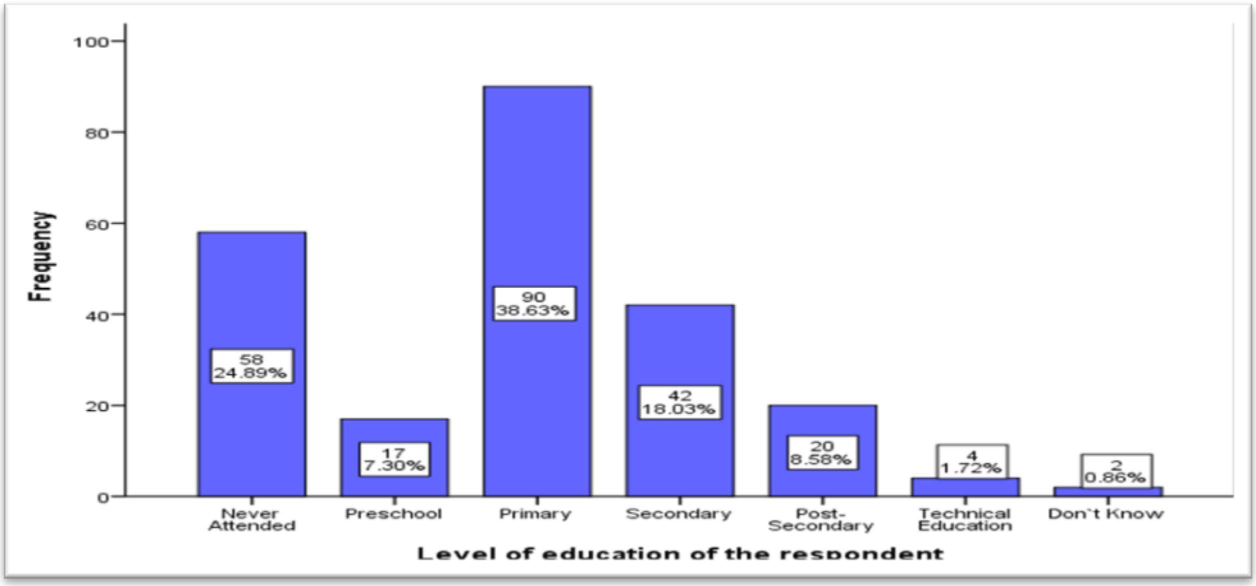


Figure 2: Education Levels of the Respondents

source: Primary Data

Figure 2 presents a data distribution reflecting the educational attainment of the respondents of the study in Lira and Oyam. The data suggests a prevalence of limited formal education within the sample. The highest percentage (38.6%) attained primary education as their highest qualification. A significant portion (24.9%) reported no formal education at all.

Collectively, these figures indicate that over 63% of the respondents lack secondary education or higher. This trend is further corroborated by the lower percentages for those attaining secondary education (18%), post-secondary education (8.6%), and technical education (1.7%).

A substantial proportion (over 63%) of the respondent pool exhibits limited formal education. Primary education represents the most common level of attainment, followed by those with no formal schooling. Access to higher education opportunities appears to be restricted for this population segment.

4.2 Characteristic of sorghum productivity in rain-fed cropland

This section delves into the characteristics of sorghum productivity within the context of rainfed croplands in the study region. A comprehensive understanding of these characteristics is essential for evaluating the efficiency of sorghum production practices employed by smallholder farmers.

4.2.1 Average size of farmland respondents have access.

Table 3: Landholding Patterns of Respondents

Landholding Size (Acres)	*Number of Respondents*	*Percentage (%)*
0-3	158	67.8
3-6	41	17.6
6-9	21	9.0
9-12	12	5.2
>12	1	0.4
Total	**233**	**100.0**

Source: Primary data

Table 3 highlights the land distribution among surveyed farmers. The majority (67.8%) cultivate relatively modest plots between 0 and 3 acres. Farms managing 3 to 6 acres represent the next largest category (17.6%). Notably, only a small percentage of respondents (9% and 5.2%) have access to larger landholdings (6-9 acres and 9-12 acres, respectively). This distribution suggests that a significant portion of sorghum production comes from smaller-scale farmers.

Sorghum is experiencing a surge in production driven by several key factors. Its strong market potential, exceptional climate resilience, and adaptability to diverse growing conditions all contribute to its increasing popularity.

4.2.2 Season B 2021 Sorghum Cultivation: Land Use Trends

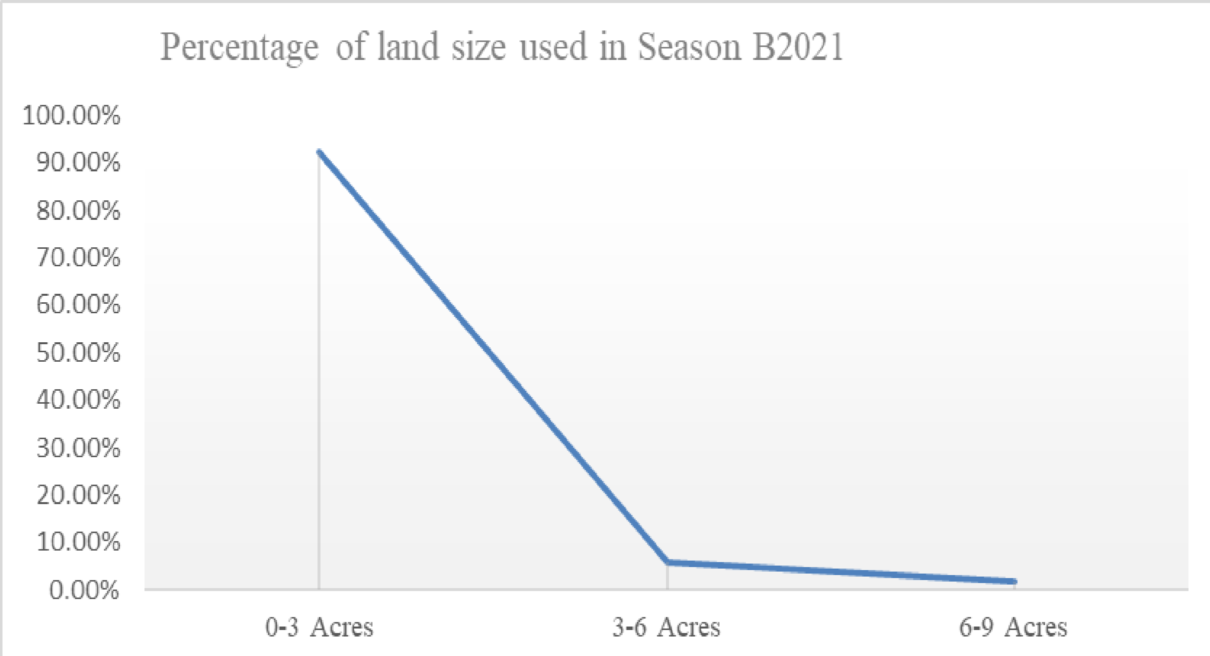


Figure 3: Land Size used in Season B2021

Source: Primary data

An examination of Figure 3 above reveals a distinct pattern in land use for sorghum cultivation during season B2021. The data demonstrates a clear dominance of small-scale operations. A significant majority (92.3%) of farmers allocated plots averaging between 0 and 3 acres for sorghum production. This is followed by a considerably smaller segment (6.0%) utilizing medium-sized areas (3-6 acres), and a minimal proportion (1.7%) employing larger plots (6-9 acres). This trend suggests that season B2021 was characterized by a prevalence of small-scale sorghum farming practices.

4.2.3 Season B 2020 Sorghum Cultivation: Land Use Trends

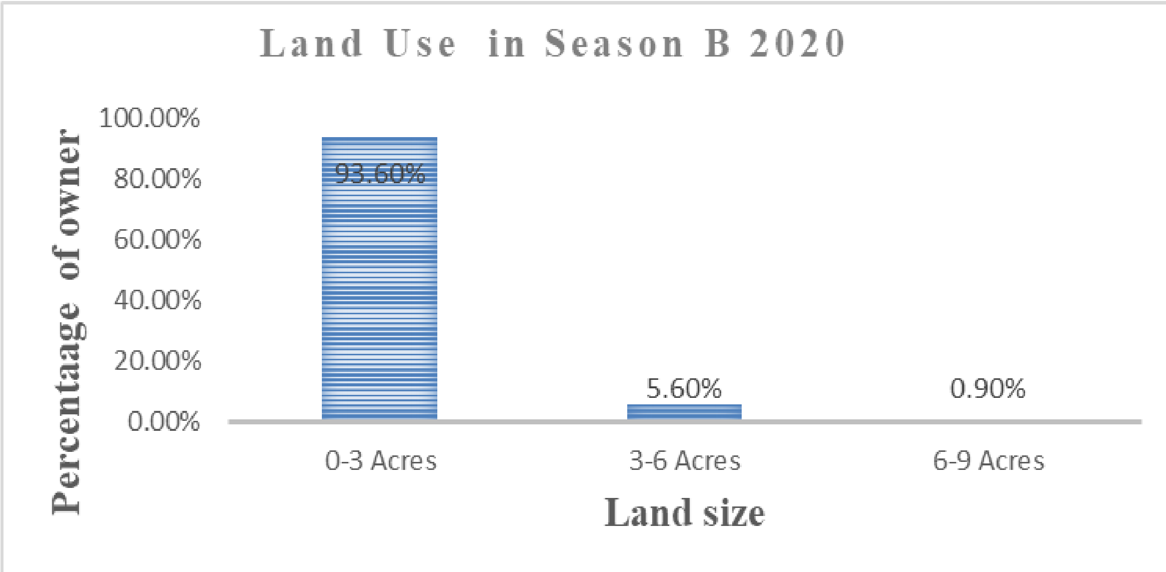


Figure 4: Land Size used in B2020

Source: Primary data

An examination of figure 4 reveals a similar pattern in land use for sorghum cultivation during season B2020. The data demonstrates a clear dominance of small-scale operations. A significant majority (92.3%) of farmers allocated plots averaging between 0 and 3 acres for sorghum production. This is followed by considerably smaller segments utilizing medium-sized areas (3-6 Acres: 5.6%) and larger plots (6-9 Acres: 0.9%) for sorghum cultivation. This trend suggests that season B2020, like season B2021, was characterized by a prevalence of small-scale sorghum farming practices. The table reveals:

Predominance of Small-Scale Farms: The data indicates that a significant majority (92.3%) of farmers used plots between 0 and 3 acres for sorghum cultivation in season B2020.

Limited Medium and Large-Scale Operations: Only a small portion of farmers utilized medium-sized areas (3-6 acres: 5.6%) and even fewer used larger plots (6-9 acres: 0.9%).

Comparison to Previous Seasons: The text suggests a similar pattern to previous seasons (e.g., B2021), implying a consistent trend of small-scale sorghum farming.

