AN EVALUATION OF THE EFFECT OF LAND FRAGMENTATION AND AGRO-ECOLOGICAL ZONES ON FOOD SECURITY AND FARM EFFICIENCY: THE CASE OF EMBU COUNTY IN KENYA

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DECLARATION

This Thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

I dedicate this thesis to my loving and supportive family

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ABSTRACT

Declining size of the farm holdings in most high agricultural potential areas as a result of continuous land fragmentation is currently a major policy concern in Kenya. The purpose of this study was to evaluate the effect of land fragmentation and agro-ecological zones (AEZs) on food security and farm efficiency in Kenya. The study used data collected from 384 farm-households that were randomly selected from three AEZs in the Embu County, using a multistage stratified sampling technique. The three agro-ecological zones were the Sunflower, Coffee and the Tea zones, based on the official AEZs classification system in Kenya. The status of household food security was determined using household caloric acquisition method which was used to compute a household food security index (HFSI). Farm efficiency was measured using stochastic frontier method. The Analysis of Variance (ANOVA) and Multinomial Logit Regression Analysis were used to evaluate the effect of land fragmentation on food security and farm efficiency. The effect of land fragmentation on household food security was found to be negative in the Sunflower and Tea zones, but not in the Coffee Zone. Further, it was found that the minimum farm-size that could ensure the attainment of threshold level of household food security (HFSI = 1) was above 2 ha in the Sunflower Zone and 0.5 ha in the Tea Zone. Land fragmentation was found to have a positive effect on farm efficiency in the Coffee and Tea zones, but not in the Sunflower Zone. For assurance of sustainable food security in Embu County, this study based on its findings recommends that further fragmentation of farms below the minimum size for attainment of threshold level of household food security should be discouraged. For the farms that are already below the minimum cut-off size for food security, measures to increase these farms' productivities so that they can support more people per ha should be devised and implemented. Other measures that should be

taken to improve food security are increased technology adoption, farmer training, market and road infrastructure and credit.

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ABBREVIATIONS

AEZ	Agro-Ecological Zone
ASCU	Agricultural Sector Coordination Unit
ASDS	Agricultural Sector Development Strategy
FAO	Food and Agriculture Organization of the United Nations
FEWS-NET	Famine Early Warning Systems Network
GOK	Government of Kenya
HFSI	Household Food Security Institute
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
KFSSG	Kenya Food Security Steering Group
KNBS	Kenya National Bureau of Statistics
LH	Low Highland
LM	Low Midland
LSRO	Life Science Research Organization
MOA	Ministry of Agriculture
UM	Upper Midland
UN	United Nations
UNHCR	United Nation’s High Commission for Refugees
UNICEF	United Nation’s Children Educational Fund

USAID	United States Agency for International Development
USCB	United States Census Bureau
USDA	United States Department of Agriculture
VIF	Variance Inflation Factor
WFS	World Food Summit
WHO	World Health Organization

CHAPTER ONE: INTRODUCTION

1.1 Background Information

1.1.1 The Status of Food Security in the World

Food security may be defined as "access by all people at all times to sufficient food for an active and healthy life" as given by the World Bank (1986). However, the World Food Summit (1986) and the Food and Agriculture Organization of the United Nations, (FAO, 2009) modified this definition to state that food security exists when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. People are said to be food insecure when their calorie intake is less than the minimum energy requirement for light physical activities and acceptable body weight as provided by the FAO

The concern about world food insecurity has dominated the global agenda for many decades as expressed in many international conferences since the 1980s (Shaw, 2007). Most of the world leaders have accepted that food insecurity is morally unacceptable, a serious impediment to sustainable socio-economic development and a threat to world peace (Shaw, 2007). For the first time in the global agenda, a target was set in 1996 by the World Food Summit (WFS) to address food insecurity. The WFS targeted to reduce the absolute number of undernourished people to 800 million by 2015, which was about half the 1996 level of global food insecurity (Shaw, 2007). The commitments were reinforced by the UN Millennium Summit that was held in 2000 which set a target to reduce by half the proportion of food insecure people in the world by 2015 (FAO, 2009).

The target on food insecurity formed part of the eight goals set by the UN Summit to spur development in the world.

Besides the concerns of the international conferences held in the last two decades, there are a number of established global bodies that are concerned with developments in food security. Top among these bodies is the Food and Agriculture Organizations (FAO). The FAO was established in 1945 with its headquarters in Rome, Italy. The FAO's main purpose is to ensure humanity's freedom from hunger by promoting programs that raise levels of nutrition and improve efficiency in production of food and agricultural products (Shaw, 2007). Other bodies that have an interest in food security and nutrition are the World Bank, IFAD, IMF, UNHCR, UNDP, WFP and WHO among many others.

The level of global food insecurity was estimated at 800 million people in 1996 (FAO, 2009). Between 1996 and 2015, the efforts by the international community reduced the number of food insecure people in the world by only 5 million, thus missing the WFS target by 385 million (FAO, 2015). During this period, the proportion of undernourished people in the less developed countries decreased from 23 percent to 13 percent, as reported by FAO (2015), and the target set by MDG was therefore considered to have been achieved. However, the proportion of undernourished people in Sub-Saharan Africa declined by only 10 percent (33 percent to 23 percent) in the period between 1990 and 2015, thus missing the target set by the MDG.

1.1.2 The Status of Food Security in Kenya

There are about 10 million people who suffer from undernourishment in Kenya (GoK, 2011; USAID 2009; KFSSG, 2010). The number of people who annually require emergency food assistance is estimated at 1.5 million to 1.6 million (FEWS-NET, 2015; UNICEF, 2015) The Agricultural Sector Coordinating Unit (ASCU, 2011) projects that food insecurity in Kenya will increase to 30 million people by 2030 if measures to alleviate food insecurity are not undertaken.

According to FEWS-NET (2015), the chronically food insecure rural households are found in pastoral areas of Northern Kenya (Garissa, Wajir, Mandera, Isiolo, Samburu, Marsabit and Turkana among others) and the marginal agricultural areas of Southeastern Kenya (Thara-Nithi, Mbeere, Kitui, Mwingi and Makueni). Others are found in Coastal marginal agricultural areas which include Tana-River, Kwale and Kilifi Counties.

Land fragmentation in high potential agricultural areas, which has resulted into economically unviable farm holdings, is cited as one of the major challenges in ensuring food security in Kenya (GOK, 2008; GOK, 2016). The adverse effect of land fragmentation on food security has been exacerbated by declining efficiencies in the production of the major crop and livestock products. According to the Kenya Vision 2030 (GOK, 2008), the productivity levels of the major crop and livestock products have either remained constant or have declined in the last five years. The declining farm efficiency negatively affects food security by reducing farm production from the available resources.

Declining land holdings in rural areas have worsened food insecurity situation by increasing urbanization (KFSSG, 2010). Rapid and rising urbanization has resulted in the urban population rising by eight times what it was at independence (KFSG, 2010). A third of 38.6 million Kenyans live in urban areas with 40 percent of them living in slums (USAID, 2009). KFSSG (2010) and USAID (2009) estimate urbanization at 35 percent (approximately 12 million people) with 5.7 million people living in slums and deriving their incomes from wage labour and petty businesses. Unprecedented rise in prices of food and non-food commodities has largely contributed to food insecurity in urban areas.

1.1.3 Land Fragmentation and Land Use Policy in Kenya

Subdivision of a single large farm into a large number of separate small land plots, which is a common agricultural phenomenon in many countries, is referred to as land fragmentation (Sundqvist, 2006). Van Dijk (2003) distinguishes four types of land fragmentation: fragmentation of land ownership; fragmentation of land use; internal fragmentation; and separation of land ownership and use. Fragmentation of land ownership refers to the number of landowners who use a given piece of land. Fragmentation of land use refers to the number of users that are also tenants of the land. Internal fragmentation emphasizes the number of parcels exploited by each user and considers holding size, shape and distance as the main issues. The dimension of land fragmentation that currently is of major concern in Sub-Saharan Africa is the declining farm sizes in both ownership and use which logically implies dis-economies of scale in food production (Kiplimo and Ngeno, 2016). The major land policy concern in Kenya today is the declining farm sizes resulting from continuing land fragmentation as population increases. Kenya National Land Use

Policy (GOK, 2016) cites land fragmentation among the major challenges facing the growth of agricultural and industrial sectors in Kenya, and recommends for determination of viable minimum land sizes based on ecological and land use carrying capacities. The policy also calls for measures to discourage cultural practices that promote land fragmentation.

According to Bullard (2007), some of the causes of land fragmentation in the developing countries include increase in population that leads to increased land subdivision, and government policies on redistribution of land formerly owned by the state or large land owners. Laws of inheritance and the social status conferred by land ownership have encouraged subdivision and sale of land particularly in African societies. Land inheritance in which land is shared among the owner's heirs is embedded in many world customs and religions. Urban encroachment into rural areas, which is a common phenomenon during rapid urbanization, has also reduced land available for agriculture. The key driver behind the declining arable farm sizes in Africa is the culture of inheritance where in most societies in Sub Saharan African are characterized by a culture of patrilineal succession and inheritance where properties including land is successively shared among the sons in a family (Holden and Mace, 2003). This implies that as the population increases the size of the holdings become increasingly fragmented into small plots (Bizimana et al. 2004). Land fragmentation in Kenya can be traced back to 1960s when major reforms were taken to subdivide and transfer the former large scale farms formerly owned by white settlers to the native Africans. Among these reforms was Million Acre Settlement Scheme (Harmsworth, 1974).

Land fragmentation has many disadvantages, but it also has a few advantages. According to Sundqvist (2006), efficient crop production is constrained by land fragmentation for it is a hindrance to economies of scale. Economies of scale exist where a producer (farm) can reduce average unit costs by increasing the scale of production. Land fragmentation is also a constraint to farm modernization, particularly mechanization. It also discourages investment in such infrastructure like transportation, communication, irrigation and drainage due to limited capacity to recover the cost of such investments (Sundqvist, 2006). Land fragmentation reduces accessibility to support services like credit and extension due to the reluctance of lending agents to accept small land parcels as guarantee for credit. It is also expensive for extension service providers to offer services to small holders. On the other hand, small plots are preferable if diseconomies of scale exist, that is, if farms can decrease average costs by operating at small scales. For instance, farmers operating in a situation of labour market failure may be unable to acquire adequate labour during peak season if they operate at large scale.

In literature, there appears to be no standard methods of measuring land fragmentation but various indicators, which can be used in developing proxies for measuring land fragmentation, have been cited. King and Burton (1989) cite the following six indicators of land fragmentation: holding size; number of parcels belonging to the holding; size of each parcel; shape of each parcel; the spatial distribution of parcels; and the size distribution of parcels. A measure of land fragmentation should capture at least one of the six parameters, which include farm size, plot number, size, shape and spatial distribution (Bentley, 1987). Since the dimension of land fragmentation that is of greatest concern in Kenya is the declining farm sizes, the current study uses farm size as a proxy for measuring land fragmentation.

1.2 Statement of the Problem

Despite the concerted global and national efforts to fight food insecurity, undernourishment is still rampant in the world in general and Kenya in particular. Food insecurity in Kenya is estimated at over 25 percent of the total population, with about 1.5 million people requiring emergency food assistance annually. Land fragmentation and declining farm efficiency are among the major causes of food insecurity as cited by available literature. This citation may be due to the fact that land fragmentation is rampant in most high agricultural potential areas in Kenya, mainly due to increasing population pressure, but there is limited evidence from empirical studies. However, reduced farm sizes as a result of land fragmentation are expected to impact on the farm's contribution to household food security through their effect on farm production and farm efficiency

A number of institutional and policy measures are being undertaken by the Government of Kenya (GOK) to address the perceived negative impacts of land subdivision on food security. Such measures include the provision of extension services and formulation of a number of legal and policy documents, including the Constitution, to guide the process of curbing the menace of land fragmentation. For example, the Article 60 of the Kenyan Constitution calls for efficient and sustainable land management practices. The Kenyan Parliament is mandated by Article 68(c) of the Constitution to regulate the size of privately owned land by prescribing the minimum and maximum acreages. The development of a land use master plan which includes the master plan for agricultural land is one of the flagship projects being implemented by Kenya Vision 2030. This project is expected to boost the efficiency of utilizing all forms of land in Kenya. However, the government efforts to address land fragmentation have been hampered by lack of adequate and reliable research-based information to guide policy formulation on land management and its impact on food security.

The results from the previous studies, which have been conducted to evaluate the impact of farm size on household food security and farm efficiency, have been found to be inconclusive. These studies have two main shortcomings: their failure to evaluate the influence of agro-ecological zones on the impact of farm size on household food security and farm efficiency, and their failure to determine the minimum farm size that can ensure household cut-off food security status. For this reason, the current study was conducted to examine the impact of land fragmentation on household food security and farm efficiency across three different AEZs in Kenya, using the data collected from Embu County in Eastern Kenya as a case study. The three agro-ecological zones were the Sunflower-Zone (UM 4 and LM 3), the Coffee Zone (UM 1-3) and the Tea Zone (LH 1-2), following the Jaetzold, et al. (2006) categorization of the AEZs in Kenya. The impact of farm-size on food security and farm efficiency was evaluated using a sample that was classified on the basis of the three AEZs. The minimum farm-size required to ensure the minimum cut-off food security status also was determined for each of the three AEZs.

1.3 Objectives of the Study

1.3.1 Broad Objective

The broad objective of this study was to evaluate the impact of land fragmentation and agro-ecological zones on food security and farm efficiency in Kenya through a case study of Embu County. Farm size was applied as an indicator of land fragmentation.

1.3.2 Specific Objectives

The following were the specific objectives of this study:

1. To characterize the effects of farm size and other key factors affecting household food security in different agro-ecological zones in Embu County;

2. To determine the minimum farm size required to ensure the attainment of threshold level of food security in different agro-ecological zones in Embu County

3. To characterize the effects of farm size and other key factors affecting farm efficiency in different agro-ecological zones in Embu County.

4. To evaluate the elasticity of output for land and other key factors of production in different agro-ecological zones in Embu County

In this study, the other key factors that were hypothesized to affect household food security and farm efficiency are gender, age, education, household income, household size, dependency ratio, livestock ownership, extension, infrastructure, credit and technology. The key factors of production are land, labour, fertilizer and seeds. The total land area (in hectares) cultivated by the household for production of food and cash crops is referred to as farm size in this study.

1.4 Hypotheses of the Study

The following hypotheses were tested:

1. That farm size and other major socio-economic and institutional factors have no statistically significant effect on household food security in different agro-ecological zones in Embu County
2. That the variations in the mean household food security index (HFSI) across farm size categories in different agro-ecological zones in Embu County are not statistically significant
3. That farm size and other major socio-economic and institutional factors have no statistically significant effect on farm efficiency in different agro-ecological zones in Embu County
4. That the elasticity of output for land and other key factors of production are not statistically significant in different agro-ecological zones in Embu County

1.5 Justification of the Study

In the formulation of land reform policies that aim at ensuring food security and efficiency among smallholder farmers in Kenya, it is important to understand how fragmentation impacts on food security and farm efficiency across different AEZs. As pointed out by the Agricultural Sector Development Strategy, about 75 percent of the total agricultural production in Kenya comes from smallholder farmers (GOK, 2010*b*). Determination of the factors that influence food security and farm efficiency across different AEZs thus offers insights on factors worthy of consideration in developing appropriate interventions for improving food security and farm efficiency in each AEZ.

Embu County was chosen as the study area for it is among the counties in Kenya that are prone to occasional food insecurity due to widespread land subdivision in the high agricultural potential areas, and also exhibits some arid conditions in other parts (KFSSG, 2012). About 74% of agricultural land in Embu County can be described as being arid or semi-arid because it receives less than 850 mm of annual rainfall, compared to less than 10% and 30% in the neighboring Counties of Kirinyaga and Meru respectively (KNBS, 2015). Areas in Embu County receiving less than 850 mm of rainfall are classified by Kenya Food Security Steering Group (KFSSG, 2012) as being in the stressed phase of food insecurity. According to KFSSG (2012), such areas form part of South Eastern Marginal Agricultural Cluster which includes Tharaka, Mbeere and Meru North, among other areas. The former Mbeere District, which has now been subdivided into two districts within Embu County, is an arid and semi-arid land (ASAL), receiving less than 900 mm annual rainfall in most parts, and borders the arid districts of Kitui and Machakos (Jaetzold, 2005). Unlike the areas classified in the critical phase of food insecurity, the areas in the stressed phase are only prone to occasional food shortages. Such areas can cope with food insecurity without resulting to such irreversible coping strategies as sale of long term assets or diverting expenses from non-food items such as education (KFSSG, 2012).

The former Embu District, which has now been subdivided into two districts within Embu County, has the highest population density in Eastern Region at 409 persons per Sq. Km according to 2009 population census, followed by Kangundo district at 290 persons per Sq. Km (KNBS, 2015). As a matter of fact, Embu County is home to two of the most densely populated constituencies in Eastern Region (KNBS, 2015). These are Runyenjes and Manyatta Constituencies at 489 and 356 persons per Sq. Km respectively. Tigania West constituency follows at a distant with 299 persons per Sq. Km (KNBS, 2015). Due to this high population density, Embu County's average farm size is among the lowest in the country, ranging from less than 1 hectare in the former Embu District to less than 4 hectares in the former Mbeere District (MOA, 2012). Despite the high potential for food insecurity in the Embu County, the effect of farm size and other key factors affecting food security and farm efficiency has not been characterized in any study conducted in the County.

The institutions that will benefit from the results generated by this study include policy making institutions, providers of agricultural extension services, institutions of higher learning and research, farmers and farmers' organizations. The results of this study would assist in the design of strategies to promote efficient and sustainable land resource management for food security, to achieve Vision 2030 and in accordance with the Kenyan Constitution. The providers of agricultural extension services can use the data collected on crop and livestock inputs and outputs as they formulate extension messages for use by farmers in Embu County and in other areas with similar economic and agro-ecological environment. The study findings will build onto the existing body of research, and also point out gaps in the findings for future research on food security and farm efficiency and how they are influenced by agro-ecological zones. The Farmers and farmers' organizations shall benefit from the findings of this as they will provide information on the implications of unregulated land subdivision on food security and farm efficiency.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The World Food Summit (WFS, 1986) and Food and Agriculture Organization of the United Nations (FAO, 2015) identify four different dimensions of food security which capture different but at times overlapping features of food security. These are availability, access, stability and utilization. The quantity, quality and diversity of food available to the people are the aspects of food security described in the availability dimension. The adequacy of calorie and protein available in the food taken are the main indicators of food availability. Food access captures the peoples' physical and economic access to food. The main indicators of food access are domestic food price index and physical infrastructure (roads, railways, and storage facilities) that make food available to the people.

Food stability captures peoples' exposure to risk of food insecurity due to incidences of shocks, such as domestic food price volatility, fluctuations in domestic food supplies, political instability and peoples' loss of income. Food utilization dimension focuses on peoples' ability to utilize food as indicated by stunting, under-weight, anaemia and vitamin A deficiency among children under five, and prevalence of iodine deficiency and anaemia among pregnant women. The severity of food insecurity depends on the extent to which any of the four dimensions of food security is violated. More practically, food insecurity manifests itself as hunger or undernourishment when people's calorie intake is below the minimum dietary energy requirement (FAO, 2009)

2.2 Evaluation of Factors Affecting Food Security

Previous studies reviewed classify the factors affecting food security as either socio-economic or institutional factors. The socio-economic factors are those factors associated with the head of household's characteristics and resources. Institutional factors are factors associated with the institutions that provide such support services as extension, technology, infrastructure and credit. The literature reviewed reveals that the nature and the significance of these factors in determining food security depend on the location and the period in which the data was collected.

