COMPARATIVE GENDERED ASSESSMENT OF PRODUCTIVITY, TECHNICAL EFFICIENCY AND TECHNOLOGY GAPS IN SORGHUM PLOTS IN THREE DISTRICTS OF UGANDA

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DECLARATION

This thesis is my original work and has not been submitted to any other university for any award.

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DEDICATION

This thesis is dedicated to my caring parents Hosea Miriti, Charity Miriti and siblings Gacheri, Munene, Kirimi, Mukami, Mutwri and Gitonga for their prayers and support that has inspired my academic and personal life.

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ACRONYMS

API	Average Productivity Index
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
FGD	Focused Group Discussion
FDH	Free Disposal Hull
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
LR	Likelihood Ratio
MPP	Marginal Physical Product
OLS	Ordinary Least Square
PFP	Partial Factor Productivity
SSA	Sub-Saharan Africa
SFA	Stochastic Frontier Analysis
SDG	Sustainable Development Goal
TE	Technical Efficiency
TGR	Technology Gap Ratio
TPF	Total Factor Productivity

ABSTRACT

The agricultural sector is faced with productivity differentials among male, female and jointly managed plots especially in developing countries, which affect technical efficiency (TE). In Sub-Saharan Africa (SSA) gender productivity differentials vary between 4 and 40%, this negatively affects the overall agricultural output both at the household and national level. Differences in efficiency have been mainly attributed to gender-related constraints that affect female plot managers differently compared to their male counterparts, together with socio-economic and institutional systems. Although past studies have tried to quantify productivity and TE differentials, they have often been faced with methodological challenges because most of them have used the head of the household as the gender variable instead of the plot manager involved in actual farm operations and management. In order to offer insights on this critical aspect, this study analyzed sex-disaggregated cross-sectional data collected from 362 farmers in three districts of Uganda (Kumi, Lira and Serere) between October and November 2017 by the International Crops Research Institute for the Semi-Arid Crops (ICRISAT). Descriptive statistics and Ordinary Least Squares (OLS) regression were used to assess determinants of productivity. A stochastic metafrontier approach was applied to analyze TE and technology gaps between the male, female and jointly -managed sorghum plots while a two-limit tobit model was estimated to assess determinants of TE.

Results of the stochastic metafrontier showed that female farmers in Serere and Kumi districts had higher TE scores compared to male-managed plots, which was attributed to women taking advantage of the informal labour rotation groups, while in Lira where sorghum farming is commercialized, male plot managers had a higher mean TE score compared to female plot managers. Jointly-managed plots had a higher mean TE score across the three study areas than female-managed plots but lower compared to male plots. Male plot managers had a higher mean

TE with respect to the metafrontier and mean technology gap ratio (TGR) compared to female-managed plots, while jointly-managed plots had a higher mean TE and mean TGR than female-managed plots but lower compared to male-managed plots.

Results of the two- limit tobit model showed that the age of sorghum plot managers, years completed in formal education, use of family labour, distance to sorghum plots and plot size had significant positive effects on TE. On other hand, sorghum plot managers' years of farming and household size influenced TE negatively. Since sorghum is commercialized in Lira district unlike in Kumi and Serere district, holding Lira district constant revealed that plot managers in Kumi and Serere district had lower TE of 2.7 % and 4.8%, respectively compared to Lira district.

The study recommends sustainable development interventions by non-governmental organizations in contrast to public or joint public-private interventions. This promotes capacity building for female sorghum plot managers to utilize various farm inputs effectively taking into account diversity in agricultural production (small-scale, medium-sized and large-scale production). Small scale plot managers require provision of farm inputs which influence productivity and TE. Medium and large-scale plot managers may need newer varieties since they may be operating optimally using the current technology available.
Moreover, policies geared towards promoting universal access to education among male and female farmers, provision of farm inputs such as certified seeds through agricultural institutions as opposed to use of military and investment in developing new seed varieties to obtain further productivity gains would play a key role in increasing sorghum productivity, TE and TGRs of small holder farmers in Uganda.

Key words: productivity, technical efficiency, technology gap, sorghum, gender.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Sorghum (*Sorghum bicolor)* is a drought tolerant crop and at the global level, it is the fifth starchy crop in terms of quantity consumed after maize, rice, potatoes and wheat, respectively (Sekoli and Morojele, 2016). In Africa it's the second staple grain crop after maize (Mundia et al. 2019). Sorghum is majorly cultivated for food and fodder especially by smallholder farmers in drylands that are characterized by low soil fertility, inadequate extension services and erratic rainfall (Shamme and Raghavaiah, 2016). Sorghum contributes approximately 50% micronutrient requirements of small-holder farmers living within the semi-arid tropics of Africa and Asia (Kumar et al., 2018)

Sorghum has morphological characteristics that make it one of the main drought tolerant crops besides millet and cowpeas. It counters water loss during the dry season by rolling its leaves, if the dry season persists the crop becomes dormant rather than drying up and the leaves are covered by a waxy substance to reduce evapotranspiration (Ramatoulaye et al., 2016).

The annual global sorghum production is approximately 60 million tonnes (USDA, 2018a). Africa and Asia contribute around 90% of the sorghum harvested area and globally, Africa contributes around 60% of the harvested area and around 40% of production while Asia accounts for 22% of the harvested area and approximately 18% of the production (Mundia et al., 2019). In Uganda, sorghum is an important dryland cereal after maize and wheat in terms of production (Wang et al., 2015). It is majorly grown in the lowland areas of North and Eastern region and the South-Western highlands. The land under sorghum cultivation has increased from 280,000 ha to 370,000 ha in the last decade. It is a staple crop for a majority of people in areas where it is grown and serves as an important raw material for processed traditional food and locally brewed beer (Awegechew et al. 2018). The main 20 sorghum producing countries in the world are shown in Figure 1.

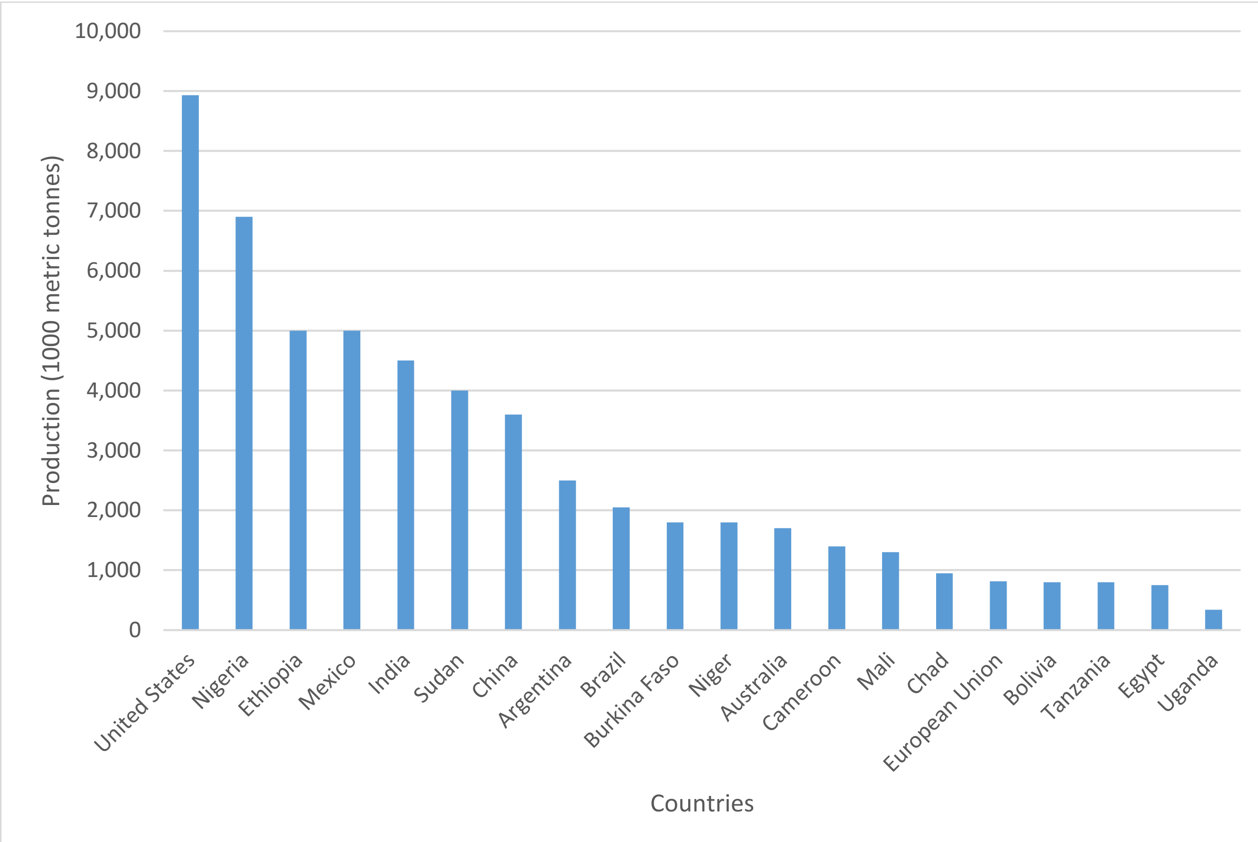

Figure 1: Top Twenty Sorghum Producing Countries in the World

Source: USDA (2018b)

Sorghum farmers in the top producing countries have adequate institutional support from their governments in terms of provision of certified seeds, pest and disease control, market access and fertilizer subsidies which enhance productivity. Uganda is the 20th largest producer of sorghum globally contributing approximately 0.5% of the world production. The annual production of sorghum has been fluctuating, however, it increased from 298,676 tonnes in 2015 to 314,553 tonnes in 2016 (Factfish, 2018). Sorghum production in Uganda can be improved through creating a conducive environment for farmers by reducing production challenges such as low soil fertility, pest infestation and exploitation by middlemen (Manyasa, 2016). The agricultural sector in Uganda accounts for 72% of all the employed women and nearly 76% of all rural women while around 65% of men in rural areas are employed in the sector (FAO, 2018). Despite the high percentage of women working in agriculture, only 20% own registered land (Sanjines et al., 2018).

Gender differentials in agricultural productivity are more evident in developing countries where female-managed plots tend to exhibit lower productivity compared to male-managed plots. Doss (2018) argued that female farmers have lower levels of human capital and resource base compared to male farmers hence they have low ability to respond to subsidy programs and agricultural incentives. A critical review of various studies undertaken in the 1990s found that in situations where there was control for differences in access and usage of inputs, TE variations between male and female farmers were not significant (Koirala et al., 2015).

In Sub-Saharan Africa (SSA), women contribute around 60 to 80% of the agricultural labour-force, but their plots are less productive compared to male-managed plots in the same localities (Palacios-Lopez et al., 2017). In Malawi, Kilic et al. (2013) found that female-managed plots were less productive by 25% compared to male-managed plots while 82% of the differences in agricultural productivity could be explained by observable characteristics between the male and female plot managers.

The gender gap in productivity has been increasing since a majority of the existing institutional arrangements are geared towards male-managed plots leading to the overall decline in production. Closing the agricultural productivity differentials between male, female and jointly- managed plots can lead to an increase in agricultural production in developing countries by 30% (AGRA, 2019). Therefore, interventions aimed at bridging gender gaps in production has been receiving focus by policy makers.

Agricultural productivity is highly determined by how efficiently plot managers are able to utilize farm inputs. Literature has shown that male and female plot managers are equally productive considering similar farm tasks (Brown, 2019). However, variances in TE between male and female-managed farms can be attributed to use of lower levels of farm inputs such as labour, seed and fertilizer. Notably, lower access to farm inputs is more dominant in female-managed farms compared to male- managed (Sell et al., 2018).

1.2 Statement of the Research Problem

Over the years, the land under sorghum cultivation in Uganda has remained relatively stable but productivity has been declining, production declined from approximately 457,500 tonnes in the year 2007 to 316,700 tonnes in 2017 (FAOSTAT, 2017) thus affecting livelihoods of rural farmers. Application of fertilizer on sorghum field is very low and only 8.3% of smallholder farmers use the readily available manure from livestock thus lowering productivity and efficiency. These coupled with lack of ready sorghum markets impact negatively on the farmers (Tenywa et al., 2018).

In Eastern and Northern rural areas of Uganda, women are intensively involved in farm work. The share of female agricultural labour in Uganda is over 50% (Palacios-Lopez et al., 2017), however, the productivity and efficiency of female managed plots remain lower than that of men, hence affecting the overall productivity negatively (Sell et al., 2018). Addressing gender gaps in productivity and TE among plot managers leads to a direct effect on the quantity of yield produced, household income and food security.

Majority of past studies on gender, TE and technology gaps in SSA have assessed TE between male and female farmers and in the efficiency model, household headship has been used as the gender indicator (Tesfaye et al., 2015; Addison et al., 2016**;** Gebremariam et al., 2019)**.** Moreover, other empirical studies have focused on two main streams of inquiry (Kilic et al., 2015). The first stream comprises studies that conduct their analyses at the household level and do not link plot level outcomes to individual plot managers; inter-household analyses (Ali et al., 2015). Inter-household analyses use agricultural production in female and male headed households as proxies for farming on male and female managed plots. They simply estimate the gap in mean yield and then test for differences in resource endowment (distribution of resources) or return to resource endowment. The second strand are referred to as intra-household studies composed of few empirical studies using plot-level data that link plot-level outcomes to individual managers within the study households (Kilic et al., 2015; Sell et al., 2018). Intra-household approaches use plot level agricultural data and the sample is restricted to households where both male and female-managed plots are present.

Little has been done on TE analyses of sorghum in male and female-managed plots using farm level data where the gender indicator is the plot manager (Owusu et al. 2017)**.** It is possible for other household members to be in charge of daily decisions on plot activities rather than the household head. Therefore, using the household head as the gender identifier constrains matching the individual in charge of the plot activities to input use and productivity (Peterman et al., 2011)**.** This study adds value and contributes to the current literature on efficiency by assessing TE and technology gap using data collected at the plot level where the plot manger was used as the gender indicator.

1.3 Research Objectives

The main objective of the study was to assess and compare gendered productivity, TE, technology gaps and factors that influence TE of sorghum farmers in three districts of Uganda.

The specific objectives were to:

1. Assess determinants of productivity of sorghum plots.
2. Compare TE and technology gaps in male, female and jointly-managed sorghum plots.
3. Analyze determinants of TE in sorghum production.

1.4 Research Hypotheses

1. Farm and farmer characteristics do not influence productivity of sorghum plots.
2. There are no differences in technical efficiency and technology gap between male, female and jointly managed plots in the three districts
3. Socio-economic characteristics of farmers do not affect TE of sorghum production.

1.5 Justification of the Study

The study contributes to the Sustainable Development Goals (SDGs) of ending poverty (SDG 1) and promoting gender equality (SDG 5) by the year 2030 (United Nations, 2015) by assessing gender differences in agricultural productivity, TE and technology gap ratios (TGRs). The findings contribute to Malabo Declaration that aims at doubling agricultural production by the year 2025 to address the issues of hunger in Africa and halving poverty levels (AU, 2014) by critically bridging the gender gap in agriculture.

Assessment of factors that influence productivity and TE of sorghum plot managers using plot levels data provides vital analytical insights. They can be used in targeting gendered policies to female, male and jointly managed sorghum plots to improve access to farm inputs. For example, providing improved sorghum varieties and intuitional support services to resource poor rural sorghum plot managers to enhance sorghum output as well as household income.

The findings on TE and technology gap differences between male and female managed plots provides insights to agricultural policy makers in understanding variance levels of technical efficiency and technology gap between the two groups. This is important in informing the design of policy instruments aimed at reducing such differences and empower female farmers who are traditionally perceived to operate at low levels of technology and efficiency (Doss, 2015).

The study is envisaged to contribute to Agricultural Sector Strategic Plan (ASSP) and the Second National Development Plan 2015/2016 – 2019/2020 which aim to provide gender sensitive mechanization and commercialization of agriculture to increase competitiveness of farmers (Republic of Uganda, 2015). Assist government agencies like National Agricultural Advisory Services (NAADS) with insights on promoting the sorghum sub-sector through appropriate targeting of programs aimed at increasing efficiency of farmers.

1.6 Study Area

The study focused on the Northern (Lang'o) and Eastern (Teso) parts of Uganda that are predominantly involved in sorghum production. In Lang'o region, the study focused on Lira district while in Teso region, Serere and Kumi districts. The study sites are indicated in Figure 2 below.

Figure 2: Map of Uganda Highlighting the Study Sites

Source**:** Uganda Bureau of Statistics (2017)**.**

Lira district lies in the Northern part of Uganda named after its main town Lira. The bordering districts are Pader and Otuke on the northern sides, Alebtong and Dokolo districts to the Eastern sides, Apac and Kole districts to the West. The major administrative and commercial town in the district is Lira, which is located southeast of the largest city in Northern Uganda, Gulu town. The district has four counties namely; Lira Town council, Erute South County, Moroto County and Erute North County. The district lies on latitude 2.2316° N and Longitude 32.9438° E and according to 2012 national census, it had a population of 403,100. Parts of the district are covered by wooded savanna. However, the areas that were originally occupied by savanna are being used for farming and grazing (Kaweesa et al.2018) . About 60% of the population have access to water, 71% depend on subsistence farming for their livelihood, 15% have access to electricity and illiteracy levels are around 72% (UBOS, 2017a). The district receives about 1300mm of convectional rainfall that is normally experienced in the afternoon and evening. Households derive their livelihood through growing of coffee, beans, maize, millet, sweet potatoes, *matoke*, sorghum and livestock keeping.

Serere district lies in Eastern Uganda and is named after the 'chief town', Serere. It is bordered by Soroti district, Kaberamaido district, Ngora district, Kaliro, Pallisa and Buyende district to the south. In the 2012 national population census, the district had approximately 294,100 people and it lies on latitude 1.4994° N and longitude 33.5490° E. The region is characterized by extreme seasonal variation in rainfall although it rains throughout the year. The district receives an average of 1250mm rainfall annually, annual mean temperature of 25° C, 83% of the households have access to water, 95% of the population depend on agriculture for their livelihood and illiteracy levels of 69% (UBOS, 2017b). The major crop grown includes cassava, rice, sweet potatoes, groundnuts sesame, maize, millet, cowpeas, beans and sorghum, while the major livestock reared are cattle and goats.

Kumi district is named after its main town Kumi and it is located in the Eastern region of Uganda. The district is bordered by Katakwi and Nakapiripirit district, Pallisa district to the South, Ngora district and Bukeda district to the East. According to the 2012 population census, the district has a population of about 255,500 and lies on latitude 1.4877° N and longitude 33.9304° E. The district receives an average of about 900mm of rainfall, mean annual temperature of 24° C, 99% of the households use wood fuel, illiteracy levels are about 72%, 61% have access to water, 85% of the population have access to health and more than half of the soils are sandy (UBOS, 2017c). Households are actively involved in cultivation of sweet potatoes, beans, maize, millet and sorghum as well as livestock rearing.

The three study sites vary in the type of temperature and rainfall received. The households have varying levels of illiteracy implying that the levels of education are not the same. Access to basic services also varies across the regions as well as the soil characteristics. Due to these differences, productivity, TE and technology gaps in the three regions is expected to vary because farmers are not operating in the same environment.

1.7 Organization of the Thesis

This thesis is organized into six chapters. Chapter one is composed of the background information of the study, statement of the research problem, research objectives, hypothesis, justification of the study and the study area. Chapter two provides an overview of sorghum production, methods of estimating productivity, TE and TGRs and their applications in empirical studies. Chapter three, four and five presents methodology and results in paper format for each specific objective. Chapter six provides the summary, conclusions and policy recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview of Sorghum Production

Improved sorghum production globally has been on the rise due to increase in demand for ethanol production. It is used as a component of livestock feed in the developed countries and human consumption in third world countries. Around 90% of world sorghum growing areas lie in developing countries especially in Africa and Asia. The area under sorghum production has increased by approximately 66% worldwide over the past five decades (Altuna, 2015).

Sorghum is mainly grown in semi-arid regions where rainfall is inadequate. Sudan has the largest area under sorghum production of about 7 million ha as shown in Figure 3. However, the United states of America (USA) has the highest annual production with 8.9 tonnes from 1.9 million ha (USDA, 2018d)

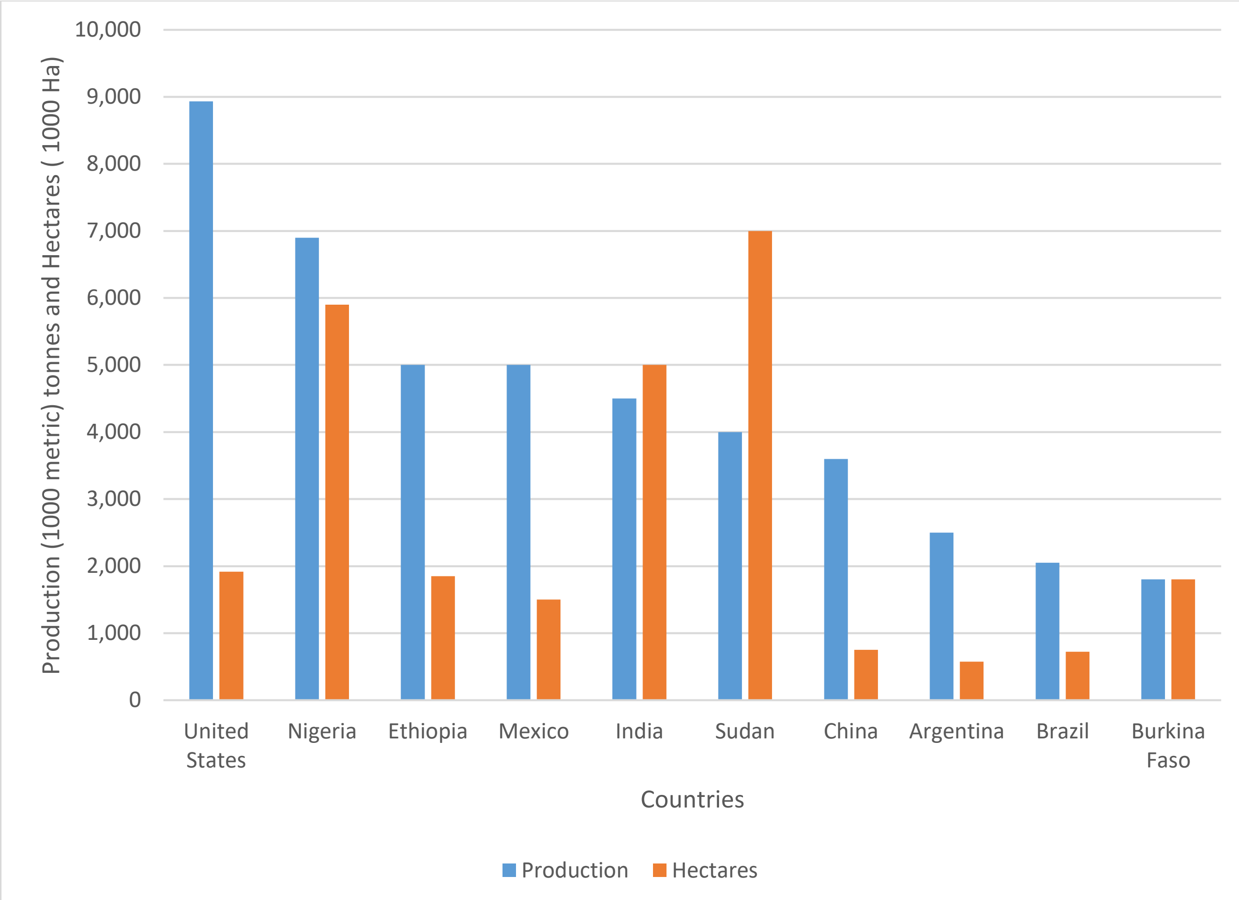

Figure 3: Top Ten Sorghum Producing Countries

Source: USDA (2018d).