4.2.4 The Major sorghum varieties' production for the last two growing seasons.

Table 4: Prevalence of Sorghum Varieties

Sorghum Variety	***Frequency (N)***	***Percentage (%)***
SESO-1	17	7.1
SESO-2	11	4.6
NAROSORG 1	2	0.8
NAROSORG 2	1	0.4
NAROSORG 3	1	0.4
NAROSORG 4	3	1.2
SESO-3	16	6.6
Indigenous Variety - Red Sorghum	104	43.2
Indigenous Variety - Brown Sorghum	46	19.1
Others	40	16.6
Total	**241**	**100.0**

Source: primary data

Table 4 above shows sorghum varietal Landscape**.** Red sorghum (46.4%) and brown sorghum (20.5%) are the most widely planted varieties, highlighting their familiarity and potential suitability to local growing conditions.

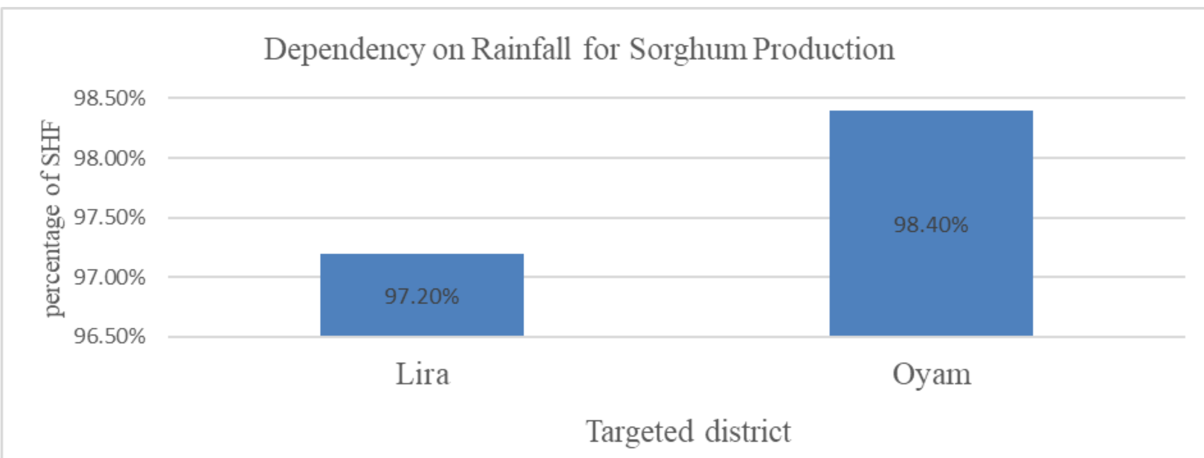
Limited Adoption of Improved Varieties (13.3%): The combined percentage of improved varieties like SESO-1, SESO-2, NAROSORG 1-4, and SESO-3 is relatively low (13.3%). This suggests a potential knowledge gap regarding improved varieties or limited access to their seeds.

Unidentified Varieties (17.9%): A sizeable proportion of respondents (17.9%) indicated planting "other" varieties, potentially additional indigenous types, or improved varieties they weren't familiar with by name. This underscores the need for further investigation into the sorghum varietal diversity in the region.

The data presented shows that Farmers primarily rely on well-established indigenous varieties, likely due to their adaptation and familiarity. The limited adoption of improved varieties highlights an opportunity to introduce higher-yielding or disease-resistant options. In addition, the presence of unidentified varieties suggests a rich biodiversity of sorghum germplasm in the region.

4.2.5 Dependency on rainfall for production of Sorghum

Figure 5: Summary of the findings



Source: primary data

An examination of Table 6 reveals a high dependency on rainfall for sorghum production among farmers in both Oyam and Lira districts. A staggering 97.8% of respondents indicated reliance on rainfall. Notably, Oyam district has a slightly higher dependence on rainfall for sorghum production, with 120 out of 122 farmers (or 98.4%) relying on rainfall compared to Lira district, where 106 out of 109 farmers (or 97.2%) depend on rainfall.

This over-reliance on rainfall poses a significant challenge due to the increasing pressures of climate change. Implementing drought-resistant sorghum varieties and exploring alternative irrigation methods are crucial steps toward ensuring sorghum production sustainability in these regions.

4.2.6 Farm Tool Usage in Sorghum Cultivation: Analysis of Primary Data

Table 5: Farm Tool Usage for Sorghum Cultivation

Farm Tool	*Frequency (N)*	*Percentage (%)*
Ox Plough		
- *Opening*	53	6.3
- *Second Ploughing*	127	15.2
- *Planting*	87	10.4
- *Weeding*	3	0.4
Hand Hoe		
- *Opening*	133	15.9
- *Second Ploughing*	84	10.0
- *Planting*	123	14.7
- *Weeding*	228	27.2
Total	**838**	**100.0**

Source: Primary data

An analysis of Table 5 reveals patterns in farm tool usage among sorghum farmers in the Lira and Oyam districts. The data suggests a reliance on both manual labor and animal traction for cultivation tasks.

Weeding: The overwhelming majority of farmers (used by 98.3% of respondents) rely on hand hoes for weeding sorghum, highlighting the labor-intensive nature of weed control in current practices.

Land preparation: Hand hoes are again the most prevalent tool for opening land (57.3%), followed by ox ploughs used for second ploughing (54.7%). This indicates a significant investment of manual effort in preparing the land for sowing, with ox plows playing a supplementary role.

Planting: Both hand hoes (53.0%) and ox ploughs (37.5%) are used for planting sorghum, suggesting a possible variation in practices or resource availability among farmers.

Secondary ploughing: Ox ploughs are the dominant tool for secondary ploughing (Ox plough), highlighting their importance in this specific task.

Overall, the data suggests a mix of traditional hand tools and animal traction for sorghum cultivation in the Lira and Oyam districts. While ox ploughs are used for some tasks, hand hoes remain the primary tools for most aspects of sorghum production. This highlights potential areas for improvement, such as the introduction of more efficient weeding tools or exploring the wider adoption of ox ploughs where feasible, to potentially reduce labor requirements and enhance productivity.

4.3 Production level of sorghum under rain-fed cropland

Building upon the examination of factors influencing sorghum productivity within rain-fed croplands (Section 4.2), this section explores the management practices implemented by smallholder farmers to achieve optimal sorghum yields under these conditions. A thorough understanding of these practices is critical for evaluating their effectiveness and identifying potential areas for improvement that could enhance sorghum production within the target region.

4.3.1 Farm Practices for Sorghum Production

Table 6: Sorghum Production Practices

Practice	*Frequency (N)*	*Percentage (%)*
Ploughing Farm Field Twice	166	20.9
Using Fertilizer	13	1.6
Allowing Land to Fallow	144	18.1
Using Crop Rotation	216	27.2
Weeding Once Before Harvesting	148	18.6
Weeding Twice Before Harvesting	89	11.2
Using Pesticides	18	2.3
Total	**794**	**100.0**

Source: Primary data

Core Practices for Sorghum Cultivation:

- **Crop Rotation (93.1%)**: The dominant practice is cropping rotation, signifying its well-established value among farmers for preserving soil health and potentially enhancing yiel
- **Double Ploughing (71.6%)**: Meticulous land preparation through double ploughing before planting emerges as another widely adopted practice, underscoring its significance in establishing a suitable seedbed for optimal sorghum germination.
- **Soil Fertility Management (62.1%) and Weed Control (38.4% - 63.8%)**: Allowing land to fallow and manual weeding remain important methods for managing soil fertility and mitigating weed competition.

The data presented in Table 6 suggests a cautious approach towards adopting modern inputs, with fertilizer use at 5.6% and pesticide use at 7.8%.   This was in line with focused group discussion and well as key informant interview outcomes. This measured adoption could be attributed to factors such as increasing adoption of agroecological practices, accessibility issues, or knowledge gaps regarding their effective application in sorghum cultivation.

This analysis explores the practices employed by sorghum farmers in Lira and Oyam districts, Uganda, to achieve good production over the past two growing seasons (data presented in Table 8). The findings reveal a blend of traditional strategies and a measured adoption of modern inputs.

4.4 The major challenge/problem in sorghum production

An examination of Table 7 reveals that inadequate rainfall is the predominant challenge faced by sorghum farmers in the Lira and Oyam districts, affecting 78.2% of respondents. This highlights the vulnerability of sorghum production to the vagaries of weather, particularly in the context of climate change.

Table 7: Major Challenges in Sorghum Production

Challenge	***Frequency (N)***	***Percentage (%)***
Inadequate Rainfall	179	23.7
Pests	142	18.8
Diseases	124	16.4
Poor Soil	69	9.2
Limited Access to Quality Seed	120	15.9
Poor Storage Facilities	102	13.5
Others	18	2.4
Total	**754**	**100.0**

Source: Primary Data

Other significant challenges presented in Table 7 include Pests (62.0%): Pest infestations can significantly reduce sorghum yields and grain quality. Diseases (54.1%): Various diseases can threaten sorghum crops, leading to yield losses. These challenges underscore the need for interventions that promote climate-resilient sorghum varieties, integrated pest management (IPM) strategies, and the development of robust disease resistance in sorghum cultivars.

While other challenges like poor soil quality (30.1%), limited access to quality seed (52.4%), and poor storage facilities (44.5%) are also present, their prevalence is lower. Addressing these challenges could involve promoting soil conservation practices, facilitating access to improved seeds, and improving post-harvest storage infrastructure.

By implementing a holistic approach that tackles these multifaceted challenges, sorghum production in the Lira and Oyam districts can be significantly enhanced and made more sustainable.

4.4.1 Experience, intensity, and effects of low rainfall

The data in Table 8 reveals that there has been a significant amount of low rainfall in Lira and Oyam districts in the past 12 months. Based on the survey results, nearly nine out of ten (89.7%) of the respondents reported experiencing low rainfall. This indicates that drought conditions have been prevalent in the region, which could pose a major challenge to rain-fed agriculture.

Table 8: Low Rainfall Experience

Low Rainfall Experience	*Frequency*	*Percentage (%)*
No	24	10.3
Yes	209	89.7
Total	233	100.0

Source: Primary data

The small percentage (10.3%) of respondents who reported not experiencing low rainfall suggests that consistent and reliable rainfall events are uncommon in the area. This highlights the importance of developing strategies to cope with drought conditions, such as: Varieties of sorghum that are more tolerant of dry conditions could be introduced to farmers in the region, techniques such as rainwater harvesting could be implemented to store water during wetter periods and use it during droughts, and educating farmers about climate-smart practices -farmers could be taught about practices that can help them adapt to changing weather patterns, such as planting crops at different times of year or using mulches to retain soil moisture.