The socio-economic factors associated with household characteristics include age, gender, farming experience and education status. Others are household size, the dependency ratio, off-farm employment and household income. The socio-economic factors associated with the farm include farm size, on- and off-farm income, livestock values, food and cash crop production, technology adoption and land tenure. The institutional factors comprise the services that are offered by the public or private institutions that promote agricultural development and include access to markets, water, infrastructure, credit, extension service, technology development and government policy.

2.2.1 Resource Factors

The total land area (in hectares) cultivated by the household for production of food and cash crops is referred to as farm size (Kuwornu *et al,* 2013). Previous studies on food security have found that farm size positively affects food security through its influence on food production, farm income and farm efficiency. Such studies include Mitiku et al (2012), Faridi and Wadood (2010), Kuwornu et al (2005) Omotesho et al (2010), Mensah (2013), Haile et al (2005) and Kaloi et al (2005). The possible explanation is that increased farm size increases farm production thus increasing the household's availability of food and income (Mensah *et al*, 2013; Mitiku *et al*, 2012 and Gumechu *et al*, 2015). Households owning large farm sizes have been found to have better chances of producing more food and cash crops, and for crop diversification (Bogale and Shimelis, 2009; Helfand, 2004; Padilla-Fernandez, 2012 and Gorton and Davidova, 2004). Large farms also generate large volumes of crop residues for livestock production. Mitiku et al (2012) found that household wealth, credit access, risk-bearing capacity and household income are influenced positively by the size of the land holding.

The previous studies conducted to examine the effect of farm size on food security have failed to examine the interaction between farm size and agro-ecological zones. The studies have not examined how this interaction influences the effect of farm size on food security and the minimum farm size that could ensure household's attainment of threshold level of food security. The main distinguishing features of an agro-ecological zone that are likely to impact on food security are climate, topography and soil type which determine the agricultural production potential. The location of a given agro-ecological zone within the Embu County deterrmines the households' proximity to market centres, road infrastructure and other institutional support services. Topography and soil type also influences the ease of providing passable road infrastructure and hence affects the marketing of agricultural produce in a particular agro-ecological zone. This study examines the effect of farm size across three agro-ecological zones and evaluates how the location and the distinguishing features of a given agro-ecological zone influence the effect of farm size on household food security.

A number of studies have found a positive relationship between food security and household income (Seid, 2007; Mengistu et al, 2009; Mitiku et al, 2012; Mensah et al, 2013; kuwornu et al, 2005; Kaloi et al, 2005 and Nyangweso et al, 2007). Seid (2007) found that an increase in the household income increases the capacity of the household to consume more food. Food production was found to be increased through investing the income generated from on- and off-farm activities, hence increasing food availability in the household (Mensah et al, 2013). The influence of the total quantity of food and cash crops produced on household food security has been found to be positively significant as reported by Kuwornu et al (2013), Langat et al (2012) Kuwornu et al (2009) and Haile et al (2005) among others. The possible explanation is that the money realized from the sale of cash crops enables the household to purchase more food thus increasing its food consumption (Babantunde et al, 2007).

According to Seid (2007), Mengistu (2009) and Mitiku (2012), the value of livestock owned by the household was found to have a positive influence on household food security through its positive influence on household income and production. Livestock increases food availability and access by providing livestock products and additional income from sale of livestock products (Mitiku et al, 2012). Livestock are also a source of farm power and manure (Gemechu et al, 2015; Getinet, 2011 and Bogale and Shimelis, 2009). According to these studies, livestock contributes to household economy as a source of income, food and farm power. In situations of crop failure or other calamities, livestock owned is also reported to offer financial security that enables the household to cope with the resulting food insecurity.

Increases in food and input prices have been found to have negative effects on household food security. Increased food prices reduce the household's food purchasing power, while increased input prices increase cost of food production (Seid, 2007). Faridi and Wadood (2010) found that the likelihood of a household being food secure in Bangladesh decreases as the price of the staple food increases. Similar results were found by Davila (2011) and Lewin (2010) in Mexico and Malawi respectively. In addition, food insecurity was found to increase as fertilizer prices increase in Malawi (Lewin, 2011).

The previous studies conducted to examine the effect of resource factors on food security have failed to examine how the effect is influenced by the location and agricultural potential of a given area. The agricultural potential of a given area is likely to impact on the productivity of the resources and hence reduce or increase their impact on food security. This study evaluates the influence of agricultural potential on resource factors affecting food security by examining the effect of those factors on food security in three agro-ecological zones in Embu County, which have differences in agricultural potential. This study also examines how the interaction between these resource factors and access to market outlets, road infrastructure and other institutional support services influence their effect on on food security.

2.2.2 Household characteristics

Household size has been found to negatively affect household food security by Seid (2007), Mengistu et al (2009), Mitiku et al (2012), Bogale and Shemelis (2009), Omotesho et al (2010), Mensah et al (2013), Haile et al (2005) and Kaloi et al (2005), among others. An increased household size has been found to increase food consumption more than its contribution to farm production especially in less developed countries where farm production is limited by inadequate capital resources (Haile et al, 2007). An increase in the number of household members was found to reduce the per capita food intake in situations of unchanged food availability and access (Abu and Soom, 2016 and Mitiku et al, 2012). Increased household size tends to increase food demand more than the food production obtained from increased labour especially in situations where dependency ratio is increased (Muche et al, 2014). The proportion of household members who are aged below 15 years, and 65 years and above is referred to as the dependency ratio or burden (Todaro and Smith, 2012). These age groups are considered to be economically unproductive and are thus dependent for livelihood on those aged 16- 59 years. Due to scarcity of farm resources, increases in number of non-working members of the household increase pressure on consumption than on food production (Muche et al, 2014).

Age of the household head has been found to have positive impact on food security. The possible explanation is that the head of household gains more farming experience, accumulates more wealth and uses better farming methods as the age increases (Bogale and Shimelis, 2009). The increased experience that comes with age may have a positive influence on food security and farm efficiency for it increases the farmer's ability to manage farm resources thus increasing farm efficiency (Hofferth, 2003 and Bogale and Shimelis, 2009). The older farmers are also more likely to own larger pieces of land than the younger ones, thus able to produce more food and cash crops (Haile et al, 2005). However, the older household heads are less likely to undertake farm innovations that have high risks. The older household heads may also be less educated and are thus less likely to adopt the technologies that boost farm production (Babatunde, 2007) thus impacting negatively on household food security.

The household head's level of formal education and that of the spouse have been found to have a positive effect on household food security. The possible explanation is that attainment of education increases awareness of opportunities to increase farm production through adoption of modern technologies (Najafi, 2003 and Fekadu, 2008). Education attainment also increases the head of household's chances of securing off-farm employment, thus increasing the household income (Kuwornu et al, 2013). The household head's educational status was found to have a significant and positive influence on the household food security as reported by Haile et al (2005) and Kaloi et al (2005). According to Kaloi et al (2005), the more educated farmers were found to enhance agricultural productivity through adoption of new technologies and farm practices. Educational attainment increases the supply of food in the household by increasing the head of household's opportunities for off-farm employment (Najafi, 2003). Engagement in off-farm activities is part of food security coping mechanisms that provide additional incomes to farm households (Seid, 2007). The household's access to more productive and diversified income opportunities, according to the reviewed studies, increases the likelihood of a household being food secure. Off-farm occupation increases household income and the working capital required for farm production thus increasing household food availability (FAO, 1999 and Dhehibi et al, 2014). However, the farmer's engagement in off-farm occupation, according to Geta et al (2013), may reduce the time and resources devoted to the farm and hence reduce farm production

The gender of the household head was found to affect household food security positively if the head is a male but negatively if the head is a female (Faridi and Wadood, 2010; Seid, 2007). Most female household heads were found to be widowed or abandoned by their husbands and owned lesser household assets (Faridi and Wadood, 2010). The cultural restrictions on resource ownership, particularly land, imposed on women are likely to limit their ability to produce enough food for the household (Kabeer, 1990). In addition, access to education among women is likely to be less than among men, thus limiting the women's capacity to adopt technologies that increase farm production (Kassie *et al*, 2012).

The previous studies have failed to examine how the agricultural potential of a given area influences the effect of household characteristics on household fod security. The proximity of an agro-ecological zone to major marketing centres determines the opportunity for household members to engage in off-farm employment which is likely to influence the effect of the household characteristics on food security. This study examines the interaction between household characteristics and agricultural potential and opportunities for off-farm employment by evaluating the effect of household characteristics in different agro-ecological zones in Embu County. The three agro-ecological zones have differences in agricultural potential, proximity to market outlets, passable road infrastructure and opportunities for off-farm employment.

2.2.3 Institutional Factors

The farm household's access to institutional services was found to have a positive effect on farm efficiency and a subsequent positive impact on food security (Faridi & Wadood, 2010; Mensah, 2013; Kuwornu et al, 2005; Haile et al, 2005; Helfand and Levine, 2004 and Gorton and Davidova, 2004). Institutional services include infrastructure (roads, water and electricity), extension, markets, credit and irrigation facilities and inputs. Faridi and Wadood (2010) found access to electricity to be a strong indicator of household welfare with households connected to electricity being more food secure than those that were not connected. Access to credit was found to have a significant and positive influence on food security as reported by Mensah et al (2013). According to Mensah et al, access to credit builds the household's capacity for more farm production through the use of improved seeds and adoption of improved technologies. Use of credit increases farm investments and adoption of improved technologies thus increasing household's food availability and access ((Devereux, 2001; Umeh and Asogwa, 2012 and Osei et al, 2013). Access to agricultural extension was expected to have a positive influence on food security.

The farm's access to extension increases transfer of technologies such as better crop production techniques and improved inputs which increase farm productivity ((Mwangi, 1998; World Bank, 1980 and Ahmed and Abah, 2014). A system of land tenure that confers more ownership security such as possession of land title for the land being operated, has been found to have a positive effect on household food security(Bizimana et al, 2004; Kariuki *et al*, 2008). Land tenure refers to the system of rights and institutions that governs access to and use of land (Maxwell and Wiebe, 1998). . The possible explanation was that possession of title confers more security of tenure and thus more likelihood for farms to undertake long-term investments

Distance to a reliable road infrastructure and market facility was found to have a negative effect on household food security. The farm's nearness to road infrastructure increases its access to output and factor markets hence increasing the farm income (Helfand and Levine, 2004; Abur et al, 2015; Ajiboye and Afolayan, 2009). The household's nearness to improved road infrastructure is likely to enhance technology adoption by increasing the frequency of visits by extension workers (Abur *et al*, 2015). The distance to the market centre determines the household's access to off-farm employment, input supply and output market (Hoddinott; 1999 Mitiku et al, 2012 and Gemechu et al, 2015). The market centre also serves as a source of market information for enhancing marketing of agricultural products (Seidu, 2015)

Household food security was found to be affected positively by the household's adoption of modern technologies. Technology adoption increases the farm's productivity and thus increasing the household's food availability and access (Haile et al, 2005; Feleke et al, 2005; Kidane et al, 2005; Geta et al, 2013). Farm household's access to inputs (mainly fertilizer) and irrigation was found to positively affect food security through its influence on production efficiency of the farm (Haile et al 2005, Faridi and Wadood, 2010 Bogale and Shimelis, 2009). According to Bogale and Shimelis (2009), availability of water in moisture stressed areas increases the potential for agricultural output. Fertilizer use, which is used by most studies as a 'proxy' for technology, boosts the overall production by increasing agricultural productivity (Haile et al, 2005).

The interactions between the institutional support services and the agro-ecological zones have not been examined by the previous studies conducted to determine the effect of the services on food security. The influence of agricultural potential, market outlets and other off-farm sources of household income have not been taken into account in the previous studies. This study examines the effect of institutional support services on food security in three agro-ecological zones in Embu

County. The three Counties have differences in agricultural potential, access to market and road infrastructure and opportunities for off-farm employment.

2.3 Effect of Agro-ecological Zones on Food security

According to FAO (1996), Agro-Ecological Zoning (AEZ) refers to the division of an area of land into smaller units, which have similar characteristics that are related to land suitability, potential production and environmental impact. Agro-ecological zoning is thus a form of classification of agricultural land area into smaller units based on characteristic associated with land suitability, production potential and environmental factors (FAO, 1996). The land units that result are known as agro-ecological zones which are defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use (FAO, 1996).

Jaetzold et al (2006) classifies the land in Kenya into 7 main AEZs based on the original natural vegetation. Zones 0-3 were originally forest zones or highlands, Zones 4-6 were originally savannah grasslands with intermittent short trees and shrubs, and Zone 7 was originally a semi desert (Jaetzold et al, 2006). The main AEZs are further classified into zone groups based on maximum temperature limits and water requirements within which the main crops grown in Kenya can flourish (Jaetzold et al, 2006). The lowland (LL) zones are based on cashew and coconut, the lower midlands (LM) zones on cotton and sugarcane, upper midland (UM) zones on coffee, the low highlands (LH) zones on tea, and the upper highlands (UH) zones on pyrethrum. Food availability and access is expected to be higher in highland zones (zone 1-3) than in savannah (zone 4-5) and semi-desert zones (zone 7), since potential for agricultural production is higher in the forest zones than in savannah grasslands and semi-desert zones. In Embu County, zone 1-3 is represented by tea zone (LH 1 and UM 1) and coffee zone (UM 1-3), while zone 4-6 is represented by sunflower-cotton zone (LM 4-6) ((Jaetzold et al, 2006)

2.4 Review of Literature on Effect of Farm Size on Farm Efficiency

Farrell (1957) categorized measures of efficiency as technical, allocative and economic measures. Sanusi and Ajao (2012) define the farm's technical efficiency as its ability to obtain maximum output from available resources and technology. Adedeji et al (2011) refers to allocative efficiency as the producers' ability to combine resources in optimal proportions based on factor prices. The product of technical and allocative efficiencies is referred to as economic efficiency, and thus according to Nauwa and Omonona (2010), a farm is economically efficient if it has obtained both technical and allocative efficiencies.

The earliest research on the impact of farm size on efficiency mainly focused on the impact of farm size on land productivity. A study done by Chayanov (1926) first documented that land productivity increased with decreasing farm-size in Russia. Sen (1962) also found that yield per acre increased as farm-size decreased in Indian Agriculture. In Africa, the negative impact of farm size on land productivity has been reported by Okezie et al (2012) in Nigeria and Ayalew and Deininger (2013) in Rwanda. Similar results were found in other countries by Assuncao and Braido (2009), Sial *et al* (2012), Vu *et al* (2012), Thapa (2007) and Mohapatra (2013).

Unlike the first wave of studies on farm efficiency, the second wave of studies used the total factor productivity approach to measure farm efficiency, either for a single or multiple farm enterprises.

However, unlike the first wave of studies that confirmed the impact of farm size on land productivity to be negative, the second wave of studies has found both negative and positive impacts depending on the region and the enterprise(s) being considered. For the last three decades, there has been no unanimity on the effect of farm size on farm efficiency among available studies.

In Southern Indian State of Tamil Nadu, small and medium scale rice farmers were found by Tadesse and Krishna-Moorthy (1997) to be more technically efficient than the large scale farms. However, Helfand and Levine (2004) found that in Centre-West Region of Brazil technical efficiency first decreases as farm size increases then starts to increase (U-shaped relationship). Pierrani and Rizzi (2003), in their efficiency study of Italian dairy farms, also found no conclusive evidence that larger farms are more technically efficient than small farms.

Recent studies conducted to determine the impact of farm size on farm efficiency continue to find inconsistent results. Padilla-Fernandez and Nuthall (2012) found the technical efficiency to be higher in large farms than in the small ones. This study by Padilla-Fernandez and Nuthall (2012) was, however, based on a single enterprise and may not be conclusive in case of many enterprises on the same farm. Mashayerkhi and Ghaderzadeh (2013), using translog cost function, found that the larger barley farms in Iran incurred less average total costs than the smaller ones. The larger farms were also more profitable than the smaller farms. Like Padilla-Fernandez and Nuthall (2012), the study by Mashayerkhi and Ghaderzadeh (2013) was done for a single farm enterprise and hence not conclusive for a mixed farming system. In the current study, farm efficiency was based on the multiple enterprises undertaken in the farm and was therefore more appropriate for the mixed farming commonly practiced in Embu County.

In a study conducted in Paraguay, using both parametric and nonparametric approaches, small scale farms were found to have a higher technical efficiency than the large scale farms (Masterson, 2007). The study, however, used only one measure of efficiency, technical efficiency. Murthy et al (2009) used DEA model to examine the impact of farm size on the efficiency of tomato production in India. They found that among the three farm size categories (small, medium and large scale) examined, the medium scale farms were found to be the most technically efficient. The small scale farms were, however, found to be the most allocatively and economically efficient than the other farm size categories. These results are not conclusive because the study only used one farm enterprise.

Ligeon et al (2013) found the influence of farm size on technical efficiency among peanut producers in Bulgaria not to be significant, but the influence of the farmer's age and gender was significant. However, the Bulgarian study measured technical efficiency based on a single output. However, this study used technical efficiency based on the major enterprises undertaken in the farm, to compare the efficiency of the small and large scale farms. Using parametric stochastic frontier method, Sharma and Bardha (2013) found the technical efficiency of smallholder milk producers in India to be higher than that of the large scale producers. However, the farm efficiency measured in this study was based on a single enterprise.

In a study conducted in Minnesota in USA by Olson and Vu (2009), farm size was found to be the only factor that consistently explained higher farm efficiencies among the economic factors considered. Khan et al (2010) found similar results among rice producers in India. Khan et al (2010) measured the efficiency of a single crop and used only technical efficiency and hence the results are not conclusive if other efficiency measures and farm enterprises are considered. Alam et al (2011)) found the influence of farm size on technical efficiency in rice farms in Bangladesh to be positive. The results were confirmed by Ali and Samad (2013), who used stochastic frontier production function to examine the resource efficiency of farming in Bangladesh. The studies were based on rice, the most predominant crop in that farming system, and, like Khan et al (2010), the studies cannot be generalized for mixed farming systems.

Like other parts of the world, studies conducted to examine the influence of farm size on efficiency in Africa have found results that are conflicting and therefore rendering them inconclusive. Musemwa et al (2013) in a study they conducted in Zimbabwe found the large scale farmers to be more technically and allocatively efficient than the smallholder farmers. However, in a study conducted in Tunisia by Dhehibi and Telleria (2012), technical efficiency among citrus farmers was found to be higher in small and medium scale farms than in the large scale farms. Similar results were found by Enwerem and Ohajianya (2013) in their study of farm efficiency among rice farmers in Nigeria. These results were in conflict with those found in the same Country by Rahman and Umar (2009), who had earlier found higher technical efficiency in larger farms than in the small ones. In a study conducted in Ethiopia, Geta et al (2013) found farm size to have a positive influence on technical efficiency among maize farmers. The results are an indication that the influence of farm size on efficiency could be dependent on the type and nature of enterprise being considered. A study conducted on mixed farms in Ethiopia found the influence of farm size on technical, allocative and economic measures of farm efficiency to be positively significant (Beshir et al, 2012). That study is one among the few studies in literature that has used multiple-output (whole farm) approach to measure farm efficiency. However, Beshir et al, (2012) failed to examine how the effect of farm size on farm efficiency is influenced by variations in agro-ecological factors, which the current study explored.