Sorghum production and consumption in Uganda has been relatively stable. However, from 2001 to 2008 as shown in Figure 4, there was an upsurge in both production and consumption that was attributed to high demand for sorghum from the brewing industry (USAID, 2011). From 2009, there were fluctuations in consumption while production remained stable from 2013 to 2015 at approximately 299,000 tonnes (USDA, 2018c)

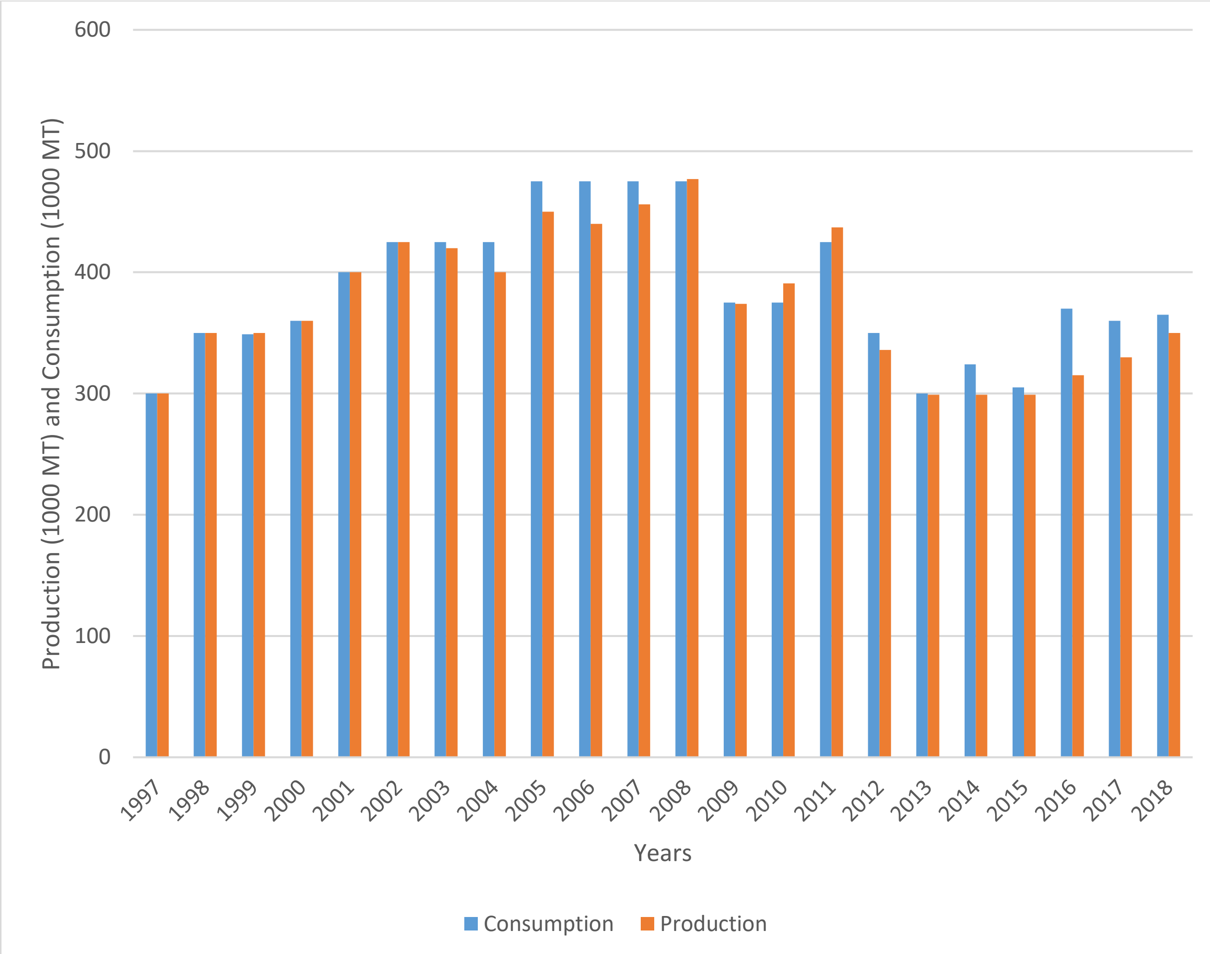

Figure 4: Sorghum Production and Consumption Trends in Uganda

Source: USDA (2018c)

Uganda imports more sorghum than it exports in order to meet domestic demand especially in the manufacture of alcohol as shown in Figure 5. There were no imports and exports between 2000 and 2002 since the domestic production was able to meet the domestic demand. However, there was a sharp increase in quantities imported from 2011 to 2014, while the highest recorded import was in 2017 of about 50,000 tonnes (UN Comtrade, 2018). In 2010, the exports exceeded the imports due to increased domestic production that was attributed to increased cultivation of improved sorghum varieties (Azuma, 2016). Therefore, enhancing sorghum farmers capacity to use improved varieties of sorghum can help increase productivity.

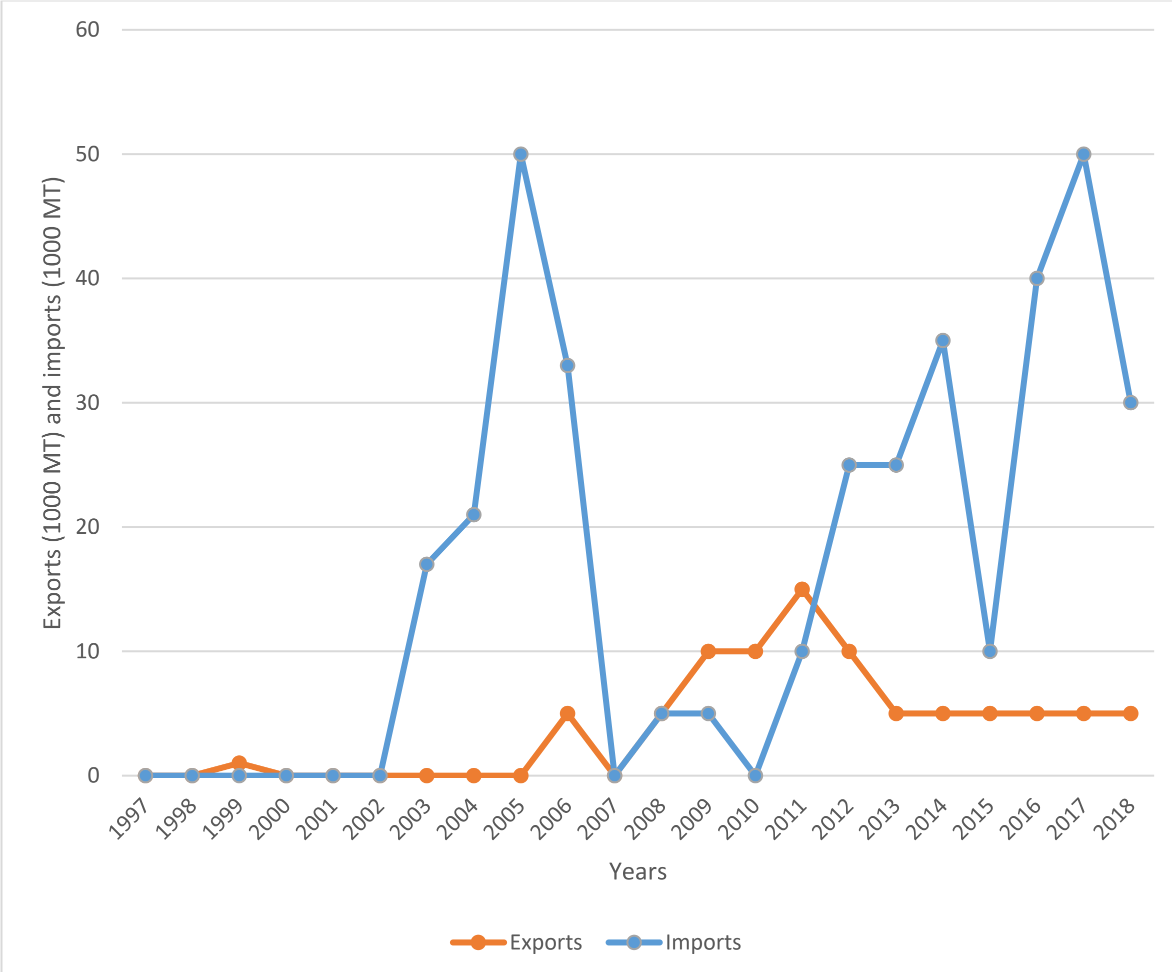

Figure 5: Sorghum Exports and Imports Trends in Uganda

Source: UN Comtrade (2018)

The overall sorghum productivity in Uganda is around 1.9 tonnes per ha (World Bank, 2016). Sorghum production in Uganda is done under pure and mixed stands and occupies approximately 400,000 ha of the total arable land (Tenywa et al., 2018).

2.2 Characteristics of Improved Sorghum

Broadly, sorghum is categorized into three distinct groups namely; grain sorghum, forage sorghum and sweet sorghum. In the USA, grain sorghum is used as a livestock feed and in ethanol production. The sweet sorghum, which refer to sorghum varieties with high content of sugar is used to produce sorghum syrup that is majorly used as a sweetener while in forage sorghum, the biomass is mainly harvested to be used as livestock feed (Cox et al., 2018). Deu et al. (2014) in a study on evolution of improved sorghum varieties noted that in Africa, the informal sorghum seed systems are more effective in ensuring supply of seeds as compared to the formal systems.

Breeders have developed improved sorghum varieties over the years; the main characteristics of these varieties include tolerance to leaf blight and birds, early maturity, tolerance to heat and drought and improved yields that range between 44 to 88 bags per ha (ICRISAT, 2015). Such varieties exhibit improved quality in human and animal food as well as brewing.

Improved sorghum varieties have the ability to mature in three to four months and can thrive well in rainfall amounts ranging between 450 and 800 mm in a season and able to regenerate rapidly after rains by producing factional tillers (OGTR, 2017). Sorghum productivity depends on the climatic conditions, variety grown and agronomic practices. In arid and semi-arid regions, yields ranging between 2.5 and 4 metric tonnes per ha can be realized, while in high potential regions sorghum production ranges between 4 to 8 metric tonnes per ha, which is similar to that of maize (ICRISAT, 2015). Under irrigation and good agronomic practices, sorghum yields can range between 10 to 15 metric tonnes per ha (FCP, 2019).

Apart from growing well in dry areas, sorghum requires less costly inputs such as seeds and fertilizer. Due to this, it is the most suitable and effective cereal crop to fight hunger in arid and semi-arid regions as well as promoting food security with onset of serious climate change issues (Phiri et al., 2019) . Sorghum is mainly used to produce ethanol in developed countries, the energy required to convert sweet sorghum juice into the ethanol is less than half that required in the conversion of maize into ethanol (World Bank, 2008). Sorghum grain is used industrially to produce sorghum syrup, starch, alcohol, edible oils, wax and dextrose *agar*. The grain can be consumed as a traditional delicacy mixed with other legumes, as fermented or unfermented porridge (Cisse et al., 2018).

Value addition of sorghum products starts at the farm level with proper harvesting once sorghum is mature, adequate drying to ensure the appropriate moisture content and proper storage to enhance its shelf life and maintenance of quality (Chimoita, 2017). Value added products such as sorghum bread is rich in carbohydrates, proteins, fats, minerals and vitamins. Improved sorghum acts as an alternative food to individuals who do not consume gluten and those with diabetes and obesity challenges. In Uganda the main sorghum varieties grown by farmers include NAROSOG-1, NAROSOG-2, NAROSOG-3, NAROSOG-4, SESO-1, SESO-2 and SESO-3 which are good for human food, forage, yeast and brewing (Lubadde et al., 2019)

2.3 Measurement of Agricultural Productivity

Agricultural productivity can be defined as the output per unit of inputs used such as land area cultivated, fertilizer, seeds or total inputs applied (Coelli et al., 2005). The overall productivity is attributed to efficient utilization of inputs as well as institutional, socio-economic and technological factors that may indirectly affect agricultural productivity (Kim and Loayza, 2017). Agricultural productivity can be measured using the following methods.

2.3.1 Total factor productivity (TPF)

The TPF measures accounts for use of a number of inputs used in production. It refers to the ratio of the farm output over the total value of all inputs that have been employed in production. TPF is estimated using the Hicks-Moorsteen (HM TPF) index and Malmquist TPF index (Coelli et al., 2005).

2.3.1.1 Hicks-Moorsteen TPF Index

This index measures changes in TPF through output and input growth using output and input quantity index numbers (Coelli et al., 2005)**.** The index is easy to compute and interpret. However, the approach does not account for the major sources of productivity growth, hence it does not differentiate the sources of TPF changes. The method is not applicable in this study because it requires data on a single farm but for an extended period of time since this study used data for one time period. The Hicks-Moorsteen TPF index can be calculated as the an index with base period t defined as a ratio of a Malmquist output index at base period t and a Malmquist input quantity index at base period t following (Bjurek, 1996):

$$HM_t(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{MO_t(x^t, y^t, y^{t+1}}{MI_t(x^t, x^{t+1}, y^t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where y and x denote output and input vectors at time t and respectively, $MO_t(x^t, y^t, y^{t+1}$ and $MI_t(x^t, x^{t+1}, y^t$ denotes output and input indices respectively.

2.3.1.2 Malmquist TPF Index

This index captures changes in productivity due to variations in efficiency and technology. It is constructed from distance functions of inputs and outputs, hence it possible to estimate and isolate changes in efficiency (Coelli et al., 2005). The input and output distance functions are estimated in reference to technology in different time periods. The index requires panel data on many firms in order to obtain robust results (Liao et al., 2016). Due to this, it is not applicable in this study since it used cross sectional data. Other indices that have been applied in productivity measures are Tornqvist and Fishers index, which are used to compare productivity between two entities or one at two different points in time. Since they require data at two different time periods, they are not applicable in this study since it used cross sectional data. Following Coelli et al. (2005) Malmquist TPF index can be estimated by the following equation.

$$M_O(y^t, x^t, y^{t+1}, x^{t+1}) = \left[\left(\frac{D_0^t(y^{t+1}, x^{t+1})}{D_0^t(y^t, x^t)}\right) x \left(\frac{D_1^t(y^{t+1}, x^{t+1})}{D_1^t(y^t, x^t)}\right)\right]^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where y and x are non-negative output and input vectors, $D_1^{t+1}(x_t, y_t)$ denotes period t observation to period $t+1$ technology.

2.3.1.3 Average Productivity Index (API)

The API approach is composed of the average yield and harvested area of a certain crop at the micro level. First, the index is approximated by constructing deviations of yields and the harvested area and dividing the outcome by the deviations of the specific crop and area that was planted. Secondly, coefficients are calculated by adding total values of all crops and the harvested area and finally the API is derived by multiplying the harvested area coefficient and yield coefficient (Dharmasiri, 2009). The method is able to classify distribution patterns of agricultural productivity of a given country hence key in determining spatial productivity of crops, marking and classifying agricultural regions. Since the objective of this study was not to classify agricultural regions, it is not applicable. Its weakness is that it approximates productivity partially because it only relies on the average yield and the area harvested.

2.3.1.4 Partial Factor Productivity (PFP)

The approach measures productivity by considering the output per unit of one input. The most common inputs that are used to estimate productivity include labour (output per agricultural person-hour) and the yield (agricultural output per unit of land) (Wang et al., 2015). The PFP is commonly used in measuring productivity using cross-sectional data unlike TFP measures, which are complex, difficult to estimate and faced with challenges of valuing inputs in areas where markets are not functional and efficient. This approach does not factor in other inputs that are used in production. However, PFP measures that are constructed carefully are valid measures of productivity. This study adopted this approach because cross sectional data was used and productivity was estimated using two indices namely, plot size and sorghum output.

2.4 Review of Determinants of Sorghum Productivity

Sorghum productivity is influenced by a number of factors. Muui et al. (2013) noted that adoption of sorghum technologies, which in turn affect productivity depends on the seed quality, grain size, adaptation of sorghum, diversity of the local varieties and tolerance to diseases. These factors affect sorghum productivity depending on the farm location as well as the prevailing weather conditions. However, adoption of improved varieties have different effects on farmers, Nguezet et al. (2011) observed that adoption of improved varieties has a positive effect on richer farmers as compared to poor farmers. On the contrary, Ahmed (2017) notes that adoption of improved varieties has a positive effect on farmers welfare irrespective of the social status.

Productivity is also influenced by the various institutional, farm and farmer characteristics. Mbando and Baiyegunhi (2016) noted that investing in education, provision of micro credit, extension services and promoting participation of farmers in associations improves adoption of improved varieties which in turn translate to increased productivity. On the other hand, Saeed et al. (2016) found that age, level of education and marital status were significant in influencing sorghum productivity among male farmers while age, off-farm income, household size, experience in farming, marital status and education level were substantially significant among female farmers.

However, in a recent study, Mundia et al. (2019) noted that apart from effects of socio-economics and institutional factors on productivity that past research work has focused on, for example see (Musafiri et al., 2014; Urgessa, 2015; Kim and Loayza, 2017). There are other key factors that influence sorghum productivity such as armed conflict, population growth of a country, climate change and variability and demand of non- food items especially from the manufacturing sector.

2.5 The Efficiency Concept

Different farmers exhibit varying degrees of efficiency depending on the location and the level of technology being used. Broadly, efficiency can be categorized into TE, allocative efficiency (AE) and economic efficiency (EE). This study assessed measurement of TE, which can be defined as the ability of a given firm to produce optimal outputs at a given level of input in the production process (Battese and Rao, 2002). The TE is also referred to as the production efficiency, which can be measured as the a ratio between the minimum input and the observed level of inputs assuming that the output is fixed or as a ratio between the observed level of output and a given maximum output assuming that the input is fixed (Porcelli, 2009)**.** The EE is given as a product of AE and TE, which refers to a broad measure of the overall performance of a farm. It is also a good measure of how well a firm is producing a given level of output given the inputs (Nargis and Lee, 2013). In addition, marketing efficiency which can be defined as a ratio of the market output (Kohls and Uhl, 1980) is esstentil for farms since it plays a central role in maximizing returns from agricultural production. Effecient marketing acts as a link between producers and consumers by ensuring a sustaible supply system of farm inputs and outputs, also it compliments technical efficiency and productivity of farms in influecing the pricing of agricultural commodities (Chandra and Rit, 2014)

2.5.1 Approaches for Measuring Efficiency

Efficiency can be measured using the input-oriented or the output-oriented approaches. Input-oriented approaches involve evaluating ways of reducing the amounts of inputs to produce a given amount of output. The output-oriented approaches on the other hand, seek ways in which a certain level of input can be used to increase the output. In this case, the more output that can be realized from the inputs, the more efficient the production system is. However, it is worthy to note that the approaches will yield similar measurement of efficiency when the technology being used is constant (Coelli et al., 2005).

Efficiency models are broadly classified into parametric and non-parametric methods. Parametric techniques are also referred to as econometric approaches and they decompose the error term into technical inefficiency and statistical noise; this allows testing of hypothesis in relation to the extent of inefficiency and the production structure (Coelli et al., 2005). In the literature, the Stochastic Frontier Analysis (SFA) is the main parametric approach that has been applied extensively since it can be used with panel or cross- sectional data (Chimai, 2011). However, this approach requires prior determination of the functional form of the production function, which can either be Cobb-Douglas or translog functional forms and involves specifying a production function that is parametric and able to represent the best technology available for production (Coelli et al., 2002). The SFA has been widely applied to asses TE in literature (see for example, Cabrera et al., 2010; Aung, 2011; Rahman et al., 2012; Wheat et al. 2019 and Sabasi et al. 2019).

On other hand, non-parametric approaches for measuring TE employ mathematical programming techniques especially linear and quadratic techniques and do not impose restrictions on prior specification of the technology being used by production units (Khanal et al., 2018). The non-parametric approaches assume the functional form of the production as unknown unlike in parametric approaches where the functional form must be specified. The general Free Disposal Hull (FDH) and Data Envelopment Analysis (DEA) are used for measuring TE. However, DEA is the most used in literature to estimate TE since data on the prices of inputs is not required but relies on the input and output data of the decision-making units (DMUs) or firms. The DEA approach has been used to investigate TE by recent studies such as Skevas et al. (2014), Madau, (2015), Toma et al. (2015) and Sreedevi et al. (2016).