4.4.2 Low rainfall occurrence

Table 9 offers critical insights into the frequency of low rainfall events experienced by smallholder farmers in Lira and Oyam Districts which affected sorghum production. This data illuminates the prevalence and severity of drought conditions within the region, enabling a more informed understanding of the challenges faced by rain-fed agriculture.

Table 9: Frequency of Low Rainfall Occurrence

Frequency of Low Rainfall Events	*Percentage (%)*
Once per Season	27.3
Twice per Season	55.5
Four Times per Year	17.2
Total	100.0

Source: primary data

Table 9 reveals a substantial majority (55.5%) of respondents reported experiencing low rainfall twice per season. This concerning statistic underscores the recurrent nature of drought stress in the region, posing a significant threat to the sustainability of rain-fed agricultural practices. An additional 27.3% of farmers indicated encountering low rainfall once per season. This further emphasizes the pervasiveness of drought conditions, albeit at a slightly lower frequency than twice-seasonal occurrences. A minority (17.2%) of respondents reported experiencing low rainfall events four times a year, suggesting that a segment of the population faces year-round drought challenges.

The data presented in Table 9 and responses from key informants accentuate the vulnerability of rain-fed sorghum production to drought. The frequent occurrence of low rainfall events, particularly the twice-seasonal episodes reported by over half of the respondents, significantly elevates the risk of sorghum crop failure and undermines overall agricultural productivity.

4.4.3 Impact of Low Rainfall on Households

Table 10 presents critical data regarding the perceived intensity of the most recent low rainfall event experienced by households in Lira and Oyam Districts, Uganda. This table offers valuable insights into the severity of drought impacts on household well-being within the region, enabling a more informed understanding of the social and economic ramifications of climate variability.

Table 10: Severity of Low Rainfall Events

Severity of Low Rainfall	***Frequency***	***Percentage (%)***
Severe	56	26.8
Moderate	127	60.8
Mild	25	12.0
None	1	0.5
Total	**209**	**100.0**

Source: primary data

Distribution of Perceived Impact of low rainfall indicated a substantial majority (60.8%) of respondents classified the intensity of the most recent low rainfall shock as moderate. While not catastrophic, this finding indicates that a significant proportion of households endured negative consequences due to drought conditions, potentially including reduced crop yields, compromised food security, and income shortfalls. A noteworthy 26.8% of respondents reported experiencing a severe low rainfall shock which aligns with focus group discussion and key informant outcomes. This highlights the substantial hardship faced by a considerable portion of the population, potentially encompassing impacts on food security, livelihoods, and overall well-being. Limited Mild Impact (12.0%) and Minimal No Impact (0.5%)**:** A smaller group (12.0%) indicated experiencing a mild impact, and a negligible number (0.5%) reported no impact from the low rainfall event. These findings suggest that a limited segment of the population may have been either less affected by the drought or have adopted effective coping mechanisms.

4.4.4 Assessment of Low Rainfall Impacts on Sorghum Production

Table 11 offers valuable insights gleaned from a survey of smallholder farmers in Lira and Oyam Districts, Uganda, regarding the perceived effects of low rainfall events on their sorghum production. This data contributes significantly to understanding the vulnerabilities of rain-fed sorghum cultivation in the face of climate variability.

Table 11: Impact of Low Rainfall on Sorghum

Impact of Low Rainfall	*Percentage (%)*
Soil Erosion	4.3
Crop Failure	49.3
Crop Damage	26.8
No Significant Impact	19.6
Total	100.0

Source: primary data

The dominant Threat of low rainfall is Crop Failure (49.3%) - A strikingly high proportion (49.3%) of respondents identified crop failure as the primary consequence of low rainfall. This concerning statistic underscores the severe negative impact of drought conditions on sorghum yields and is inline with focus group discussion views. These losses can have cascading effects on household food security and income generation, potentially jeopardizing the well-being of farming communities in the region. However substantial crop damage (26.8%) is in line with key informant interviews - A noteworthy 26.8% of respondents reported experiencing crop damage due to low rainfall. This finding suggests that even when complete crop failure is avoided, drought stress can significantly reduce sorghum yields. This can have substantial negative consequences for overall agricultural productivity and farmer livelihoods.

A smaller percentage of respondents (4.3%) indicated soil erosion because of low rainfall. While this suggests that soil erosion may not be the most prevalent concern, it nevertheless highlights the importance of incorporating soil and water conservation strategies into agricultural practices within the region. Interestingly, 19.6% of respondents reported no negative impacts from low rainfall on their sorghum production.

4.4.5 Analysis of Pest and Disease Prevalence

Table 12 offers critical data regarding smallholder farmer experiences with pests and diseases in Lira and Oyam Districts, Uganda, over the past 12 months. This information sheds light on the constraints faced by sorghum producers in the region, enabling a more comprehensive understanding of factors influencing sorghum production and potential areas for intervention.

Table 12: Pest and Disease Prevalence

Pest and Disease Occurrence	*Percentage (%)*
Absent	36.9
Present	63.1
Total	100.0

Source: primary data

Predominant Pest and Disease Challenges (63.1%) - A substantial proportion (63.1%) of respondents reported encountering pest and disease problems during the past year. This concerning statistic underscores the pervasiveness of these challenges within the region's agricultural sector. Pest and disease infestations have the potential to significantly reduce crop yields, disrupt food security, and negatively impact the livelihoods of farming communities. Incidence of Pest-Free Farms (36.9%) **-** Interestingly, a noteworthy minority (36.9%) of respondents indicated experiencing no pest or disease issues. This observation warrants further investigation, and potential explanations could include sorghum crop variety selection strategies**:** Farmers cultivating crops with inherent resistance to prevalent pests and diseases in the region might be less likely to encounter these problems. Effective Pest Management Practices: A segment of the farming population might be implementing successful pest management practices such as crop rotation, utilizing bio-controls, or employing targeted application of pesticides. These practices can help mitigate pest and disease outbreaks. Spatial Variations in Pest Pressures: Uneven distribution of pest and disease pressures across the districts could explain why some farms are less affected than others.

4.4.5.1 Pest and Disease Outbreaks

Table 13 sheds light on the frequency of pest and disease outbreaks experienced by smallholder farmers in Lira and Oyam Districts, Uganda, during the past 12 months. This information is crucial for understanding the challenges faced by agricultural producers and informing the development of targeted interventions to mitigate crop losses.

Table 13: Frequency of Pest and Disease Outbreaks

Frequency of Outbreaks	*Percentage (%)*
Once a Season	32.7
Twice a Season	53.1
Four Times a Year	14.3
Total	**100.0**

Source: Primary data

Table 13 reveals the predominant Frequency of sorghum pests and diseases: Twice per Season (53.1%) - A noteworthy majority (53.1%) of respondents indicated experiencing pest and disease outbreaks twice per season. This highlights the significant threat that these recurrent infestations pose to crop yields and agricultural productivity within the region. Incidence of Seasonal and Less Frequent Outbreaks - While twice-seasonal outbreaks are most prevalent, a substantial proportion of respondents (32.7%) reported encountering pests and diseases only once per season. Conversely, a smaller segment (14.3%) indicated experiencing outbreaks as many as four times a year.

4.4.5.2 Pest and Disease Impact Intensity on Households

Table 14 furnishes critical data regarding the perceived severity of the most recent pest and disease outbreak experienced by households in Lira and Oyam Districts, Uganda, during the past 12 months. This table complements the findings from previous analyses on pest prevalence and frequency, providing a more nuanced understanding of the challenges faced by smallholder farmers and the potential ramifications for household well-being.

Table 14: Severity of the Last Pest and Disease Shock

Severity of Shock	*Frequency*	*Percentage (%)*
Severe	21	14.3
Moderate	99	67.3
Mild	16	10.9
None	11	7.5
Total	**147**	**100.0**

Source: Primary data

Distribution of Perceived Impact Intensity reveals the predominant moderate impact of a substantial majority (67.3%) of respondents classified the intensity of the most recent pest and disease outbreak as moderate. While not catastrophic, this finding indicates that a significant proportion of households endured negative consequences due to infestations or diseases. These consequences could potentially encompass reduced crop yields, compromised food security, and income shortfalls. A noteworthy 14.3% of respondents reported experiencing a severe pest and disease shock. This highlights the substantial hardship faced by a considerable segment of the population, potentially encompassing impacts on food security, livelihoods, and overall well-being. Mitigating Factors: Mild Impact (10.9%) and Minimal No Impact (7.5%): A smaller group (10.9%) indicated experiencing a mild impact, and a lesser segment (7.5%) reported no impact from the pest and disease outbreak. These findings suggest that a portion of the population may have been either less affected by the outbreak or have adopted effective pest management practices that helped mitigate negative consequences.

4.4.5.3 Pest and Disease Impacts on Sorghum Production

Table 15 offers valuable data gleaned from a survey of smallholder farmers in Lira and Oyam Districts, Uganda, regarding the perceived effects of pests and diseases on their sorghum production over the past 12 months. This table complements the information on pest prevalence and frequency presented earlier, providing a more comprehensive understanding of the specific challenges faced by sorghum cultivation in the region.

Table 15: Impact of Pests and Diseases on Sorghum

Impact	***Frequency***	***Percentage (%)***
Soil Erosion	5	3.4
Total Crop Loss	7	4.8
Significant Crop Damage	126	85.7
No Significant Impact	9	6.1
Total	147	100.0

Source: primary data

Table 15 reveals a dominant threat of pests and diseases on sorghum production as crop damage - A strikingly high proportion (85.7%) of respondents identified crop damage as the primary consequence of pest and disease infestations on their sorghum crops. This concerning statistic underscores the severe negative impact that pests and diseases can have on sorghum yields.

These losses can have cascading effects on household food security and income generation, potentially jeopardizing the well-being of farming communities in the region.

Limited Impact: Crop Failure (4.8%) and Soil Erosion (3.4%) - A significantly smaller percentage of respondents reported experiencing crop failure (4.8%) or soil erosion (3.4%) due to pests and diseases. While these findings suggest that complete crop failure and soil erosion are not the most prevalent consequences of pest and disease outbreaks on sorghum, they nevertheless highlight the potential for these issues to occur.

4.4.6 Rainfall Intensity

Table 16 provides insights into the experiences of smallholder farmers in Lira and Oyam Districts, Uganda, regarding high rainfall intensity events over the past 12 months. This information is valuable for understanding potential climate patterns and their implications for sorghum production in the region.

Table 16: High Rainfall Intensity Experience

High Rainfall Intensity	*Frequency*	*Percentage (%)*
No	209	89.7
Yes	24	10.3
Total	**233**	**100.0**

Source: Primary data

The data in Table 16 suggests that high rainfall intensity events were infrequent during the past year in Lira and Oyam Districts. A substantial majority (89.7%) of respondents reported not experiencing high rainfall intensity. This finding could be indicative of a drier-than-usual period in the region. A smaller segment of respondents (10.3%) indicated experiencing high rainfall intensity within the past 12 months. While the exact nature and impact of these events are not captured in the table, it is possible that these occurrences resulted in localized flooding or disruptions to agricultural activities.