In Kenya, Ng'eno et al (2011) found the technical efficiency of large scale maize farmers in Uasin Gishu County to be higher than that of the smallholder farmers. Similar results were found in a study of dairy farmers in Meru County of Kenya (Nganga et al, 2010).The results in Meru County were in contrast to the result of a study by Bardhan and Sharma (2013) which found smallholder dairy producers in India to be more technically efficient than the large scale producers. The two dairy studies, however, have the shortcoming of dealing with only a single enterprise in the farm.

The preceding accounts show that the available literature on the effect of farm size on efficiency have some conflicts in the findings, and these would need to be addressed before the findings can be generalized for policy making. A number of earlier studies have attributed the differences in the findings to various environmental factors that influence the impact of farm size on efficiency (Tadesse and Krishna-Moorthy, 1997; Helfand and Levine, 2004; Gorton and Davidova, 2004; Odulaja and Kiros, 1996). These studies point out rainfall, land quality, soil type, humidity, temperature, soil erosion and vegetation as among the key environmental factors that have an influence on the impact of farm size on farm efficiency.

The reviewed studies on farm efficiency have overlooked the influence of agro-ecological zones on farm size and other key factors affecting farm efficiency. They have also measured farm efficiency based on single enterprises which they have considered to be dominant in their areas of study. Studies based on single enterprises fail to take into account the contribution of other enterprises in the same farm and their interaction with one another in determining total farm efficiency. The results generated by such studies cannot therefore be used to inform policies targeted towards land reforms in mixed farming systems commonly found in Kenya. This study evaluates the effect of agro-ecological zones on other facors that affect farm efficiency evaluating the effect of farm-size and other key factors affecting farm efficiency in three different agro-ecological zones in the Embu County. The interaction between farm size, agricultural potential and access to institutional support services are therefore captured in this study. The study also measured farm efficiency using multiple enterprises which were selected for each agro-ecological zone on the basis of the percentage of total land area occupied and their contribution to total farm income.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

The current study measured food security status of a representative sample of 384 farms drawn from three agro-ecological zones in Embu, using household food security index (HFSI). The HFSI was computed as a ratio of the total household's daily calorie intake to the recommended total daily calorie requirement (Omotesho *et al*, 2010). This study covered Sunflower, Coffee and Tea zones. The farms in the sample were stratified on the basis of these three agro-ecological zones and farm size categories and an average HFSI was determined for each strata. The study evaluated the impact of farm size and other key factors that affect household HFSI in and across different agro-ecological zones and the results were compared. The farm size that guarantees the attainment of threshold level of food security in each agro-ecological zone was determined as the one in which HFSI= 1.

This study determined farm technical efficiency for each farm in the sample. The sample were then stratified on the basis of agro-ecological zones and the effect of farm size and other key factors affecting farm efficiency was evaluated for each agro-ecological zone and the results compared. The value of farm output was determined for each farm in the sample using the quantities of farm outputs and their respective farm gate prices. The sample was then stratified on the basis of the Sunflower, Coffee and Tea Zones. The input elasticity of production for land and other key factors of production were evaluated for each agro-ecological zone and the results compared.

3.2 Conceptual Framework

From the previous studies reviewed, the relationships between farm size and other key factors affecting household food security and farm efficiency are conceptualized as shown in Figure 3.1. The independent variables are categorized into socio-economic and institutional factors. The extent to which the independent variables affect food security and farm efficiency is conceptualized to be influenced by the agro-ecological factors. The agro-ecological factors include rainfall, temperature, soil type, topography altitude and land quality. These factors will therefore influence the extent to which land fragmentation affects household food security and farm efficiency. Agricultural areas with similar agro-ecological factors are grouped into agro-ecological zones (AEZs). The current study examines the effect of land fragmentation (in terms of farm size) and other socioeconomic and institutional factors on household food security, farm efficiency and farm output in three agro-ecological zones in the Embu County of Kenya. The conceptualized relationships between the independent and dependent variables are shown in Figure 3.1.

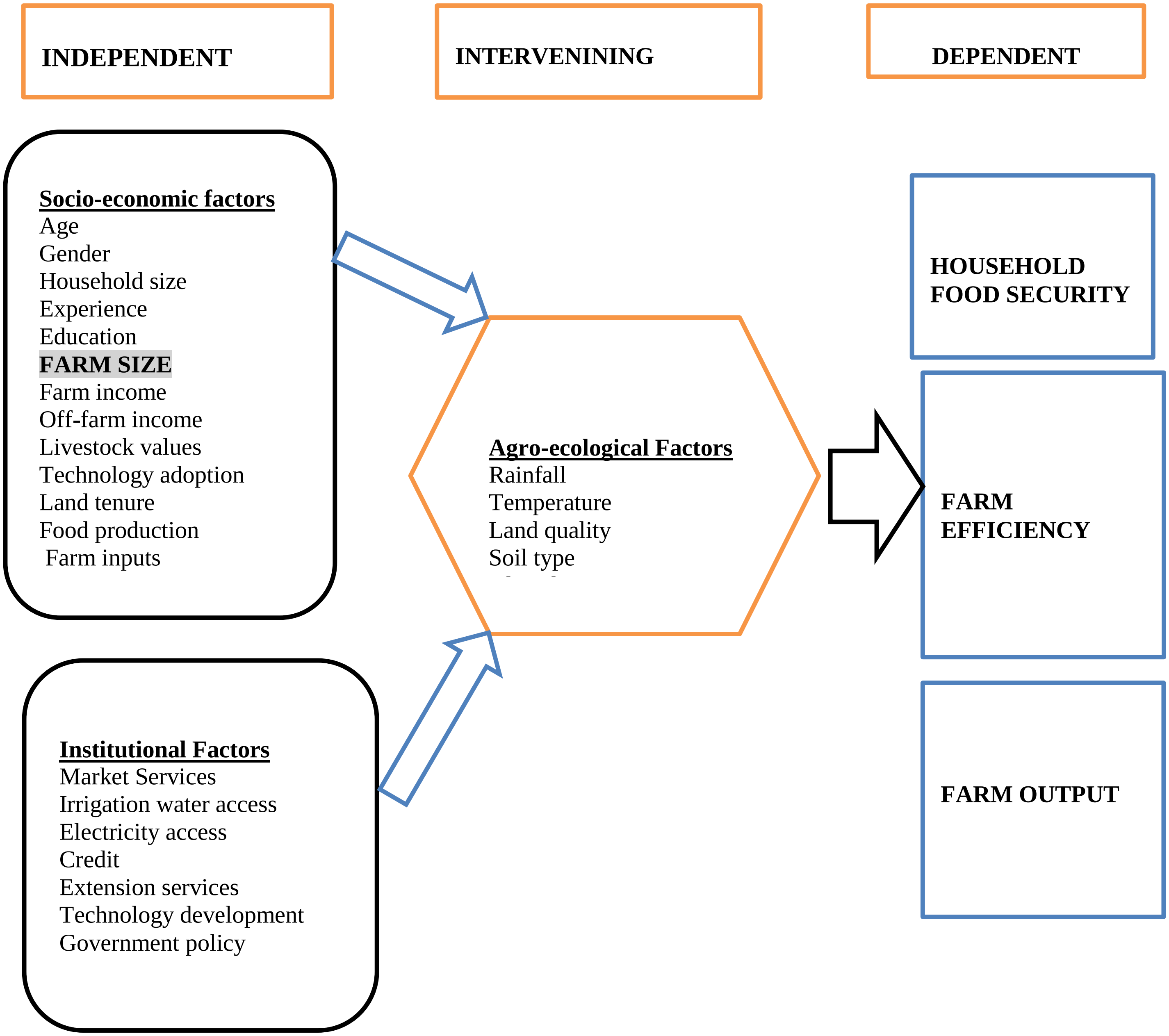

Figure 3.1: Conceptual Framework: Factors Affecting Food Security and Farm Efficiency

Source: Synthesis by the Author, based on the review of literature (2015)

3.3 Theoretical Framework

The current study is based on economic theory of production which provides the concepts of production functions, economies of scale and size, returns to scale, elasticity of production and efficiency in production. The principles and concepts are discussed here below.

3.3.1 Production Function

Production is the process that transforms inputs or resources into outputs or commodities (Webster, 2003). According to Webster, a firm or producer is an organizational unit that transforms factors of production or productive inputs, into outputs of goods and services that satisfy human wants. The scarcity of these resources demands that the resources be allocated in such a way that they maximize returns. The theory of production provides the basic economic principles and concepts that guide the firms on how to optimize production of goods and services from available resources.

A production function describes the relationship between the inputs to the production process and the resulting output. A production function indicates the highest output that a firm can produce for every specified combination of inputs (Pindyck and Rubinfeld, 2001). A production function utilizing capital, labor, and land inputs shows the maximum amount of output that can be produced using alternative combinations of the three inputs (Nicholson and Snyder, 2008). Mathematically, such a production function may be expressed as:

$$q = f(k, l, m) \qquad (1)$$

Where:

q= firm's output of a particular good in a given period

k = capital usage during the period,

l = hours of labor input, m represents raw materials used

The marginal physical product (MPP) of a particular input is the additional output that can be produced by employing one more unit of that input while holding all other inputs constant (Nicholson and Snyder, 200). Average physical product (APP) refers to the total output per unit of a particular input. Input productivity is often used as a measure of efficiency for a particular input. As an illustration for a particular input, MPP and APP for capital can be expressed as:

$$MPP_K = \frac{\Delta q}{\Delta k} \quad (2)$$

$$APP_k = \frac{q}{k} \quad (3)$$

Where:

Δq = additional output

Δk= change in capital usage

This study is a production study of the small scale farmers who produce food and cash crops with the key objective of maximizing farm output from scarce resources for attainment of food security and livelihood. The principles and concepts of the production function is applied to guide farmers on how to allocate resources to maximizing farm output from available scarce resources especially land that is most constraining.

3.3.2 Law of diminishing returns

The law of diminishing returns states that when one productive resource is increased while at least one other productive input is held fixed output will also increase but by successively smaller increments. The law of diminishing marginal product is a short-run concept in production which refers to that period of time during which at least one factor of production is held fixed in amount. The law of diminishing returns limits the use of a variable input while other resources are fixed, for example the use of labour and fertilizer on a fixed land size. From the law of diminishing returns, we learn that there is a limit to which we can intensify production using purchased inputs. However, improved technology can relax the constraint imposed by the fixed resource base (mainly land), making technology adoption and extension a key factor in food production.

3.3.3 Economies of size and scale

In a situation where all the inputs are changed proportionally, the concepts of economies or diseconomies of size and scale are depicted in the production theory (Debertin, 2012). According to Debertin, economies or diseconomies of size describes what happens the unit cost of production when output is changed by changing the amounts of all inputs but not necessarily in the same proportionate amounts. For example in farming, economies or diseconomies of size describes changes in unit cost of production when output is increased by increasing land size and other inputs such as labour and fertilizer but at different proportions. The economy or diseconomy of scale shows the change in unit cost of production when all the input categories are increased proportionately. In the economy of scale the unit cost of production decreases when all the inputs are increased at the same proportion while diseconomy of scale occurs when unit cost of production decreases when all the inputs are increased proportionately (Debertin, 2012).

This study focuses on land subdivision that is common in areas with high agricultural potential but highly populated. The concept of economies of scale and size helps the study to understand the relationship between land fragmentation and the unit cost of food production. The expected increase in unit cost of producing food would eventually increase food prices which would negatively affect access to food which is a key dimension in food security.

3.3.4 Returns to Scale

According to Pindyck and Rubinfeld (2001), return to scale describes the rate at which output increases as inputs are increased proportionately. In economic theory three forms of returns to scale are examined: increasing, constant, and decreasing returns to scale. In increasing returns to scale, the output increases more than the proportion at which the inputs are increased. In constant returns to scale, the output increases proportionately and in decreasing returns to scale the output is less than the proportion at which the inputs are increased.

According to Nicholson and Snyder (2008), if the production process is depicted by a production function given by $q = f(k,l,m)$ and if all inputs are multiplied by the same positive constant t (where t > 1), then the returns to scale of that production process can be expressed mathematically as:

$$f(tk,tl,tm) = t^{a} f(k,l,m) = t^{a} q \qquad (4)$$

For constant returns to scale a =1 hence $f(tk,tl,tm) = t^a(f(k,l,m) = t^a q$. For decreasing returns to scale, a < 1 making $f(tk,tl,tm) < t^a(f(k,l,m) = t^a q$. For increasing returns to scale, a >1 making $f(tk,tl,tm) > t^a(f(k,l,m) = t^a q$. 'a' is referred to as the homogeneity of the production function.

The concept of returns to scale is used in understanding the consequences of reducing the scale of farm production through land subdivision. The rate of reduction in farm production is especially serious in situations of increasing returns to scale in which the rate of decrease in inputs would result in output decreasing at a higher rate than that of inputs.

3.3.5 Elasticity of output

The elasticity of production is a measure of the responsiveness of output in the production function to changes in the use of the input (Debertin, 2012). The elasticity of production is computed as the percentage change in output divided by the percentage change in input, as the level of input use is changed. Suppose that k_1 represents some original level of input use that produces q_1 units of output. The use of k is then increased to some new amount called k_2, which in turn produces q_2 units of output. The elasticity of production (Ep) is defined by the following formula (Debertin, 2012):

$$E_p = \frac{q_2 - q_1 / q}{k_2 - k_1 / k} \qquad (5)$$

Elasticity of production can also be expressed as a ratio of percentage change (Δ) in output to percentage change (Δ) in a particular input as follows:

$$E_p = \frac{\Delta q / q}{\Delta k / k} \qquad (6)$$

Where:

$\Delta q = q_2 - q_1$

$\Delta k = k_2 - k_1$

Rearranging equation 4 gives elasticity of output in terms of marginal physical product and average physical product as given below:

$$E_p = \frac{\Delta q}{\Delta k} . \frac{k}{q} = \frac{MPP}{APP} \qquad (7)$$

The concept helps the study to understand and explain the response of farm output output to changes in farm size and other key factors of production. Land subdivision reduces the size of the land available for farm production. The concept helps the study to quantify the elasticity of land and other key factors of production applied in food production and their likely consequence to availability of food in the household.

3.3.6 Efficiency in Production

Nicholson and Snyder (2008), use the concept of Pareto optimality to define efficiency in production as an allocation of resources in such a way that further reallocation would permit more of one good to be produced without necessarily reducing the output of the other good. A frontier production possibility curve is used to show alternative combinations of two outputs that can be produced with fixed quantities of inputs if those inputs are employed efficiently. All combinations of goods outside the production possibility frontier are not feasible due to resource limitation. All alternative combinations inside the production possibility curve are technically inefficient because it is possible to increase the output of a particular good without necessarily reducing the output of the other good. All alternative combinations of inputs occurring along the production possibility curve are technically efficient since the inputs have been exhausted and none of the outputs can be increased without reducing the amount of the other.

This concept of efficiency is applied in stochastic frontier approach where a frontier production function is determined using econometric method and the efficiency of the firm measured relative to the frontier production function. A technically efficient farm would allocate resources in such a way that more outputs cannot be increased without reducing the amounts of other outputs. In small scale farms, which are the focus of this study, efficient allocation of resources would imply more food production from available resources (especially land) which are limiting factors in farm production.

3.4 Empirical Models

3.4.1 Effect of Farm Size and Other Key Factors Affecting Food Security

a) Measurement of Household Food Security

In the literature on food security five methods of measuring food security are identified. The methods are grouped into direct and indirect methods. The direct methods are individual food intake and household caloric acquisition methods. The indirect methods are dietary diversity, indices of household coping strategies and household food expenditure method. Individual food intake method measures the amount of calories, or nutrients, consumed by an individual in a given time period, usually 24 hours (Hoddinot, 1999). The individual food intake is then compared against individual caloric requirements. Household caloric acquisition method measures the number of calories, or nutrients, available for consumption by household members over a defined period of time. If the estimated total energy in the food that the household acquires daily is lower than the sum of its member's daily requirements, the household is classified as food energy deficient (Kamau et al, 2011).

The indices of household coping strategies method use indices that are based on severity and frequency of actions which households take when they do not have enough food or money to buy food (Maxwell et al, 1996). In food expenditure method the percentage of household expenditure spent on food is used as an indicator of food security (Faridi and Wadood, 2010). The percentage of total household expenditure that is spent on food can be used as a measure of vulnerability to food deprivation in the future (Kamau et al, 2011). Dietary diversity method uses indices that are based on the frequency and the number of different foods consumed by a household over a specified time period. The use of this measure stems from the observation made in many parts of the developing world that as households become better-off, they consume a wider variety of foods.

The household caloric acquisition method based on Hoddinott (1999) was used in this study to measure the level of household food security in the study area. One of the main advantages of using the household caloric method is that the level of skill and time required to obtain food security information is considerably less than that required for individual food intake method (Hoddinott, 1999). The other advantage cited is that household caloric acquisition method is more accurate than the indirect methods of measuring food security such as dietary diversity and indices of coping strategies. Household caloric method collects data on quantities of food consumed in a given household and it is therefore possible to estimate the extent to which diets are inadequate in terms of caloric availability (Hoddinot, 1999; Maxwell et al, 1999). Other studies that have used the household caloric acquisition method include Abu and Soom (2016), Okwoche and Asogwa (2012), Omotesho *et al* (2010, 2006), Bogale and Shimelis (2009), Joshi and Maharjan (2007) and Kaloi *et al* (2007. Other studies that have used the caloric acquisition method are Mahzabin et al (2014), Muche et al (2014), Gumechu et al (2015) and Abu and Soom (2016).

The main limitation of household caloric acquisition method emanates from its reliance on the respondent's memories of the types and quantities of foods consumed over the defined recall period (Hoddinot, 2002). Smith *et al* (2006) identifies two types of systematic bias that may arise from this limitation: "recall bias" and "telescoping bias". Recall bias may arise from the respondent's difficulties in recalling the foods prepared over the recall period. Telescoping bias arises from cases where the respondent may include foods eaten before the recall period, thus inflating the amounts of foods consumed by the household over the defined period. According to Smith *et al* (2006), the two types of bias can be controlled by the choice of the appropriate recall period. The shorter the recall period, the more the likelihood of telescoping bias occurring. The longer the recall period, the more the likelihood of the recall bias occurring. The biases can also be controlled by careful checking of data collected both in the field and during data analysis (Hoddinot, 2002). According to Hoddinot (1999) the 24 recall period is appropriate for Individual Food Intake method where the individual calorie intake is measured. The 7 day recall period is recommended in household caloric acquisition method where household calorie intake is measured.