2.5.2 Review of Determinants of Technical Efficiency

Efficiency analysis does not only require estimating the efficiency level but also sources of efficiency and factors that influence it for the purpose of policy implication. A number of past empirical studies have assessed the relationship between TE, institutional variables and socio-economic characteristics such as age, gender, household size and level of education. For example, empirical evidence on determinants of TE of smallholder paddy producers in Malaysia showed that the TE scores of farmers were significantly influenced by the size of land, labour, fertilizer application, use of herbicides, experience of the farmer in paddy growing, level of education and extension contacts with the farmers to be significant (Shokur et al., 2015). However, the authors used OLS to estimate determinants of technical efficiency. This may lead to biased results. The study addressed this by using a two limit tobit model and the one step SFA with inefficiency estimates.

Nyagaka and Obare (2010) observed that group membership, level of education, access to agricultural credit and extension services had positive effects on the TE of smallholder Irish potato farmers in Kenya. A study by Asefa (2012) in Tigray, Ethiopia found that education, household size and age of the farmers as key significant determinants of TE, farmers off-farm activity and the livestock kept were found to be significant determinants but negative while the gender of the farmer and irrigation had no significant effect on the TE. In both studies, authors did not compare between the one and two step approach in assessing determinants of technical efficiency. This study goes further to compare between the two methods and examines which yields better results.

A study to assess the TE in rain-fed and irrigated small-scale agriculture by Gebregziabher et al., (2012) found that, education levels, and distance to the road and access to agricultural credit were negative but significant variables in influencing TE while age was not significant. Etich (2013) and Chavas et al. (2016) noted that efficiency can be influenced by the level of managerial effectiveness. Therefore, differences in efficiency levels between groups can be explained from the management context through experience exposure, training and motivation. These studies used household level data in assessing determinants of technical efficiency thus there could be challenges matching efficiency directly to those involved in actual farm management. Therefore, to address this gap, the study used plot level data.

2.6 Measuring Technology Differences

The parametric and non-parametric approaches mentioned in section 2.5.1 do not account for technology differences among various groups. The approaches assume that farms operate at the same level of technology. However, in instances where the groups being evaluated operate at technology levels that are differing, use of the approaches may lead to measurement errors (Tsionas, 2002).

The following methods have been used in literature to account for technology differences between groups: latent class stochastic frontier, predetermined sample classification, non-parametric stochastic frontier, continuous parameters method and metafrontier. The metafrontier method is the most applied approach because it uses both cross sectional and panel data (Battese et al., 2004). Metafrontier analysis has been applied to account for technology heterogeneity in literature by Battese and Rao (2002), Dadzie and Dasmani (2010), Otieno et al. (2011) and Kamper (2016).

2.7 Conceptual Framework

Figure 6 shows the link between institutional, farm and farmer characteristics and sorghum productivity. Farm, farmer and institutional characteristics affect sorghum productivity of households (Danso-Abbeam et al. 2018). Gender relations are influenced by social and cultural factors that in turn determine responsibilities between men and woman in accessing and controlling farm resources. This influences productivity and TE among female, male and jointly managed sorghum plots.

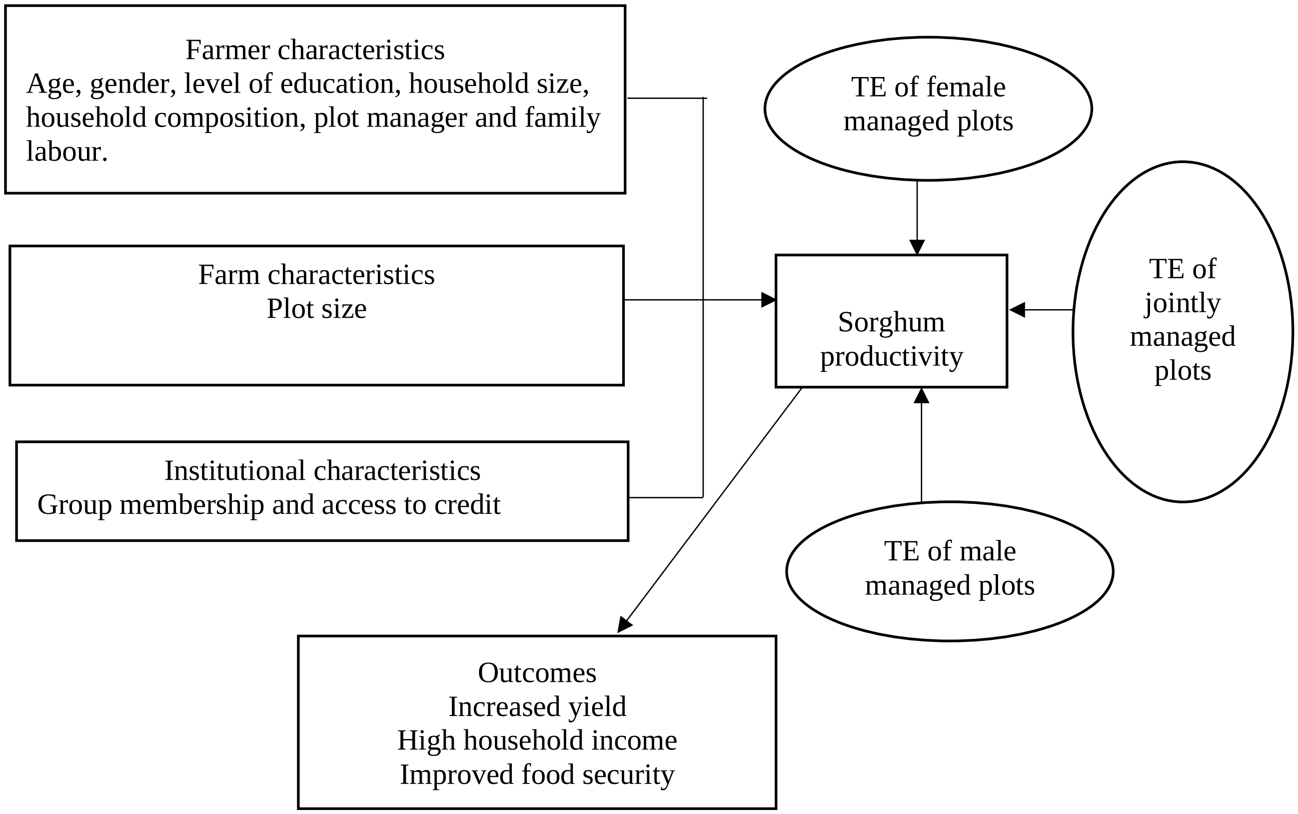

Figure 6: Link between Farm, Farmer and Institutional Characteristics and Sorghum Productivity

Source: Adapted and modified from Zhengfei et al. (2006).

In line with Boserup, (1970) argument that roles are stereotyped based on the sex of farmers, roles influence various farm activities such as division of labour among male and female farmers which in turn influence their productivity. Based on these roles, female, male and joint plot managers have varying access and utilization of farm inputs such as seed varieties, farm equipment, fertilizer and pesticides, institutional support services such as weather information, access to credit, and extension services thus leading to productivity and TE differentials.

Efficiency tends to be high in male-managed plots while low in female-managed plots and in jointly managed plots it can either be high or low. Therefore, productivity in female managed plots will be low compared to male managed plots (Addison et al., 2016). The efficiency in input use affects sorghum production which in turn leads to an outcome effect on the household income, household food security and yields

2.8 Theoretical Framework

2.8.1 Theory of Production

This study is anchored on the theory of production. Production can be defined as a process of converting various inputs into final products and services. This involves using input and technology levels that maximize output levels while minimizing costs (Debertin, 2012). In line with this theory, sorghum plot managers in this study are assumed to be rational. They use farm input combinations in such a way that they will achieve maximum possible output while minimizing their costs. The main motive of a rational producer is to maximize profits by maximizing output or minimizing costs. Following Cobb and Douglas (1928), a production function assuming use of two inputs and production of a single output can be presented as follows:

$Q = AK^{\alpha}L^{\beta}$……………………………………………………………………….............3

where K is capital, L is labor, A denotes a factor of productivity, α and β are elasticities. In equation (3) there is an assumption that all units of labor and capital that are used are homogenous of degree k and the technology in the production is constant. Therefore, it is possible to derive concepts relying on short run where all factors of production are fixed and in the long run where all factors are variable. However, in practice the regularity conditions may not be maintained. For example, using excess inputs in relation to other factors of productions leads to congestion of inputs hence relaxing the monotonicity assumption (Coelli et al., 2005). The output level can be varied in the long run by changing the mix of all inputs.

A producer who is rational will always try to reach the optimum level of production at the point where marginal physical product (MPP) of inputs equals zero. Optimal combination of inputs is key in the production process. Coelli et al. (2005) noted that efficiency can only be attained within a certain point in stage II where marginal product value is equivalent to the marginal cost for each input.

2.8.2 Gendered Organization Theory

Gendered organization theory stipulates that various organizational structures are designed and gendered based on stereotypical male traits (Acker, 1990). The organizational structures are primarily created by men who consider masculine characteristics on how systems work thus favoring men more at the expense of women.

Since these organizational structures tend to favour men, their productivity and efficiency in tasks tend to be higher compared to their female counterparts. Organizational structures such institutional support services and leadership evaluations are not gender biased and do not pay attention to key gender issues that are specific to women. However, currently there are radical female activists who are lobbying for changes in the current structures to create new organizational systems that are gender sensitive in order to empower women (Fishman, 2017).

In line with this theory, traditional agricultural extension and other institutional support services especially in agriculture do not pay sufficient attention to heterogeneity in female and male roles in the agricultural sector and social networks for information dissemination. Thus, female plot managers do not get adequate agricultural support services. They purchase lower amounts of farm inputs compared to male farmers which impacts negatively on their productivity (Lambrecht et al., 2018).

CHAPTER THREE

3.0 A COMPARATIVE ASSESSMENT OF SORGHUM PRODUCTIVITY IN MALE, FEMALE AND JOINTLY MANAGED PLOTS

3.1 Abstract

This chapter provides a comparative assessment of sorghum productivity among male, female and jointly managed sorghum plots and determinants of sorghum productivity. Productivity was estimated using partial factor productivity while determinants of sorghum productivity were assessed using an ordinary linear regression. Results showed that sorghum plot managers across the three study sites had plots that are less than 1 ha on average, meaning that they were smallholder farmers. The mean age was less than 48 years thus majority of the farmers were adults. The mean years completed in school was less than 6 years indicating that most farmers had only attained primary education. Male managed plots had higher productivity across the three study areas (1,433.59Kg/ha, 1162.82 Kg/ha and 918.9Kg/ha) compared to female (704.57 Kg/ha, 637.79Kg/ha and 550.16 Kg/ha) and jointly managed plots (992.09Kg/ha, 695.56Kg/ha and 550.16Kg/ha) for Lira, Serere and Kumi, respectively. However, jointly managed plots had higher productivity compared to female plots but were lower compared to male plots. The amount of seed, hired labour, family labour, age of the plot manager and years completed in school had positive and significant effects on productivity, while plot size and household size had negative influence on sorghum productivity. This call for interventions from development partners aimed at reducing productivity gaps among plot managers and promotion of access to universal education and design of incentives specifically targeted to girls' access to education as well as adult education for the elderly.

Key words: productivity, sorghum plots, gender

3.2 Introduction

Agricultural productivity plays an important role in welfare and stimulating growth in non- farm activities of rural households. In view of this, achieving agricultural productivity has been one of the main global objectives to ensure increased agricultural output in order to meet food demands of the growing population as well as reduce poverty levels, more so in developing economies. There has been an emphasis on improving labour and land productivity through intensive use of farm inputs such as fertilizers, seeds, machinery and human labour (Mason-D'Croz et al., 2019).

Empirical literature has shown that there exist gender gaps in agricultural production. Female farmers have lower productivity compared to male farmers which has been linked to constraints that female farmers encounter in access and utilization of farm inputs in African countries (Slavchevska, 2015). This has drawn considerable interest from policy makers and development agencies on how to close the gender gap to ensure that female farmers are able to realize their full agricultural potential.

In Asia however, some evidence has shown that agricultural productivity of men is equal to that of women. For instance, in China, female farmers have almost similar productivity and revenue from crops as those of men (Karamba and Winters, 2015). In situations where differences in access to inputs is controlled for, literature has shown that women are as equally productive as male farmers (Doss, 2018). In order to assess factors that influence productivity, socio-economic and institutional variables are used in regression models to estimate their effect on productivity.

3.3 Methodology

3.3.1 Data Sources and Sampling Procedure

The study used secondary sex-disaggregated data from ICRISAT that was collected through the Gender research program in Uganda between October and November 2017.A multistage sampling technique was used where the first stage involved selection of Lira, Serere and Kumi districts purposively because they predominantly grow sorghum. Secondly, four sub-counties within the districts were purposively selected since sorghum growing is widely grown as compared to other sub-counties; Amach and Agali sub-counties in Lira, Katete in Kumi and Mukongoro in Serere. Finally, simple random sampling was used to select respondents and interviewed using semi-structured questionnaires to gather plot level data.

The sample size was determined following Fink and Kosecoff (1998) formula:

$$n = (\frac{Z}{e})^2 pq \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where;

n = calculated sample size;

Z = standard limit depending on the confidence interval. In this case 1.96 relating to 5% level;

e = sampling error 0.05;

p =0.5. The variation of TE among sorghum plot managers was unknown therefore it was assumed to be 0.5

Q = 1-p.

Therefore,

$$n = (\frac{1.96}{0.05})^2 (0.5)(0.5) = 385 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

A sample size of 362 respondents was used for this study after data cleaning where incomplete questionnaires were dropped to allow for comprehensive analysis of data, 47% from Lira (171), 31% from Serere (111) and the rest from Kumi district (80). The distribution of the sample size among the three districts was allocated proportionate to their population sizes. In addition, previous studies on productivity and TE studies that used a sample size that was slightly below or above 362 include Aly and Shields, (2010), Abdulai et al. (2018) and Myeni et al. (2019).

3.3.2 Test for Multicollinearity

To test for multicollinearity among variables fitted in the ordinary least square model and the inefficiency variables in the stochastic frontier model, variance inflation factors (VIFs) were calculated (Gujarati, 2004).

$$VIF = \frac{1}{1-R_i^2} \qquad \text{...6}$$

where R_i^2 represents the coefficient of determination from a regression of an independent variable onto all other predictors. All the calculated VIFs were below 10 thus variables were assumed not to be correlated. The VIF scores are shown in Appendix 2 and 3.

3.3.3 Data Analysis

Productivity was measured using partial factor productivity (PFP) due to data limitations and more specifically plot size and sorghum output was used to estimate land productivity.

Sorghum productivity was computed using PFP.

$$PFP_i = \frac{Y}{X_i} \qquad \text{...7}$$

where Y is the output while X_i is the plot size. Since the dependent variable is continuous in nature, the OLS regression was subsequently fitted to evaluate determinants of sorghum productivity.

The OLS regression model was specified below:

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7 + X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}$$

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} + \mu \quad \text{.......} 8$$

$$Y \alpha + i \sum X + \mu$$

where Y = Sorghum productivity (Kgs/ha)

α = Constant and βs are the coefficients to be estimated

X_1= Access to sorghum extension (1=Yes)

X_2 = Access to credit (1=Yes)

X_3= Years of farming sorghum

X_4= Plot size (ha)

X_5 = Seed (Kgs)

X_6= Hired labour (Person hours)

X_7 = Family labour (Person hours)

X_8 = Distance to farm from the household (Meters)

X_9= Household size

X_{10}= Age of the farmer

X_{11}= Years completed in school by the farmer

X_{12}= Farmer group membership (1= Yes)

X_{13}= Gender (1=Male)

μ = error term.

3.4 Results and Discussions

3.4.1 Socio-economic Characteristics of the Households

Majority of sorghum farmers across the three study areas are adults with the mean years of schooling less than 6 years as shown in Table 1. This shows that many rural sorghum farmers in Uganda have little formal human capital since they have only attained lower primary school education.

Table 1: Sample Characteristics

Socio-economic characteristics	**Serere (n = 111)**		**Lira (n = 171)**		**Kumi (n = 80)**		***p*-value***
	Mean/ frequency	**SD**	**Mean/ frequency**	**SD**	**Mean/ frequency**	**SD**	
Gender (male %)	59.50[a]		35.70[b]		48.80[a]		**0.000**
Age (mean years)	47.51[a]	14.07	42.77[b]	15.5	47.25[a]	13.52	**0.007**
Average years completed in school	5.37[a]	6.23	5.11[a]	3.68	4.84[a]	3.22	0.737
Average years of growing sorghum	16.85[a]	12.16	8.50[b]	9.76	17.03[a]	12.83	**0.000**
Average household size	7.52[a]	3.11	5.43[b]	2.68	7.36[a]	3.45	**0.000**
Household type							0.218
Male and female adult living on plot (%)	66.70[a]		59[a]		57.50[a]		
Female adult only (%)	22.50[a]		24[a]		42.50[a]		
Female adult living without male on plot (%)	10.80[a]		17[a]		10[a]		
Plot manager							0.535
Male manager (%)	15.30[a]		18.10[a]		10[a]		
Female manager (%)	33.30[a]		32.20[a]		42.50[a]		
Joint manager (%)	51.40[a]		49.70[a]		47.50[a]		

Note: SD-standard deviation, Pairwise comparisons done using Bonferroni test, different superscripts ***(ab, ba)*** *imply significant statistical difference between the sub-samples, same letter* ***(aa, bb)*** *imply no statistically significant difference between the sub-samples.*

Source: Survey Data (2017).

The mean years of sorghum growing in the three study sites was more than 8 years, showing that majority of the farmers have been growing sorghum for quite long. The mean household size for the three regions is slightly above the national mean household size of 4.7 persons which has relatively remained stable in the last one decade (UBOS, 2016). This variance from the national household mean can be explained by the polygamous nature of rural households where the study sites are located.

Most variables in Serere and Kumi districts were not statistically different. This can be explained by the minimal difference of 1°C mean annual temperature between the two sites and considering that sorghum cultivation is done during the same season of April. However, Lira district had a significant statistical difference, the area had the lowest mean annual temperature, the highest average rainfall as discussed in Section 1.6 and also farmers have commercialized sorghum farming.

Male and female adults living on the plot was the highest form of household type for the three study sites while there were no households with male adults only on plot, implying that there is a low probability of men living alone in rural Uganda where cultural practices require men to marry. Ninsiima et al. (2018) noted that approximately half of all girls in Uganda below the age of 18 years especially in rural areas are already married or pregnant, which forces them to early marriages. Consequently, joint plot management in the three study areas was the highest compared to male and female sorghum plot managers.

3.4.2 Farm Characteristics

The mean plot size of sorghum farmers is less than 2 ha as shown in Table 2, implying that they are smallholder farmers. This is consistent with Cervantes-godoy (2015) who defined smallholder farmers as those owning less than 2 ha of land. However, the average plot size in the three study areas is below the national average farm size of 1.1ha (CGAP, 2016). This can be attributed to high household size in rural areas of Uganda, thus leading to subdivision of agricultural land. This corroborates the earlier findings in Table 1 where the mean household size was higher than the national average.

Table 2: Farm Characteristics

Variable	Serere (n = 111)		Lira (n = 171)		Kumi (n = 80)		p-value*
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Pot size (mean Ha)	0.41[a]	0.08	0.52[b]	0.34	0.41[a]	0.68	**0.0002**
Average distance to the plot (meters)	284.97[b]	330.86	804.13[a]	1372	363.41[ab]	347.40	**0.0058**
Average quantity of seed used (Kgs)	15.97[b]	23.95	9.51[a]	13.40	7.49[a]	6.22	**0.0001**
Average amount of fertilizer used (Kgs)	0[a]	0	0.47[a]	0.61	0[a]	0	0.5708
Hired labour (mean person hours)	7.63[a]	10.06	5.35[b]	7.82	6.70[a]	7.71	**0.0001**
Family labour (mean person hours)	27.71[a]	9.13	36.70[b]	14.56	27.51	8.71[a]	**0.0203**
Average sorghum output (Kgs)	294.96[a]	282.68	463.02[b]	448	291[a]	225.90	**0.0001**

*Note: *Pairwise comparisons done using Bonferroni test, different superscripts **(ab, ba)** imply significant statistical difference between the sub-samples, same letter **(aa bb)** imply no statistically significant difference between the sub-samples.*

Source: Survey Data (2017).

Distance to the plot from the homestead was largest in Lira district. This can be attributed to sorghum contract farming especially in Agali sub-county, implying the likelihood of farmers leasing in land from various parts in order to increase their profit margins. Sorghum farmers will tend to hire more labour compared to use of family labour due to leasing in of farmland away from their homestead (Arthur, 2013).

Among the three study areas, only Lira district had minimal fertilizer use for sorghum cultivation. This was a result of sorghum contract farming by some farmers. Similarly, Tenywa et al. (2018) found that fertilizer usage in sorghum growing especially in developing countries like Uganda is minimal, only less than 8% use the commonly available fertilizers in the market such as Diammonium Phosphate (DAP) and Calcium Ammonium Nitrate (CAN) (Mbowa et al., 2015). Use of seed varied across the study areas with Serere district having the largest amount of seed planted. Lira district had the highest sorghum output and this could be attributed to the use of fertilizer unlike in Kumi and Serere districts (Nhamo et al., 2016). All farm variables in Lira district had a significant statistical difference compared to Serere and Kumi districts except the average distance to the plot and the average quantity of seeds used, as earlier discussed. This can be as a result of growing sorghum for commercial purposes in the district.