4.4.6.1 Frequency of High Rainfall Events

Table 17 provides insights into the frequency of high rainfall intensity events experienced by a subset of respondents in Lira and Oyam Districts, Uganda, during the past 12 months. While the overall incidence of high rainfall intensity was low (refer to Table 16), this table sheds light on the distribution of these events among those who did experience them.

Table 17: perceived frequency of rainfall

Revised Table: Frequency of High Rainfall Events

Frequency of High Rainfall Events	***Percentage (%)***
Once per Season	66.7
Twice per Season	33.3
Total	**100.0**

Source: Primary data

Dominant Frequency: Once per Season**-** Among the respondents who reported experiencing high rainfall intensity in the last 12 months, the majority (66.7%) indicated that it occurred once a season. This suggests that high rainfall events, while not frequent, tended to be isolated occurrences within a given season for most farmers. Less Frequent Events: Twice per Season A smaller portion of respondents (33.3%) reported experiencing high rainfall intensity events twice during a season. This finding highlights the potential variability in rainfall patterns within the region, even within a single year.

4.4.6.2 Perceived Impact Intensity of High Rainfall Events

Table 18 sheds light on the perceived severity of the most recent high rainfall event experienced by a subset of respondents in Lira and Oyam Districts, Uganda, during the past 12 months. While the overall incidence of high rainfall intensity was low (refer to Table 16), this table provides valuable insights into the potential consequences of these events for households within the region.

Table 18: Intensity of the Last High Rainfall Shock

Severity of Shock	***Percentage (%)***
Severe	41.6
Moderate	33.3
Mild	25.1
Total	100.0

Source: Primary data

A noteworthy proportion (41.6%) of respondents who experienced high rainfall intensity events classified the impact on their households as severe. This finding suggests that these events can have substantial negative consequences, potentially encompassing damage to property, and infrastructure, and disruptions to livelihoods. Mixed Impacts were revealed during key informant interviews and focus group discussions: Moderate (33.3%) and Mild (25.1%): A portion of respondents reported experiencing moderate (33.3%) or mild (25.1%) impacts from high rainfall events. This variability in perceived intensity could be attributed to factors such as the specific characteristics of the rainfall event (e.g., duration, intensity), variations in household vulnerability (e.g., location, preparedness measures), and the coping mechanisms employed by individual households.

4.4.6.3 Effect of high rainfall on sorghum production

Table 19 indicates that the main effect of high rainfall on sorghum is Crop damage, reported by 83.3% of respondents who experienced high rainfall in the last 12 months. Other minor effects include Crop failure, Soil erosion, and None.

Table 19: Perceived effect of high rainfall on sorghum

Revised Table: Impact of High Rainfall on Sorghum

Impact of High Rainfall	***Percentage (%)***
Soil Erosion	4.2
Total Crop Loss	8.3
Significant Crop Damage	83.3
No Significant Impact	4.2
Total	**100.0**

Source: Primary Data

A substantial proportion (83.3%) of respondents who experienced high rainfall events indicated crop damage to their sorghum crops. This finding highlights the potential for these events to significantly reduce sorghum yields. Limited impact - soil erosion and crop failure: A smaller percentage of respondents reported experiencing soil erosion (4.2%) or crop failure (8.3%) due to high rainfall. These findings suggest that while high rainfall events can be detrimental, their severity may vary.

4.4.7 Analysis of Hailstone Occurrence in Lira and Oyam Districts

Table 20 sheds light on the experiences of smallholder farmers in Lira and Oyam Districts, Uganda, regarding hailstorms within the past 12 months. This information is valuable for understanding the prevalence of hailstorms and potential risks to agricultural production in the region.

Table 20: Hailstorm Experience in the Last 12 Months

Hailstorm Experience	***Percentage (%)***
No	**63.5**
Yes	**36.5**
Total	**100.0**

Source: Primary Data

Hailstone Occurrence (36.5%): A noteworthy portion of respondents (36.5% - representing 85) reported experiencing hailstones during the past year. This indicates that hailstorms are not uncommon in Lira and Oyam Districts. Limited Hailstone Exposure (63.5%): The remaining 63.5% of respondents did not experience hailstones within the past 12 months which was appreciated by focus group discussion and key informant interviews. This suggests that hailstone occurrence may not be evenly distributed throughout the districts, or hailstorms may be seasonal.

While Table 20 provides a general overview of hailstone occurrence, additional data would be beneficial for a more comprehensive understanding: Information on the specific locations where hailstorms occurred could reveal variations in hail patterns across different areas within Lira and Oyam Districts. Data on the intensity and duration of hailstorm events would provide insights into the potential level of damage caused to crops. However, investigating the specific consequences of hailstorms on sorghum yields in the region would be valuable for assessing their overall agricultural impact.

4.4.7.1 Hailstorm Frequency in Lira and Oyam District

Table 21 delves deeper into the experiences of those who reported hailstones in the past year(refer to Table 20). This table focuses on the frequency of these events.

Table 21: Frequency of Hailstorne

Frequency of Hailstorms	***Percentage (%)***
Once a Season	43.5
Twice a Season	25.9
Four Times a Year	30.6
Total	100.0

Source: Primary data

Dominant Frequency: Once per Season (43.5%)**:** Among respondents who experienced hailstones, the most frequent occurrence (43.5%) was once per season. This suggests that while hailstones are a concern, they may not be a constant threat throughout the year for most farmers. varied frequency: twice and four times per season**:** A significant portion of respondents (25.9%) reported experiencing hailstones twice a season, while another noteworthy segment (30.6%) indicated hailstorm occurrences as frequent as four times a year. This highlights the potential variability in hailstone frequency within the region.

The data in Table 21 underscores the importance of considering hailstorms when planning agricultural activities. Farmers who experience frequent hailstorms (twice or four times a year) may need to adopt mitigation strategies such as hail netting or adjusting planting times to minimize crop damage.

4.4.7.2 Perceived Impact of Hailstones on Households

Table 22 sheds light on how hailstorms impacted households engaged in sorghum production that experienced them in the past year. This information helps gauge the potential severity of these events.

Table 22: Perceived impact of hailstorms

Hailstone Shock Intensity	*Percentage (%)*
Severe	43.5
Moderate	32.9
Mild	23.5
Total	100.0

Source: Primary Data

Predominant Impact: Severe (43.5%): A substantial proportion of respondents who experienced hailstorms (43.5%) indicated that the most recent hailstorm had a severe impact on their households. This suggests that hailstones can cause significant disruption and hardship. Moderate and Mild Impacts (56.5%): It's important to note that a significant portion of respondents (32.9% reporting moderate impact and 23.5% reporting mild impact) experienced less severe consequences from hailstones. This highlights the potential variability in the intensity of hailstorm events and their effects on households. The data in Table 22 suggests that hailstorms can have a range of impacts on households engaged in sorghum production.

4.4.7.2 Impact of Hailstones on Sorghum Production

Table 23 provides valuable insights into the consequences of hailstones for sorghum cultivation in Lira and Oyam Districts. This information is crucial for understanding the risks posed by hailstorms to food security in the region.

Table 23: Perceived impact of Hailstones on sorghum production

Outcome	*Percentage (%)*
Total Crop Loss	1.2
Significant Crop Damage	94.1
No Significant Impact	4.7
Total	**100.0**

Source: Primary Data

Dominant Impact: Crop Damage (94.1%)**:** A clear majority (94.1%) of respondents who experienced hailstones reported crop damage to their sorghum. This finding supports the information obtained from key informants and focus group discussion which highlights the significant threat that hailstones pose to sorghum yields. Minimal Crop Failure (1.2%)**:** A small percentage of respondents (1.2%) reported complete crop failure due to hailstones. This suggests that while hailstones can cause substantial damage, they may not always result in total crop loss. Limited No Impact (4.7%)**:** A minor portion of respondents (4.7%) indicated no impact on their sorghum from hailstones. This could be due to factors such as the timing of the hailstorm (e.g., occurring before sorghum emerged) or the varying intensity of hailstorms across locations. The data in Table 23 underscores the potential devastation of hailstones for sorghum production. Strategies to mitigate hail damage, such as hail netting or insurance programs, warrant further consideration to enhance the resilience of sorghum cultivation systems in the Lira and Oyam Districts.

4.4.8 Flood Occurrence in Lira and Oyam Districts

Table 24 sheds light on the prevalence of floods in the Lira and Oyam Districts during the past 12 months. This information helps assess the potential risk of floods for agriculture in the region.

Table 24: Flood Experience

Flood Experience	Frequency	Percentage (%)
No	207	88.8
Yes	26	11.2
Total	**233**	**100.0**

Source: Primary data

Limited Flood Occurrence (11.2%): A relatively small proportion of respondents (11.2%) reported experiencing floods within the past year. This suggests that floods are not a frequent event in these districts. Dominant Absence of Floods (88.8%): Many respondents (88.8%) indicated no experience with floods during the past 12 months. This finding highlights that floods may not be a major concern for most farmers in the region. While Table 24 suggests limited flood occurrence, it's important to consider the timeframe (past year) and the potential for seasonal variations.

4.4.8.1 Flood Frequency in Lira and Oyam Districts

Figure 6 provides insights into the frequency of flood occurrences among those who experienced floods in the past year (refer to Table 24). This information helps understand the potential predictability and severity of flood risks.