The household food security index (HFSI) that was used as a measure household food security in this study and was computed as a ratio of the household daily calorie intake to the recommended daily energy requirement for the household. This is expressed as (Omotesho *et al*, 2010):

$$HFSI = \frac{HDCI}{HDCR} \qquad (8)$$

Where: HFSI= household food security index

HDCI= Household daily calorie intake (kcal/day)

HDCI= Household daily calorie requirement (kcal/day)

Household calorie intake was determined by collecting data on the types and quantities of food items taken by each household in the sample using a semi-structured questionnaire (Appendix 5). The study used a 7-day recall period based on Hoddinott (1999) and Smith and Subandaro, 2007). The quantities of food items taken by the household were all converted into a common unit, kilograms. The food quantities were then converted into calories using the food composition table provided by Technical Centre for Agricultural and Rural Cooperation/ East, Central and Southern Africa Food and Nutrition Centre (CTA/ECSA, 1987) as given in Appendix 1. The total calorie availability was determined by summing the calorie acquired from each food item taken. The daily household calorie acquisition was calculated by dividing the total calorie intake by seven

. The household daily calorie requirement was determined by collecting data on the number of household members (household size), their ages and gender. For the purpose of this study, the household size is defined as a collection of people who take common food consumption decisions and feed from the same kitchen. The members of a household were categorized into their respective genders, and further into seven age brackets. These are the age brackets used by FAO /WHO/UNU

(2001) in providing the recommended human energy requirements. The human energy requirement is defined as the amount of dietary energy required by a human being to maintain body size, body composition and a light level of physical activity (FAO, 2001). The energy requirement is dependent on gender, age and body weight.

For the adolescents and children the study used four age brackets which are 1- <5 years, 5 - <10 years, 10 - <15 years and 15 - <18years. The energy requirement for children and adolescents provided by FAO (2001) in collaboration with WHO and UNU ranges with ages from 1 - <18 years as given in Appendix 2. The average for each age bracket was used as the energy requirement for the group. The average recommended energy requirements for children and adolescents used in this study are given as part of Table 3.1.

The FAO (2001) provides the adult's energy requirement for different body weights ranging from 50kg to 90kg as given in Appendix 4. The age brackets used for adult males and females are 18 - <30 years, 30 - <60 years and above 60 years. The study used the average energy requirements for each age brackets as given in Table 3.1

Table 3.1: The recommended daily energy requirement (kcal/day) for all age brackets

Age (Years)	Male	Female
1 - < 5	1169	1075
5 - < 10	1500	1485
10 - < 15	2180	1910
15 - < 18	2808	2125
18 - < 30	2528	2100
30 - < 60	2433	1989
> 60	2061	1811

Source: FAO (2001)

The energy requirement for each age bracket in the household was determined by multiplying the number of household members in the bracket by the respective daily recommended energy requirement. The total daily calorie requirement for the household was calculated by summing the daily energy requirements for all the age brackets in the household. The HFSI for each household in the sample was calculated as a ratio of household daily calorie intake to household daily calorie requirement. A household is food insecure if its HFSI is less than one which implies that the household is unable to meets its daily calorie requirement. HFSI of more than or equal to one implies that the household is food secure for it is able to meet and exceed its daily energy requirement.

b) Determination of Effect of Farm Size and Other Factors Affecting Food Security

In literature on determination of factors that affect food security in a given area, two main methods have been used, namely Logit model and Probit model. The two methods are similar in most applications except that Logistic distribution has a slightly fatter tail (Bogale and Shimelis, 2009). Logit model is used in most studies due to its simplicity in the interpretation of the coefficients (Kuwornu et al, 2013). Two types of logit models are cited in literature, namely binary logit model and multinomial logit model (Kennedy, 1998). The binary logit model is used to analyze relationships involving binary or dichotomous dependent variables which have only two choice categories. For instance, food security status in this study would take 2 choice categories: 0 for food insecurity and 1 for food security.

The multinomial logit model is a generalization of binary logit model and is based on a random utility model, and is used to analyze relationships involving dependent variables which are classified into more than two categories (Verbeek, 2004). Such variables are referred to as polychotomous variables. In multinomial logit regression, the dependent variable is required to be categorical (non-metric) while the independent variables could be both continuous (metric) and categorical (Verbeek, 2004). The multinomial logit model is used in this study, since the household food security status was classified into more than two categories. By categorizing household food security status into more than two categories, the study is able to take into account the possible variations within food secure and food insecure categories used in the binary logit model, thus improving the analysis.

Multinomial Logit Regression (MLR) model was used to characterize the effect of farm size and other key factors affecting household food security in and across different agro-ecological zones in Embu County (objective 1). The MLR has the advantage of producing parameters that are easy to interpret for a particular category of the dependent variable (Bogale and Shimelis, 2009). The multinomial logit model is used in this study, since the household food security status was classified into more than two categories. Unlike the binary logit model that categorizes the dependent variable into food secure and food insecure categories, MLR is able to take into account the possible variations within the two categories, thus improving the analysis.

MLR is a generalized binary logit model which is developed from random utility model in which the utility of each alternative choice is a linear function of observed characteristics (individual and/or alternative specific) plus an additive error term (Verbeek, 2004). Individuals are assumed to choose the alternative that has the highest level of utility. The MLM is appropriate in analyzing relationships that involve categorical dependent variables, which have been classified into more than two categories (polychotomous variables), and independent variables that are either categorical (discrete) or metric (continuous) variables (Gujarati, 2004). The MLM described below is based on Verbeek (2004) and Heij *et al* (2004).

Suppose there are M alternatives to choose from, which are numbered as j=1,2,3,..,m. The utility level that an individual derives from each alternative is given by U_{ij}. Then an individual chooses the alternative that maximizes utility, that is, $U_{ij} = Max(U_{i1}, \ldots, U_{im})$. Suppose U_{ij} is dependent on k observable characteristics of the individual, then U_{ij} can be expressed as (Verbeek, 2004; Heij *et al*, 2004):

$$U_{ij} = \mu_{ij} + \varepsilon_{ij} \quad (9)$$

Where μ_{ij} is a non-stochastic function of observed characteristics and associated unknown parameters and ε_{ij} is an unobservable error term. U_{ij} can therefore be expressed as (Heij *et al*, 2004):

$$U_{ij} = x_{ij}^{/} \beta_j + \varepsilon_{ij} \quad (10)$$

Where:

$x_{ij}^{/}$ = 'k x 1' transpose vector matrix of observed characteristics for individual i under the j^{th} alternative.

β_j = 'k x 1' vector matrix of parameters to be estimated in the model for alternative j.

If the random error terms are assumed to be independently and identically distributed as a log Weibull distribution or extreme value distribution, the probability that the ith individual chooses the jth alternative is given by (Verbeek, 2004):

$$P(y_i = j) = \frac{\exp(\mu_{ij})}{\exp(\mu_{i1}) + \exp(\mu_{i2}) + ... + \exp(\mu_{iM})} = \frac{\exp(x_{ij}^{/}\beta_j)}{\exp(x_{i1}^{/}\beta_1) + \exp(x_{i2}^{/}\beta_2) + ... + \exp(x_{iM}^{/}\beta_M)} \quad (11)$$

Where

P(y_i = j) denotes the probability that the ith individual chooses the jth alternative (j = 1,2,…,M).

If the utility derived from one of the alternatives, which is referred to as the reference alternative, is equated to zero then the probability that individual i chooses the jth alternative is given by (Verbeek, 2004):

$$P(y_i = j) = \frac{\exp(x_{ij}^{/}\beta_j)}{1 + \exp(x_{i2}^{/}\beta_2) + ... + \exp(x_{iM}^{/}\beta_M)} \quad (12)$$

Where:

P(y_i = j) denotes the probability that the ith individual chooses the jth alternative (j = 1,2,…,M)

X^{l}_{ij} denotes a vector of explanatory variables specific to the ith individual under the jth alternative

β denotes the coefficients of the model

The above function constitutes the multinomial logit model in which the probability of an individual choosing alternative j is expressed as a function of explanatory variables and β-coefficients. The function is estimated using maximum likelihood estimate (MLE). If only two alternatives are considered the function becomes the standard binary logit model ((Verbeek, 2004). The β- coefficient shows the effect of a given explanatory variable on the probability that an individual chooses a given alternative. A negative β- coefficient for a particular explanatory variable, under a given alternative, implies that the probability of the alternative being chosen is reduced if the variable is increased. A positive β- coefficient for a particular explanatory variable, under a given alternative, implies that the probability of the alternative being chosen is increased if the variable is increased.

The HFSI determined for each household in the sample as described in section 3.3.1(a) were classified into four food security categories. These are low food security category (HFSI<0.5), moderately low food security category (0.5 -<0.75), moderately high food security category (0.75 - <1.00) and preferred food security category (HFSI ≥1.00). To analyze the factors that significantly affect household food security in each agro-ecological zone, the categorized HFSI was regressed against the possible explanatory variables using Multinomial Logit Regression (MLR) algorithm in the computer programme SPSS. All the four food security categories were regressed against the explanatory variables at the same time. The explanatory variables were categorized into discrete (non-metric) and continuous (metric) variables. In MLR, the discrete variables are entered as “factors” and the continuous variables as “covariates”.

The results of MLR analyses use Chi-square (likelihood ratio) as an indicator of the degree of association between a given independent variable and the dependent variable (HFSI). The results also give the significance of the effect of each independent variable in differentiating between a given food security category and the reference category using the Wald test. The Wald test uses the β-coefficient to show the contribution that an independent variable makes to change the odds (probability) of a household being in one food security category rather than the preferred category. In this study, the category of preferred food security (HFSI ≥1.00) was used as the reference category. A positive β-coefficient indicates that an increase in the independent variable increases the probability of a household being in the lower food security category rather than the preferred one, thus implying a negative effect on food security. However, a negative β-coefficient indicates that an increase in the independent variable decreases the odds of a household being in the lower food security category in favour of the preferred category, thus implying a positive effect on food security (Bogale and Shimelis, 2009).

One major shortcoming of MLM is the requirement that the error terms be independent, implying that utility levels (which are functions of the explanatory variables) of any two alternatives must be independent. This assumption fails particularly if two or more alternatives are very similar. Specifically, the assumption requires that the probability that a household appears under one food security category must be independent of the probability that the household falls under an alternative category. This property of the multinomial logit model is referred to as “independence of irrelevant alternatives (IIA)” (Verbeek, 2004).

One major cause of the failure of the assumption of the IIA to hold is the existence of multicollinearity, which is defined as linear dependence of explanatory variables. Before the commencement of multinomial logit regression the existence of multicollinearity among continuous explanatory variables must be ruled out through testing using the Variance Inflation

Factor (VIF). Similarly, multicollinearity among discrete variables must be ruled out through testing using Contingency Coefficients (CC). Following Gujarati (1995) and Mitiku *et al* (2012), each of the continuous independent variable was regressed against the other continuous variables and the coefficient of VIF was determined using the following formula:

a) $$VIF(X_i) = \frac{1}{1 - R_i^2} \qquad (13)$$

Where:

$VIF(X_i)$ = the VIF of the ith continuous variable

R_i^2 = the coefficient of determination

As a rule of thumb, a value of VIF>10 indicates a high degree of association (multicollinearity) among the continuous independent variables (Gujarati, 1995 and Mitiku *et al* 2012)

Similarly, multicollinearity among discrete variables was ruled out by determining the association between them using Chi-square. The CC was computed using the following formula (Gujarati, 1995 and Mitiku *et al*, 2012):

b) $$CC = \sqrt{\frac{X^2}{n + X^2}} \qquad (14)$$

Where:

CC= Contingency Coefficient

X^2= a Chi-square value

n = total sample size.

As a rule of thumb, a CC>0.75 indicates a high degree of association (multicollinearity) between discrete variables (Gujarati, 1995 and Mitiku *et al* 2012).

3.4.2 Determination of Minimum Farm Size for Attainment of Threshold Food Security

The household food security index (HFSI) was determined for each household in the sample using the procedure given in Section 3.4.1(a). The sample was stratified on basis of the three AEZs. The households in each AEZ were further categorized into five farm-size categories. Determination of the minimum farm size for attainment of threshold food security in and across different AEZs (objective 2) was achieved by computing the mean HFSI for each of the 5 farm size categories given in Table 3.2. The farm-size category in which the mean HFSI was equal to 1 was taken to be the minimum farm size for attainment of threshold food security. To test the significance of the variation between the computed threshold HFSI and other indices computed for other farm size categories, the analysis of variance (ANOVA). The ANOVA procedure described hereafter is adopted from Lind *et al* (2012).

Table 3. 2: The farm size categories used in the analysis

Category	Hectares
1	0 - <0.25 Ha
2	0.25 - <0.5 Ha
3	0.5 - <1.0 Ha
4	1.0 - < 2.0 Ha
5	≥2.0 Ha

The ANOVA is a statistical procedure that examines and identifies the sources contributing to variation in a given data. One-way ANOVA or one-factor ANOVA refers to the procedure when it is applied to data that is classified into one criterion, for example if the data is classified into agro-ecological zone or farm-size criteria. ANOVA identifies three sources of variation in a sample. The first source is the total variation due to differences within the sample and which is referred to as total sum of squares (TSS). The second one is variation due to differences between the categories or groups and which is referred to as treatment sum of squares (SST). The third is the variation due to error and which is referred to as error sum of squares (SSE). Total variation is the sum of treatment sum of squares and the error sum of squares and is expressed as (Lind *et al*, 2012):

a) $$TSS = \sum_{i=1}^{n} (X_i - \overline{X})^2 \qquad (15)$$

Where: X_i = i^{th} observation in the sample, $\overline{X}$ = sample mean, n = number of observations

SST is given by:

b) $$SST = \sum_{i}^{k} n_j (\overline{X}_j - \overline{X})^2 \qquad (16)$$

Where: n_j = sample size of j^{th} category, $\overline{X}_j$ = the sample mean of j^{th} category, k = number of categories

c) $$SSE = TSS - SST \qquad (17)$$

The test statistic for ANOVA is the F-ratio given by (Lind et al, 2012):

d) $$F - ratio = \frac{MST}{MSE} \qquad (18)$$

Where MST and MSE are given by (Lind et al, 2012):

e) $MST = \frac{SST}{k-1}$ (19)

f) $MSE = \frac{SSE}{n-k}$ (20)

Where n= number of observations and k=number of categories

The null hypothesis for no differences between categories is expressed as (Lind *et al*, 2012):

H_0: $\mu_1 = \mu_2 = \ldots = \mu_k$, where μ_j is the mean of the j^{th} category (j= 1, 2, …, k)

The H_0 is rejected if the calculated F-ratio is larger than the critical F-value as given in the F-distribution table at 5% level at (k-1) and (n-k) degrees of freedom. The analysis fails to reject the alternative hypothesis (H_1) of at least two categories being unequal.

In this study, the F- ratio was determined and its significance at 5% level determined using the computer package SPSS.

3.4.3 Effect of Farm Size and Other Key Factors Affecting Farm Efficiency

a) Measurement of farm efficiency

From literature on efficiency, two approaches to measuring efficiency have been identified: non-parametric approach and parametric approach (Thiam et al, 2001). Non-parametric approach develops a relationship between inputs and outputs from empirical observations without any apriori specification of the functional relationship between the inputs and outputs (Mohapatra, 2014). The approach was first developed by Farrell (1957) followed by improvements from Battese (1998), Coelli (1995) and Fare *et al* (1985). Among these improvements and extensions is the data envelopment analysis (DEA) which was developed by Charnes *et al* (1978).

The DEA is a non-parametric method that determines the relative efficiency of a given farm by comparing its output with the maximum possible output that the farm can get from a given set of inputs (Charnel *et al,* 1978).The DEA model determines a frontier of `best practice' by minimizing inputs per unit of output (or maximize output per unit of input) using a linear programming procedure. The maximum possible output is referred to as frontier of "best practice" to differentiate it from frontier production function that is determined in the parametric approach. The efficiency of each firm is determined by comparing it with the 'best practice' frontier (Gorton and Davidova, 2004). The main weakness of the DEA model is that it is a deterministic model which does not separate the deviation from the frontier of `best practice' into inefficiency component and random noise and so the model is sensitive to measurement errors and other noise in the data (Sharma et al, 1999). In addition, issues are raised on the use of parametric models of statistics to analyze the parameters of the efficiency measures generated by the non-parametric DEA model.

Parametric approach involves estimation of a production function (or profit or cost function) by specifying a parametric form for the function and then fitting the observed data by minimizing some measure of their distance from the estimated function. Parametric models are further classified into deterministic and stochastic models. The deterministic model assumes that any deviation from the frontier production function is due to inefficiency while stochastic model attributes deviation from frontier production function to inefficiencies and random errors (Gorton and Davidova, 2004).

The stochastic frontier production method was developed by Aigner *et al* (1977) and Meeusen and van den Broeck (1977), followed by improvements from Battese (1998) and Coelli (1996). Unlike the non-parametric DEA method, the stochastic frontier method separates the deviation from the frontier production function into inefficiency component and random noise and so the model is relatively more accurate and less sensitive to measurement errors in the data. The efficiency measures generated by the stochastic frontier method can also be subjected to parametric models of statistics. On the basis of these strengths the stochastic frontier production method was used in this study to measure farm efficiency for the farms in the sample.

The stochastic frontier production function is expressed as follows (Sedu, 2012):

$$Y_i = f(X_a, \beta) + \varepsilon_i \qquad (21)$$

Where:

Y_i = quantity of output from the i^{th} farm,

X_a = vector of input quantities,

β =vector of parameters to be estimated and

ε_i i= composite error term, where i=1,2,…,n farms.

The composite error term, ε_i, is further expressed as follows:

$$\varepsilon_i = V_i - U_i \qquad (22)$$

Where:

V_i = symmetric component that accounts for pure random factors on the production process which is outside the farmers' control, such as weather, diseases, topography and other unobserved inputs on production. V_i = randomly distributed as $N(0, \sigma_v^2)$.

U_i = non-negative, one-sided efficiency component with half normal or truncated normal distribution as $N|(0,\sigma_u^2)|$.

σ_v^2 and σ_u^2 = variances of the parameters V_i and U_i

The total variance from both the random factors and inefficiency component can therefore, be expressed as:

$$\delta^2 = \delta_V{}^2 + \delta_U{}^2 \qquad (23)$$

The proportion of total variation of output from the frontier production function, attributable to technical efficiency is expressed as:

$$\lambda = \delta_U / \delta \quad \text{or} \quad \gamma = \delta_U{}^2 / \delta^2 \qquad (24)$$

On the assumption that V_i and U_i are independent and normally distributed, the parameters β, σ^2, σ_v^2, σ_u^2, λ and γ, can be estimated by method of Maximum Likelihood Estimates (MLE) and the technical efficiency determined using computer program called Frontier Version 4.1 (Coelli, 1996).

The stochastic frontier production function used in this study was specified as a Cobb-Douglas function of the following form (Tadesse and Krishnamoorthy, 1997):

$$LnY = Ln\beta_0 + \beta_1 LnX_1 + \beta_2 LnX_2 + \beta_3 LnX_3 + \varepsilon \qquad (25)$$

Where:

Y= Aggregate farm output in Ksh.

X_1= farm size in ha

X_2= total farm labour in man-days

X_3= total cost of fertilizer in Ksh.

ε= composite error term ($\varepsilon_i = V_i - U_i$)

$\beta_0, \beta_1, \beta_2, \beta_3$ = parameters associated with the constant, farm size, labour and fertilizer

Ln = natural logarithm

The aggregate farm output used in determining the frontier production function was based on three major enterprises which varied with the agro-ecological zones. The choice of the major enterprises was based on the average land area occupied by each the enterprise as a percentage of the farm-size. The selection of the three inputs used in the function was based on their expenditure relative to total production cost. To enable the study to aggregate different types of outputs, the outputs from the selected enterprises were converted into values using their average farm gate prices. Table 3.3 gives the percentage of crop acreage in each agro-ecological zone. In the sunflower zone, maize (44 percent), beans (33 percent) and mangoes (23 percent) were selected for computing aggregate farm outputs. In the coffee zone, maize (28 percent), coffee (29 percent) and bananas (22 percent) were selected. Tea (54 percent), maize (18 percent) and coffee (12 percent) were selected in the tea zone.