3.4.3 Institutional Support Services

Farmers in the three study areas experienced high levels of weather uncertainty such as drought, erratic rainfall and floods as shown in Figure 7. This can be attributed to farmers' inability to control weather uncertainty hence highly vulnerable to its effects on farm productivity. This induces smallholder farmers to selling of productive assets in an attempt to smooth household consumption (Sibiko at al. 2018)

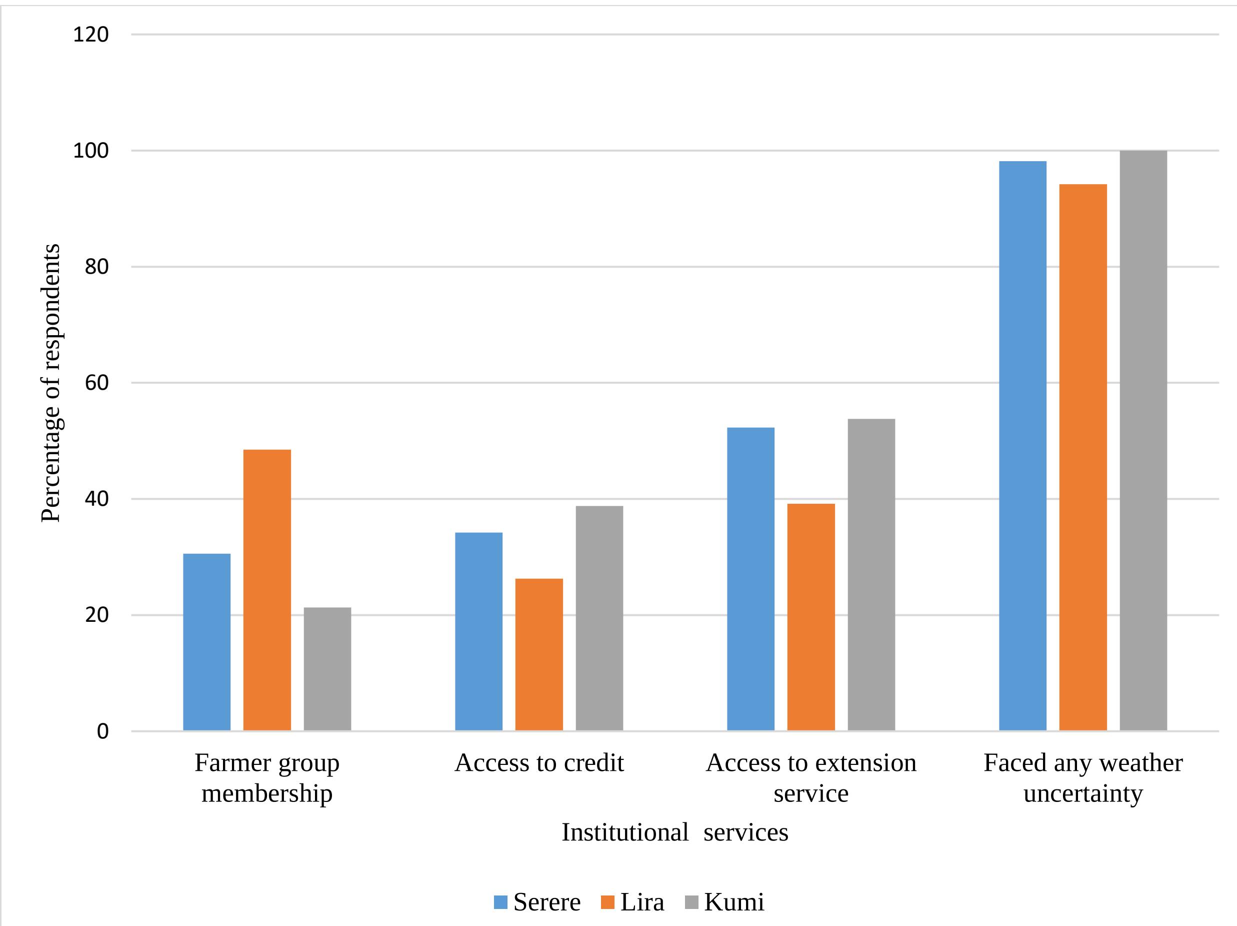

Figure 7: Institutional Characteristics

Source: Survey Data (2017).

Access to credit facilities, agricultural extension services and farmer group membership were relatively low across the study areas. However, access to extension services was higher in comparison to farmer group memberships and credit facilities. This can be attributed to decentralization of planning, implementation and management of agricultural extension services in Uganda from the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) to lower levels of administrative units such as local district governments (Rivera and Alex, 2004). This led to increased access to extension services especially by rural farmers who initially could not.

Sorghum farmers in the study areas majorly got credit facilities from Savings and Credit Co-operatives (SACCOs) as shown in Figure 8. This can be attributed to flexible terms that SACCOs offer to their clients as opposed to mainstream banks that have more stringent regulations on loans. Serere district had the highest percentage of farmers who had credit. However, this is not reflected in sorghum production where it was expected to have a higher effect on productivity as shown in Table 4. This implies that farmers who got agricultural credit did not necessarily use it for crop production.

Agricultural credit is key in improving agricultural production. However, empirical evidence on the effects of credit on productivity is mixed. Chandio, (2018) and Myeni et al. (2019) found that smallholder farmers who had access to credit facilities had increased agricultural production compared to the non-recipients. Credit enables the resource-poor smallholder farmers to purchase fertilizer, high yielding seed varieties and farm implements hence increasing their agricultural output (Linh et al. 2019). On the contrary, Reyes et al. (2012) found that short term credit had no effect on agricultural production.

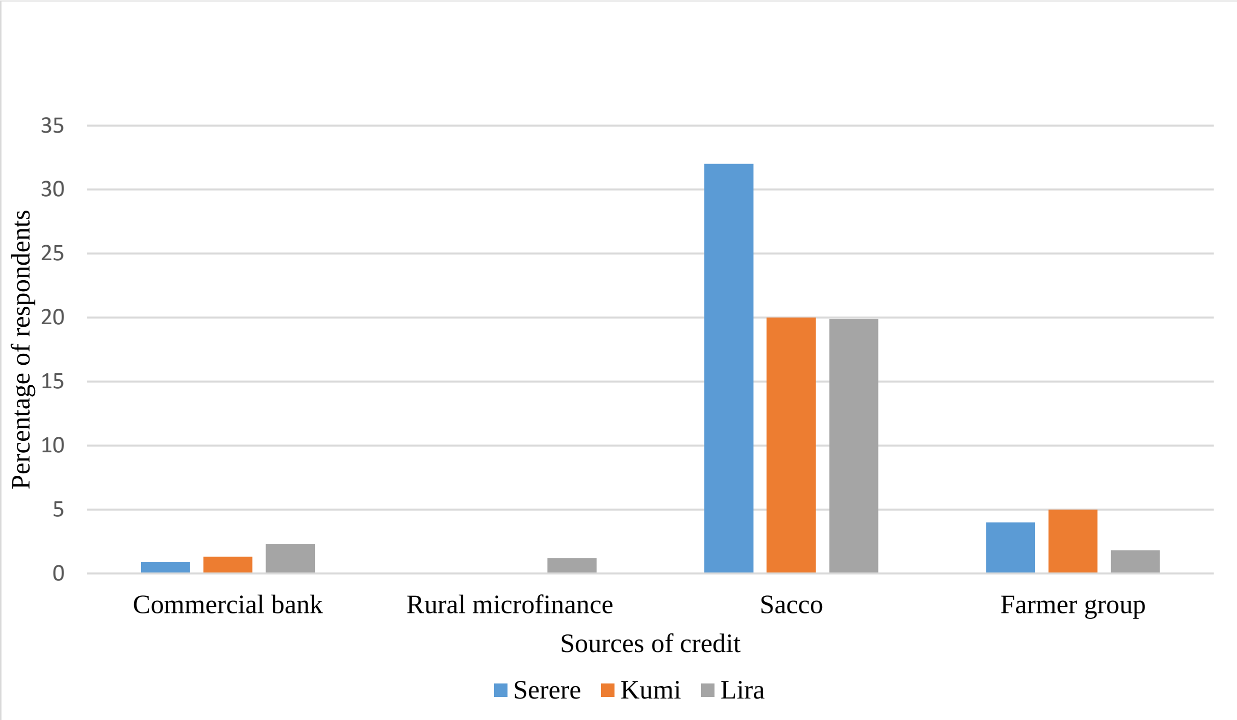

Figure 8: Main Sources of Credit Sources

Source: Survey Data (2017).

Jayne et al. (2014) and Deresse and Zerihun (2018) noted that micro-credit institutions have not critically addressed credit needs of smallholder farmers because of some perceived challenges, which include; poor credit repayment, high risk nature of agricultural investments, technicality of agricultural production systems and seasonality experienced in agricultural production. This leads to inadequate credit provision to farmers.

3.5 Agricultural Productivity

Agricultural productivity was computed using plot-level data on the male, female and joint plot manager. Male plot managers had higher productivity compared to female plot managers as shown in Table 3. Peterman et al. (2011) noted that female farmers have lower levels of human capital, resource base, access and utilization of farm inputs compared to male farmers, hence they have low ability to respond to subsidy programs and agricultural incentives, thus leading to low productivity.

Female plot managers spend more time doing domestic chores compared to male plot managers as well as disproportionate responsibility of care work to their children thus limiting the time spent on their plots (Donald et al., 2018). Consequently, this impacts negatively on the productivity of their sorghum plots.

Table 3: Land Productivity Estimates

Mean productivity (Kgs/ha)	**Lira district (n = 171)**	**Kumi district (n = 80)**	**Serere district (n = 111)**
Male plot managers	1433.59	918.9	1162.82
Female plot managers	704.57	550.16	637.79
Joint plot managers	992.09	766.66	695.56
Pooled	973.37	689.87	747.87

Source: Survey Data (2017).

Sorghum plots with joint management by male and female persons had a higher productivity compared to female plot managers but lower compared to male-managed plots (Table 4). This shows the complementary role that men play due to their easier access and utilization of farm inputs (Doss, 2018). Generally, Lira district had the highest productivity estimates. Farmers in this region have commercialized sorghum farming and use fertilizer. There was significant statistical differences in the overall productivity among male plot managers, female plot managers and the joint plot management as shown in Table 4.

Table 4: Overall Land Productivity Estimates

Plot manager	**Male plot managers**	**Female plot managers**	**Joint plot managers**	**Pooled**	***p*-value***
Average productivity	$1,258.67^{a}$	643.29^{b}	850.60^{c}	841.57	**0.000**
Standard deviation	1,195.03	539.51	585.92	727.56	

*Note: *Pairwise comparisons done using Bonferroni test, different superscripts* ***(a, b** *and* **c)** *imply significant statistical difference between the sub-samples.*
Source: Survey Data (2017).

3.6 Determinants of Sorghum Productivity

Table 5 shows results for the OLS regression model for determinants for sorghum productivity.

Table 5: Determinants of Sorghum Productivity

Variable	Coefficient	Robust standard error	*p*-value
Access to sorghum extension (1= Yes)	-0.103	0.073	0.160
Access to credit (1= Yes)	-0.033	0.090	0.716
Years of farming sorghum	-0.037	0.026	0.166
Plot size (ha)	-1.407***	0.243	0.000
Seed (Kgs)	0.011***	0.003	0.000
Hired labour (person hours)	0.029***	0.004	0.000
Family labour (person hours)	0.017***	0.003	0.000
Distance to farm (meters)	0.007	0.018	0.718
Household size	-0.131**	0.064	0.043
Age	0.005*	0.003	0.063
Years completed in school	0.012**	0.006	0.037
Farmer group membership (1 = Yes)	0.038	0.075	0.610
Gender (1= male)	0.020	0.075	0.785
Constant	6.284***	0.271	0.000
Adjusted R-squared = 0.25			
F = 15.56			
Prob > F = 0.0000			

**** denotes significance at 1% level, ** denotes significance at 5% level; * denotes significance at 10% level*

Source: Survey Data (2017).

About 25% of variations in the productivity of sorghum are explained by the variations in the explanatory variables. Further, the F-statistics was highly significant at 1% showing that all the explanatory variables were important in jointly accounting for the variation on the sorghum productivity.

Farm input variables such as amount of seed, hired and family labour were positive and highly significant thus a one unit increase in each would result at increase in sorghum productivity. Comparing the magnitude of change between hired and family labour, hired labour had a bigger magnitude. This shows that farmers realize a higher increase in productivity per each increase in hired labour due to strict supervision as compared to family labour where farmers can be more lenient. These results are consistent with Kloss and Petrick (2018) who found that a higher share of hired labour force tends to be more productive compared to pure family labour.

There was a significant inverse relationship between plot size and sorghum productivity. This implies a 1 ha increase in plot size would result to a decline in sorghum productivity. Empirical evidence has shown that small farms are more manageable thus increasing efficiency in using farm inputs as well as close monitoring of farm activities. These results are consistent with Muyanga and Jayne (2019) and Sheng et al. (2019) who found that productivity tends to decline as the farm size increases.

The coefficient of age and number of years of formal learning are positive and significant. Formal education plays a crucial role in decision making especially in farm input use thus the more years of formal education, the more they are likely to exhibit higher productivity compared to those with little or no education. This corroborates findings by Wouterse and Badiane (2019) that investment in human capita such as education stimulates productivity.

Years of sorghum farming was insignificant and with a negative coefficient showing that as the farming experience increases, sorghum productivity tends to decrease. This can be attributed to the fact that as sorghum farmers gain more experience in farming. there is a tendency of not adopting new innovations and stick to old practices which may lead to a decline in their productivity. These result corroborates findings by Mwalupaso et al. (2019) in Zambia where maize farmers who had more experience in farming had lower productivity and TE.

Credit had a negative but insignificant effect on sorghum productivity showing that as farmers get credit their productivity tends to decline. This can be attributed to fungibility of money where farmers may divert the credit acquired for other uses specially to cater for basic needs such as food and other forms of investment. Similar findings were obtained by Mukasa et al. (2017) in Ethiopia where smallholder farmers who accessed credit had lower productivity due to misallocation of the credit obtained.

Access to sorghum extension had a negative, but insignificant effect on sorghum productivity. This shows that the extension service farmers were getting was not effective in achieving the desired output. Similar results were reported by El-juhany (2010) who found that as a result of ineffective extension service there was approximately 37% decline in productivity of date trees in Balochistan, Pakistan. Baloch and Thapa (2018) noted that since extension services are inadequate, this results to reluctance by farmers to seek these services, while Ghosh (2012) argued that inadequate extension services, unskilled extension workers and failure to take into account actual challenges facing farmers leads to a decline in productivity.

CHAPTER FOUR

4.0 ANALYSIS OF TECHNICAL EFFICIENCY AND TECHNOLOGY GAP RATIOS IN FEMALE, MALE AND JOINTLY MANAGED SORGHUM PLOTS

4.1 Abstract

Technical efficiency of farmers is determined by how well they use the available farm inputs. High TE and TGRs lead to increased sorghum outputs. The study used SFA to determine TE scores while the metafrontier was applied to account for heterogeneity in technology by estimating TGRs of female, male and jointly managed sorghum plots. The results showed that female farmers had higher TE scores in Serere (0.60) and Kumi (0.89) compared to male managed plots who had 0.59 and 0.72, respectively. This was attributed to women taking advantage of the informal labour rotation groups while in Lira where there is sorghum contract farming, male plot managers (0.62) had a higher mean TE score compared to female plot managers (0.54). Jointly managed plots had a higher mean TE score across the three study areas than female plots but lower compared to male plots. Male plot managers had a higher mean TE with respect to the metafrontier (0.60), (0.56), (0.15) and mean TGR (0.98), (0.92), (0.21) for Lira, Serere and Kimi respectively compared to female plots. Jointly managed plots had a higher mean TE and mean TGR than female plots but lower compared to male managed plots.

Key words: metafrontier, technology gap ratios, production structure.

4.2 Introduction

Efficiency in use of farm inputs is a key factor in enhancing productivity among female, male and jointly managed sorghum plots. Unpredictable weather patterns impact negatively on agricultural output of farmers especially smallholder farmers in Africa who primarily depend on rain-fed agriculture. This affects food security as well as livelihoods of rural households who solely depend on agriculture. This calls for interventions to address production inefficiencies among smallholder farmers which limits agricultural productivity greatly (Mango et al., 2015).

Use of female labor in agricultural production and existence of gender gap in productivity and TE are prevalent in SSA countries. These differences depend on the crop type under study, data representativeness as well as the economic level of the country and closely related factors such as political and cultural practices. Past literature indicates that gender gaps in agricultural productivity varies between 4 to approximately 40% (Koirala et al., 2015).

There is mixed literature in regards to women TE. Most have documented that female farmers have lower TE compared to their male counter parts. However, some have found the opposite (see for example, Simonyan et al., 2011). Female farmers' low TE has been linked to lack of official land titling that acts as a hindrance to accessing micro-credit since most mainstream banks require collateral for loans. Due to this, purchase of improved farm inputs and agricultural innovations becomes a challenge thus impacting negatively on women's efficiency (Effendy et al., 2019).

Past studies quantifying gender gaps in TE have concentrated on female and male plots. However, recent literature has focused on farms where both male and female were involved in joint plot management. This study contributes to the literature by assessing TE and TGRs in female, male and jointly managed plots.

4.3 Methodology

In order to estimate TE and TGRs, data on farm inputs such as amount of seed, hired labour, family labour and the plot size were used in SFA and estimation of metafrontier.

4.3.1 Stochastic Metafrontier Approach

This method is useful in estimating the TE among different groups that operate at varying levels of technology. In this study, the groups were male, female and jointly managed plots. The approach involved estimation of separate stochastic frontiers for the male, female and jointly managed plots. In this study, it was assumed that sorghum plots operate at different levels of technology, however a Likelihood Ratio (LR) test was done to determine if differences in technology between sorghum plots are statistically significant to endorse the construction of the metafrontier.

The stochastic frontier of male, female and jointly managed sorghum plots assuming there are z regions is specified as**:**

$$Q_{ik}^{z} = f\left(X_{ijk}^{z}; \beta_{k}^{z}\right)e^{\epsilon k} \quad i = 1,2,3 \ldots N; j\,; k = \textit{Female managed plot}(1), \textit{Male managed plot}(2), \textit{Jointly mananged plot}\ (3) \ldots\ldots 9$$

Q_{ik}^{z} represents sorghum output of z^{th} region from the i^{th} plot for the k^{th} plot manager group, X_{ijk}^{z} represents a vector for the j^{th} variable input used in z^{th} region by the k^{th} plot manager group the i^{th} plot, β_{k}^{z} is a vector of coefficients associated with the independent variables for the stochastic frontier for the k^{th} plot manager group involved in z^{th} region, $e^{\epsilon k} = v_{ik}^{z} - u_{ik}^{z}$ denote an error time that is decomposed to statistical noise v_{ik}^{z} and inefficiency term u_{ik}^{z} (Aigner et al. 1977).

Battese and Corra (1977) noted that the variation of output from the frontier due to u_{ik}^{z} can be defined by:

$$\gamma = \frac{\sigma_{u_{ik}^{z}}^{2}}{\sigma_{ik}^{2}} \text{ and } 0 \leq \gamma \geq 1 \ldots\ldots 10$$

where $\sigma^{2} = \sigma_{uik}^{2} + \sigma_{vik}^{2}$

Stochastic frontiers modeling requires specification of the functional form; the functional form adopted can influence the efficiency estimate (Battese et al., 2004). Data was tested to check which functional form fitted better. The LR test showed that Cobb-Douglas functional form would provide a better fit for the data. The Cobb-Douglas production frontier for male, female and jointly managed sorghum plots was specified as shown in equation (11):

$$LnQ_{ik}^{z} = \beta_{0k}^{z} + \sum_{j=1}^{6} \beta_{ik}^{z} \, LnX_{ijk}^{z} + v_{ik}^{z} - u_{ik}^{z} : k =$$

$$male\ managed\ plots\ (1), female\ managed\ plots (2), Jointly\ managed\ plots \quad \ldots\ldots..11$$

where Q_{ik}^{z} represents sorghum output (kg), X_{ijk}^{z} denotes vectors for variable inputs used in the plots such as sorghum seeds (kg), plot size (acres), family labour (man hours) and hired labour (man hours), β_{0k}^{z} denotes the constant term, β_{ik}^{z} denotes coefficients of the inputs used which were estimated, v_{ik}^{z} denotes statistical noise and u_{ik}^{z} denotes technical inefficiency.

The technical efficiency of the i^{th} plot in the z^{th} region with respect to the specific stochastic frontier is defined as the ratio of the observed output Q_{ik}^{z} to Q_{ik}^{z*} given that there are no inefficiencies in the production (Aigner et al., 1977; Battese et al., 2004).

$$TE_{ik}^{z} = \frac{Q_{ik}^{z}}{Q_{ik}^{z*}} = \frac{f(X_{ik}^{z} ; \beta_{k}^{z}) e^{u_{ik}^{z} - v_{ik}^{z}}}{f(X_{ik}^{z} ; \beta_{k}^{z}) e^{v_{ik}^{z}}} = e^{-u_{ik}^{z}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

Battese and Coelli (1988) noted that the most appropriate predictor of TE can be derived by specifying equation (12) as;

$$TE_{ik}^{z} = E\left[\exp\left(-u_{ik}^{z}\right)\right] \quad 0 \leq TE_{ik}^{z} \leq 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

In order to necessitate the construction of the metafrontier, the likelihood ratio (LR) test was used to test the presence of technology gaps between the male, female and jointly-managed sorghum plots. The test has been used by Otieno et al., (2011), Kamper (2016) and Dadzie and Dasmani (2016) to assess existence of technology gaps between different groups. The test involves estimation of specific stochastic frontiers for the two groups separately followed by a pooled sample from the two groups and assumes a null hypothesis that the stochastic frontiers for the male, female and jointly managed plots are equal. The LR test is given by;

$LR = -2\left\{ln\left(\frac{LH_0}{LH_1}\right)\right\} = -2\{Ln(LH_0) - Ln(LH_1)\}$……………………………………14

where $Ln(LH_0)$ denotes log likelihood function value for stochastic frontier of the pooled sorghum farmers sample and $Ln(LH_1)$ denotes the summed functions for the stochastic frontiers estimated separately for the male, female and jointly managed sorghum plots as shown in equation (15).

4.3.2 Likelihood Ratio Test for Stochastic Frontier Specification

Since SFA require prior determination of the functional form to test which form fits data well between Cobb-Douglas and Trans-log functional, a likelihood ratio test was done.

$LR = -2\left\{ln\left(\frac{LH_0}{LH_1}\right)\right\} = -2\{Ln(LH_0) - Ln(LH_1)\}$……………………………………...15

LH_0 = Log likelihood of Cobb Douglas functional form

LH_1 = Log likelihood of Translog functional form

LR = -2(-379.322- -348.561) = 61.522

The LR results does not support rejection of the hypothesis that Cobb-Douglas functional form would provide a better fit for the data, with a LR statistic of 61.522 compared to the chi-square critical value of 17.67 at 5% level and 10 degrees of freedom. The chi-square critical value was obtained from Kodde and Palm (1986) statistical table.