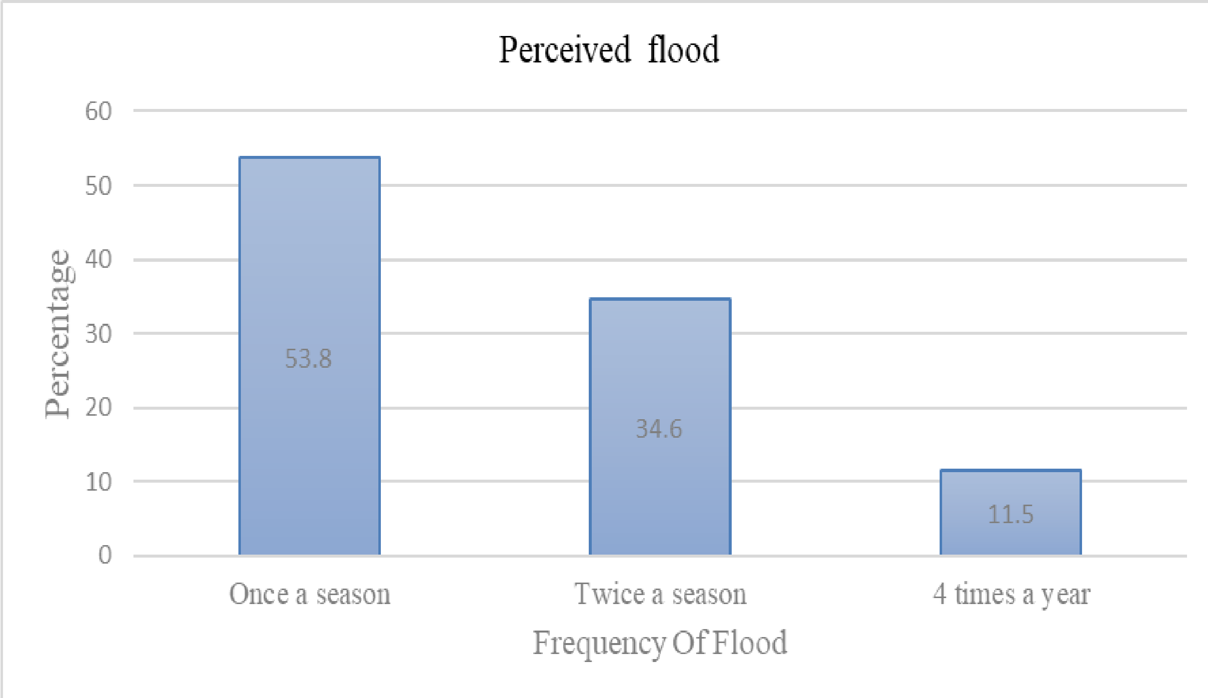


Figure 6: Perceived frequency of flood

Source: Primary Data

Dominant Frequency: Once per Season (53.8%)**:** Among respondents who experienced floods, the most frequent occurrence (53.8%) was once per season. This suggests that those who do experience floods may have some level of predictability regarding flood events. Varied frequency: twice and four times per season**:** A noteworthy portion of respondents reported experiencing floods twice a season (34.6%) and four times a year (11.5%). This highlights the potential for variability in flood frequency within the region.

4.4.8.2. Perceived Impact of Floods on Households

Figure 7 sheds light on how floods impacted households that experienced them in the past year. This information helps gauge the potential severity of these events.

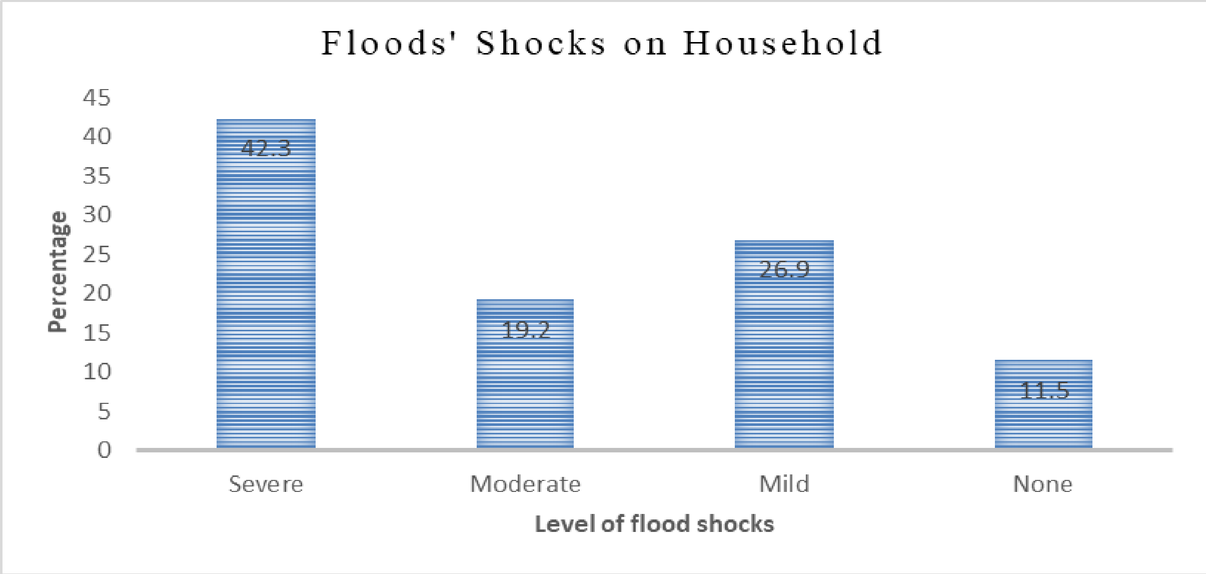


Figure 7: Intensity of the last shock

Source: Primary Data

Predominant Impact: Severe (42.3%): A substantial proportion of respondents who experienced floods (42.3%) indicated that the most recent flood had a severe impact on their households. This suggests that floods can cause significant disruption and hardship. Moderate and Mild Impacts (46.1%): It's important to note that a significant portion of respondents experienced less severe consequences from floods. This includes 26.9% reporting moderate impact and 19.2% reporting mild impact. This highlights the potential variability in the intensity of flood events and their effects on households. Limited no impact (11.5%): A small portion of respondents (11.5%) reported no impact on their households from the most recent flood. This could be due to factors such as the location of their home or the varying intensity of floods across locations. The data in the figure 8 and key informant interviews with extension workers suggest that floods can have a range of impacts on households producing sorghum.

4.4.8.3 Impact of Floods on Sorghum Production

Figure 8 sheds light on the consequences of floods for sorghum cultivation in the Lira and Oyam Districts (considering those who experienced floods in the past year - refer to Figure 7). This information is crucial for understanding the risks posed by floods to food security in the region.

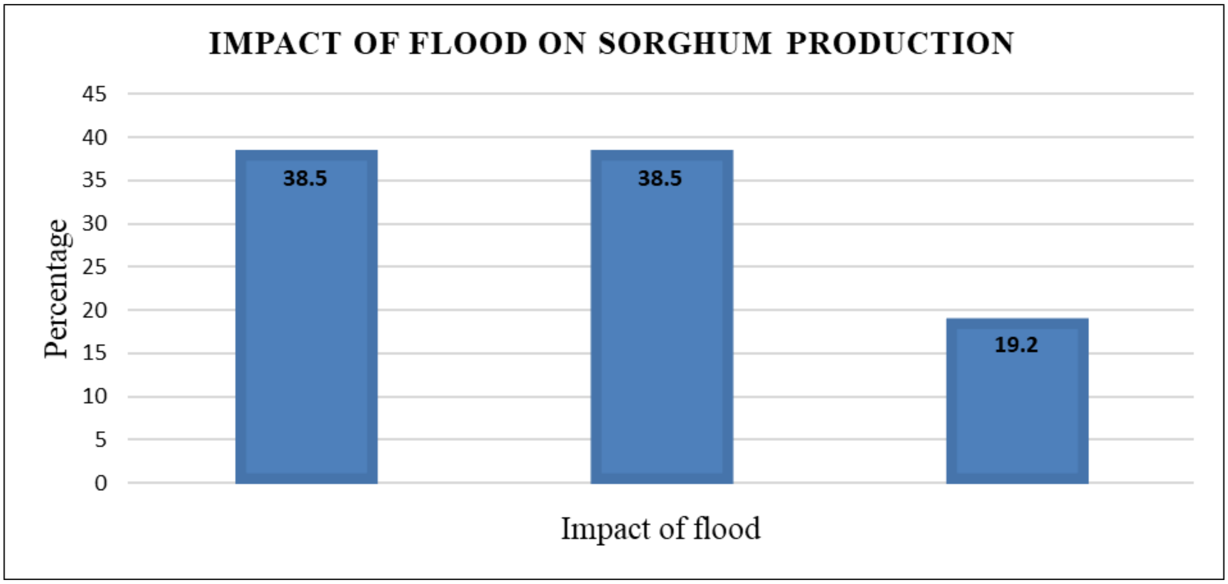


Figure 8: Impact of flood on sorghum

Source: Primary data

Dual Threat: Crop Damage and Soil Erosion (38.5% each)**:** An equally significant proportion of respondents who experienced floods (38.5%) reported both crop damage and soil erosion as consequences for their sorghum crops. This finding highlights the potential for floods to inflict double damage, reducing yields through direct crop damage and also degrading soil quality for future cultivation. Limited Crop Failure (3.8%)**:** A small percentage of respondents (3.8%) reported complete crop failure due to floods. This suggests that while floods can cause substantial damage, they may not always result in total crop loss. Variable impact (19.2% no impact)**:** A minor portion of respondents (19.2%) indicated no impact on their sorghum from floods. This could be due to factors such as the timing of the flood (e.g., occurring before planting) or the varying intensity of floods across locations.

Highlighting the Risks - The data in figure 9 and key informants' interviews underscores the potential for floods to disrupt sorghum production in several ways. Strategies to mitigate flood damage, such as adjusted planting times or improved drainage systems, warrant further consideration to enhance the resilience of sorghum cultivation systems in Lira and Oyam Districts.

4.5 Productivity efficiency of rain-fed cropland sorghum among smallholder farmers

This section delves into a thorough analysis of rain-fed sorghum production efficiency among smallholder farmers in Oyam and Lira Districts, Uganda. This report examines the dependency of sorghum production on four key farm inputs: land size, seed quality, fertilizer application, and pesticide use.

Hypothesis Testing

A multiple linear regression model was employed to test the following hypotheses:

- Null Hypothesis (Ho): There is no statistically significant relationship between sorghum production and the four farm inputs.
- Alternative Hypothesis (Ha): There is a statistically significant relationship between sorghum production and farm inputs. (This is a two-tailed test.)

Table *25*: Table showing a test of linearity of the explanatory variables.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
					R Square Change
1	.756[a]	.571	.287	1.08010	.571

Source: Primary Data

Regression Results: The model yielded an R-squared (R^2) value of 0.571. This indicates that 57.1% of the variance in sorghum production can be explained by the combined effects of land size, seed quality, fertilizer application, and pesticide use.

Interpretation: The obtained R^2 value suggests a moderately strong positive association between the farm inputs and sorghum production. In other words, as the quality and quantity of land, seeds, fertilizer, and pesticides increase, sorghum production generally tends to increase as well. However, it is crucial to acknowledge that nearly 43% (100% - 57.1%) of the variation remains unexplained by the model. This could be attributed to the influence of other relevant factors not incorporated in the analysis, such as weather patterns, specific farming practices, or unforeseen pest infestations.

Table 26 : Table showing the level of significance of the effect of explanatory variables on sorghum production.

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.106	4	.776	.666	.000[b]
	Residual	2.333	2	1.167		
	Total	5.439	6			
a. Dependent Variable: LnPdctn2021						
b. Predictors: (Constant), LnLandSize2021, LnSeed2021, LnPesticides2021, LnFertilizer2021						

Sources: Primary Data

Impact of Key Inputs on Sorghum Production:

- Land Size: The regression coefficient (0.660) for land size (LnLandSize2021) is positive and statistically significant ($p < 0.005$). This indicates that a unit increase in land area dedicated to sorghum cultivation leads to an average increase of 0.316 units in sorghum production (based on the standardized coefficient, Beta). In simpler terms, allocating more land to sorghum production has a positive and significant effect on yields.