Table 3.3: Percentage crop acreages across the three AEZs

Crop	Sunflower	Coffee	Tea
Maize pure stand	29	12	12
Maize/beans intercrop	15	16	6
Beans pure stand	18	5	5
Mangoes	23	0	0
Bananas	7	22	6
Coffee	1	29	12
Macadamia	0	7	5
Tea	0	8	54

Source: Field survey, 2016

The technical efficiency for each farm in the sample was computed using the Frontier Programme Version 4.1 software as developed by Coelli (1996).

b) Determination of Effect of Farm size and Other Key Factors affecting Farm Efficiency

To determine the effect of farm size and other key factors affecting farm efficiency in different AEZs in Embu County this study used the multinomial Logit Regression (MLR) model as discussed in section 3.4.1 (b). The economic efficiency measured for each farm was categorized into four efficiency levels: low (0-<0.25), medium low (0.25-<0.50), medium high (0.50-<0.75) and high (0.75-1.00). The effect of each hypothesized independent variable in changing the odds of a farm being in a given efficiency category rather than in the reference (preferred) category was evaluated using 0.75-1.00 farm efficiency category as the preferred one.

The β-coefficient given in the MLR analysis provides the percentage change in the probability of a farm being in a lower farm efficiency category rather than the preferred one, per unit change in a particular independent variable. The 1- β provides the percentage change on the probability that it will not occur (Pindyck and Rubin, 1981). The variable has a positive β-coefficient if the probability of a farm being in the lower efficiency category rather than the preferred one increases as the variable increases, which implies a negative effect on farm efficiency. If an increase in a particular variable decreases the probability of a farm being in the lower efficiency category in favour of the preferred category, then the variable has a negative β-coefficient, implying a positive effect on technical efficiency (Bogale and Shimelis, 2009).

3.4.4 Elasticity of Output for Land and Other Key Factors of Production

The estimated parameters of stochastic Cobb-Douglas production function were estimated as elasticity of output for the key factors of production in different agro-ecological zones. The main advantage of Cobb-Douglas production function is that it provides parameters that are easy to estimate and interpret (Byringiro and Reardon, 1996). In addition, the use of the function allows the analysis to capture the interaction among the variables. The specification of this model is as given in equation 25 in Section 3.4.3 of this thesis.

The parameters of log-linearized Cobb-Douglas model were estimated using the multiple linear regression in computer software SPSS. The β-coefficient associated with a particular input indicates the input's elasticity which is the response of farm output to 1 percent change in the quantity of the input. The β-coefficients were determined in different agro-ecological zones to evaluate the influence of the AEZs on the elasticity of land and other the key farm inputs.

3.5 Research Design

3.5.1 Determination of the Sample Size

The sample size was determined using the following formula (Cochran, 1977):

$$N = \frac{z^2 pq}{d^2} \qquad (26)$$

Where:

N = the desired sample size

Z = the standard normal deviate at the required confidence level

P = the proportion in the target population estimated to have the characteristic being measured

q = 1-p = the proportion of the population without the characteristic being measured

d = the level of statistical significance set

In the current study, the standard normal deviate is set at 1.96 which corresponds to 95% confidence level. Since there is no available estimate of the target population with the characteristic of interest, 50% is assumed to have that characteristic. The level of statistical significance corresponding to 95% confidence level is 0.05. The sample size was therefore calculated as follows:

$$N = \frac{(1.96)^2 (0.5)(1-0.5)}{(0.05)} = 384 \qquad (27)$$

3.5.2 Sampling Procedures

The current study used a combination of a multistage stratified sampling and probability proportionate to size sampling procedures as outlined below:

1. Four administrative divisions were randomly selected from each of the three agro-ecological zones (Sunflower, Coffee and Tea zones). One administrative location was randomly selected from each administrative division thus making four administrative locations in each AEZ and a total of 12 locations in the study area.
2. One administrative sub-location was randomly selected from each of the 12 locations, followed by random selection of one administrative village from each sub-location and therefore making a total of 12 villages in the study area
3. The area assistant chiefs and village elders assisted to establish the number of households in each village selected. The village population as a proportion of total population for all the villages selected was used to determine the number of households to be interviewed in each village using the following formula:

   $$M = \frac{n}{N} * 384 \qquad (28)$$

   Where: M = number of households to be interviewed

   n = No. of households in the village

   N = total No. of households in the 12 villages
4. The first household to be interviewed in each village was randomly selected while the other households were selected along the road transect at intervals determined by dividing the village population by the number of households to be interviewed (n/M)

Table 3.4 shows the 12 villages selected the number of the households in each village sampled and the number that were interviewed from each village.

Table 3.4: The number of households selected for interview in each of the village

AEZ	Village	Sub-location	Location	Division	No. of HH	No. of HH interviewed
Sunflower	Kamwambia	Kageri	Kanyuambora	Kanyuambora	152	20
	Managia	Kiringa	Kagaari-south	Kanja	368	46
	Kandete	Kasafari	Kyeni-south west	Kyeni	344	43
	Mwondu	Riandu	Riandu	Siakago	200	25
Coffee	Ngui	Gitare	Runyenjes west	Runyenjes	152	19
	Kibugua	Kirigi	Ngandori west	Manyatta	352	44
	Gatunduri	Kiangima	Mbeti-North	Central	408	51
	Kyetheru	Ena East	Gaturi south	Nembure	160	20
Tea	Munyutu	Kanja-North	Kagaari- North	Kanja	304	38
	Kathande	Kianjokoma	Kagaari-west	Runyenjes	296	37
	Muvandori	Kathangariri	Kathangariri	Manyatta	96	12
	Rukuriri	Rukuriri	Kyeni-North West	Kyeni	240	30
TOTAL					3072	384

3.5.3 Data Collection

The study collected household food security and farm efficiency related data from the 384 households using a structured questionnaire given in Appendix 6. Data was collected on the types and quantities of food taken and produced by each of the household in the sample. The farm efficiency related data was also collected, which included crop and livestock outputs, inputs used and their respective prices. Each household in the sample provided data on household socio-economic characteristics and its access to institutional services. Data was collected during the two crop growing seasons in March to August and September to February.

3.6 Area of Study

3.6.1 Embu County Profile

The Embu County is one of the eight counties in the Eastern Region of Kenya, formerly called Eastern Province. The Kirinyaga County borders Embu County to the West, and Tharaka-Nithi, Kitui and Machakos counties to the East, South-East and South respectively. Figure 3.2 shows a map of Kenya showing the location of Embu County. Embu County comprises five sub-counties, namely Embu West covering Embu Municipality, Embu North, bordering Mt. Kenya forest, Embu East bordering Tharaka Nithi County and covering Runyenjes Town, Mbeere South bordering Machakos County and Mbeere North bordering Kitui County. Embu County has four electoral units (constituencies), namely Manyatta, Runyenjes, Mbeere North and Mbeere South. The Embu County has a total area of 2,818 Km^2, with about 202.8Km^2 being part of Mt Kenya Forest. The County's total population is about 516,212 (2009 Population Census). The average farm size in the County ranges from 0.5 ha in Embu West to 4.0 ha in Mbeere North (Ministry of Agriculture, 2012). Figure 3.2 shows a map of Embu County showing the administrative boundaries.

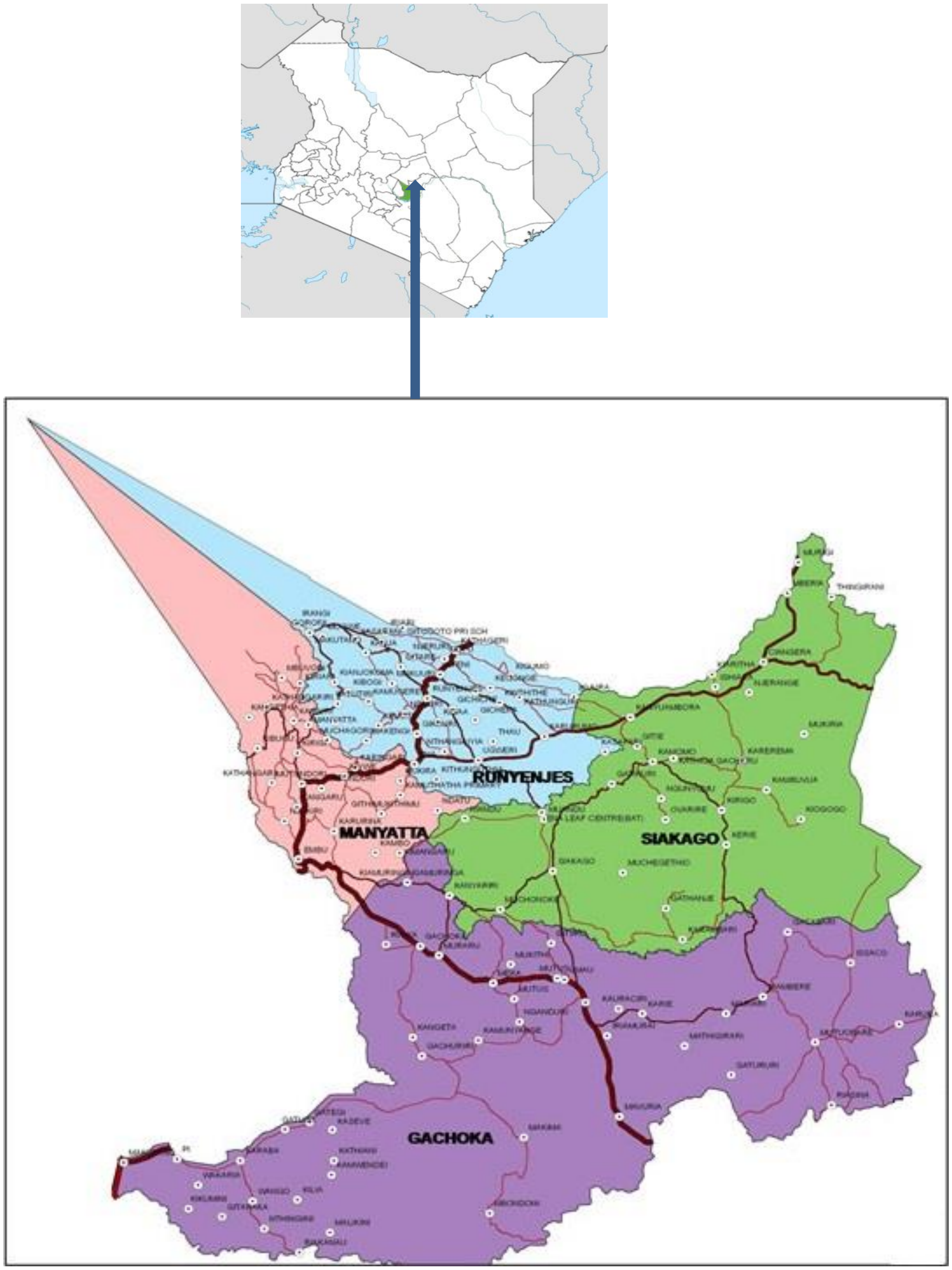

Figure 3.2: A map showing administrative boundaries in Embu County

3.6.2 Main Agro-Ecological Zones in Embu County

The altitude of Embu County ranges from 800m in Mbeere South to 4500m in Embu North Sub-Counties. Agro-ecological zones are diverse and range from Lower Midland (LM) zones 3-5 in Mbeere, Upper Midland (UM) zones 1-4 in parts of Embu West, Embu North and Embu East, and Lower Highlands (LH) zones 1 and 2 in upper areas of Embu North. The rainfall pattern is bimodal with rainfall amounts ranging from 600 mm–1800 mm per annum. The two peak rains in Embu County are received from March to May and from October to December. However, showers of varying amounts are also received from July to August (Jaetzold, 2006). Soil fertility ranges from high fertility in forest zone of Mount Kenya, and the bordering lower highlands and upper midland zones, to moderate and low fertility in lower midland zones. While the soil depth ranges from deep soils in upper midland zones to generally shallow soils in lower midlands (Jaetzold, 2005).

3.6.3 Study Coverage

The study covered three AEZs in Embu County, namely the Sunflower-Cotton Zone (hereafter referred to as Sunflower Zone), Coffee Zone and Tea-Dairy Zone (hereafter referred to as Tea Zone) zones. The Sunflower Zone comprises upper midland 4 (UM 4) and lower midland 3 (LM 3). The Zone receives the lowest amount of annual rainfall among the three AEZs (900mm - 1200mm), with maize, beans and mangoes being the main crops grown (Jaetzold et al, 2006). The Coffee Zone comprises upper midland zones 1 to 3 (UM 1-3). The annual rainfall in the Coffee Zone ranges from 1200mm to 1400mm, with the main crops being coffee, maize, beans, bananas and macadamia. The Tea Zone comprises low highland zone 1(LH 1), low highland zone 2 (LH

2) and some parts of upper midland 1 (UM 1). The Zone receives average annual rainfall ranging from 1400mm to 1800mm, which is the highest among the three AEZ. Tea, maize, beans and macadamia are the main crops grown in the Tea Zone (Jaetzold et al, 2006). Dairy and beef cattle, poultry, sheep and goats, are the main livestock kept in Embu County. Figure 3.3 shows a map of the main agro-ecological zones in Embu County.

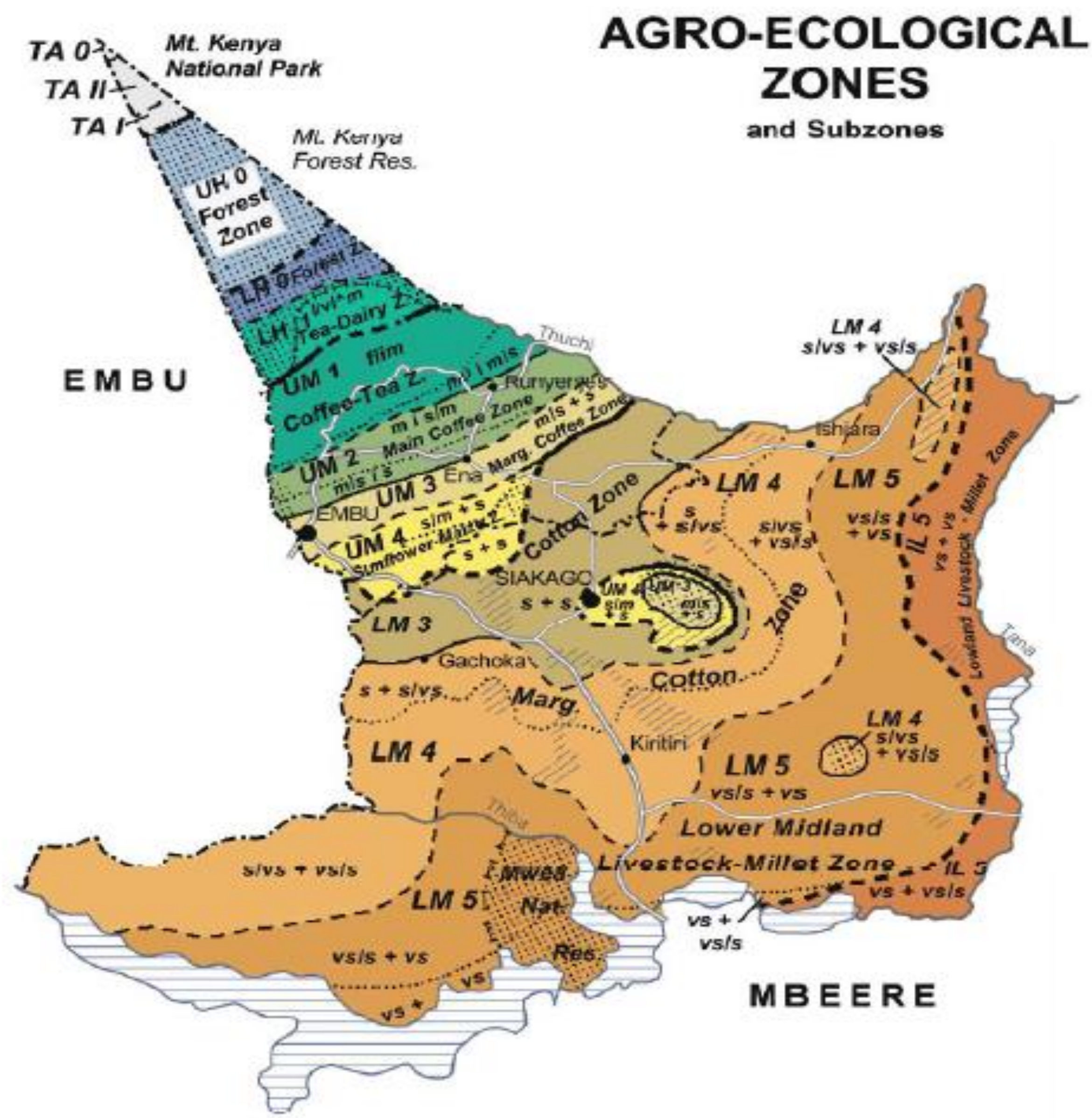

Figure 3. 3 A map showing agro-ecological zones in Embu County

CHAPTER FOUR: EMPIRICAL RESULTS AND DISCUSSIONS

4.1 Effect of Farm Size and Other Factors Affecting Household Food Security

The household food security indices for the households in the sample were determined using the household caloric acquisition method as described in section 3.4.1 of this thesis. The details on some of the major food items that were used to compute the household calorie intake are given in appendix 4. The descriptive statistics for the main food security measures are given in Table 4.1 below. From Table 4.1, it is observed the mean household daily energy requirement was more than the household daily energy intake. The mean household food security index (HFSI) was less than 1 (0.90) thus indicating that on average the households in the study area are food insecure.

Table 4.1: Descriptive statistics on major food security measures for the total sample

Food security measures	N	Minimum	Maximum	Mean	Std. Deviation
HH food security index	384	0.14	2.67	0.90	0.35
HH daily energy requirement (kcal/day)	384	1811	21914	7580	3140
HH daily energy intake (kcal/day)	384	1213	29069	6443	2973
HH size (No.)	384	1.00	10.00	3.75	1.57

Source: Survey data, 2016

Based on computed HFSI, the households in the total sample were classified into 4 food security categories namely, low (0-<0.50), moderately low (0.5-<0.75), moderately high (0.75-<1.00) and preferred (≥1.00). Table 4.2 gives the number of households in each food security category for the sample. About 34% of the households in the sample were found to be food secure (high food security category) while about 66% were found to be food insecure (HFSI<1). This implies that about 66% of the households were not meeting their daily energy requirement, with 11% acquiring less than half of their daily calorie requirement (low food security category).

Table 4.2: The household numbers per food security category for the whole sample

Category	Range	Number	Percent
Low	0 - <0.50	41	10.7
Moderately low	0.5 - <0.75	98	25.5
Moderately high	0.75 - <1.00	116	30.2
High	1.00 & above	129	33.6
Total		384	100.0

Source: Survey data, 2016

The sample was categorized into Sunflower, Coffee and Tea zones and further into the four food security categories. The factors that affect HFSI in each AEZ were determined using multinomial logit regression in SPSS computer programme. The results of analysis for each AEZ are given in the sections below.