4.3.3 The Metafrontier

Technology differences between the male, female and jointly-managed sorghum plots were addressed by the metafrontier, which is assumed to be a smooth function that envelopes the specific male, female and jointly managed plots' stochastic frontiers (Battese and Rao, 2002)**.** The metafrontier of the pooled sorghum plots' managers is given by:

$lnQ_i^{z*} = \beta_0^{z*} + \sum_{j=1}^{6} \beta_j^{z*} \, lnX_{ij}^{z*} + \varepsilon_{ij}^{z}, j = 1,2,3, \ldots, j$ ……………………………………….16

where;

Q_i^{z*} represents the metafrontier output from z^{th} regions

X_{ij}^{z*}denotes vectors for variable inputs used in the plots such as sorghum seeds (kg), plot size (acres), family labour (person hours) and hired labour (person hours),

β_0^{z*} represents the constant,

β_j^{z*}denotes parameters to be estimated,

Asterisk (*) represents the metafrontier

ε_{ij}^{z} denotes the error term.

In this model, only the output and input variables were fitted. The metafrontier approach accounts for deviation between an observed level of output and the highest output that is realized in the group frontiers given a specific input level as well as accounting for the differences in technology (Battese et al., 2004).

The parameters β_j^{z*} of the metafrontier were estimated through solving a linear minimization problem, which can be written as:

$$min \sum_{i=1}^{N} \left| \ln f(X_i^z, \beta^{z*}) - lnf(X_i^z, \beta^{z^\wedge}) \right|$$

$$s.t. \ln f(X_i^z, \beta^{z*}) \geq lnf(X_i^z, \beta^{z^\wedge}) \ldots\ldots\ldots 17$$

Where $\ln f(X_i^z, \beta^{z*})$ denotes the metafrontier and $lnf(X_i^z, \beta^{z^\wedge})$ denotes the plot manager frontiers (Battese et al., 2004).

In reference to the metafrontier, the observed sorghum output in z^{th} region of the i^{th} plot in the k^{th} plot manager measured using the stochastic frontier shown earlier in equation (13) is illustrated as:

$$Q_i^{z*} = e^{-u_{ik}^z} . \frac{f(x_{ijk}^z;\beta_k^z)}{f(x_{ijk}^z;\beta_k^{z*})} . f(x_{ijk}^z;\beta_k^{z*})\, e^{v_{ik}^z} \ldots\ldots\ldots 18$$

In equation 18, $\frac{f(x_{ijk}^{z};\beta_k^{z})}{f(x_{ijk}^{z};\beta_k^{z*})}$ refers to the technology gap and it is a measure that lies between 0 and 1, hence:

$$TGR_{ik}^{z} = \frac{f(x_{ijk}^{z};\beta_k^{z})}{f(x_{ijk}^{z};\beta_k^{z*})} \quad \text{……………………………..……………………………………} 19$$

Therefore mathematically, TE_{ik}^{z*} can be derived through multiplying the TE in relation to the stochastic frontier of the individual group and the TGR such that:

$$TE_{ik}^{z*} = TE_{ik}^{z} \times TGR_{ik}^{z} \quad \text{……………………………………………………..……………….} 20$$

4.4 Results and Discussions

4.4.1 Hypotheses Tests on the Production Structure

The null hypothesis in Table 6 assumes absence of technical inefficiency in the specific plot management frontiers and also in the pooled frontier. Results indicate that there are significant technical inefficiency for the pooled sorghum frontiers, specific group frontiers for female and male plot managers since the calculated LR statistic is greater than the χ^2 critical values obtained from Kodde and Palm, (1986). However, technical inefficiency was less significant for the joint plot management frontier.

Table 6: Results on the Hypothesis Test of the Production Structure

Test	Null hypothesis	*LR* statistic	Degree of freedoms	χ^2 critical values at 5%	Decision
Poolability of group frontiers	H_0: $\gamma_{pooled} = \gamma_{female} = \gamma_{male} = \gamma_{joint} = 0$	54.62	8	14.853	Reject H_0
Presence of technical inefficiency	H_0: Female plot managers = 0	17.78	9	16.274	Reject H_0
	H_0: Male plot managers = 0	19.11	9	16.274	Reject H_0
	H_0: Joint plot managers = 0	10.378	9	16.274	Accept H_0

Note. χ^2 *critical values were obtained from Kodde and Palm, (1986) chi square table at 5% level of significance.*

Source: Survey Data (2017).

4.4.2 Technical Efficiency and Technology Gap Ratios of Female, Male and Jointly Managed Sorghum Plots

Table 7 shows a comparative assessment of TE scores and TGRs for Lira, Serere and Kumi districts. From the mean TE with respect to the pooled frontier as shown in Table 7, male plot managers have the highest mean TE scores in Kumi district. This is similar to findings by (Sell et al., 2018).

Table 7: Metafrontier Results for Female, Male and Jointly Managed Plots

		Lira n = 171			Serere n = 111			Kumi n = 80		
		Plot manager			Plot manager			Plot manager		
Model		**Female**	**Male**	**Jointly**	**Female**	**Male**	**Jointly**	**Female**	**Male**	**Jointly**
TE *w.r.t* to stochastic frontiers	Mean	0.53934	0.61745	0.99799	0.60454	0.59424	0.73562	0.89850	0.71698	0.99858
	Min	0.10856	0.26531	0.99798	0.26358	0.11973	0.46525	0.87591	0.36936	0.99858
	Max	0.91904	0.82704	0.998	0.8482	0.95018	0.86889	0.91803	0.99981	0.99859
	SD	0.23363	0.14063	0.000004	0.14604	0.26467	0.083442	0.013209	0.28081	0.000002
TE *w.r.t* to metafrontier										
	Mean	0.45697	0.60525	0.59555	0.42112	0.55932	0.5798	0.086095	0.15021	0.10228
	Min	0.00355	0.26531	0.29045	0.14574	0.07382	0.22417	0.050182	0.06119	0.04617
	Max	0.869	0.82704	0.97636	0.74585	0.91304	0.84955	0.22315	0.28461	0.19182
	SD	0.23604	0.15065	0.15778	0.1476	0.26968	0.1489	0.02836	0.7127	0.37256
TGRs										
	Mean	0.83843	0.98218	0.59675	0.69844	0.92298	0.78798	0.095811	0.20812	0.10243
	Min	0.20529	0.44761	0.29104	0.28656	0.53084	0.31165	0.056635	0.14792	0.046231
	Max	1.00000	1.00000	0.97834	1.00000	1.00000	1.00000	0.24806	0.28466	0.19209
	SD	0.21424	0.099213	0.02499	0.17319	0.14308	0.18458	0.03146	0.044289	0.037309

Source: Survey Data (2017).

However, female plot managers in Serere and Kumi district have the highest mean TE compared to male and jointly managed sorghum plots. The high mean TE in female managed sorghum plots in these districts can be attributed to efficient use of informal rotational labour groups locally referred to as ‘Aleya’ by female plot managers (Läderach et al., 2017). Due to the informal labour groups, efficiency of input utilization is high thus women are able to overcome labour constraints. Jointly managed sorghum plots have the highest mean TE across the three study sites meaning that inputs utilization is more efficient in households with joint plot management.

Contrary to these findings, Alene et al., (2008) found out that male and female managed farms have no significant differences in TE and allocative efficiency in Westerns parts of Kenya while similar results were found by Karki et al. (2015) where gender of the farmer did not influence the TE in production of indigenous vegetables in Kenya.

The mean TE with respect to the metafrontier is lower across the three study sites for male, female and jointly managed sorghum plots compared to those with respect to the sorghum plot management frontiers as expected. This illustrates that there is potential to improve sorghum production given the available technologies. The TE with respect to the metafrontier distributions for the pooled female, male and jointly managed plots are shown in Figure 9 below.

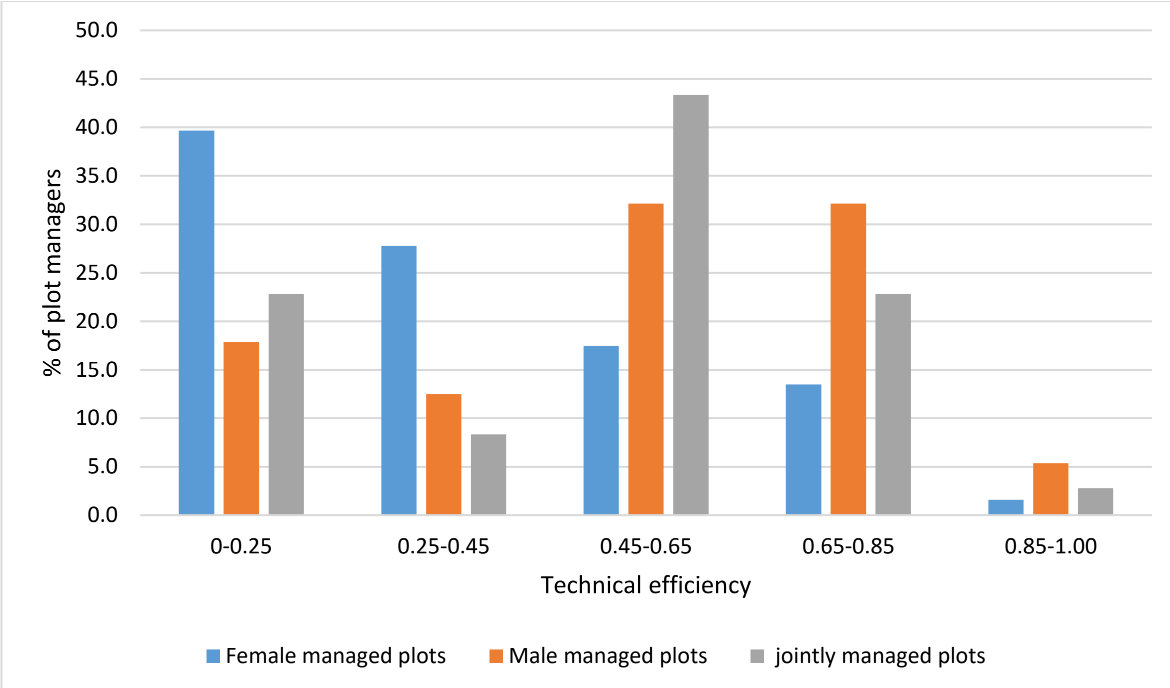

Figure 9: Distribution of Metafrontier Technical Efficiencies

Source: Survey Data (2017).

The mean TGR is highest for male sorghum plot managers across the three study sites compared to female and jointly managed sorghum plots. However, male plot managers have the highest overall TGR (0.98) meaning that male sorghum farmers in Lira district achieve 98% of the maximum possible sorghum output from the available technology (sorghum variety). Across the three study sites, TGR for female (0.84), male (0.98), and jointly managed sorghum plots (0.60) are highest in Lira district compared to those of female, male and jointly managed plots in Serere and Kumi districts. This is due to commercialization in sorghum farming in Lira district where farmers have contract farming arrangement with leading alcohol brewers such as Nile Breweries Limited, Century and Uganda Breweries Limited (Busuulwa, 2014). Therefore, they have adequate provision of farm inputs thus they are able to exhibit high utilization of the available technology.

Farmers in Kumi district have the lowest TGR, female (0.09), male (0.21) and jointly managed plots (0.10). In Eastern Uganda where Kumi district lies, the agricultural sector is not well developed. Sorghum farming is driven by cultural values of the local people and farming inputs are not readily available. It is important to note that a higher TE does not translate to a high TGR because in real world there are other factors rather than technology that affect a farmers' ability to produce maximally.

The standard deviation of TGR is lowest among farmers in Kumi district, female (0.03), male (0.04) and jointly managed sorghum plots (0.04) meaning that farmers in this district could be cultivating traditional sorghum varieties compared to other districts where the standard deviation is higher indicating that farmers could be growing both traditional and improved sorghum varieties.

Figure 10 shows the distribution of TGRs for the pooled male, female and jointly managed plots. However, in Serere district, the maximum TGR for female, male and jointly managed plots is 1, as well as for female and male sorghum plot managers in Lira district. This implies that male, female and jointly manages sorghum plot frontiers are tangent to the metafrontier (Battese et al., 2004). Since the group frontiers are tangent to the metafrontier, in order for further increases in sorghum production it would require introduction of a better technology (sorghum varieties to farmers) who have exhausted the potential of existing technology.

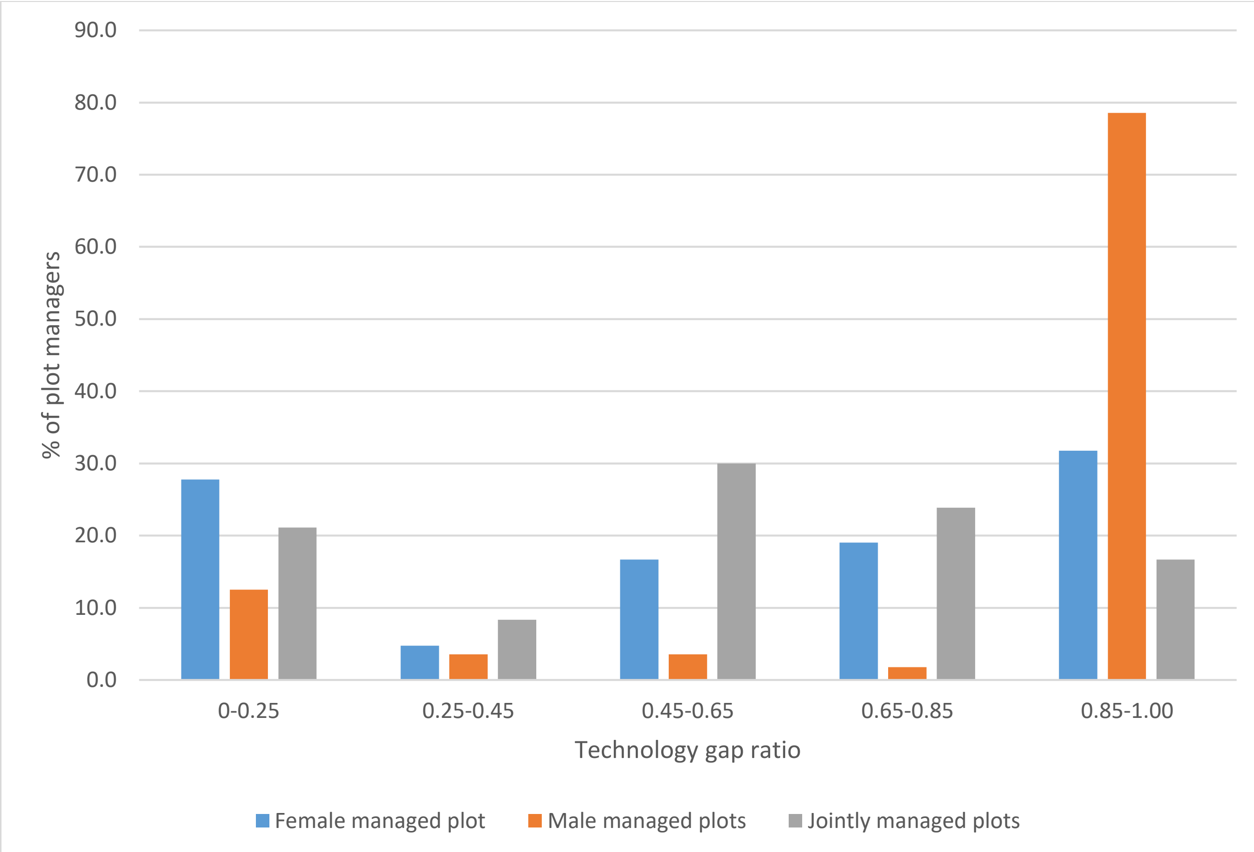

Figure 10: Distribution of Technology Gap Ratios

Source: Survey Data (2017).

Figure 11 shows metafrontier technical efficiencies for female, male and jointly managed plots in Serere district. The highest number of female plot managers had their TE w.r.t metafrontier ranging from 0.25 to 0.45 while for joint plot manages and male plot managers was 0.45 to 0.65 and 0.85 to 1 respectively. There were no female and joint plot managers who had TE scores ranging 0.85 to 1. This can be attributed to low input use and access to support services such as credit and agricultural extension that is characterized by female managed plots.

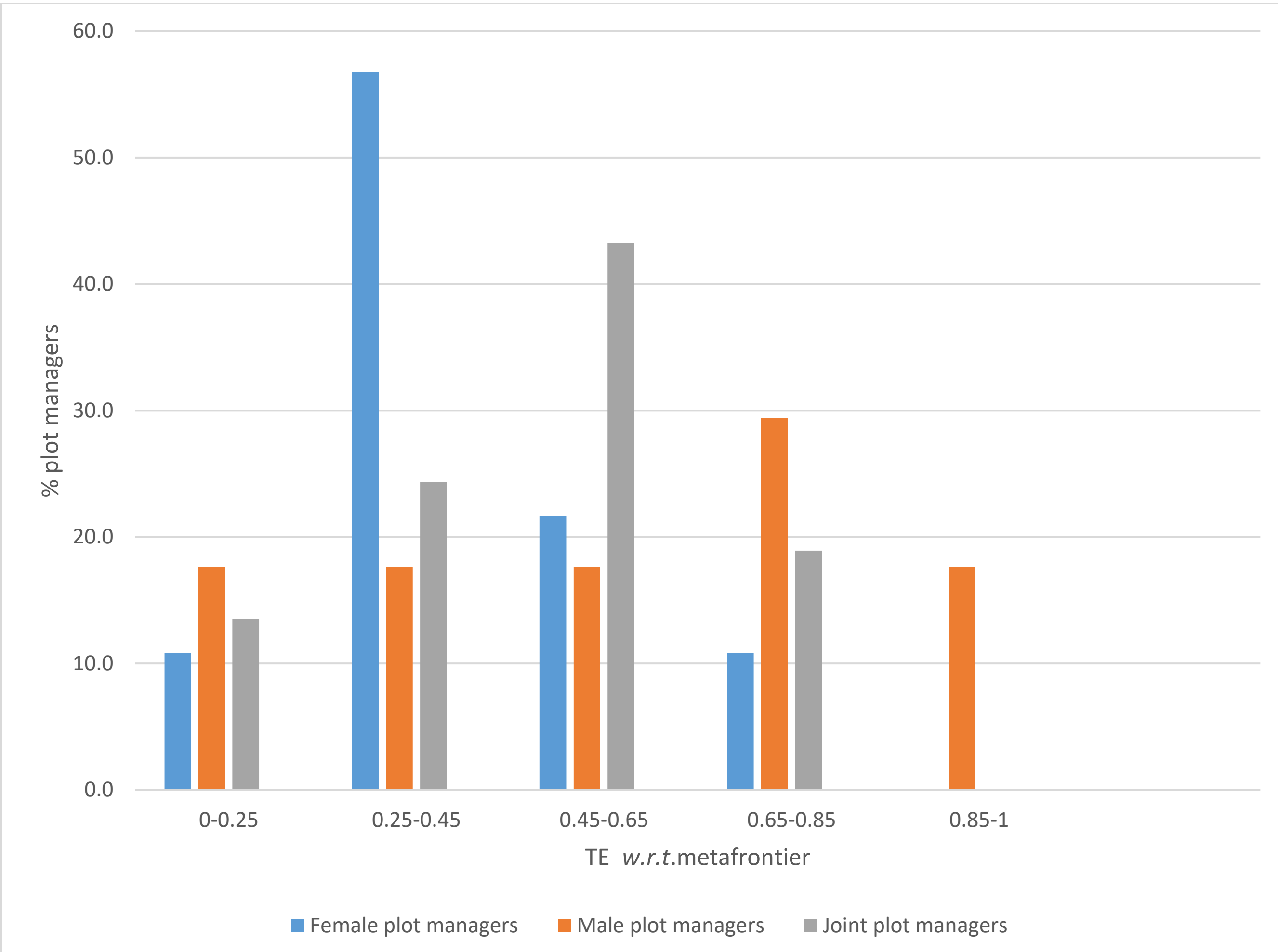

Figure 11: Distribution of Metafrontier Technical Efficiency for Female, Male and Joint Plot Managers in Serere District

Source: Survey Data (2017)

Technology gap ratios of female plot managers and joint plot managers were concentrated between 0.45 and 0.65. The highest percentage of male plot managers (29.4%) had TGRs ranging from 0.65 to 0.85 as shown in Figure 12.

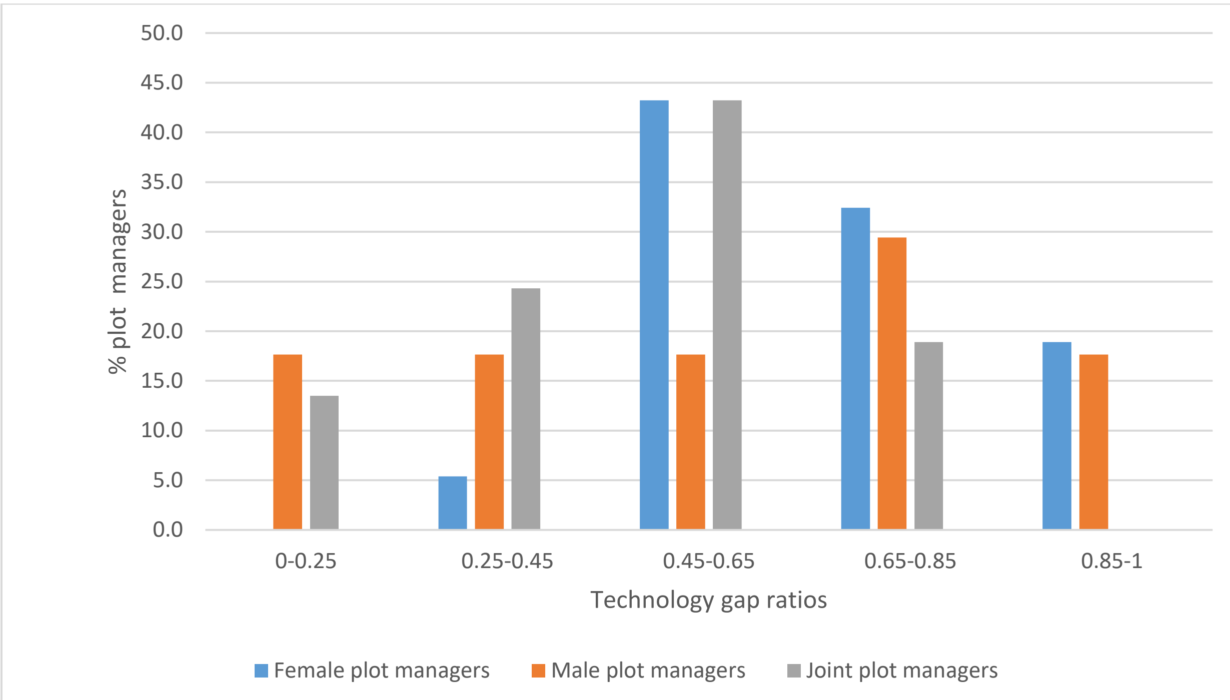

Figure 12: Distribution of Technology Gap ratios for Female, Male and Joint Plot Managers in Serere District

Source: Survey Data (2017)

Figure 13 shows metafrontier technical efficiencies for female, male and joint plot managers in Lira district. Majority of sorghum plot managers had TE scores ranging from 0.45 to 0.65. However, joint plot managers were the highest group within category with 51.8 %.