- Fertilizer Application: The coefficient (0.022) for fertilizer application (LnFertilizer2021) is also positive and statistically significant ($p < 0.005$). A unit increase in fertilizer use translates to an average increase of 0.259 units in sorghum production. This finding highlights the importance of fertilizer application in boosting sorghum yields.
- Pesticide Use: The coefficient (0.006) for pesticide use (Lnpesticides2021) is positive but with a lower level of significance ($p = 0.045$) compared to land size and fertilizer. This suggests that a unit increase in pesticide application results in a smaller average increase (0.030 units) in sorghum production, but the impact is still statistically relevant.
- Seed Quality: The coefficient (0.006) for seed quality (LnSeed2021) is positive and highly statistically significant ($p < 0.005$). A unit increase in seed quality translates to an average increase of 0.309 units in sorghum production. This finding emphasizes the critical role of using high-quality seeds for achieving optimal sorghum yields.

Overall, the analysis highlights that land size, fertilizer application, seed quality, and to a lesser extent, pesticide use, are all significant factors influencing rain-fed sorghum production among smallholder farmers in the study area**.**

Additional Notes:

- The model includes a constant term (4.11) which represents the predicted sorghum production level when all independent variables are zero (hypothetically impossible).
- The p-values associated with each coefficient indicate the level of statistical significance. A p-value less than 0.05 suggests that the observed relationship between the independent variable and sorghum production is unlikely to be due to chance.

This thorough analysis provides valuable insights for policymakers, agricultural extension services, and farmers themselves. By focusing on strategies that increase land availability, promote fertilizer and high-quality seed use, and encourage judicious pesticide application, stakeholders can work collaboratively to enhance rain-fed sorghum production efficiency and improve food security in the region.

From the multiple linear regression module above, the R^2 =0.571 shows that 57.1% of the variations in the level of sorghum production can be explained by land size, fertilizer, pesticides, and quality of seed planted hence a good fit.

From the Analysis of Variance statistics above, the joint probability (0.000) of the F statistics shows that land size, quality of seed, and application of pesticides and fertilizer significantly affect the level of sorghum production

Table 27: Table showing the Cobb-Douglas regression.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.11	16.614		2.207	.006
	LnLandsize	.660	.933	.316	5.032	.000
	LnFertilizer	.022	.005	.259	4.947	.000
	Lnpesticides	.006	.011	.030	.585	.045
	LnSeed	.006	.001	.309	5.000	.000
a. Dependent Variable: LnPdctn2021						

Source: primary data

From the regression coefficient table above, the coefficient 0.316 shows that a unit increase in the size of land would lead on average to a 0.316 increase in the quantity of sorghum produced and the P-Value (0.000) <0.05 implies that the size of land used for growing sorghum significantly affects the level of production of sorghum, other factors held constant.

The coefficient 0.259 shows that a unit increase in fertilizer would lead on average to a 0.259 increase in the quantity of sorghum produced and the P-Value (0.000) <0.05 implies that the quantity of fertilizer used for growing sorghum significantly affects the level of production of sorghum, other factors held constant.

The coefficient 0.030 shows that a unit increase in pesticides would lead on average to a 0.030 increase in the quantity of sorghum produced and the P-Value (0.045) <0.05 implies that the quantity of pesticides used for growing sorghum significantly affects the level of production of sorghum, other factors held constant.

The coefficient 0.309 shows that a unit increase in the quality of seed would lead on average to a 0.309 increase in the quantity of sorghum produced and the P-Value (0.000) <0.05 implies that the quality of sorghum grown significantly affects the level of production of sorghum, other factors held constant.

Conclusion: We reject the null hypothesis and take the alternative hypothesis, concluding that land size, quality of seed, size of fertilizer, and pesticides significantly affect the level of production of sorghum.

4.5.1 Statistical Analysis of Sorghum Production Differences

This section employs statistical methods to assess potential variations in sorghum production between growing seasons B2020 and B2021.

Hypothesis Testing

A one-sample t-test was conducted to evaluate the following hypotheses:

- **Null Hypothesis (H_0):** The mean sorghum production for season B2020 is statistically equivalent to the mean production for season B2021.
- **Alternative Hypothesis (H_1):** The mean sorghum production exhibits a statistically significant difference between seasons B2020 and B2021. (This is a two-tailed test.)

Table 28: Table showing One-Sample Test for mean difference in Sorghum production in two seasons.

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
D Diff2	3.259	2 0	.006	19.41126	- 128.4726	167.295 1

Source: Primary data

Results: The analysis yielded a t-statistic of 3.259 and a two-tailed significance level (p-value) of 0.006.

Interpretation

- The p-value (0.006) falls below the commonly accepted significance threshold of 0.05. This statistically significant result suggests that the observed difference in average sorghum production between the two seasons is not likely due to random chance.
- Consequently, we reject the null hypothesis (H_0) and conclude that a significant difference exists in the mean sorghum production between seasons B2020 and B2021.
- The positive t-statistic (3.259) indicates that the mean production in one season is likely higher than the other. However, further examination of the data is necessary to pinpoint which season yielded the superior results.

Additional Considerations

Table 28 provides supplementary details for further investigation:

- **Mean Difference:** 19.41 units (the table doesn't specify the units, but it represents the average difference in production between the two seasons).

- **Confidence Interval:** The range (-128.47 to 167.29) indicates a 95% confidence interval within which the true difference in average production is likely to fall. While the interval encompasses a negative value (suggesting season B2020 could have been higher), the positive mean difference implies season B2021 was more likely to have a higher yield.

In Conclusion**,** the statistical analysis confirms a statistically significant difference in average sorghum production between seasons B2020 and B2021. To gain a more comprehensive understanding:

- Identify which season had the higher yield by examining the table or associated data.
- Conduct further research to explore potential factors contributing to the observed production difference. These could include weather patterns, pest or disease outbreaks, changes in farming practices, or other relevant variables.

By delving deeper into these aspects, we can glean valuable insights into the reasons behind the production disparity and potentially inform strategies to optimize sorghum yields in future growing seasons.

4.5.1 Cost Disparity in Labor- versus Oxen-Based Sorghum Production

This section investigates the potential cost differences between two dominant sorghum production methods: labor-intensive and ox-plow-driven approaches. A one-sample t-test was employed to assess the following hypotheses:

Null Hypothesis (H_0): The average cost of labor-based sorghum production is statistically equivalent to the average cost of ox plow-based production.

Alternative Hypothesis (H_1): A statistically significant difference exists between the average costs of the two production methods.

Table 29: Table showing Mean Difference in Cost of means of production.

	Test Value = 0					
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Diff_Cost	5.709	25	.000	-6346.15385	-24779.2469	12086.9392

Source: Primary Data

Statistical Results: The analysis yielded a statistically significant result (p-value < 0.000), indicating a strong rejection of the null hypothesis (H_0). This implies that the observed cost difference between the two methods is highly unlikely due to random chance.

Cost Differential: Further examination of Table 29 reveals a mean difference of -6346.15 units. While the specific cost unit remains unspecified, this value suggests that, on average, labor-based production incurs a lower cost compared to ox plow methods. The associated 95% confidence interval (-24779.25 to 12086.94) further strengthens this conclusion, as the entire interval falls within the negative range.

Considerations for Further Inquiry

- Cost Unit Clarification: Identifying the specific unit of cost (e.g., currency per unit of land area) would provide a more precise understanding of the cost differential.
- Cost Drivers: Exploring the potential factors influencing cost disparity is crucial. Labor costs might vary based on regional wage rates, while ox plow methods could involve upkeep or depreciation costs associated with the oxen.
- Comparative Efficiency: Investigating the efficiency and yield potential of each method would offer a more comprehensive perspective on cost-effectiveness. This could involve analyzing the amount of land cultivated per unit of labor or ox plow effort, along with the resulting sorghum yields.

By delving deeper into these aspects, a more comprehensive understanding of the relative costs and benefits of each production method can be achieved. This knowledge can inform strategies for sorghum producers in the region, enabling them to make data-driven decisions regarding the most cost-effective production approach for their specific context.

4.6 DISCUSSION OF THE FINDINGS

This study presented critical insights for stakeholders invested in improving sorghum production within the target region.

Farmer Demographics

The study predominantly surveyed male farmers (55.4%) with a diverse age range. Notably, over 63% lacked formal education beyond primary school. This highlights the importance of extension services in guiding these smallholder farmers in sorghum seed selection, appropriate production techniques, and soil management practices to optimize yields.

Sorghum Cultivation Practices

Land allocated for sorghum cultivation is typically small-scale, with most farms utilizing 0-3 acres. Red and brown sorghum varieties dominate plantings. Rainfed agriculture is the primary practice, with over 97% of farmers relying solely on precipitation. Cultivation involves a combination of manual labor (hand hoes) and animal traction (ox ploughs). Weeding is the most labor-intensive activity, primarily performed by hand.

Sorghum Variety Landscape

The presentation highlights the dominance of traditional sorghum varieties and the critical challenge posed by rain-fed agriculture. This finding is in line with a study undertaken by Kaliba et al(2018). The findings suggest potential avenues for improvement through:

- Introduction of improved varieties that are demonstrably well-adapted to local conditions.
- Addressing knowledge gaps or access limitations related to the adoption of improved varieties.
- Investigation and potential utilization of the diverse sorghum germplasm identified in the region, which could contribute to breeding programs.
- Implementation of drought-resistant varieties and exploration of alternative irrigation methods to mitigate the current over-reliance on rainfall.

These findings can inform future research endeavors, guide agricultural extension efforts, and influence policy decisions aimed at bolstering sorghum production and promoting food security within the target region.

Sorghum Production Analysis

Data collected from smallholder farmers over the past twelve months revealed the following key points:

- **Dominant Threat: Crop Damage:** A statistically significant proportion (85.7%) of respondents identified crop damage as the primary consequence of pest and disease infestations. This underscores the substantial negative impact these biological agents have on sorghum yields.
- **Limited Crop Failure and Soil Erosion:** While a smaller percentage of respondents reported experiencing complete crop failure (4.8%) or soil erosion (3.4%) due to pests and diseases, these occurrences can still materialize and pose a threat.

It is important to acknowledge that the one-year survey timeframe may not capture the full spectrum of pest and disease impacts, which can vary depending on seasonal conditions. Additionally, the data suggests that while high-intensity rainfall events were infrequent during the study period, they can have severe negative consequences for households and sorghum production when they do occur.

Enhancing Rain-Fed Sorghum Production Efficiency

This section of the study evaluated the influence of four key farm inputs on sorghum yields: land size, seed quality, fertilizer application, and pesticide use. A multiple linear regression model quantified the relationship between these inputs and sorghum production. This approach effectively isolated and measured the independent effect of each input while controlling for the influence of other variables.