4.1.1 Effect of Farm Size and Other Factors Affecting HFSI in the Sunflower Zone

Table 4.3 gives the mean HFSI, daily household energy requirement and intake, and household size for the Sunflower Zone. The mean HFSI in the Sunflower Zone was found to be less than one

(0.75), thus implying that on average the households in this AEZ were food insecure. The HFSI in the sunflower zone was therefore below the average for the total sample (0.90). The mean household size of 3.93 found in the sunflower zone was above the total sample average of 3.75, thus implying that the household sizes in this zone are larger and thus require more food than households in the other zones.

Table 4.3: Descriptive statistics on major food security measures for the Sunflower Zone

Variables	N	Minimum	Maximum	Mean	Std. Deviation
HH food security index	134	0.14	1.88	0.75	0.30
HH daily energy requirement (kcal/day)	134	1989	21914	7971	3461
Household daily energy intake (kcal/day)	134	1213	15077	5587	2525
Household size (No.)	134	1.00	9.00	3.93	1.74

Source: Survey data, 2016

The results from the Sunflower Zone were then categorized into the four food security levels. Table 4.4 gives household numbers for each category. In the Sunflower Zone, the preferred food security category was found to comprise about 17% of the households while the low category comprised about 23%.

Table 4.4: The household numbers per food security category in the Sunflower Zone

Category	Range	Number	Percent
Low	0 - <0.5	31	23.1
Moderately Low	0.5 - <0.75	38	28.4
Moderately high	0.75 - <1.00	42	31.3
High	1.00 & above	23	17.2
Total		134	100

Source: Survey data, 2016

Farm size, household size, household income (farm- and off-farm), credit and extension access, and access to market and road infrastructure were the factors hypothesized to affect household food security in Embu County. The other factors were the modern and emerging technologies adopted, land tenure, and household head's age, gender, experience and educational status.

As per the results of multinomial logistic regression (MLR) analysis, the factors that were found to significantly affect HFSI in the Sunflower Zone at levels of 5% and below are farm-size ($p<0.027$), family size ($p<0.046$) and the adoption of tissue culture bananas ($p<0.018$). The other factors are the levels of education of both the head of household and the wife ($p<0.045$, 0.027). These independent variables are then discussed separately after the presentation of the results of multinomial logistic regression analysis in Table 4.5.

Table 4.5: The results of MLR analysis on factors that affect HFSI in the Sunflower Zone

		FS Categories' B-coefficients		
Independent Variables	Chi-Square	Low	Moderately Low	Moderately High
		(0 - <0.5)	(0.5 - <0.75)	(0.75 - <1.00)
Farm-size (ha)	9.150	-2.890	0.466	-0.044
	(0.027)**	(0.032)**	(0.453)	(0.957)
Distance from market (km)	4.352	0.236	0.142	0.322
	(0.226)	(0.231)	(0.438)	(0.057)
Wife's age (years)	3.995	0.063	0.01	0.054
	(0.262)	(0.166)	(0.793)	(0.126)
Wife's education level	9.197	-2.030	0.06	0.986
	(0.027)**	(0.015)**	(0.932)	(0.137)
Access to electricity	3.498	-0.335	1.443	0.312
	(0.321)	(0.212)	(0.238)	(0.813)
Land tenure	2.557	-0.165	-0.833	-1.038
	(0.465)	(0.866)	(0.338)	(0.189)
Head of house's educ. level	8.067	-0.741	-1.012	0.061
	(0.045)**	(0.477)	(0.094)*	(0.915)
Household size (No.)	8.010	0.838	0.707	0.479
	(0.046)**	(0.019)**	(0.027)**	(0.118)
Adoption of TC bananas	10.04	-2.220	0.591	-0.732
	(0.018)**	(0.042)**	(0.482)	(0.325)
Irrigation access	3.696	0.641	1.201	1.482
	(0.296)	(0.535)	(0.188)	(0.087)
Pseudo-R^2	0.552			

The figures in parenthesis are levels of significance

** 5% level of significance   * 10% level of significance

Source: Survey data, 2016

Based on the MLR results, the following are the individual factors that significantly affect HFSI in the Sunflower Zone:

Farm-size: Farm-size was found to significantly influence food security in the Sunflower Zone at 5% level (Table 4.5). The β-coefficient in the low food security category was negative 2.890 and was significant at 5% level. This indicates that a one unit increase in the farm-size decreases the probability of a household being in the low food security category by a factor of 2.890, in favour of the household being in the preferred food security category (the reference category). The negative impact of land fragmentation on food security would thus be more felt in the households that acquire less than 50% of the required calorie intake. The category forms about 23% of the house in the sunflower zones (Table 4.4). The possible explanation is that a decreased farm-size decreases the area under food crop production, and thus decreasing food availability in the household. A decreased farm-size also decreases food access by decreasing household income through decreased cash crop production.

Household size: The influence of household size on HFSI in the Sunflower Zone was found to be significant at 5% level (Table 4.5). The β-coefficients were positive and significant at 5% level in the low and the moderately low food security categories (Table 4.5). The β-coefficients were 0.838 and 0.707 in the low and the moderately low food security categories respectively. This indicates that the odds of a household being in the low and the moderately low food security categories increases by about 84% and 71% respectively per unit increase in household size. The possible explanation is that the additional family members increase the number of people to be fed and thus decreases the individual energy intake, especially for the households in which the increased family size does not translate into more food production and farm income. The low and the moderately low food security categories account for about 52% of the households in the sunflower zone (Table 4.4).

Education level: The education level of the head of the household was found to significantly influence food security in the Sunflower Zone at 5% level (Table 4.5). The β-coefficient in the moderately low food security category was negative (-1.012) and was significant at 10% level. This indicates that the odds of a household being in the low food security category decreases by a factor of 1.012 per unit increase in the household head's level of education, in favour of the household being in the preferred food security category. The possible explanation is that education increases the head of the household's capacity to increase farm production through better management of farm resources and adoption of modern technologies. Education also increases the head of household's opportunity for off-farm employment thus increasing the household income.

The education status of the head of household's wife was also found to significantly influence food security at 5% level. The β-coefficient in the low food security category was negative 2.030 and was significant at 5% level (Table 4.5), thus implying that the odds of a household being in the low food security category increases by a factor of 2.030 per unit increase in the wife's level of education, in favour of the preferred food security category. The possible explanation is that education increases the wife's capacity to increase farm production through better management of farm resources and adoption of modern technologies. Education also increases the wife's opportunity for off-farm employment and ability to make food choices that improve the household's food utilization.

Adoption of tissue culture bananas: The influence of the adoption of tissue culture bananas was found to significantly affect HFSI at 5% level of significance (Table 4.5). The β-coefficient in the low food security category was negative 2.22 and was significant at 5% level. This indicates that by adoption of tissue culture bananas, a household reduces the odds of being in the low food security category by a factor of 2.22, in favour of the preferred food security category. The possible explanation is that the adoption of the disease-free tissue culture bananas increases farm production, and thus increasing the available food and income in the household.

4.1.2 Effect of Farm Size and other Factors Affecting HFSI in the Coffee Zone

The descriptive statistics for food security measures in the coffee zone are given in Table 4.6. The mean HFSI in the coffee zone was found to be slightly less than one (0.98), implying that on average the households in the coffee zone are able to meet their daily dietary energy requirement or are food secure. The HFSI in the coffee zone was above the average for the total sample (0.90). The mean household size in this zone was 3.59, which was lower than the mean of the total sample (3.75).

Table 4.6: Descriptive statistics on major food security measures for the Coffee Zone

Variables	N	Minimum	Maximum	Mean	Std. Deviation
HH food security index	133	0.33	2.67	0.98	0.38
HH daily energy requirement (kcal/day)	133	1811	18694	7316	3129
HH daily energy intake (kcal/day)	133	1862	29069	6719	3161
HH size (No.)	133	1.00	10.00	3.59	1.59

Source: Survey data, 2016

After the data drawn from the Coffee Zone was categorized into the four food security categories (low, moderately low, moderately high and high), 41.4% of the households were found to be food secure, and only about 4% of the households in the coffee zone were found to be unable to meet half of their daily energy requirement. Further, it was found that about 67% of the household in the coffee zone are able to meet at least 75% of their daily energy requirement (moderately high and high categories). The number of households per food security category is given in Table 4.7.

Table 4.7: The number of households per food security category in the Coffee Zone

Category	Range	Number	Percent
Low	0-<0.5	5	3.8
Moderately low	0.5-<0.75	38	28.6
Moderately high	0.75-<1.00	35	26.3
High	1.00 & above	55	41.4
Total		133	100

Source: Survey data, 2016

Table 4.8 presents the results of the MLR analysis of the factors that affect HFSI in the Coffee Zone. Based on the results from the MLR analysis, it was found that the number of households in the poor food security category in the coffee zone was insignificant. The socio-economic and institutional factors that were found to have a significant effect on HFSI in the coffee zone are access to agricultural extension ($p<0.001$), adoption of improved coffee varieties ($p<0.002$), dependency burden ($p<0.045$) and household size ($p<0.001$). The effect of farm size was not found to be significant in the coffee zone.

Table 4.8: The results of MLR analysis on factors that affect HFSI in the Coffee Zone

Independent Variables	Chi-Square	FS Categories' B-coefficients Moderately Low (0.5 - <0.75)	Moderately High (0.75 - <1.00)
Farm size (ha)	1.457	-0.639	0.435
	(0.483)	(0.457)	(0.51)
Access to extension	12.433	-1.993	-0.555
	(0.002)***	(0.001)***	(0.352)
Dependency burden	7.945	-1.84	3.725
	(0.019)**	(0.242)	(0.045)**
Household size (No.)	16.494	0.898	0.107
	(0.000)***	(0.001)***	0.672)
Adoption of improved coffee	14.401	-2.99	0.197
varieties	(0.001)***	(0.002)***	(0.782)
Pseudo-R^2	0.408		

The figures in parenthesis show the levels of significance

*** significance at 1% ** significant at 5% * Significant at 10%

Source: Survey data, 2016

Drawing on the results from Table 4.8, the following are the individual factors that significantly influence HFSI in the Coffee Zone:

Access to extension services: The influence of the farm's access to extension services was found to be significant at 1% level. The β-coefficient in the moderately low food security category was negative 1.993, which indicates that by accessing agricultural extension services a household reduces the odds of being in moderately low food security category by a factor of 1.993, in favour of the preferred food security category. Access to extension services increases the household's food availability and access by enhancing the transfer and adoption of technologies which increase food and cash crop production in the farm.

Dependency burden: From the household point of view, dependency burden or ratio is the proportion of household members aged 0 to 15 years and 65 years and above. These age groups are considered to be economically unproductive and dependent on those aged 16- 59 years for their livelihood (Todaro and Smith, 2012). The current study found an average dependency ratio of 62% for the households in the coffee zone. The influence of the dependency ratio on HFSI was significant at 5% level. The β-coefficient for the dependency ratio in moderately high food security category was positive 3.725 and was significant at 5% level, which implies that the probability of a household being in the moderate food security category increases by a factor of 3.725 per unit increase in dependency ratio, rather than the preferred food security category. The possible explanation is that an increase in dependency ratio implies an increase in non-working household members who increase the number of people to feed without increasing food production, thus decreasing each individual's food availability. The moderately high food security category accounts for 26% of the households in the coffee zone (Table 4.7).

Household size: The influence of household size on HFSI was found to be significant at 1% level. The β-coefficient for the moderately low food security category was positive 0.898 and was significant at 1% level, indicating that a one unit increase in the household size increases the probability of a household being in moderately low food security category by about 90%. The possible explanation is given in Section 4.2.1 of this thesis. The moderately low food security category accounts for 28.6% of the households in the Coffee Zone (Table 4.7)

Improved coffee variety: The influence of the farmer's adoption of improved coffee varieties on food security was significant at 1% level (Table 4.7). The recommended coffee varieties were Ruiru 11 and Batian. The β-coefficient in the moderately low food security category was -2.99, implying that the farmer's adoption of the recommended coffee varieties reduces the probability of the household being in the low food security category by a factor of 2.99. A possible explanation is that the improved coffee varieties have higher yields and decrease the cost of production because the farmers apply less spray chemicals against diseases. This study actually found a significant and positive correlation between the value of coffee output and the adoption of improved coffee varieties.

4.1.3 Effect of farm size and other Factors Affecting HFSI in the Tea Zone

The descriptive statistics for food security measures in the Tea Zone are given in Table 4.9. The mean HFSI in the tea zone was found to be slightly less than one (0.98) implying that on average the households in the tea zone are able to meet their daily energy requirement or are food secure. The HFSI in the tea zone was above the average for the total sample (0.90). The mean household size in the Tea Zone was 3.73, while the mean for the total sample was 3.75.

Table 4.9: Descriptive statistics on major food security measures for the Tea Zone

Variables	N	Minimum	Maximum	Mean	Std. Deviation
HH food security index	117	0.35	1.90	0.98	0.32
HH daily energy requirement (kcal/day)	117	1989	17459	7432	2722
HH daily energy intake (kcal/day)	117	1331	22626	7112	3021
HH size (No).	117	1.00	8.00	3.73	1.30

Source: field survey 2016

After the data drawn from the Tea Zone was categorized into the four food security categories (low, moderately low, moderately high and high), about 43.6% of the households were found to be food secure, and only about 4% were found to be unable to meet half of their energy daily requirement. Further, it was found that about 77% of the household in the tea zone are able to meet at least 75% of their daily energy requirement (moderately high and high categories). The frequency data are given in Table 4.10.

Table 4.10: The number of households per food security category in the Tea Zone

Category	Range	Number	Percent
Low	0-<0.5	5	4.3
Moderately low	0.5-<0.75	22	18.8
Moderately high	0.75-<1.00	39	33.3
High	1.00 & above	51	43.6
Total		117	100

Source: field survey 2016

Table 4.11 presents the results of the MLR analysis of the factors that affect HFSI in the Tea Zone. Based on the multinomial logit regression (MLR) results, the socio-economic factors that were found to have significant effect on HFSI in the tea zone are farm-size ($p<0.014$), household head's age ($p<0.002$) and that of the wife ($p<0.006$). Other factors found to be significant were access to agricultural extension ($p<0.006$) and dependency burden ($p<0.007$). The individual variables are discussed separately after the presentation of the MLR results as given in Table 4.11.

Table 4.11: MLR analysis results on factors that affect HFSI in the Tea Zone

Independent Variables	Chi-Square	FS Categories' B-coefficients Moderately Low (0.5 - <0.75)	Moderately High (0.5 - <0.75)
Farm-size (ha)	8.566	-1.853	-2.171
	(0.014)**	(0.026)**	(0.035)**
Head of household's age (years)	12.803	0.026	0.288
	(0.002)***	(0.832)	(0.003)***
Access to extension services	10.105	-3.317	-0.423
	(0.006)***	(0.012)**	(0.732)
Adoption of certified seeds	5.281	0.719	1.545
	(0.071)	(0.374)	(0.028)**
Age of the wife (years)	10.097	-0.008	-0.238
	(0.006)***	(0.942)	(0.009)***
Household's road distance (km)	3.315	0.007	-0.222
	(0.191)	(0.663)	(0.175)
Dependency burden	9.984	-2.491	6.726
	(0.007)***	(0.436)	(0.019)**
Pseudo-R^2	0.506		

The figures in parenthesis show the levels of significance

*** significance at 1% ** significant at 5% * Significant at 10%

Source: Survey data, 2016

Drawing on the results from Table 4.11, the factors that significantly influence HFSI in the Tea Zone are as discussed hereafter:

Farm-size: The influence of farm-size on HFSI was significant at 5% level (Table 4.11). The β-coefficients in both the moderately low and moderately high food security categories were -1.853

and -2.171, implying that a one unit increase in farm size decreases the probability of a household being in the moderately low food security category by a factor of 1.853 and by a factor of 2.171 in the moderately high food security category (Table 4.11). As discussed in Section 4.21 of this study, increased farm-size enables the household to produce more food and to generate more farm income, thus increasing the household's access to food. This study found farm size to be positively correlated to farm income at 1% level of significance.

Household head's age: Household head's age was found to significantly influence HFSI at 1% level (Table 4.11). The β-coefficient in the moderately high food security category was positive 0.288, implying that the odds of a household being in the moderate food security category increases by about 29% per unit increase in the household head's age (Table 4.11). A possible reason could be that the younger household heads are more educated and have more opportunities for off-farm employment. This study actually found the age of family head to be negatively correlated to the level of education and off-farm income.

Age of the wife: The wife's age was found to significantly influence HFSI at 1% level (Table 4.11). The β-coefficient in the moderate food security category was negative 0.238, implying that the odds of a household being in moderate food security category decreases by about 24% per unit increase in the wife's age, in favour of the preferred category (Table 4.11). A possible explanation could be that increased farming experience with age increases the wife's knowledge and skills in farming, thus increasing farm production. This study actually found that 59% of the farms in the tea zone were managed by females. Therefore, any improvement in managerial capabilities of wives would improve farm production. As supporting evidence, this study found the wife's age to be positively correlated to the value of cash crops produced in the farm.

Extension services: Extension access was found to significantly influence HFSI at 1% level (Table 4.11). The β-coefficient in the moderately low food security category was negative 3.317, implying that increased extension access increases the odds of a household being in moderately low food security category by a factor of 3.317 (Table 4.11). Agricultural extension provides the farmers with information on technologies that can increase farm production. As supporting evidence, this study found access to extension services to be positively correlated to total value of food crops produced in the farm

Dependency Burden: The effect of the household's dependency ratio was found to have a significant influence on HFSI at 1% level (Table 4.11). The β-coefficient in the moderately high food security category was positive 6.726, implying that the probability of a household being in the moderately high food security category increases by a factor of 6.726 per unit increase in dependency ratio. A possible explanation is that an increase in the dependency ratio increases the household daily energy requirement without increasing its capacity to acquire more food, thus decreasing the per capita energy intake.

4.2 Determination of Minimum Farm Size for Attainment of Threshold HFSI

The household food security index (HFSI) was determined for each household in the sample using the procedure given in Section 3.4.1(a) of this thesis. The sample was stratified on the basis of farm-size categories as given in Section 3.4.2 and the three AEZs (Sunflower, Coffee and Tea).

The numbers and the percentages of farms for each farm size category in the sample are given in Table 4.12.

Table 4. 12: The number of farms per farm-size category in the whole sample

Farm-size category	Number	Percent	Cumulative percent	Mean HFSI
0 - <0.25 ha	78	20	20	0.77
0.25 - <0.5 ha	109	28	48	0.89
0.5 - <1.0 ha	92	24	72	0.97
1.0 - <2.0ha	69	18	90	1.04
2.0 ha & above	36	10	100	0.84
Total	384	100		0.90

Source: Survey data, 2016

Table 4.12 shows that farms below 1 ha in size formed 72% of the sample, implying that the sample was dominated by small scale farms. This indicates the intensity of land fragmentation in the study area where only 10% of the farms in the sample had land areas of 2 ha and above (Table 4.12). From Table 4.12, it is observed that the minimum farm size required for attainment of threshold level of household food security (Mean HFSI=1) for the sample is in the farm size category of 1.0 -<2.0ha. The minimum farm size required for attainment of threshold level of household food security in each AEZ are determined and discussed in the sections that follow hereafter.