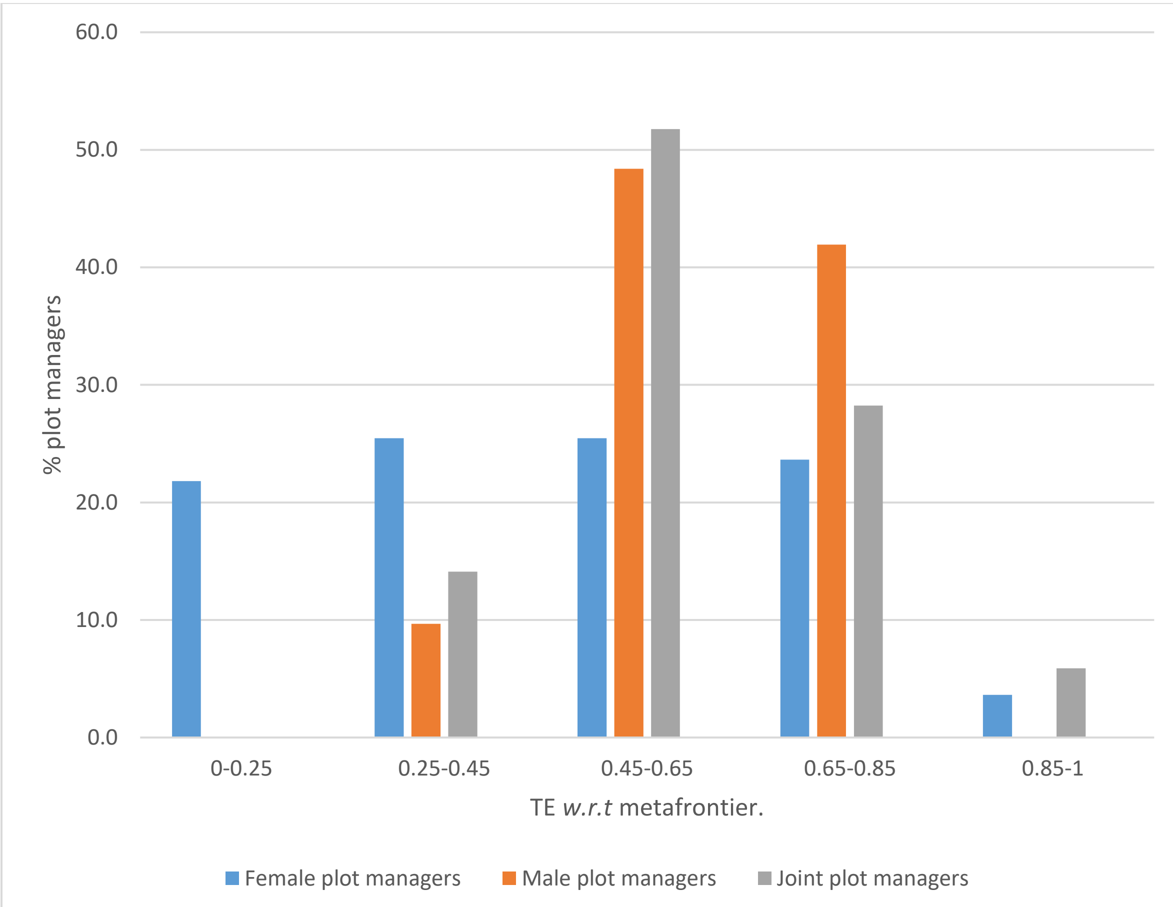

Figure 13: Distribution of Metafrontier Technical Efficiencies for Female, Male and Joint Plot Managers in Lira District

Source: Survey Data (2017)

As shown in Figure 14, 96.2 % of male plot managers had their TGRs between 0.85 to 1, 60 % of the female plot managers had their TGRs between 0.85 and 1 while the majority of joint plot managers (51.7%) had TGRs ranging from 0.45 to 0.65.

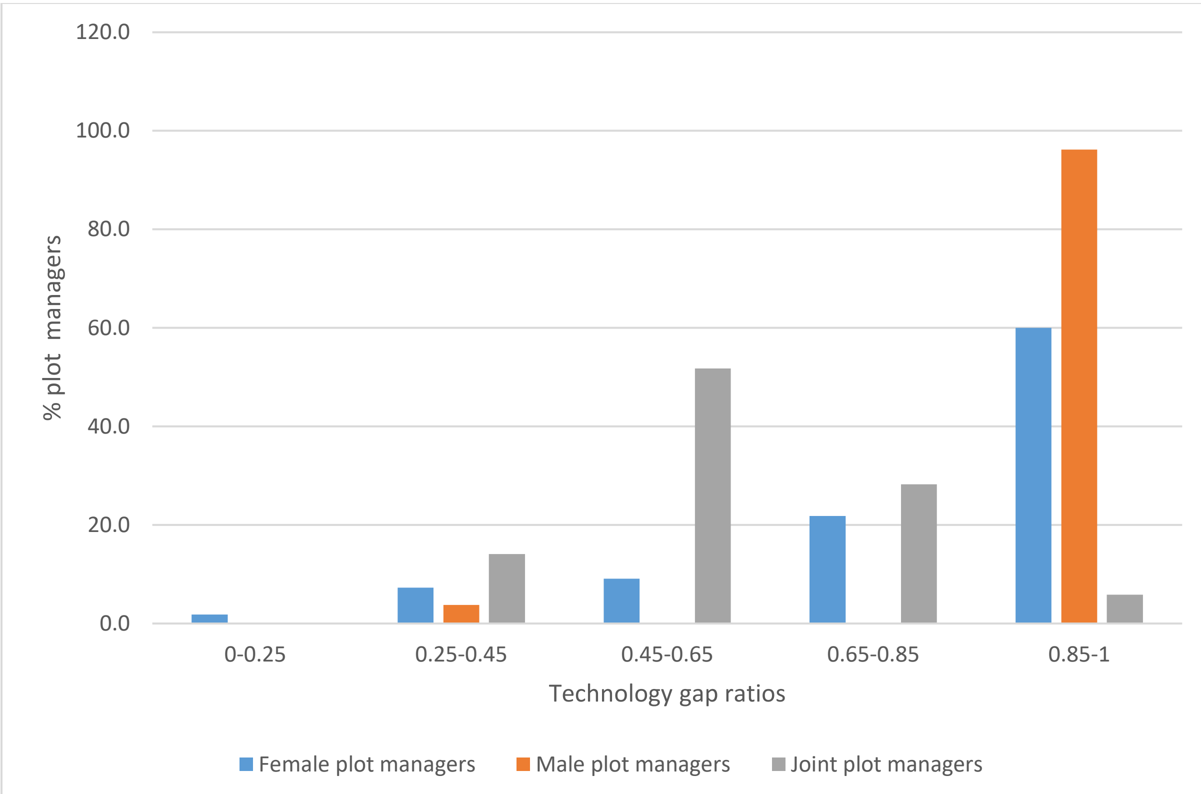

Figure 14: Distribution of Technology Gap Ratios for Female, Male and Joint Plot Managers in Lira District

Source: Survey Data (2017)

Majority of the female, male and joint sorghum plot managers in Kumi district had metafrontier technical efficiencies between 0 and 0.25 as shown in Figure 15. The were no plot managers who had TE scores between 0.45 and 1.

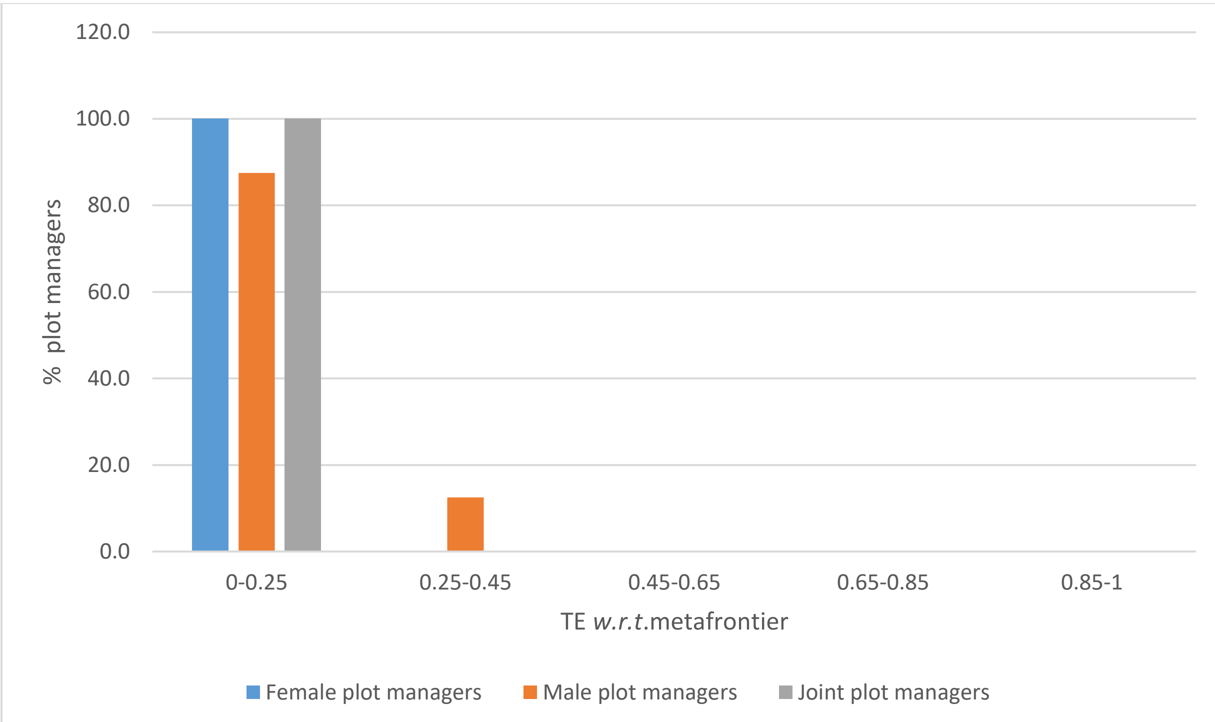

Figure 15: Distribution of Metafrontier Technical Eeficiencies for Female, Male and Joint Plot Managers in Kumi District

Source: Survey Data (2017)

Similarly, majority of all sorghum plot managers in Kumi district had TGRs ranging from 0 to 0.25 as indicated in Figure 16.

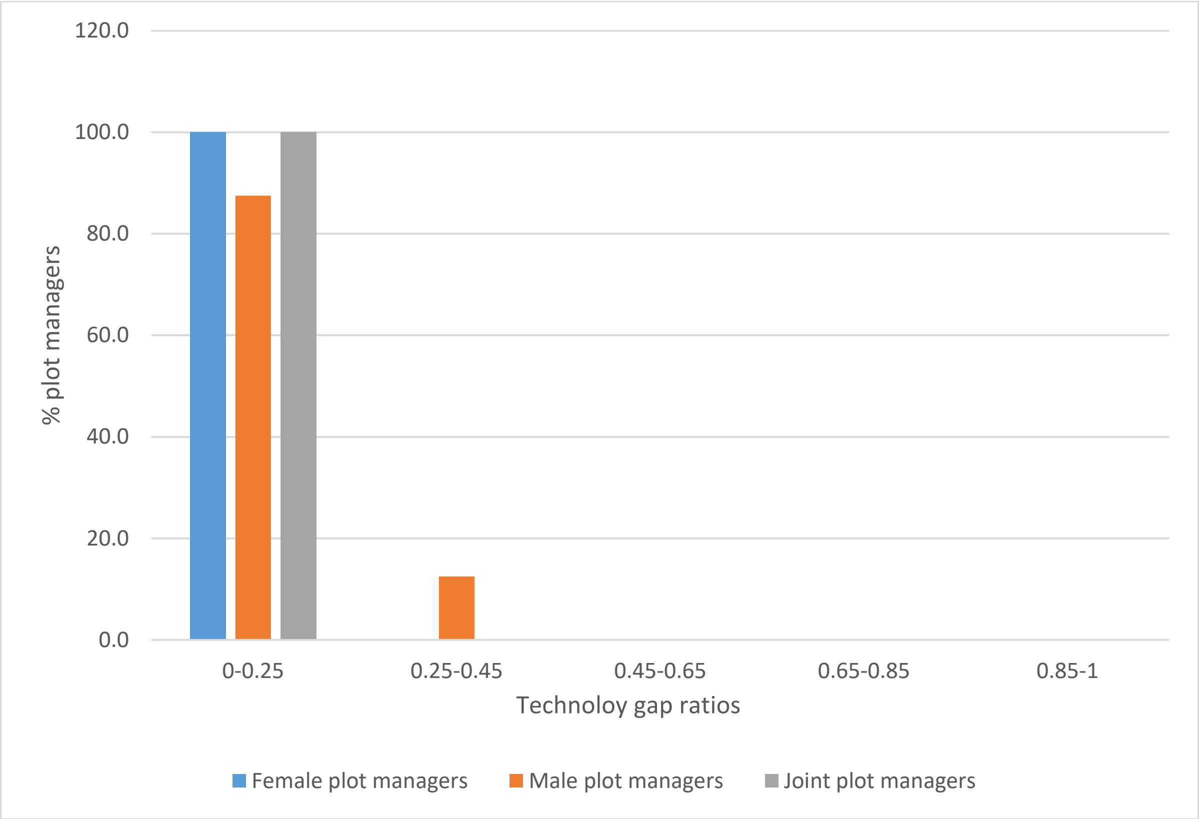

Figure 16: Distribution of Technology Gap ratios for Female, Male and Joint Plot Managers in Kumi District.

Source: Survey Data (2017)

Figure 17 shows a comparative distribution of metafrontier technical efficiencies across Lira, Serere and Kumi districts. Majority of plot manages who had the least TE score were from Kumi district. For Lira and Serere districts majority of the plot managers had TE score between 0.45 to 0.85.

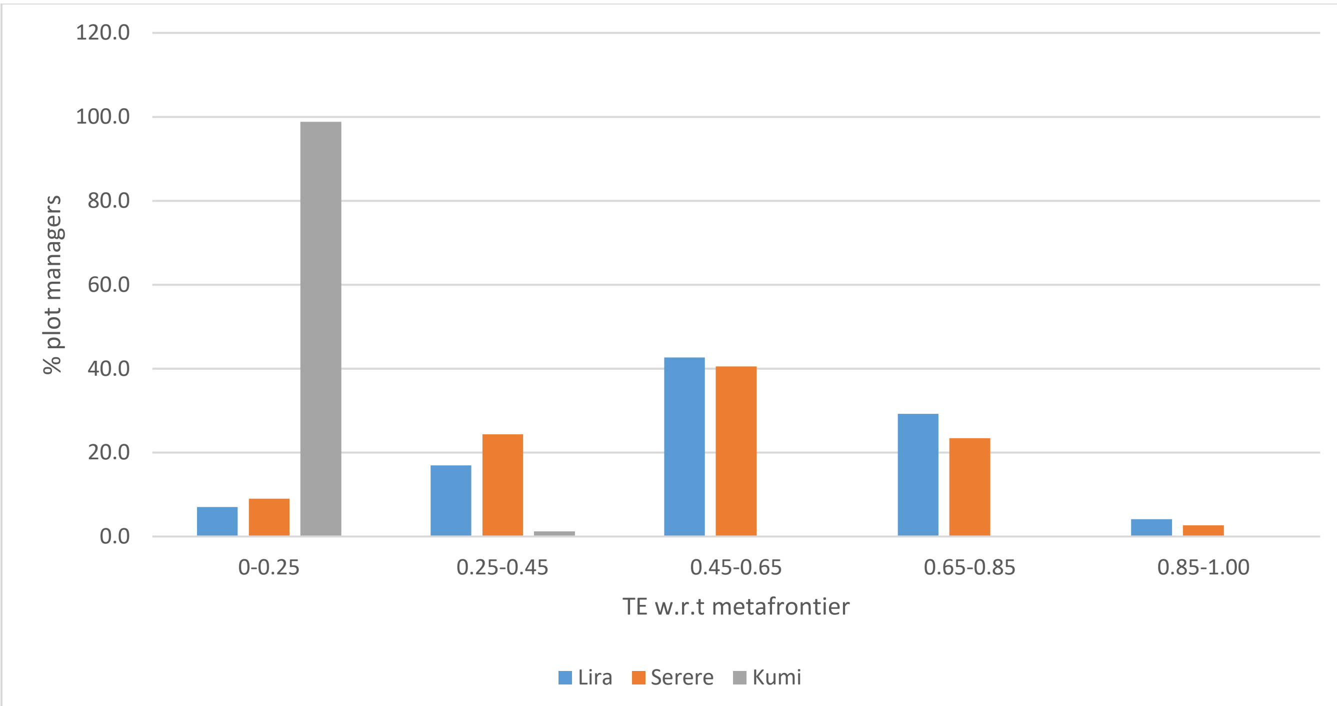

Figure 17: Distribution of Metafrontier Technical Efficiencies for the Study Areas.

Source: Survey Data (2017)

Figure 18 shows distributions of TGR across Lira, Serere and Kumi districts. Serere district had the highest percentage (41.4 %) of plot managers with TGRS ranging between 0.85 to 1 closely followed by Lira district at 39.8%. Kumi district had the highest percentage of farmers with the least TGRs while majority of plot managers in Lira and Kumi district had TGRs ranging 0.45 to 0.85.

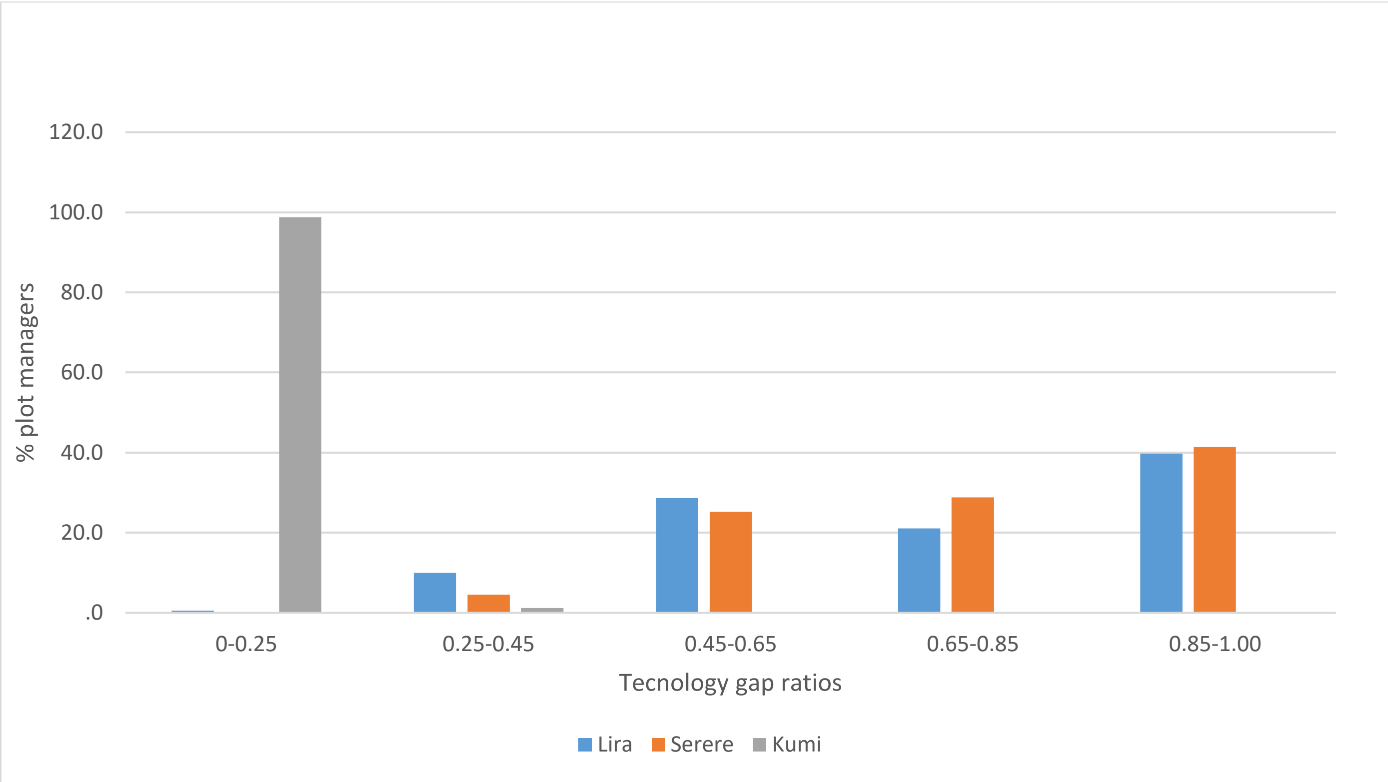

Figure 18: Distribution of Technology Gap Ratios for Sorghum Plot Managers in Lira, Serere and Kumi Districts

Source: Survey Data (2017)

CHAPTER FIVE

5.0 DETERMINANTS OF TECHNICAL EFFICIENCY OF SORGHUM PLOT MANAGERS

5.1 Abstract

Due to the importance TE plays in agricultural activities, it is prudent to evaluate various factors that might influence efficiency of sorghum farmers. The study applied a two-limit Tobit model to assess how various socio-economic and institutional characteristics of farmers affect their TE. The results showed that the age of sorghum plot managers, years completed in formal education, use of family labour, distance to sorghum plots and plot size had a significant and positive effect on TE thus an increase in these variables would result to an increase in TE. On other hand, sorghum plot managers' years of farming and household size influenced TE negatively. The inefficiency model showed that age of the plot manager and years completed in school reduces technical inefficiency while household size tends to increase the inefficiency of sorghum plot managers. Since sorghum is commercialized in Lira district unlike in Kumi and Serere district, holding Lira district constant revealed that plot managers in Kumi and Serere district had lower TE of 2.7 % and 4.8% compared to Lira district.