The model yielded a statistically significant R-squared value of 0.571, indicating that 57.1% of the variation in sorghum production can be attributed to the combined effects of the four investigated farm inputs. Land size emerged as the most prominent factor influencing sorghum production, followed by seed quality, fertilizer application, and pesticide use. All four farm inputs exhibited a statistically significant positive association with sorghum production. This implies that increasing land allocation, using high-quality seeds, applying fertilizer judiciously, and employing appropriate pesticides can lead to demonstrably higher sorghum yields.

Conclusion and Recommendations: The findings presented offer valuable insights for policymakers, agricultural extension agencies, and farmers in the region. By prioritizing strategies that:

- Enhance land availability for sorghum cultivation.
- Promote the adoption of high-quality seeds.
- Encourage the wise use of fertilizer.
- Advocate for the judicious application of pesticides.

Stakeholders can work collaboratively to achieve significant improvements in rain-fed sorghum production efficiency. This, in turn, can contribute to bolstering food security and livelihoods within local communities.

The study also highlights the vulnerabilities faced by smallholder sorghum farmers in the Lira and Oyam Districts due to their reliance on rain-fed agriculture and limited use of modern inputs. These factors leave them exposed to the negative impacts of climate variability, particularly droughts. These findings provide valuable insights for policymakers and development agencies to design interventions that can improve sorghum production in the region. Possible areas of focus include promoting the adoption of drought-resistant sorghum varieties, implementing water management techniques, and improving access to high-quality seeds and appropriate technologies.

CHAPTER FIVE

SUMMARY, CONCLUSION, AND RECOMMENDATION

5.1 INTRODUCTION

This chapter presents the culmination of a study that investigated the influence of rain-fed cropland characteristics on sorghum productivity achieved by smallholder farmers in Uganda's Oyam and Lira Districts. The chapter summarizes the key findings, conclusions drawn from the analysis, and recommendations for future action

5.2. SUMMARY OF THE FINDINGS

5.2.1. Farmer Demographics and Rainfed Cropland Characteristics

This section delves into the demographic characteristics of sorghum farmers and the attributes of their rain-fed croplands in Oyam and Lira Districts.

Gender Distribution: The study revealed a gender disparity in sorghum production, with males constituting the majority (55.4%) of respondents. Lira District exhibited a slightly lower proportion of male farmers compared to Oyam. Age analysis indicated that adult farmers comprised the largest group (58.4%), followed by youth (23.2%) and elderly individuals (18.4%). This trend was consistent across both districts.

Educational Attainment: A significant portion of the sorghum farming population (38.6%) possessed a primary education as their highest level of formal education. A substantial number (24.9%) lacked any formal schooling. Secondary education was achieved by 18% of the respondents, while post-secondary and technical education were less prevalent (8.6% and 1.7%, respectively). This finding suggests a limited educational background among sorghum farmers.

Land Access and Utilization: Land access was predominantly restricted, with 67.8% of farmers cultivating on plots between 0-3 acres. The availability of larger landholdings progressively decreased, with 17.6% having access to 3-6 acres, 9% to 6-9 acres, and only 5.2% to 9-12 acres. This implies that most farmers practice sorghum cultivation on small plots. Land use analysis for seasons B2021 and B2020 revealed a similar pattern. The vast majority (92.3%) of farmers utilized an average land size of 0-3 acres for sorghum production. Only a minimal portion employed larger land sizes (3-6 acres and 6-9 acres) during these seasons.

Water Reliance: Rainfed agriculture emerged as the dominant irrigation practice, with 97.8% of respondents relying solely on precipitation. Oyam District exhibited a slightly higher dependence on rainfall (51.9%) compared to Lira District (45.9%). This highlights the vulnerability of farmers to the vagaries of climate change due to their dependence on unpredictable rainfall patterns.

Farm Mechanization: The study observed a reliance on rudimentary tools for farm operations. Hand hoes were the primary implements for both weeding (98.3%) and land preparation (57.3%). Ox ploughs played a secondary role in secondary tillage (54.7%), while hand hoes remained the prevalent tool for planting (53%). The utilization of other farm tools was minimal. This finding suggests a prevalence of traditional farming practices

5.2.2. Sorghum Production Practices and ChallengesPrevalent Cultivation Practices:

The analysis revealed that crop rotation and double ploughing before planting were the most prevalent practices associated with enhanced sorghum yields. These practices were implemented by 93.1% and 71.6% of the respondents, respectively. Land fallowing and single weeding before harvest were less frequently reported.

Sorghum Variety Selection: The predominant sorghum cultivars grown during the past two seasons were indigenous red sorghum (46.4%) and brown sorghum (20.5%). A significant proportion (17.9%) of respondents cultivated unspecified sorghum varieties. This finding suggests a potential reliance on traditional, potentially unimproved, sorghum cultivars among a substantial number of farmers.

Production Obstacles**:** The primary constraint identified by sorghum producers was insufficient rainfall, impacting 78.2% of respondents. Subsequent challenges included pest infestations (62%), diseases (54.1%), and limited access to high-quality seeds (52.4%). Storage limitations and poor soil fertility were identified as less prevalent obstacles.

5.2.3 Analysis of Productive Efficiency

Econometric Modeling: A Cobb-Douglas regression model was employed to assess the factors influencing sorghum production. The model's R-squared value of 0.571 indicates that 57.1% of the variation in sorghum production can be attributed to the explanatory variables: land size allocated for sorghum cultivation, fertilizer application, pesticide use, and seed quality. This suggests a statistically robust fit between the model and the observed data.

Hypothesis Testing: The F-statistics joint significance level (0.000) implies a statistically significant collective influence of land size, seed quality, pesticide application, and fertilizer use on sorghum production levels ($p < 0.05$).

5.2.4 Impact of Key Inputs on Sorghum Production

Land Size: The regression coefficient (0.316) signifies a positive and statistically significant relationship ($p < 0.05$) between land size dedicated to sorghum cultivation and sorghum yield. A unit increase in land area cultivated with sorghum leads to, on average, a 0.316 unit increase in sorghum production.

Fertilizer Application: The coefficient (0.259) suggests a statistically significant positive impact ($p < 0.05$) of fertilizer use on sorghum yields. A unit increase in fertilizer application results in an average increase of 0.259 units in sorghum production.

Pesticide Use: The coefficient (0.030) indicates a statistically significant but relatively smaller positive impact of pesticides compared to land size and fertilizer ($p < 0.05$). A unit increase in pesticide use leads to an average increase of 0.030 units in sorghum production.

Seed Quality: The coefficient (0.309) emphasizes the significant positive influence of high-quality seeds on sorghum yields ($p < 0.05$). A unit increase in seed quality translates to an average increase of 0.309 units in sorghum production.

5.2.5 Production Seasonality and Cost Variations

Production Season Differences: A one-sample t-test revealed a significant mean difference in sorghum production between seasons B2020 and B2021 ($p < 0.05$), suggesting that production levels varied between the two growing seasons.

Production Cost Fluctuations: The one-sample t-test analysis indicated a significant mean difference in the costs associated with labor and ox plow use between the two seasons ($p < 0.05$). This suggests variations in production costs across the growing seasons.

5.2.6 Climate Shocks and Pest Outbreaks

Low Rainfall: A substantial majority (89.7%) of respondents reported experiencing low rainfall in the past year. The most frequent occurrence of low rainfall events was twice per season (55.5%). Crop failure was identified as the primary consequence of low rainfall (49.3%).

Pest and Disease Outbreaks: Over 60% (61.3%) of farmers encountered pest and disease outbreaks in the past year. The most frequent occurrence was twice per season (53.1%). Crop damage was the predominant effect of pests and diseases (85.7%).

Hailstones: Hailstones affected 36.5% of respondents in the past year, primarily occurring once a season (43.5%). Crop damage was reported as the major consequence (94.1%).

Floods: Floods were the least frequent climate shock, impacting only 11.2% of respondents in the past year. The primary effect of floods was crop damage (38.5%).

These findings highlight the vulnerability of rain-fed sorghum production to climate variability and pest outbreaks. They underscore the need for strategies to enhance resilience and mitigate these production risks.

5.3. CONCLUSION

This study investigated the factors influencing rain-fed sorghum production among smallholder farmers in Oyam and Lira Districts, Uganda. The findings highlight the importance of land size, fertilizer application, pesticide use, and high-quality seeds in achieving greater sorghum yields. However, the predominance of traditional farming practices and reliance on rain-fed agriculture leave farmers vulnerable to climate variability and pest outbreaks.

The report also reveals significant variations in production levels and costs across seasons, suggesting the need for strategies to enhance resilience and promote sustainable production practices.

In conclusion, adopting improved seeds, implementing integrated pest management approaches, and promoting drought-resistant varieties and water-saving irrigation techniques are crucial for boosting productivity and building resilience to climate shocks. Strengthening access to credit, inputs, and extension services can further empower smallholder farmers to achieve sustainable sorghum production in the region.

5.4. RECOMMENDATION

The analysis presented in this report offers valuable insights into the factors influencing rain-fed sorghum production among smallholder farmers in Oyam and Lira Districts. Based on these findings, several recommendations are proposed to enhance productivity, improve resilience, and promote the long-term sustainability of sorghum cultivation in the region.

5.4.1 Farm Management Practices

High-Quality Sorghum Seed Adoption: The report highlights the significant positive impact of high-quality seeds on sorghum yields. Encouraging the widespread adoption of improved, disease-resistant sorghum varieties can significantly enhance production. Collaborative efforts with seed companies and agricultural extension services are crucial to ensure the accessibility and affordability of these improved seeds for smallholder farmers.

Land Management and Resource Optimization: The analysis indicates a positive correlation between land size and sorghum production. Strategies to support land tenure security and optimize land use for sorghum cultivation should be explored. Additionally, promoting practices like crop rotation and proper soil management techniques can significantly improve soil fertility and ensure long-term productivity gains.

Integrated Pest Management (IPM) Training: The prevalence of pest and disease outbreaks underscores the need for capacity building through the implementation of IPM training programs. Equipping farmers with the knowledge and skills to identify pests and diseases, implement preventative measures, and utilize appropriate control methods, when necessary, will contribute to improved crop health and yield protection.

5.4.2 Enhancing Resilience to Climate Variability

Drought Mitigation Strategies: Given the high dependence on rain-fed agriculture and the negative impact of low rainfall on sorghum production, promoting drought-resistant sorghum varieties and water-saving irrigation techniques, such as rainwater harvesting, is crucial.

Climate-Smart Agricultural Practices: Encouraging farmers to adopt climate-smart agricultural practices can enhance their resilience to weather variability. This could involve mulching, early planting, and utilizing appropriate spacing for crops to optimize water use efficiency and minimize water stress during dry periods.

Access to Weather Information and Insurance Schemes: Providing farmers with timely and accessible weather information can help them make informed decisions regarding planting schedules and resource allocation. Exploring the feasibility of micro-insurance schemes to mitigate financial losses due to extreme weather events can also be beneficial in building resilience.