4.2.1 Minimum Farm-Size in the Sunflower Zone

Based on the study results, the mean household food security index (HFSI) for each farm size category in the Sunflower Zone is given in Table 4.13. The mean average HFSI in the Sunflower

Zone was found to increase as farm size increases, implying that farm size has a significant influence on HFSI in this zone However, the study found that none of the farm-size categories considered had attained the threshold level of household food security (HFSI=1).

Table 4.13: The mean HFSI for the farm-size categories in the Sunflower Zone

Farm- size	Number	Percent	Mean HFSI
0- <0.5 ha	32	23	0.49
0.5- <1.0 ha	41	31	0.71
1.0- <2.0 ha	37	28	0.83
2.0 ha & above	24	18	0.80
Total	134	100	0.75

Source: Survey data, 2016

Figure 4.1 is drawn from Table 4.13. The figure shows that the mean HFSI increases as the farm size increases, implying a positive relationship between farm size and household food security status in the Sunflower Zone.

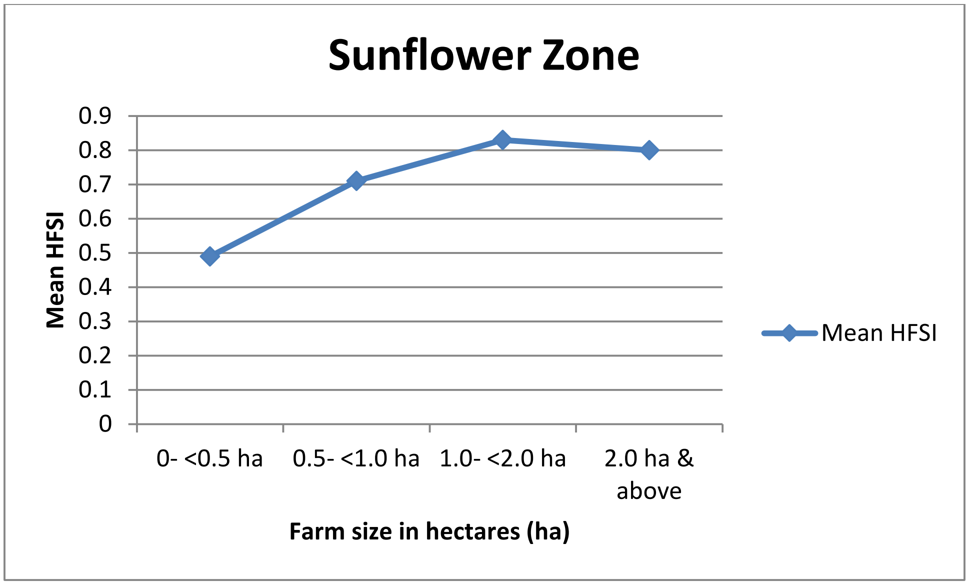

Figure 4.1: The mean HFSI across farm size categories in the Sunflower Zone

Source: Survey data, 2016

The significance of the variations in HFSI across the farm size categories in the Sunflower Zone was tested using the ANOVA test as given in Table 4.14. Variations in HFSI across the farm size categories in the Sunflower Zone were found to be significant at 1% level (p=0.002), implying that the level of household food security in this zone increases as farm size increases. The highest household food security level in the Sunflower Zone was found in farm size category1.0- <2.0 ha, which is lower than the threshold food security level. This study concluded that the farm size that could attain the highest level of household food security in the Sunflower Zone would have to be greater than 1-2 ha farm size category, based on a trendline between HFSI equals 0.5 and HFSI equals 0.8 (Figure 4.1). However, measures should be taken to increase farm productivity in the Sunflower Zone for attainment of threshold household food security level.

Table 4.14: The ANOVA test for variations in HFSI across farm size categories in the sunflower zone

Source of var.	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.277	3	0.426	5.119	0.002
Within Groups	10.809	130	0.083		
Total	12.086	133			

Source: Survey data, 2016

4.2.2 Minimum Farm-Size in the Coffee Zone

Based on the study results, the mean HFSI for each farm size category in the Coffee Zone are given in Table 4.15. The mean average HFSI was found to increase slightly as farm size increases, indicating a positive relationship between farm size and food security in the coffee zone. The threshold household food security level in the Coffee Zone is attained at farm-size of 0.25-<0.5 ha farm size category (Table 4.15).

Table 4.15: The mean HFSI for the farm-size categories in the coffee zone

Farm-size	Number	Percent	Mean HFSI
0- <0.25 ha	43	32	0.91
0.25- <0.5 ha	43	32	1.03
0.5- <1.0 ha	25	19	1.01
1.0 ha & above	22	17	1.11
Total	133	100	0.98

Source: Survey data, 2016

Figure 4.2 is drawn from Table 4.15. The figure shows that the mean HFSI increases as the farm size increases, implying a positive relationship between farm size and household food security status in the Coffee Zone.

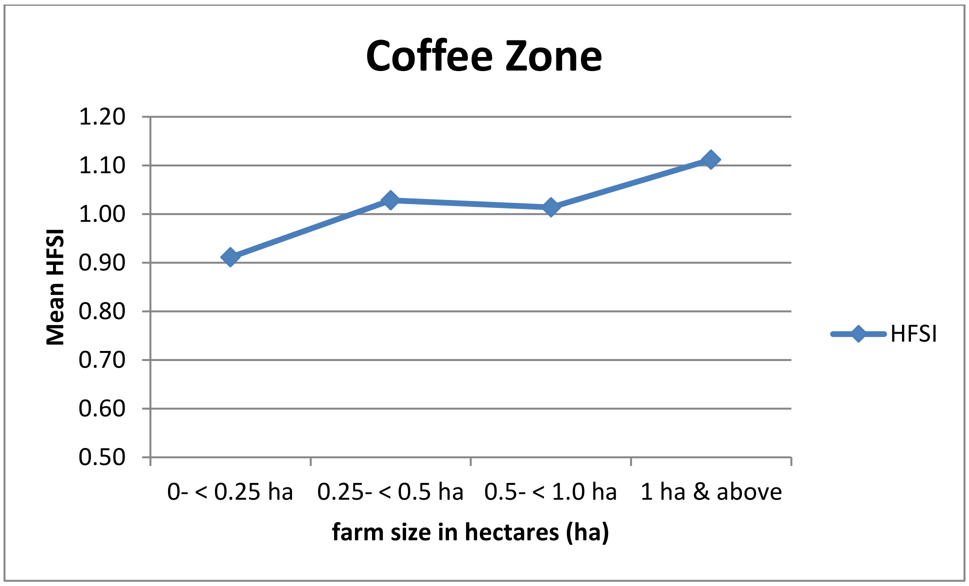

Figure 4.2: The mean HFSI across farm size categories in the coffee zone

Source: Survey data, 2016

The significance of the variations in HFSI across the farm size categories in the Coffee Zone was tested using the ANOVA test as given in Table 4.16. Variations in HFSI across the farm size categories in the Coffee Zone were found not to be significant at 5% level (p=0.191), implying that the determined minimum farm size (0.25-0.5 ha) for attainment of threshold level of household food security was not conclusive.

Table 4.16: The ANOVA test for variations in HFSI across farm size categories in the Coffee Zone

Source of variance	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.682	3	0.227	1.606	0.191
Within Groups	18.248	129	0.141		
Total	18.93	132			

Source: Survey data, 2016

4.2.3 Minimum Farm Size in the Tea Zone

Based on the study results, the mean HFSI for each farm size category in the sample drawn from the Tea Zone are given in Table 4.17. The mean average HFSI in the Tea Zone was found to increase as farm size increases, indicating a positive relationship between farm size and food security in this zone. The minimum farm size for attainment of threshold household food security in the Tea Zone was found to be in 0.5-<1 ha farm size category (Table 4.17)

Table 4.17: The mean HFSI for the farm-size categories in the Tea Zone

Farm-size	Number	Percent	HFSI
0- <0.25 ha	27	23	0.92
0.25- <0.5 ha	42	36	0.94
0.5- <1.0 ha	26	22	1.07
1.0 ha & above	22	19	1.21
Total	117	100	1.00

Source: Survey data, 2016

Figure 4.3 is drawn from Table 4.17. The figure shows that the mean HFSI increases as the farm size increases, implying a positive relationship between farm size and household food security status in the Tea Zone.

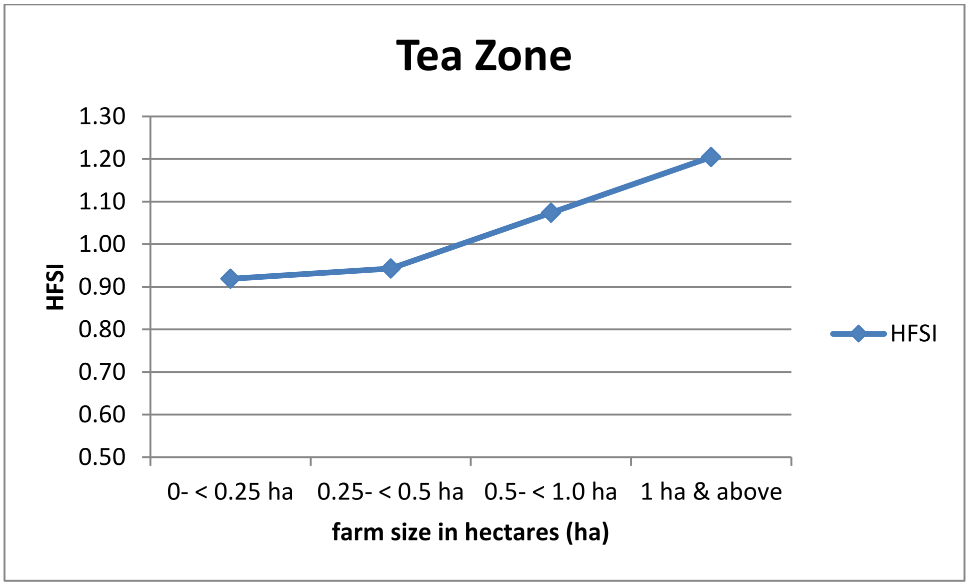

Figure 4.3: The mean HFSI across farm size categories in Tea Zone

Source: Survey data, 2016

The significance of the variations in HFSI across the farm size categories in the Tea Zone was tested using the ANOVA test as given in Table 4.18. Variations in HFSI across the farm size categories in the Tea Zone were found to be significant at the 5% level ($p=0.015$), implying that farm-size had a significant positive effect on food security in this zone.

Table 4.18: The ANOVA test for variations in HFSI across farm size categories in the Tea Zone

Source of var.	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.054	3	0.351	3.66	0.015
Within Groups	10.842	113	0.096		
Total	11.896	116			

Source: Survey data, 2016

4.3 Effect of Farm Size and other Factors Affecting Farm Efficiency (FE)

The stochastic frontier analysis method was used to determine farm technical efficiency of each farm in the sample as described in section 3.4.3 of this thesis and detailed findings given in Appendix 5. The efficiency measures for the sample were categorized into the 4 efficiency categories as described in section 3.4.3. Table 4.19 gives the number of farms in each efficiency category and the mean efficiency for the sample. The mean for the sample was 0.51 with 44 percent of the firms attaining less than 50 percent technical efficiency, implying that 44 percent of the farms in the three AEZs could increase farm output by more than 50 percent by increasing efficiency.

Table 4. 19: The number of farms per farm efficiency category in the sample

Efficiency Category	Efficiency Range	Number	Percent	Cum. Percent
Low	0-<0.25	38	10	10
Moderately low	0.25-<0.50	131	34	44
Moderately high	0.50-<0.75	158	41	85
High	0.75-1.00	57	15	100
MEAN	0.51			

Source: Survey data, 2016

The farm in the sample were categorized on the basis of the three agro-ecological zones and further into the 4 farm efficiency categories as described in Section 3.3.2 of this thesis. The significance of the factors hypothesized to affect farm efficiency in different agro-ecological zones in Embu County was determined using Multinomial Logit Regression as described in sections 3.3.1 and 3.3.3 of this thesis. The findings for each agro-ecological zone are discussed hereafter.

4.3.1 Effect of Farm Size and other Factors Affecting FE in the Sunflower Zone

The mean farm efficiency in the Sunflower Zone was found to be 0.50 which was almost equal to the sample mean (0.50). Table 4.20 gives the number of farms in each efficiency category for the Sunflower Zone. From this table, it is observed that 44 percent of the farms in the Sunflower Zone were less than 50 percent efficient, implying that there was considerable level of inefficiency in the sunflower zone.

Table 4. 20: The number of farms per farm efficiency category in the Sunflower Zone

Eff. Category	Eff. Range	Number	Percent	Cum. Percent
Low	0-<0.25	10	7	7
Moderately Low	0.25-<0.50	49	37	44
Moderately high	0.50-<0.75	69	51	95
High	0.75-1.00	6	4	100
Mean	0.50			

Source: Field survey data, 2016

The low and moderately low efficiency categories were merged due to the small number of farms in the low efficiency category. The high and the moderately high efficiency categories were also merged and resulting efficiency category (0.50-1.00) was used as the reference category in Multinomial Logit Regression. The significance of the factors affecting farm efficiency was determined using Multinomial Logit Regression (MLR) as described in section 3.3.3 of this thesis.

The results of the MLR are given in Table 4.21. The effect of farm size on farm efficiency was not found to be significant. The effect of distance to market ($p<0.031$), head of household's level of education, ($p<0.038$), access to irrigation water ($p=0.017$) and off-farm income ($p=0.027$) were found to significantly affect farm efficiency in the Sunflower Zone. The factors that were found to be significant in affecting farm efficiency in the moderately low efficiency category in the Sunflower Zone are discussed hereafter.

Table 4.21: The results of MLR analysis of factors that affect farm efficiency in the Sunflower Zone

Independent Variables	Chi-Square	β-coefficients Moderately low (0.25 - <0.50)
Distance to market (km)	5.116	0.676
	(0.024)*	(0.031)*
Access to extension (contact No.)	0.456	0.306
	(0.499)	(0.502)
Education level (years)	6.79	-1.933
	(0.009)**	(0.038)*
Farming experience (years)	2.598	0.320
	(0.107)	(0.113)
Access to electricity (yes/no)	1.009	-0.736
	(0.315)	(0.314)
Off-farm occupation (yes/no)	1.304	0.789
	(0.253)	(0.265)
Access to irrigation water (yes/no)	6.135	-1.390
	(0.013)*	(0.017)*
Off-farm income (Ksh.)	5.552	0.618
	(0.018)*	(0.027)*
Pseudo-R square	0.505	

Reference category: Efficiency category 0.50-1.00

The figures in parenthesis are levels of significance:

** 1% level   * 5% level

Source: Field survey data, 2016

Distance to market: The β-Coefficient for distance to the market was positive 0.676 and was significant at 5 percent level (Table 4.21), implying that a one unit increase in distance to market increases the odds of a farm being in the moderately low efficiency category by about 68 percent rather than being in the high efficiency category. Farm efficiency in the Sunflower Zone was therefore found to be affected negatively by the distance to the market. This could be explained by the crucial role played by the market in supplying farm inputs and providing an outlet for farm products, so that the nearer the market the better. This implies that farms in the moderately low efficiency category in the Sunflower Zone can largely be improved by establishing more factor and product markets near them.

Head of household's Level of education: The β-Coefficient for formal education was negative 1.933 and was found to be significant at 5 percent level (Table 4.21). This implies that formal education decreases the odds of a farm being in the moderately low efficiency category by a factor of 1.933 in favour of the high efficiency category, implying that education has a positive effect on farm efficiency. Therefore, encouraging formal education and giving incentives for educated people to engage in agriculture increases farm efficiency in the Sunflower Zone. The plausible explanation is that education increases the farmer's capacity to manage resources and for adoption of technologies that augment farm productivity.

Access to irrigation water: The β-Coefficient for access to irrigation water was negative 1.390 and was significant at 5 percent level. This implies that in the Sunflower Zone farm's access to water for irrigation decreases the odds of a farm being in the moderately low efficiency by a factor of 1.390 in favour of the high efficiency category. Thus access to irrigation water has a positive effect on farm efficiency. The plausible explanation is that access to water increases crop productivity in the Sunflower Zone which on average receives less than 1000 mm of rainfall per annum. Access to water for irrigation reduces the farmer's over-reliance on rain fed agriculture and enables him or her to produce crops through out the year, thus increasing farm productivity. This study found that 32 percent of farms in the sample drawn from the Sunflower Zone had access to piped water which they could use for irrigation. This study found that in the Sunflower Zone, the mean farm efficiency was higher for farms that had access to piped water (0.54) than for those with no access to piped water (0.43).

Off-farm income: The β-Coefficient for off-farm income was positive 0.618 significant at 5 percent level and was significant at 5 percent level, implying that contrary to expectation one unit increase in off-farm income increases the odds of a farm being in the moderately low efficiency category by about 62 percent. Thus off-farm income was found to have a negative effect on farm efficiency. The plausible explanation is that farmers who earn more off-farm income are engaged more in off-farm employment and hence had a tendency to pay limited attention to their farms, resulting to a reduction in farm productivity. This study found that 60 percent of the farms earning an off-farm income of less than Ksh. 25,000 per year are in the moderately high efficiency category compared to 23 percent for the farms earning off-farm income of more than Ksh.200,000 per year. The moderately efficiency category was the reference category in the Multinomial Logit Regression for the Sunflower Zone.

4.3.2 Effect of Farm Size and other Factors Affecting FE in the Coffee Zone

Table 4.22 presents the number and percent of farms in each efficiency category in the Coffee Zone. The mean farm efficiency in the Coffee Zone was found to be 0.43 which was lower than the sample mean (0.51), and the lowest among the three AEZs. Table 4.21 shows that 65 percent of farms in the Coffee Zone are below 50% level of efficiency, indicating a considerable level of inefficiency.

Table 4.22: The number and percent of farms in each farm efficiency category in the Coffee Zone

Efficiency Category	Efficiency Range	Number	Percent	Cum. Percent
Low	0.0-<0.25	28	21	21
Moderately Low	0.25-<0.50	59	44	65
Moderately high	0.50-<0.75	37	28	93
High	0.75-1.00	9	7	100
MEAN	0.43			

Source: Field survey data, 2016

Table 4.23 gives the results of the multinomial logit regression analysis in the Coffee Zone. Farm-size (p=0.013), distance to market (p=0.000) and head of household's educational level (p=0.041) were found to have significant effects on farm efficiency. Other significant factors were head of household head's age (p=0.003) and off-farm occupation (p=0.014), and distance to all-weather road (p=0.024).