Key words: technical efficiency, inefficiency estimates, commercialization

5.2 Introduction

Sorghum growing in Eastern and Northern parts of Uganda is a major agricultural activity where it is the main driver of rural households' livelihoods. Some farmers in these areas continue to grow local sorghum varieties that averagely take around nine months to mature and produce averagely 1000Kgs/ha, while others especially in Lira district grow improved varieties that are early maturing and approximately take three months to mature and have a potential of producing around 3500Kgs/ha (Awori et al., 2016)**.**

Notably, the land on which sorghum is grown has relatively remained constant. However, productivity and efficiency have been fluctuating due to both abiotic and biotic factors such as low nutrients in soil, poor seed quality, poor agricultural practices and unpredictable weather patterns thus affecting productivity negatively. These lead to adverse effects on households that depend on sorghum. Concerted efforts are required in ensuring that high efficiency is achieved in utilization of farm inputs and ensuring availability of targeted institutional support such as provision of specialized extension services and agricultural credit that is able to meet the needs of small holder sorghum farmers (Chepng'etich et al., 2015).

Sorghum production in Uganda can be improved through creating a conducive environment for farmers by reducing production bottlenecks such as low soil fertility, pest infestation and exploitation by middlemen (Manyasa, 2016). In order to address declining efficiency and productivity, this study assessed how socio-economic and institutional variables of sorghum plots managers influence sorghum TE in Uganda.

5.3 Description of Variables in the Tobit Model and their Expected Signs

Table 8 below shows a description and expected signs of farmer, farm and institutional characteristics of sorghum plot managers that were included in the two limit Tobit model to assess their effect on TE.

Table 8: Description of the Independent Variables Used in the Two-Limit Tobit Model

Variable	Description of the variable	Expected sign
Socio-economic characteristics		
Gender	Dummy: I if farmer is a male plot manager, and 0 otherwise	+/-
Age	Age of the farmer in years	-
Years completed in school	Number of years of formal education completed	+
Household size	Number of people living in the household	+
Years of farming sorghum	Number of years in sorghum farming	+
Farm characteristics		
Plot size	Size of all sorghum plots in acres	-
Family labour	Family labour used in man-hours	+
Hired labour	Hired labour used in man-hours	+
Technological variable		
Seeds	Quantity of seeds used in kilograms	-
Institutional characteristics		
Farmer group membership	Dummy:1 if the household head belonged to any group, 0 if otherwise	+
Access to extension services	Dummy: 1 if sorghum farmer received extension service, 0 if otherwise	+
Access to credit	Dummy: 1 if sorghum farmer received credit, 0 if otherwise	+

Gender

The literature on the effect of gender on TE is mixed. Empirical evidence from Nepal showed that differences between male and female farmers are not significant after controlling for differences in the levels of input use and socio-economic characteristics of households (Aly and Shields, 2010). However, Owusu et al. (2017) noted that male and female farm efficiencies differ with female farmers often having lower levels of efficiency. Therefore, the sign of gender was expected to be either positive or negative. This is explained by the predominant gender gaps that exist in developing countries where access, utilization of farm inputs and institutional variables vary between male and female farmers.

Age

Age has a significant effect on the TE of the farmer. Older farmers tend to be less technically efficient compared to younger farmers who are energetic and aggressive in agricultural production (Saiyut et al., 2017). In this study, it was expected that age would affect TE negatively. This is because plot managers who are older tend to be less enthusiastic and are more rigid in adopting newer technologies

Years completed in school

The level of education plays a key role in improving the quality of decisions that are made by the farmer and act as an empowerment tool (Abdallah, 2016). The more educated a farmer is the more technically efficient he or she will be hence the variable was hypothesized to assume a positive sign.

Household size

Larger households are able to supply more labour that can be used in agricultural production thus leading to an increase in TE compared to households that are smaller in size (Abate et al., 2019). Therefore, the household size was hypothesized to affect TE positively. This is attributed to household's ability to overcome labour constraints thus improving their TE.

Plot size

Farmers with smaller plots are more technically efficient compared to farmers with large plots. It is easy to manage smaller plots and use the available inputs maximally in contrast to large plot sizes which require more rigorous monitoring (Balogun et al., 2017). In this study, plot size was hypothesized to have a negative sign. This is because, sorghum plot managers are able to oversee plot activities more effectively and use the limited farm inputs efficiently.

Family and hired labour

Labour increases agricultural production as well as TE since it facilitate usage of other farm input (Hua et al., 2018). In this study, hired and family labour are hypothesized to have positive signs. Family labour increases households TE because resource poor smallholder farmers who are not able to afford hired labour are able to address farm labour needs by using family members. On the other hand, use of hired labour also increases TE of plot managers, however, hired labour has a higher effect on TE compared to family labour because of strict supervision and the casual laborer's motivation for higher wages (Kloss and Petrick, 2018).

Seeds

Farmers who use high quantities of seeds compared to those whose use smaller quantities of seeds given that the size of land used is fixed tend to be less technically efficient (Trujillo and Iglesias, 2013). The quantity of seeds in this study was hypothesized to influence TE negatively. This because sorghum plot managers who use increased quantities of seed on fixed plots will be less efficient due to diminishing marginal returns.

Institutional variables

Institutional support services help in capacity building of farmers thus increasing their productive potential and TE (Danso-Abbeam et al., 2018). In this study, credit, farmer group membership and extension services were expected to have a positive sign. Farmers who belong to groups have a higher social capital that they can exploit to access farm inputs and access markets more easily, access to credit empowers farmers to purchase farm inputs while access to extension services increases farmers' capacity to utilize new technology as well as respond to pests and diseases appropriately.

5.4 Methodology

Two methods were applied. First, a one-step procedure was used by estimating SFA with inefficiency estimates. Secondly a two-step approach by first estimating TE scores using maximum likelihood method in stochastic frontier analysis and then using the estimated TE scores as the dependent variable in a two-limit Tobit model. The TE scores are regressed against the socio-economic and institutional variables of the respondents. Since the study had three study areas; namely, Lira, Serere and Kumi districts, a second two-limit Tobit model was run while holding Lira constant to control for sorghum commercialization.

A two-limit Tobit model was used to assess determinants of technical efficiency in sorghum production in Uganda since measures of TE scores are normally bounded between 0 and 1 (Mirza et al., 2015). Use of OLS in assesing TE scores that are derived from stochastic analysis is not appropriate due to measurement errors (Gujarati, 2011). Results from the two step procedure tends to be biased due to misspecification of the model while results from one step appraoch yields robust results since the model correctly specifies the distribution of the dependent variable given the independent and inefficiency variables (Wang and Schmidt, 2002).

A two-limit Tobit model was estimated and the independent variables included in the model are illustrated in section 5.3. The model can be expressed as:

$$u^* = X\beta + e$$

$$u = \begin{Bmatrix} 0 \; if \; u^* < 0 \\ u^* \; if \; 0 < u^* \\ 1 \; if \; u^* > 1 \end{Bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 21$$

where u^* denotes a continuous latent value of the TE score:

u denotes the observed value of the metafrontier TE score;

X denotes a matrix various socio-economic characteristics of sorghum farmers and other independent variables that may affect efficiency:

βs represents vectors to be estimated;

e represents the random term.

5.5 Results and Discussions

5.5.1 Second Order Regularity Conditions

Table 9 shows the results of a concavity test. In production theory, input parameters are expected to fulfil concavity test where the second order derivatives of input coefficients should be negative (Debertin, 2012). The marginal physical product for each input used in production should be diminishing such that further use of the input results to lower levels of output. In this study, the second order regularity conditions are fulfilled for the female, male and joint plot managers as well as in the pooled sample since all the inputs had a negative sign on the coefficient even though some variables were not significant.

Table 9: Second Order Derivatives of Production Coefficients

Change in variable	Female plot managers n=126	Male plot managers n=56	Joint plot managers n=180	Pooled N=362
Family Labour	-0.294	-1.846***	-0.283	-0.874*
(∂MPP1)	(0.402)	(0.545)	(0.481)	(0.476)
Hired labour	-0.034	-0.321	-0.042	-0.127
(∂MPP2)	(1.189)	(1.307)	(1.251)	(1.247)
Seed	-0.111	-0.352	-0.137	-0.313
(∂MPP3)	(0.653)	(1.249)	(0.692)	(0.794)
Plot size	-0.466	-4.513***	-0.587*	-1.784***
(∂MPP4)	(0.319)	(0.349)	(0.334)	(0.333)

**** denotes significance at 1%, * denotes significance at 10% level, corresponding standard errors are in parenthesis*

5.5.2 Stochastic Frontier Analysis with Inefficiency Effects

Table 10 shows Cobb-Douglas estimation of inefficiency effects for the pooled data from the three study sites.

Table 10: Stochastic Frontier Analysis Results with Inefficiency Estimates

Variable	Coefficient	Standard error	t-ratio
Constant	4.891***	0.577	8.473
Family labour	0.363***	0.078	4.648
Hired labour	0.156***	0.031	5.025
Seed	0.238***	0.047	5.101
Plot size	-0.652***	0.112	-5.805
Inefficiency			
Constant	1.874**	0.755	2.481
Age	-0.345*	0.184	-1.874
Years completed in school	-0.111*	0.063	-1.765
Years of sorghum farming	0.088	0.061	1.444
Distance to farm	-0.013	0.022	-0.599
Household size	0.187*	0.098	1.915
Farmer group membership	-0.052	0.106	-0.488
Agricultural extension	0.153	0.107	1.437
Credit access	0.022	0.108	0.203
Gender	-0.035	0.096	-0.370
Sigma-squared	0.503***	0.089	5.657
Gamma	0.504**	0.231	2.186
Maximum TE	0.789		
Minimum TE	0.118		
Mean TE	0.446		
log likelihood function	-370.952		

**** denotes significance at 1%, ** denotes significance at 5% level;* denotes significance at 10% level; TE is technical efficiency*

Source: Survey Data (2017).

From Table 10 above, the average TE for Serere, Lira and Kumi is 0.45 and approximately 50% of variation in sorghum output is due to technical inefficiency. The sum of coefficients for the input variables is less than 1 meaning that if the inputs are doubled, sorghum output would less than double thus the production function exhibits decreasing returns to scale.

Age has a negative effect on technical inefficiency, an increase in the age of the farmer will result to a decline in technical inefficiency. This is similar to Saiyut et al. (2017) who found that an increase in the age of a farmer tends to reduce technical inefficiency due to experience gained and networks that a farmer can exploit to produce more output while those who were above sixty years and increased technical inefficiency.

As years completed in school by a sorghum plot manager increase, the more they reduce their technical inefficiency. Education plays a central role in empowering sorghum farmers in that they are able to understand and apply extension services given much better compared to illiterate farmers and also able to learn new be innovative farming methods. Kidane and Ngeh (2016) found similar results in Tanzania where Tobacco farmers who had formal education had a lower technical inefficiency.

Household size has a positive effect on inefficiency thus an increase in the number of households tends to increase the technical inefficiency. An increase in the household size increases expenditure the household incurs therefore there might be little or no resources to invest in farms thus increasing farmers' inefficiency. This is similar to findings by Mango et al. (2015) in Zimbabwe where maize farmers who had larger households had higher technical inefficiency.

5.5.3 Determinants of Technical Efficiency from the Tobit Model

The coefficient of years that a farmer has grown sorghum is negative and significant as shown in Table 11. This shows that as the years of growing sorghum increases, the TE of farmers tend to decline. This results to failure and reluctance of farmers to adopt modern innovations that are aimed at enhancing sorghum productivity. They stick to the old ways of sorghum farming they have been practicing over time. This is similar to findings by Zalkuwi (2015) who found out that farmers who have grown sorghum for several years had lower productivity due to inefficiencies compared to farmers who had grown sorghum for fewer years.

Table 11: Two-Limit Tobit Model Results for Determinants of Technical Efficiency

Variable	Coefficient	Standard error	*p*- value
Gender	-0.001375	0.005590	0.806
Age	0.002706***	0.000226	0.000
Years completed in school	0.007400***	0.000617	0.000
Household size	-0.001930**	0.000878	0.029
Years of farming sorghum	-0.003314***	0.000282	0.000
Distance to farm	0.000054***	0.000003	0.000
Access to credit	-0.000378	0.006192	0.951
Access to sorghum extension	-0.006093	0.005456	0.265
Farmer group membership	0.001420	0.005852	0.808
Family labour	0.000556**	0.000221	0.012
Hired labour	0.000459	0.000323	0.156
Seed	-0.000079	0.000162	0.625
Plot size	0.104510***	0.010960	0.000
Constant	0.462306***	0.017192	0.000
Log likelihood	569.98244		
Prob > chi2	0.0000		
Number of obs	362		

**** denotes significance at 1% level; ** denotes significance at 5% level*

Source: Survey Data (2017).

Distance of the sorghum plot from the household had a positive and a significant effect on sorghum. A longer distance indicates the possibility of farmers leasing in land for sorghum cultivation as well as having many scattered plots. Such farmers tend to be commercially inclined thus they tend to use various farm inputs more efficiently thus leading to an increase in technical efficiency. This is consistent with findings by Olarinde (2011) who found out that maize farmers whose farm distance from the household was high had a higher TE.

Family labour has a positive effect on TE of sorghum farmers and highly significant at 1%. Rural sorghum households tend to depend more on family labour compared to hired labour. Since agriculture is the only source of livelihood, family members devout their time entirely on farming activities thus improving the TE in sorghum farming. Similar results were found by Chowdhury, (2016) where family labour had a higher relative efficiency compared to hired labour among rice farmers.

The coefficient of the plot size had a positive and a significant effect on TE. This result suggests that as the plot size increases, the TE tends to increase. This can be attributed to the fact that larger farms tend to be more mechanized and commercial oriented compared to small plots thus input utilization in such farms is higher and more efficient. These findings are similar to Bhat and Ahmad (2014) in a study to assess farm size and TE in India. Further, the results corroborates Otieno, (2011) who noted that the size of the farm had a positive and significant effect on the TE of beef cattle farmers.

Comparing the one step and the two step approach, the two step approach yields results with more significant variables (age, years completed in school, household size, years of farming sorghum, distance to the farm from the household, family labour and plot size while in one step approach only; age, years completed in school and household size are significant. Similar comparison approach was used by Otieno, (2011).

5.5.4 Determinants of Technical Efficiency while holding Lira District Constant to Control for Commercialization of Sorghum

For completeness of analysis, Table 12 below shows how various socio-economic and institutional variables influence TE while controlling for sorghum commercialization which is predominant in Lira district.

Table 12: Two-Limit Tobit Results for Determinants of Technical Efficiency while holding Lira District Constant

Variable	Coefficient	Std error	*p* -value
Gender	-0.0078	0.005355	0.147
Age	0.0027***	0.000213	0.000
Years completed in school	0.0074***	0.000582	0.000
Household size	-0.0007	0.000850	0.383
Year of sorghum farming	-0.0029***	0.000274	0.000
Distance to farm	0.0001***	0.000003	0.000
Access to credit	0.0048	0.005890	0.417
Access to sorghum extension	-0.0029	0.005170	0.576
Farmer group membership	-0.0050	0.005681	0.377
Family labour	0.0002	0.000216	0.363
Hired labour	0.0006**	0.000306	0.036
Seed	0.0001	0.000157	0.431
Plot size	0.0882***	0.010644	0.000
District			
Kumi	-0.0273***	0.00754	0.000
Serere	-0.0484***	0.00719	0.000
Constant	0.4988***	0.01722	0.000
Number of obs	362		
LR chi2(15)	528.3900		
Prob > chi2	0.000		
Log likelihood	591.3585		

**** denotes significance at 1% level; ** denotes significance at 5% level*

Source: Survey Data (2017).

As shown earlier in Table 11, age, years completed in school, hired labour and plot size have similar coefficients signs and have the same level of significance, respectively. The coefficient of Kumi district is negative and highly significant at 1%. This means that farmers in Kumi district have their TE reduced by 2.7% relative to farmers in Lira district where sorghum is commercialized.

Also, Serere has a negative and a significant coefficient meaning that farmers in this district have lower TE by 4.8% in comparison to sorghum farmers in Lira district. From the above findings, it can be argued that farmers who have commercialized sorghum farming have a higher TE and that sorghum commercialization should be encouraged among farmers.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Sorghum plays a crucial role in welfare of households in rural Northern and Eastern parts of Uganda where sorghum growing is domiciled. The study used plot level data on female, male and jointly managed sorghum plots on three study sites namely Lira, Kumi and Serere districts. In Lira district, sorghum growing is used for commercial purposes compared to Serere and Kumi district where growing is mainly traditional and culturally centered.

A comparative assessment of productivity, TE and TGR was done among female, male and jointly managed sorghum plots. The specific objectives of the study were to assess determinants of productivity, to assess TE and TGRs and to assess factors that influence TE. Determinants of sorghum productivity were analyzed using a multiple linear regression, TE using stochastic frontier analysis, TGRs using metafrontier while determinants of TE were assessed using a two limit Tobit model.

The results revealed existence of significant differences in productivity, TE and TGRs among female, male and jointly managed plots. Across the three study sites male managed sorghum exhibited high productivity compared to female and jointly managed plots. However, jointly managed sorghum plots had higher productivity than female plots but lower than male managed sorghum plots.

The study found that various socio-economic and institutional variables influenced sorghum productivity. Particularly, the quantity of seed, hired labour, family labour, age of the plot manager and years completed in school had a positive and significant influence on sorghum productivity while the size of plot and the household size had a negative and a significant effect on sorghum productivity.

The results showed that male plot managers had a higher TE compared to female managed plots. Female managed sorghum plots in Serere and Kumi districts had a higher TE compared to male plot managers. This was a result of informal institutions such as the rotational labour groups. Women tend to do well in such settings unlike in Lira where there is sorghum growing is commercial hence such formal institutions tend to favor men more. However, the TE of jointly managed farms across the three sites is the higher compared to female plots meaning that farmers that are involved in joint management tend to be better.

Results of TE with respect to the metafrontier showed that men had a higher TE across the three study sites compared to female managed plots while jointly managed sorghum plots had a higher TE compared to female managed plots but lower than that of male managed sorghum plots. Male plot managers had a higher TGR across the three study sites meaning that male managed farms are producing close to the metafrontier compared female managed plots. Likewise, jointly managed plots have a higher TGRs than female managed plots but lower than TFRs of male managed plots.

The age of plot managers, years completed in school, distance to sorghum farms and family labour influenced TE positively and significantly while household size and years of farming sorghum of the plot managers had a significant negative effect.

The study contributes to the existing body of literature on productivity, TE and TGRs on sorghum farming using plot level data among farmers using plot level data from plot sorghum managers rather than the household level data where previous research has greatly focused on. In addition, it compared the one step and two step approach in assessing determinants of TE of sorghum plot managers.

6.2 Conclusions

Based on the findings, generally female managed plots tend to have lower sorghum productivity, TE and technology gap ratios compared to male managed sorghum plots across the three study areas. However, jointly managed sorghum plots have a higher productivity, TE and TGRs compared to female managed plots but lower than male managed sorghum plots.

In Serere and Kumi districts women had a higher TE compared male sorghum plots unlike in Lira where their TE was lower. This shows women resilience in taking advantage of informal rotational labour groups in those areas to overcome labour constraints and utilize the available farm inputs since informal institutions tend to favour women more compared to men who are majorly favored by formal institutions at the expense of women.

The findings showed that investment in provision of farm inputs such as seed, family and hired labour can play a central role in improving productivity of sorghum. Further, education also plays a pivotal role in enhancing agricultural productivity. The number of years completed in school by farmers influences productivity. Farmers who are educated would be more efficient in utilization of farm inputs thus ensuring increased production. This calls for comprehensive investment and development of the education system so that farmers can be more empowered to make informed farm decisions.

Education also plays an important role in increasing TE. The more years a farmer spends in school the more they are efficient technically. Age of sorghum farmers and distance to the farm also influences technical efficiency positively, showing that the probability of farmers leasing in land for sorghum farming away from their homestead hence they will be more motivated to produce sorghum for commercial purposes.

6.3 Recommendations

6.3.1 Policy Recommendations

Female-managed plots had lower TGR across the three study sites compared to male-managed farms. This calls for development interventions from non-governmental organizations in order to build capacity for female sorghum plot managers to utilize various farm inputs efficiently so that productivity and technical efficiency gaps can be reduced and realize greater output and possibly be at par with the male plot managers. Unlike public or public private partnerships that are profit oriented thus they may not fully address challenges facing female plot managers.

Based on the findings of this study, education plays a key role in increasing sorghum productivity TE of sorghum farming. This calls for concerted efforts from the government to invest in adult education targeting plot managers and promote conducive environment for the elderly to access education. Moreover, ensure universal access to primary and secondary education to both women and men is of high quality and sustainable. Incentives should be included in the universal education policy to promote girls' access to education and investment.

Provision of farm inputs such as certified seed should be promoted as it plays a role in increasing sorghum productivity. Efficient supply of farm inputs should be enhanced through agricultural institutions as compared to use of military who may not understand various aspect of farming. Therefore, initiatives such as the Operation Wealth Creation (OWC) program which is aimed at supplying of inputs to small holder farmers should incorporate various agricultural stakeholders to ensure timely delivery of quality farm inputs and ensure the targeted smallholder farmers benefit from the program fully.

In Lira and Serere district, some farmers had a TGR of 1 meaning that they were producing optimally using the current technology; this calls for introduction of a better sorghum varieties by research institutions such as the National Agricultural Research Organization that is more suited to those areas so that they can realize more productivity gains. Therefore, the government needs to allocate adequate research funds to such institutions to help increase their capacity in breeding and come up with better sorghum varieties.