5.4.3 Strengthening Financial and Extension Support Systems

Credit and Input Availability: While not explicitly mentioned in the report, it can be assumed that financial limitations might hinder some farmers from adopting improved seeds or fertilizers. Facilitating access to credit or microloans for purchasing essential inputs can encourage investment in productivity-enhancing practices.

Strengthening Agricultural Extension Services: The findings suggest a potential lack of awareness regarding improved sorghum varieties or best practices. Strengthening agricultural extension services and promoting farmer-to-farmer knowledge exchange programs are critical to bridge this gap and ensure the widespread adoption of productive and sustainable sorghum cultivation methods.

By implementing these recommendations, policymakers, agricultural development agencies, and extension service providers can empower smallholder farmers to achieve higher sorghum yields, build resilience to climate shocks, and ensure the long-term sustainability of rain-fed sorghum production in the region.

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APPENDICES.

APPENDIX I: Focus Group Guiding Questions

Focus Group Discussion Guiding Question

Introduction:

Good morning/afternoon everyone. Thank you for joining me today. My name is Jasper Okello, and I'm a master's student in Agroecology at Uganda Martyrs University. I'm conducting research on sorghum productivity in rain-fed croplands in the Oyam and Lira Districts. As part of my research, I'm interested in understanding your experiences and knowledge of sorghum farming practices in these districts. Your insights will be invaluable in helping me achieve a comprehensive understanding of this topic...

Sorghum Production in Rain-Fed Croplands:

1. What are the typical practices for planting and managing sorghum in your community? *(This aims to understand general practices related to rain-fed cropland sorghum production.)*
2. Can you describe the challenges you face in cultivating sorghum on rain-fed croplands? *(Focuses on factors potentially impacting productivity.)*
3. In your experience, what are some ways to improve sorghum yields in rain-fed croplands? *(Explores potential solutions and best practices from the farmers' perspective.)*

Sorghum Productivity:

1. How would you define a "good sorghum harvest" in your community? *(Establishes local benchmarks for productivity.)*

2. Have you noticed any changes in sorghum productivity over the past few years? If so, what factors do you attribute these changes to? *(Gathers insights on sorghum production trends and influencing factors.)*
3. Are there any farmers in your community known for consistently high sorghum yields? If so, what practices do they employ that might contribute to their success? *(Identifies potential best practices among local farmers.)*

Efficiency and Levels of Production:

1. In addition to the amount of sorghum harvested, are there other factors you consider important when evaluating the efficiency of sorghum production? *(Explores the concept of efficiency from the farmers' perspective.)*
2. What are the typical resources used for sorghum production (e.g., seeds, labor, fertilizer)? How have these resources changed over time? *(Focuses on production inputs and potential changes impacting efficiency.)*
3. Are there any government programs or initiatives in place to support sorghum production in your communities? If so, how effective have they been in improving yields or efficiency? *(Examines external factors affecting production levels.)*

- THE END –

APPENDIX II: SURVEY TOOL HOUSEHOLD SURVEY

Guidance for introducing yourself and the purpose of the interview:

- My name is ___________________ and I am collecting this information on behalf of Okello Jasper, a student of Agro-Ecology at Uganda Martyrs University.
- Your household has been selected by chance from all households in the area for this interview. The purpose of this interview is to obtain information about households' production of sorghum and maize that depend on rainfed in this area.
- The survey is voluntary and the information that you give will be confidential. The information will be used to prepare reports but will not include any specific names. There will be no way to identify that you gave this information.
- Could you please spare some time (around 30 minutes) for the interview? Consent given □

Please DO NOT suggest in any way that household entitlements could depend on the outcome of the interview, as this will affect the answers.

Basic Information			**BAIN**
Date of Data Collected ____/_______/_____ *DD/MM/YYYY*	Name of Data Collector _______________________	Village: _______________	Parish: ___________________
Sub County ___________________	District 1 2		

District Code: Lira (1), Oyam (2)

Demographic Information DMHH			
1. Are you the household head (HH)		Yes= 1 No= 0	
Ask for and record the name, age, and sex of the household head as follows			
2. Name of HH	Sex	**Age** Year_______________ Month ___________ Not sure__________________	
3. What is the highest level of schooling you have attained? Never attended= 0, Preschool=0, Primary /Basic =2, Secondary= 3, Post-Secondary=4, technical education=5, Don't know =10.			

Sex: Male= 1, Female = 2

Household asset	**HHAS**
4. What is the average size of farmland you have access to?	1. 0 – 3 acres 2. 3 - 6 acres 3. 6 – 09 acres 4. 09 – 12 acres 5. Other... specify
5. How much land do you use for growing sorghum in Season B 2021?	1. 0 – 3 acres 2. 3 - 6 acres 3. 6 – 09 acres

	4. 09 – 12 acres 5. Other... specify
6. How much land do you use for growing sorghum in Season B 2020?	1. 0 – 3 acres 2. 3 - 6 acres 3. 6 – 09 acres 4. 09 – 12 acres 5. Other... specify
7. Do you depend on rainfall for the production of Sorghum?	Yes = 1 No = 0
8. What do you use for growing and managing sorghum?	*Enter right multiple answers!* 1. Ox plough for opening land 2. Ox plough for second ploughing, 3. Ox plough for planting 4. Ox plough for wedding 5. Hand hoe for opening land 6. Hand hoe for second ploughing 7. Hand hoe for planting 8. Hand hoe for weeding

	9. Others, specify………
Sorghum production	
9. What do you do to ensure that have a good production of sorghum in the last 2 growing seasons?	Yes = 1, No = 0
Plough the farm field twice before planting	
Use fertilizer	
Allow land to fallow	
Use crop rotation	
Weed once before harvest	
Weed twice before harvest	
Use pesticide	
10. Which sorghum variety have you been planting for the last two growing seasons	Yes = 1, No = 0
SESO-1	
SESO-2	
NAROSORG 1	
NAROSORG 2	
NAROSORG 3	
NAROSORG 4	
SESO- 3	
Indigenous Variety – Red sorghum	
Indigenous Variety – Brown Sorghum	
Others(Specify)	

11.	What is the major challenge/problem in sorghum production?	Multiple answers 1. Rainfall 2. Pest 3. Diseases 4. Poor soil 5. Access to seed 6. Storage facilities 7. Other. specify …..

12. Sorghum production cost in the last two growing seasons 2020/2021			
Season B 2021		**Season B 2020**	
Land Size =		**Land Size=**	
Particular	Estimate cost	Particular	Estimated Cost
Land hire		Land hire	
Opening of land		Opening of land	
First ploughing		First ploughing	
MSecond ploughing		Second ploughing	
Weeding		Weeding	
Fertilizer		Fertilizer	
Pesticides		Pesticides	
Seeds		Seeds	
Harvesting		Harvesting	
Transportation to store		Transportation to store	
Storing and bagging		Storing and bagging	

Others (Specify)		Others (Specify)	
Total Volume produced in Kg		**Total Volume produced in Kg**	

13. Access to Services _ Sorghum production cost in the last two seasons 2020/2021			
Season B 2021		**Season B 2020**	
Human Labor			
Land Size=		**Land Size=**	
Particular	**Estimate cost**	**Particular**	**Estimated Cost**
Land hire		Land hire	
Opening of land		Opening of land	
First ploughing		First ploughing	
Second ploughing		Second ploughing	
Weeding		weeding	
Applying Fertilizer		Applying fertilizer	
Spraying with Pesticides		Spraying pesticide	
Harvesting		Harvesting	
Drying and Bagging		Drying and bagging	
Transportation to home		Transportation to home	

14. Access to Services _ Sorghum production cost in the last 12 months 2019/2020			
Season B 2021		**Season B 2020**	
Ox plough			
Land Size=		**Land Size=**	
Particular	Estimate cost	Particular	Estimated Cost
Opening of land		Opening of land	
First ploughing		First ploughing	
Second ploughing		Second ploughing	
Applying Fertilizer		Applying fertilizer	
Transportation		Transportation	

15. Rainfall shocks experienced on sorghum production in the last two planting seasons 2020/2021				
	Did you experience rainfall shocks in the last 12 months? 1=Yes, 0=No	If yes, how many times has it occurred? Once a season = 0 Twice a season= 1 Thrice a year = 2 Four times a year = 3 None = 00	What was the intensity of the last shock to this household? Severe = 0 Moderate = 1 Mild = 2 None = 3	How was your sorghum affected? Erosion of gardens = 1 Crops failure = 2 Crop damage =3 None = 4
Low rainfall intensity				

High intensity				
Hailstorm				
Flood				
Pest and diseases				

- THE END-

APPENDIX III: Key Informant Interview Guide

General Background (for all Key Informants):

1. Can you tell me a little bit about yourself and your experience with sorghum farming in [District Name]?
2. For how long have you been involved in sorghum production?
3. In your experience, what are the main challenges faced by smallholder farmers when growing sorghum in rainfed cropland?

Specific Objectives:

Characterize Sorghum Productivity:

- In your experience, what are the typical sorghum yields achieved by smallholder farmers in this district?
- Have you observed any changes in sorghum productivity over the past few years? If so, what factors do you attribute to these changes?
- What are the different varieties of sorghum commonly grown in this area? Are there any specific varieties known for their high yields or drought tolerance?

Production Level:

- On average, how much sorghum do smallholder farmers typically harvest from their rain-fed cropland each season?
- Are there any factors that influence the amount of sorghum produced by farmers (e.g., land size, access to inputs, weather patterns)?
- How important is sorghum production for household food security and income generation in this region?

Productive Efficiency:

- In your opinion, how efficient are smallholder farmers in utilizing their rain-fed cropland for sorghum production?
- Are there any practices or technologies that could help improve the efficiency of sorghum production in this area (e.g., improved seed varieties, water management techniques)?
- What are the main constraints that limit the productive efficiency of rain-fed cropland for sorghum production?

Probing Questions:

Characteristics of Increased Productivity:

- **Follow-up questions based on responses**
- Can you elaborate on the specific practices or factors associated with increased sorghum productivity in this region?
- Are there any successful examples of farmers achieving high sorghum yields in rainfed cropland? If so, what are their key strategies?

Rainfed Cropland and Sorghum Production:

- **For Farmers and Community Leaders:**
- How does the availability and distribution of rainfall during the growing season impact sorghum production in this area?
- Have you observed any changes in rainfall patterns in recent years? How has this affected sorghum yields?
- Are there any traditional or modern techniques used by farmers to manage water resources and improve sorghum production in rainfed cropland?

Levels of Efficiency:

- **Follow-up questions based on responses**
- Can you provide specific examples of practices that could improve the efficiency of resource use (land, water, labor) for sorghum production?
- Are there any initiatives or programs currently in place to support farmers in improving their sorghum production efficiency? If so, what are their strengths and weaknesses?

-THE END -