6.3.2 Suggestions for Further Research

Future studies can focus on using plot level panel data that would give greater insights on productivity, TE and TGRs. The present study used secondary plot level cross sectional data which was limited in scope thus it was not possible to estimate productivity using total factor approach which provides a more detailed analyses compared to using PFP. Further, rather than just estimating determinants of productivity and TE, future research can focus on correlating productivity and TE to household indicators such as assets, food security, nutrition and income.

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APPENDICES

Appendix 1: Household Survey Questionnaire

Introduction

The data was collected by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in October 2017 in Uganda. The survey sought to learn about gender gaps in agricultural production of sorghum farmer households in Northern and Eastern parts. The information would be used to guide programs and policies targeting sorghum production in Uganda.

The survey includes both a section that was asked about the household generally, In addition to sections which were asked to a primary adult male or female in the household where applicable.

In this study sections on household composition and farmer characteristics, time spent on off-farm activities, daily gender calendar, land ownership and titling, land characteristics and management of sorghum plots in the parcel, membership to farmer groups and social networks, knowledge on sorghum varieties, production of sorghum, output/yield of plot, access to information and extension, climate uncertainties and credit facilities will be used.

Identifying variables

Survey date ________________________

Enumerator name____

Household identification number____

Respondents' name____

Respondent contact information____

GPS of the homestead ____

Region____

District ____

County____

Sub-County____

Parish ____

Village ____

1 General information

1.1 Household composition and farmer characteristics

Household Member Number(*start with the respondent*)	Name	Gender *1= male 2= female*	Relation to the HH	Age	Years of schooling	How many months the household member has been present in the house in the last 12 months	Main Occupation of the household member	Farm labour participation of the household member in agricultural production
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Relation to HH	**Main Occupation of the member**	**Farm labour participation in agricultural production**
1=Household head 2=Spouse 3=Son/daughter 4=Parent/grand child 5=Son/ daughter in law 6=Hired worker 7=Relative 8=Don't know 9=Not applicable 10=other	1=Farming (crop and livestock) 2=Self-employment off farm 3=Salaried employment 4=Casual labourer on /off farm 5=School/college child 6=Herds boy/girl 7=Household chores 8=Non-school child 9=Unpaid family worker 10=Petty trade 11=Disabled 12=Old 13=Don't know 14=Not applicable 15=Other	1=Full time 2=Part-time 3=Not a worker 4=Not applicable 5=Other

1.2 Household size……………………………………………

1.3 Number of years involved in sorghum farming…………………………………

1.4 Marital status of the household head

1 = Married living with wife/husband, 2 = Married but wife/husband away, 3 = Divorced/ separated , 4 = Window /widower, 5 = Never married, 6 = Don't know, 7 = Not applicable, 8 = Other………………………………………….

1.5 Type of household

1 = Male and female adult living on plot, 2 = Female adult only, 3 = Female adult living without male on plot, 4 = Male adult only, 5 = Not applicable, 6 = Other………………………………..

1.6 What is the family lineage system?

1= Matrilineal, 2 = Patrilineal

3 = Other……………………………………………………………

2 Time spent on off-farm activities

2.1 Off-farm activity (one can tick more than one)

1 = Business/ trader

2 = Office worker

3 = Artisan/mechanic/factory

4 = Other……………

2.2 Time spent on off-farm activities (hours per day)………………………………….

3 Daily gender calendar (less than 20 hours per day)

3.1 How many hours per day do you spend on household tasks (women)……………………..……

3.2 How many hours per day do you spend on household tasks (men) …………………………..

3.3 How many hours per day do you spend on water collection (women)……………………..…….

3.4 How many hours per day do you spend on water collection (men)…………………….……..….

3.5 How many hours per day do you spend on fuelwood collection (women)…………………….

3.6 How many hours per day do you spend on fuelwood collection (men)………………………..

3.7 How many hours per day do you spend on livestock management (women)………………….

3.8 How many hours per day do you spend on livestock management (men)……………….…….

3.9 How many hours per day do you spend on crop production (women)…………………..……..

3.10 How many hours per day do you spend on crop production (men)…………………………

3.11 How many hours per day do you spend on soil and water conservation (women)………….

3.12 How many hours per day do you spend on soil and water conservation (men)…………….

3.13 How many hours per day do you spend on off farm activities (women)……………………...

3.14 How many hours per day do you spend on off farm activities (men)…………………………

4 Land ownership and titling

4 .1 How many parcels of land do you own ?…………

4 .2 Of all these parcels how many do you use for sorghum production (Maximum 2 parcels)…….

Parcel number	Parcel ownership	Value of parcel if sold today (USHS / acre)	Type of titling	Type of ownership of parcel	Who acquired the parcel	How was the parcel acquired
1						
2						

Parcel ownership 1=self (if respondent is not HH head) 2=Household head 3=Spouse 4=Self and spouse jointly Others……….	**Type of titling** 1=Government title 2=Communal title 3=Awaiting title (formalization processing) 4=Private 5=lease 6=No title 7=Other…..	**Type of ownership of parcel** 1=Own land use 2=Renting out (Respondent rents out own land to a tenant) 3=Renting in (Respondent rents land from outsider as a tenant) 4="Pure share" cropping out (Respondent shares crop yields with tenant) 5="Cost" share cropping in (Respondent shares costs for the crop with land owner) 6="Cost share" cropping out (Respondent shares costs for crop with tenant) 7=Communal land (|Traditional ownership) 8=Borrowed land (from family, relative, institution etc.) 9=Others….
Who acquired the parcel 1=self (if respondent is not HH head) 2=Household head 3=Spouse 4=Self and spouse jointly		**How was the parcel acquired** 1=Inherited 2=Purchased 3=Allocated by the government 4=Allocated by the community 5=Rent 6=Other

Others……….		

4.3 Have you sold land? 1=Yes 2= No

4.4 Have you purchase land? 1= Yes 2=No

4.5 What was your total land holdings in 2012? (acres)…………………………………

4.6 What are your total land holdings in 2017? (acres)………………………………….

5 Land characteristics and management of sorghum plots in the parcel

5.1 How many plots of sorghum do you have on this parcel…………………..

5.2 Size of plot in acres……………………………..

5.3 Which varieties of sorghum you grow on plot in March – July 2017 (multiple responses allowed)

Variety	Tick if grown	Variety	Tick if grown
1=Serena		16=IESV 92043 DL (NARO SORGHUM 3)	
2=Lulu D		17=IS 8193 (NARO SORGHUM 2)	
3=Lulu Tall,		18=ICSR 160 (NARO SORGHUM 1)	
4=Dobbs Bora		19=GE 17/2013 (NARO SORGHUNM 4)	
5=Seredo		20=Edeidei	
6=Sekedo		21=Abir (Kabir)	
7=Epuripur		22=lladir	
8=SES01		23=Eterema	
9=SES02		24=Sila (hybrid)	
10=SES03		25=Belango (Local variety)	
11=Hijack		26=Local Brown (Taar)	
13=Humidi		27=Eiyera	
14=Hibred		28=Others	

5.4 Distance of the plot from homestead? (meters)…………………………………………….

5.5 Who managers the plot?

1 = Male manger, 2 = Female manager, 3 = jointly managed

4 = Others…………………..

6 Membership to farmer groups and social networks

6.1 Are you a member to a farmer, community of cooperative group? 1= Yes 2= No

6.2 How many groups do you have membership with?..................……

6.3 Name of the group……………………………………………

6.4 Type of the group

1 = Farmers group, 2 = Youth group, 3 = Religious group, 4 = Professional group, 5 = Women's group ROSCAs, 6 = Men's group ROSCAs, 7 = Other………………………………………..

6.5 What is the main function of the group?

1 = Produce marketing, 2 = Seed production, 3 = Input access, 4 = Input credit, 5 = Farmer research group, 6 = Social group, 7 = Tree planting, 8 = Natural resource management, 9 = Religious affairs, 10 = Other……………………..

6.6 Which year did you join……………………..

6.7 How frequently do you meet?

1 = Weekly, 2 = Monthly, 3 = Every three months, 4 = Every six months, 5= Annually,

6=Other……………………………………………………..

6.8 Are you able to attend all the meetings? 1=Yes 2= No

6.9 How much is the entry fee? (USHS)………………………………

6.10 How much is the annual subscription (USHS)…………………………………

6.11 What is your role in the group?

1 = Elected official, 2 = Ordinary member, 3 = Other……………………………………….

7 Knowledge on sorghum varieties

7.1 Have you ever grown any improved sorghum variety?

1 = Yes 2 = No if yes

7.2 What are you reasons for participating in improved sorghum enterprise and or project? (*multiple responses allowed*)

1 = Food security, 2 = Commercial purposes, 3 = Culture/tradition, 4 = Religious reasons, 5 = Group enterprise, 6 = Community influence, 7 = Other…………………………………………..

7.3 When did you first start growing improved sorghum varieties? (year)…………………………

7.4 What is the number of improved sorghum varieties have you grown? (multiple responses allowed)

Variety	Tick if grown	Variety	Tick if grown
1=Serena		16=IESV 92043 DL (NARO SORGHUM 3)	
2=Lulu D		17=IS 8193 (NARO SORGHUM 2)	
3=Lulu Tall,		18=ICSR 160 (NARO SORGHUM 1)	
4=Dobbs Bora		19=GE 17/2013 (NARO SORGHUNM 4)	
5=Seredo		20=Edeidei	
6=Sekedo		21=Abir (Kabir)	
7=Epuripur		22=lladir	
8=SES01		23=Eterema	
9=SES02		24=Sila (hybrid)	
10=SES03		25=Belango (Local variety)	
11=Hijack		26=Local Brown (Taar)	
13=Humidi		27=Eiyera	
14=Hibred		28=Others	

7.5 What the area planted? (acres)…………………………………….

7.6 What are your main sources of improved varieties information? (*multiple responses allowed*)

1 = Government extension/NAADS, 2 = NaSARRI, 3 = ICRISAT, 4 = Farmer cooperative/union, 5 = Contract farmers, 6 = NGO/CBO, 7 = Research center: on- farm trials, demos and field days, 8 = Seed/ grain stockiest/ agro dealer, 9 = Other farmers, 10 = Radio/Tv/newspapers, 11= Others…………………………………….

8 Production of sorghum

8.1 How many plots of sorghum did you cultivate in the last season……..

8.2 Year Planted………………..

8.3 Who managed the sorghum plot?

1 = Male manager, 2 = Female manager, 3 = Jointly managed ,4 = Others………

8.4 Plot size in acres …………..

8.5 Distance of the plot from homestead? (meters)………………..

8.6 Variety grown on the plot (Multiple responses allowed)

Variety	Tick if grown	Variety	Tick if grown
1=Serena		16=IESV 92043 DL (NARO SORGHUM 3)	
2=Lulu D		17=IS 8193 (NARO SORGHUM 2)	
3=Lulu Tall,		18=ICSR 160 (NARO SORGHUM 1)	
4=Dobbs Bora		19=GE 17/2013 (NARO SORGHUNM 4)	
5=Seredo		20=Edeidei	
6=Sekedo		21=Abir (Kabir)	
7=Epuripur		22=lladir	
8=SES01		23=Eterema	
9=SES02		24=Sila (hybrid)	
10=SES03		25=Belango (Local variety)	
11=Hijack		26=Local Brown (Taar)	
13=Humidi		27=Eiyera	
14=Hibred		28=Others	

8.7 Family labour input of males on plot in man hours (*I day cannot exceed 20 hours*)

Activity	Man hours	Number involved	Number of days used
labour for land preparation of plot			
Labour for planting			
labour for weeding of plot			
labour for fertilizer application of plot			
labour for chemical application of plot			
labour for bird scaring of plot			
labour for harvesting of plot			
labour for threshing/ shelling			

8.8 Family labour input of females on plot in man hours *(I day cannot exceed more than 20 hours)*

Activity	Man hours	Number involved	Number of days used
Labour for land preparation of plot			
Labour for planting			
Labour for weeding of plot			
Labour for fertilizer application of plot			
Labour for chemical application of plot			
Labour for bird scaring of plot			
Labour for harvesting of plot			
Labour for threshing/ shelling			

8.9 Amount of farmer saved seed used in kilogram on the plot?............

8.10 Value of saved seed (hybrid) used on the plot (USHS per kilo)………..

8.11 Amount of purchases seed (Hybrid) used in kilogrammes………………

8.12 Value of purchased seeds (USHS per kilo)…………………….

8.13 Amount of DAP used in kilograms…………………

8.14 Value of DAP used (USHS per kilo)

8.15 Amount of CAN used in kilograms ………………..

8.16 Value of CAN used (USHS per kilo)…………………

8.17 Amount of manure used………………………..*Choose the unit*

1 = Kilo, 2 = Wheel barrow, 3 = Ox-cart, 4 = Other……………………………………………..

8.18 Value of manure used (USHS)………………………………………..

8.19 Hired labour cost for males on the plot

Activity	Number of hours hired	Daily wage rate (USHS or / day)	Total cost
Labour for land preparation			
Labour for planting			
Labour for weeding			
Labour for harvesting			
Labour for threshing/shelling			

8.20 Hired labour cost for females on the plot

Activity	Number of hours hired	Daily wage rate (USHS or / day)	Total cost
Labour for land preparation			
Labour for planting			
Labour for weeding			
Labour for harvesting			
Labour for threshing/shelling			

9 Output/yield of plot

9.1 How much yield did you harvest (shelled) from this plot (kgs)? 90 kgs per bag……………….

9.2 Out of the total harvest, how many kgs was sold? ....

9.3 Out of the total harvest, how many kgs was barter -traded? ....

9.4 Out of the total harvest, how many kgs was given out for free? ....

9.5 Out of the total harvest, how many kgs was retained as seed for this season? …..........

9.6 Out of the total harvest, how many kgs was consumed? …..........

9.7 What was the average selling price of sorghum grain (USHS/kg)………

9.8 Your household income from sorghum sales……………………..

10 Climate uncertainties

10.1 Have faced any climate uncertainties in the last five years? 1=Yes 2= No

If yes, which one?

1 = Drought, 2 = Floods, 3 = Erratic rainfall, 4 = Hailstorms, 5 = Fire break-out, 6 = Disease outbreak, 7 = Pest outbreak, 8 = Others……………………………………………..

10.2 Estimate the amount of loss financially in USHS………………

11 Credit facilities

11.1 Did you borrow money last year? (2016) 1 = Yes 2 = No

if yes, borrowing from?

1 = Commercial bank, 2 = Rural microfinance, 3 = Sacco, 4 = Money lender, 5 = Merry go-rounds (ROSCAs), 6 = Farmer group/coop, 7 = Relative, 8 = Other farmer, 9 = Don't know, 10 = Not applicable 11 = Other…………………

11.2 What collateral was used?

1 = No collateral land, 2 = Livestock, 3 = Guarantor, 4 = Don't know, 5 = Not applicable

6 = Other…………………………

11.3 What is the value (USHS) of collateral? …………….

11.4 Amount borrowed/ lent (USHS)………………….

11.5 Borrowing purpose

1 = Seed, 2 = Livestock breeding, 3 = Soil and water conservation, 4 = Education, 5 = Social obligation, 6 = Oxen traction, 7 = Fertilizer, 8 = Farm equipment, 9 = Buying food, 10 = Health/medical, 11 = Chemicals rent land, 12 = To improve house,

13 = Others……………….

11.6 Lending duration…………………

11.7 Lending interest rate (% per year)…………………………………

11.8 Amount paid/received with interest by end of 2016 (USHS)………………………………..

11.9 Amount outstanding……………………………………..

12 Access to information and extension

12.1 Did receive any information on sorghum production?

1 = Yes   2 = No

12.2 Who in the household receives the information? *(multiple responses allowed)*

1 = Household head, 2 = Spouse, 3 = Son/daughter, 4 = Grandchild, 5 = Other relatives,

6 = Other…………….

12.3 What type of information do they receive on sorghum production? *(multiple responses allowed)*

1 = Information on crop production, 2 = Information on crop protection, 3 = Information on crop varieties, 4 = Information on crop utilization, 5 = Information on post- harvest, 6 = Information on value addition, 7 = Information on soil and water conservation,

8 = Other…………………………………………………………………

12.4 What are your sources of information?

1 = Private extension agent, 2 = Government extension agents, 3 = Television, 4 = Radio, 5 = Agro dealer, 6 = Agricultural shows, 7 = Field days, 8 = Progressive farmer,

9 = Others…………………………………………………..

12.5 How frequently do you receive the information?

1 = Daily, 2 = Weekly, 3 = Monthly, 4 = Twice a year, 5 = Annually

6= Other………………………………..

12.6 Is the information you get adequate to meet your needs?

1 = Yes, 2 = No, 3 = Sometimes, 4 = Don't know.

13 Any other suggestions
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………..

Thank you for your participation

Appendix 2: Variance Inflation Factor (VIFs) for the Ordinary Least Square Regression

Variable	VIF
Years of farming sorghum	1.61
Age	1.57
Access to credit	1.18
Farmer group membership	1.15
Family labour	1.14
Hired labour	1.14
Gender	1.13
Plot size	1.1
years completed in school	1.1
Household size	1.1
Distance to farm	1.08
Seed	1.07
Access to sorghum extension	1.06
Mean VIF	1.19

The VIFs are all less than 10, this indicates multicollinearity is not a problem (Gujarati, 2004).

Appendix 3: Variance Inflation Factor (VIFs) for Stochastic Frontier Analysis

Variable	VIF
Age	1.53
Years spent in school	1.25
Household size	1.1
Years of sorghum farming	1.49
Distance to farm	1.03
Years of sorghum farming	1.06
Access to credit	1.15
Farmer group membership	1.13
Gender	1.19
Mean VIF	1.21

The VIFs are all less than 10, this indicates multicollinearity is not a problem (Gujarati, 2004)

The file was edited in modelling other study sites

Appendix 4: Stochastic Frontier Instruction File

Code	Interpretation
1	1 = Error components model, 2 = TE effects model
lww-dta.txt	data file name
lww-out.txt	output file name
1	1 = production function, 2 = cost function
y	logged dependent variable (y/n)
171	number of cross sections
1	number of time periods
171	number of observations in total
4	number of regressor variables (Xs)
y/n	mu (y/n) [or delta0 (y/n) if using TE effects model]
y/n	delta (y/n) [or number of TE effects regressors (Zs)]
n	starting values specified (y/n)

Appendix 5: Metafrontier Code

The file FEML.txt, MALL.txt and JOIN.txt contains 171 data observations for group the three groups
* The file parmet1.shd contains estimated parameters of group stochastic frontiers (by column)
* The file Metcoef.txt| contains estimated parameters of the metafrontier
* The file WHL.txt contains observed values of the dependent variable (output)

```
*1. READ DATA AND ESTIMATED PARAMETERS OF GROUP STOCHASTIC FRONTIERS
sample 1 171
genr one = 1
dim group 171 t 171 y 171 famlab 171 hirlab 171 Lnseed 171 Lnplot 171
read (FEML.txt) group t y     famlab hirlab  Lnseed Lnplot/ beg=1 end=55 list
read (MALL.txt) group t y     famlab hirlab  Lnseed Lnplot/ beg=56 end=86 list
read (JOIN.txt) group t y     famlab hirlab  Lnseed Lnplot/ beg=87 end=171 list
sample 1 171
print group t y famlab hirlab  Lnseed Lnplot
matrix x = one|famlab|hirlab|Lnseed|Lnplot
print x
dim x1 55 5 x2 31 5 x3 85 5
copy x x1 / frows = 1;55 trows = 1;55
copy x x2 / frows = 56;86 trows = 1;31
copy x x3 / frows = 87;171 trows = 1;85
dim fem 5 mal 5 joi 5
read (parmet1.shd) fem mal joi / beg=1 end=5 list
matrix s = fem|mal|joi
print s
sample 1 5
```

```
dim s1 5 s2 5 s3 5
copy s s1 / fcols = 1;1 tcols = 1;1
copy s s2 / fcols = 2;2 tcols = 1;1
copy s s3 / fcols = 3;3 tcols = 1;1

*2. CONSTRUCT DATA MATRICES AND ESTIMATE METAFRONTIER
matrix g1 = x1*s1
matrix g2 = x2*s2
matrix g3 = x3*s3
print g1
print g2
print g3
matrix b = -(g1'|g2'|g3')'
print b
stat x / means = xbar
matrix c = (-xbar'|xbar')'
matrix A = (-x|x)
print A
print C
?lp c A b /iter = 6000 primal = bstar
print bstar

*3. USE METAFRONTIER ESTIMATES TO OBTAIN TECHNOLOGY GAP RATIOS
dim meta 5
read (Metcoef.txt) meta / beg=1 end=5 list
sample 1 5
matrix starb = meta
print starb
matrix g1star = x1*starb
matrix g2star = x2*starb
matrix g3star = x3*starb
print g1star
print g2star
print g3star
matrix dev1 = g1star-g1
matrix dev2 = g2star-g2
matrix dev3 = g3star-g3
print dev1
print dev2
print dev3
matrix tgr1 = exp(g1)/exp(g1star)
matrix tgr2 = exp(g2)/exp(g2star)
matrix tgr3 = exp(g3)/exp(g3star)
sample 1 55
print group tgr1
stat tgr1
sample 1 31
```

```
print group tgr2
stat tgr2
sample 1 85
print group tgr3
stat tgr3

*4. COMPUTE STANDARD DEVIATIONS FOR METAFRONTIER PARAMETERS THROUGH BOOTSTRAPPING
dim cowva 171
read (WHL.txt) WHLva / beg=1 end=171 list
sample 1 171
matrix q = WHLva
matrix qstar = x*starb
matrix e = q-qstar
dim beta 5 1000
set nodoecho
set nooutput
set ranfix
print q
print qstar
print e
do #=1, 1000
gen1 k=4
gen1 n=$n
genr sampe = samp(e)
genr df=N/(N-k)
*genr newe = samp(e)*SQRT(N/(N-K))
genr newe = sampe*SQRT(df)
sample 1 171
stat newe
genr qnew = qstar+newe
OLS qnew famlab    hirlab   Lnseed Lnplot / COEF=beta:5
endo
matrix bstre = newe'
matrix beta = beta'
set output
sample 1 1000
stat bstre
sample 1 1000
stat beta
stop
```

The code was modified to fit other study areas.