Table 4. 23: The results of MLR analysis of factors that affect farm efficiency in the Coffee Zone

		β-coefficients	
Independent Variables	Chi-Square	Low	Moderately low
		(0-<0.25)	(0.250- <0.50)
Farm size (ha)	7.277	0.879	0.523
	(0.026)*	(0.013)*	(1.224)
Distance to market (km)	16.452	1.853	1.224
	(0.000)**	(0.000)**	(0.008)**
Access to extension (contact No.))	3.741	-1.106	-0.172
	(0.154)	(0.079)	(0.732)
Off-farm income (ksh)	4.105	0.834	0.227
	(0.128)	(0.054)	(0.452)
Education level (years)	5.127	-1.075	-0.708
	(0.077)	(0.041)*	(0.081)
Household head's age (years)	10.389	-0.622	-0.875
	(0.006)**	(0.081)	(0.003)**
Off-farm occupation (yes/no)	7.347	3.834	1.726
	(0.025)*	0.014*	(0.103)
Distance to all-weather road (km)	5.513	1.296	0.708
	(0.064)	(0.024)*	(0.143)
Pseudo-R square	0.551		

Reference category: Eff. category 0.50-1.00

The figures in parenthesis are levels of significance: ** 1% level * 5% level

Source: Field survey data, 2016

Farm size: In the low efficiency category in the Coffee Zone, the β-Coefficient for the farm-size was found to be significant at the 5 percent level (Table 4.23). The β-Coefficient was positive 0.879, implying that the odds of a household being in the low efficiency category increases by a factor of about 88 percent in response to one unit increase in farm-size. Therefore, in the low efficiency category, farm efficiency was found to be affected negatively by farm-size. In the moderately low efficiency category, the β-Coefficient was not significant at the 5% which suggests that the influence of farm-size diminishes as the farm becomes more efficient.

Distance to market: The β-Coefficients for the effect distance to the market for the low and moderately low efficiency categories were significant at 1 percent level (Table 4.23). The β-Coefficient was positive 1.853 and positive 1.224 for the low and moderately low efficiency categories respectively. This implies that a one unit increase in distance to market increases the odds of a farm being in the low efficiency category by a factor of 1.853 and by a factor of 1.224 in the moderately low efficiency category. Thus farm efficiency in the Coffee Zone, like in the Sunflower Zone, was found to be affected negatively by the distance to the market. This could be explained by the crucial role played by the market in supplying farm inputs and providing an outlet for farm products, so that the nearer the market the better. This implies that farms in the moderately low efficiency category in the Sunflower Zone can largely be improved by establishing more factor and product markets near them.

Head of household's Level of education: The β-Coefficient for level of education was negative 1.073 and was found to be significant at 5 percent level (Table 4.23). This implies that in the Coffee Zone, the household head's level of education decreases the odds of a farm being in the low efficiency category by a factor of 1.073 in favour of the high efficiency category, implying that education has a positive effect on farm efficiency. Therefore, encouraging formal education and giving incentives that attract engagement of educated in agriculture would increase farm efficiency in the Coffee Zone. The plausible explanation is that education increases the farmer's capacity to manage resources and for adoption of technologies that augment farm productivity.

Household head's age: The β-Coefficient associated with the age of household head's age found to be significant at 1 percent level (Table 4.23) and was negative 0.875. This implies that a one unit increase in the household's age decreases the odds of a household being in the moderately low efficiency category by about 88 percent in favour of being in the high efficiency category. Therefore, age of the household head has a positive effect on farm efficiency. The plausible explanation is that the increased experience that comes with age may have a positive influence on farm efficiency for it increases the farmer's ability to manage farm resources thus increasing farm efficiency. In addition, the older farmers are also more likely to have accumulated resources for the purchase of farm inputs and adoption of technologies that enhance farm productivity.

Off-farm occupation: For off-farm occupation in the low efficiency category, the β-Coefficient was positive 3.834 and significant at the 5% level (Table 4.23), implying that the farmer's employment in off-farm activities increases the odds of a farm being in the low efficiency category by a factor of 3.834. Off-farm employment was however not found to have significant influence on farm efficiency in the moderately low efficiency category, implying that the negative effect off-farm employment decreases as the farms become more efficient. The plausible explanation is that the farmer's increased engagement in off-farm occupation, may reduce the time and resources devoted to the farm and hence reduce farm productivity.

Distance to all-weather road: The β-Coefficient for distance to all- weather road was positive and significant at the 5% level. The β-Coefficient was found to be positive 1.296 in the low efficiency category implying that a one unit increase in the distance to all-weather road increases the odds of a farm being in the low efficiency category by a factor of 1.296. Farm efficiency was therefore found to be negatively influenced by the distance to all-weather road in the Coffee Zone, implying that the closer to the road the higher the farm efficiency. The plausible explanation could be that the farm's nearness to the road infrastructure increases its access to the output and factor markets, and extension hence increasing the farm productivity.

4.3.3 Effect of Farm Size and other Factors affecting FE in the Tea Zone

The mean farm efficiency in the Tea Zone was found to be 0.61 which was higher than the sample mean (0.51) and the highest among the three AEZs. Table 4.24 presents the number and percent of farms in each efficiency category in the Tea Zone. This table shows that about 19 percent of the farms in the Tea Zone had less than 50 percent level of efficiency, implying a considerable low level of inefficiency compared to the Sunflower Zone (44 percent) and Coffee Zone (65 percent). None of the firms in the Tea Zone was in the low efficiency category (0- <0.25) and therefore three efficiency categories were used in the MLR analysis (moderately low, moderately high and high efficiency categories.

Table 4. 24: The number and percent of farms in each efficiency category in the Tea Zone

Efficiency Category	Efficiency Range	Number	Percent	Cum. Percent
Low	0-<0.25	0	0	0
Moderately Low	0.25-<0.50	23	19	19
Moderately high	0.50-<0.75	77	65	84
High	0.75-1.00	17	14	100
MEAN	0.61			

Source: Field survey data, 2016

Table 4.25 presents the results of MLR analysis for the factors affecting farm efficiency in the Tea Zone. Farm-size (p=0.046), access to credit (p=0.013), Land tenure (p=0.040) and access to extension (p=0.044) were found to have significant effect on farm efficiency in the Tea Zone. The significant factors are discussed hereafter.

Table 4.25: The results of MLR analysis of factors that affect farm efficiency in the Tea Zone

		β-coefficients	
Independent Variables	Chi-Square	Moderately Low	Moderately High
		(0.25-<0.50)	(0.50-<0.75)
Farm size (ha)	6.083	1.016	0.210
	(0.048)*	(0.046)*	0.614
Distance to all-weather road (km)	3.944	0.097	-0.769
	(0.139)	(0.887)	(0.139)
Household size (No.)	4.382	-0.128	-0.929
	(0.112)	(0.859)	(0.12)
Access to credit (yes/no)	6.806	-1.319	-1.988
	(0.033)*	(0.255)	(0.013)*
Off-farm occupation (yes/no)	4.919	3.791	0.467
	(0.085)	(0.075)	(0.659)
Land tenure	6.494	-0.266	-1.865
	(0.039)*	(0.818)	(0.040)*
Household head's age (years)	3.097	-0.288	-0.31
	(0.213)	(0.224)	(0.117)
Access to extension (contact no.)	5.941	-1.797	-0.293
	(0.051)*	(0.044)*	(0.656)
Distance to market (km)	4.24	-0.155	0.873
	(0.120)	(0.844)	(0.130)
Pseudo-R square	0.504		

Reference category: 0.75-1.00

The figures in parenthesis are levels of significance:** 1% level * 5%

Source: Field survey data, 2016

Farm-size: For farm size in the moderately low efficiency category, the β-Coefficient was positive 1.016 and significant at 5 percent level, implying that the odds of a farm being in the low efficiency category increases by a factor of 1.016 per unit increase in farm size (4.25). Therefore, the effect of farm-size on technical efficiency was found to be negative in the low efficiency category. The β-Coefficient in the moderately high efficiency category was not significant, implying diminishing influence of farm size as farm efficiency increases in the Tea Zone. The impact of land fragmentation in the tea zone could therefore be reduced by taking such measures that increase farm efficiency as the production of high value crops, use of manure and fertilizer and farmer training.

Access to credit: The β-Coefficient for access to credit in the moderately high efficiency category was negative 1.988 and was significant at the 5% level, implying that access to credit decreases the odds of a farm being in the moderately high efficiency category by a factor of 1.988 in favour of high efficiency category (Table 4.25). Farm efficiency in the moderately high efficiency category was therefore affected positively by access to credit. The β-Coefficient for access to credit was not significant at the 5% level in the moderately low efficiency category, which meant that farms at high levels of efficiency benefit more from credit than those at lower levels. This could be due to the fact that farm credit enables the farms to get capital for purchases of farm inputs and for long term investments that boost farm efficiency.

Land tenure: In the moderately high efficiency category, the β-Coefficient for land tenure was found to be significant at the 5 percent level (Table 4.25). The coefficient was negative 1.865 in the moderately high efficiency category, implying that by increasing the tenure security through issuance of a land title the odds of a farm being in the moderately high efficiency category in the Tea Zone decreases by a factor of 1.865 in favour of the high efficiency category. The effect of ownership of land title on farm efficiency was therefore found to be positive in the moderately high efficiency category. The types of land ownership identified in the Tea Zone were: land title owned by farmer (59 percent), land title not owned by farmer (40 percent) and rented land (1 percent). The mean farm efficiency for farmers owning land titles was 0.63 and 0.57 for farmers not owning titles. Ownership of land (titles) gives farmers incentives to invest in long-term investments which have a positive impact on farm efficiency, implying that farm efficiency could be improved through issuance of titles to farmers who do not have them.

Access to Extension: The β-Coefficient associated with access to extension was found to be significant at 5 percent level in the moderately low efficiency category. The coefficient was negative 1.797, implying that farmer's access to extension decreases the odds of a farm being in the moderately low efficiency category by a factor of 1.797 in favour of the high efficiency category in the Tea Zone. The plausible explanation is that farm's access to extension increases transfer of technologies such as better crop production techniques and improved inputs which increase farm productivity.

4.4 Elasticity of Output for Land and Other Key Factors of Production

The elasticity of output for land and other key farm inputs were determined using the log-linear form of Cobb-Douglas production function as discussed in Section 3.4.4 of this thesis. The other key farm inputs considered were labour, fertilizer and seeds. The value of farm output for each farm in the sample was determined by summing the values of outputs obtained from the major enterprises undertaken by the farm. The major enterprises undertaken varied across different agro-ecological zones. In the Sunflower Zone, the main enterprises undertaken were maize, beans, bananas, mangoes and dairy. The main enterprises in the Coffee Zone were maize, beans, coffee, bananas, macadamia and dairy. In the Tea Zone, the main enterprises were tea, bananas, maize, beans, macadamia and dairy. The mean farm output for the sample was Ksh.135,970.

The sample was categorized on the basis of the three agro-ecological zones and the parameters of log-linear Cobb-Douglas production function was determined using log-linear regression in the Computer SPSS programme. The results of the linear regression for each agro-ecological zone are given hereafter.

4.4.1 Elasticity of Output in the Sunflower Zone

In the Sunflower Zone this study found the average farm output to be Ksh. 91,855 per year which was below the sample average of Ksh. 135,970 per year. Table 4.26 gives the linear regression analysis results for the data drawn from the Sunflower Zone and the discussions given thereafter.

Table 4.26: The results of linear regression analysis for the Sunflower Zone

VARIABLES	B	SE	Sig.	VIF
CONSTANT	1.491	0.352	0.000	
LNLANDSIZE	0.101	0.139	0.008	1.018
LNLABOR	0.765	0.172	0.000	2.962
LNFERT	0.156	0.067	0.015	2.959
R-SQUARE	0.819			

Source: Field Survey data, 2016

Based on the results of linear regression analysis, the farm inputs that were found to have significant elasticity of production in the Sunflower Zone at levels of 5% level and below are land-size ($p<0.008$), labour ($p<0.000$) and fertilizer ($p<0.015$). The R-square was found to be 0.819, implying that the independent variables explain about 82 percent of the total variation in farm output in the Sunflower Zone. The cost of planting seeds was found to have a Variance Inflation Factor (VIF) of more than 10, indicating the existence of a serious multicollinearity and was therefore removed from the analysis. The independent variables are discussed separately below:

Land-size: The land elasticity of production was found to be significant at 1 percent level in the Sunflower Zone (Table 4.25). The β-coefficient was 0.101, implying that 1 percent increase in farm-size increases the farm output by about 0.1 percent. The converse is true if farm size decreases as a result of land fragmentation, implying that 1 percent decrease in farm size decreases farm output by 0.1 percent. Geta et al (2013), Khan et al (2010), Rahman and Umar (2009) and Dhehibi et al (2014) found similar findings in their studies.

Labour: The labour elasticity of production was found to be significant at 1 percent level in the Sunflower Zone (Table 4.25). The β-coefficient was 0.765, implying that 1 percent increase in farm labour increases the farm output by about 0.8 percent. The results confirm other studies by Enwerem and Ohajiang (2013), Omondi and Shikuku (2013), Beshir et al (2012), Abur et al (2015) and Oyinbo (2015). The possible explanation is that an increased labour use in the Sunflower Zone would enable the farmer to expand the land area under food and cash crop production and also improve the timeliness of carrying out such farm operations as land preparation, planting weeding and harvesting. This study found that on average the value of food crops (maize and beans) forms 40% of the total farm output in the Sunflower Zone. An increase in food crop production would improve the household food security status.

Fertilizer: Fertilizer elasticity of production was found to be significant at 5 percent level affect in the Sunflower Zone (Table 4.25). The β-coefficient for fertilizer was 0.156, implying that output would increase by about 0.2 percent per 1 percent increase in quantity of fertilizer used. The possible explanation is that increased fertilizer application in food crop production increases crop productivity thus increasing the farm output. Similar results were obtained by Ngeno et al (2011), Ali and Samad (2013), Obare et al (2010), Vu et al (2012) and Ataboh (2014).

Based on the linear regression analysis results, this study specifies the underlying Cobb-Douglas production function in the Sunflower Zone as:

$$LnY = 1.491 + 0.01LnX_1 + Ln0.765X_2 + Ln0.156X_3 \quad (28)$$

Where:

Y= farm output in Ksh.

X_1= farm-size in ha

X_2= quantity of labour in man-days

X_3= fertilizer cost in Ksh.

The sum of the computed β-coefficients $(\sum_{i=1}^{3} \beta_i)$ of the function indicates the returns to scale of a given production process (Nicholson and Snyder, 2008). $\sum_{i=1}^{3} \beta_i < 1$ Indicates decreasing returns to scale (DRS), $\sum_{i=1}^{3} \beta_i = 1$ indicates constant returns to scale (CRS) and $\sum_{i=1}^{3} \beta_i > 1$ indicates increasing returns to scale (IRS). The sum of the estimated parameters in the Sunflower Zone was found to be equal to 1 (Table 4.25), implying that a proportionate change in the scale of farm production would change farm output by the same proportion or constant returns to scale

4.4.2 Elasticity of Output in the Coffee Zone

The mean farm output in the Coffee Zone was found to be Ksh. 143,554 per year which was above the sample mean of Ksh. 135,970 per year. Table 4.27 gives the linear regression analysis results for data drawn from the Coffee Zone.

Table 4.27: The results of linear regression analysis for the Coffee Zone

VARIABLES	B	SE	t	Sig.	VIF
CONSTANT	4.089	0.547	7.473	0.000	
LNLAND	-0.034	0.179	-0.56	0.576	1.298
LNLABOR	0.855	0.179	11.088	0.000	2.114
LNFERT	-0.032	0.058	-0.427	0.670	1.988
LNSEEDS	-0.066	0.047	-1.106	0.271	1.275
R-SQUARE	0.637				

Source: Field Survey data, 2016

Based on the results of linear regression analysis given in Table 4.27, the land elasticity of production was found not to be significant at 5 percent level. The labour elasticity of production was found to be significant at 1 percent level in the Coffee Zone. The β-coefficient for labour was 0.855, implying that 1 percent increase in farm labour in the Coffee Zone increases the farm output by about 0.9 percent.The R-square was found to be 0.637, implying that the independent variables explain about 64 percent of the variations in farm output in the Coffee Zone. The input elasticity of production for fertilizer and seeds were not found to be significant at 5 percent level in the Coffee Zone.

Based on the linear regression analysis results, this study specifies the underlying Cobb-Douglas production function in the Coffee Zone as:

$$LnY = 4.089 - 0.034X_1 + 0.855X_2 - 0.032LnX_3 - Ln0.066X_4 \quad \textbf{(29)}$$

Where:

Y= farm output in Ksh.

X_1= farm-size in ha

X_2= quantity of labour in man-days

X_3= fertilizer cost in Ksh.

X_4= seed cost in Ksh

The sum of the computed β-coefficients was 0.723, implying decreasing returns to scale. Therefore, a 1 percent change in the scale of farm production would change farm output by about 0.7 percent, implying decreasing returns to scale.

4.4.3 Elasticity of Output in the Tea Zone

The mean farm output in the Tea Zone was found to be Ksh. 163,554 per year which was above the sample mean of Ksh. 135,970 per year. Table 4.28 gives the linear regression analysis results for data drawn from the Tea Zone and the results discussed thereafter.

Table 4.28: The results of linear regression analysis for the Tea Zone

VARIABLE	B	SE	t	Sig.	VIF
CONSTANT	2.936	0.443	6.628	0.000	
LNLAND	0.037	0.128	0.821	0.414	1.687
LNLABOR	0.812	0.114	14.509	0.000	2.555
LNFERT	0.141	0.048	2.755	0.007	2.142
LNSEEDS	-0.038	0.031	-1.247	0.215	1.246
R-SQUARE	0.860				

Source: Field Survey data, 2016

Based on the results of linear regression analysis given in Table 4.28, the farm inputs that were found to have significant input elasticity of production at levels of 5 percent level in the Tea Zone are labour ($p<0.01$) and fertilizer ($p<0.01$). The R-square was found to be 0.860, implying that independent variables explain about 86 percent of the variations in farm output in the Tea Zone. The effect farm-size on farm output in the tea zone was not found to be significant at 5 percent level. The independent variables that were found to be significant are discussed separately below:

Labour: The labour elasticity of production was found to be significant at 1 percent level in the Tea Zone (Table 4.27). The β-coefficient was 0.812, implying that 1 percent increase in farm labour increases the farm output by about 0.8 percent. The possible explanation is that an increase in labour use in the Tea Zone would increase the amount of tea picked. The current study found that on average tea contributes about 60 percent of the total farm output in the Tea Zone. In addition, expenditure on labour forms about 75 percent of the farm costs in the Tea Zone. The increased farm income as a result of increased labour use increases the access and availability of food in the household thus improving the household food security status.

Fertilizer: The fertilizer elasticity of production was found to be significant at 1 percent level in the Tea Zone (Table 4.27). The β-coefficient was 0.141, implying that in the Tea Zone, farm output decreases by 0.141 percent per 1 percent increase in fertilizer use. The possible explanation is that increased fertilizer application in tea production would increase its productivity thus increasing the farm output and subsequently improves the household food security status. This study found fertilizer to be a major farm input in the Tea Zone, accounting for about 24 percent of the total farm cost.

Based on the linear regression analysis results, this study specifies the underlying Cobb-Douglas production function in the Tea Zone as:

$$LnY = 2.396 + 0.037LnX_1 + 0.812X_2 + 0.0141X_3 - 0.038LnX_4 \quad \textbf{(30)}$$

Where:

X_1= farm-size in ha

X_2= quantity of labour in man-days

X_3= fertilizer cost in Ksh.

X_4= seed cost in Ksh

The sum of the estimated parameters in the Tea Zone was found to be equal to 0.825, implying that a 1 percent change in scale of production would change farm output by about 0.8 percent or decreasing returns to scale.

4.5 The Summary of the Study Findings

4.5.1 Effect of Farm Size and other Factors Affecting Food Security

The study findings show that a total of 10 factors significantly affect food security in the study area (Table 4.29). These factors are discussed hereafter.

Table 4.29: The effects of the factors affecting food security in different AEZs

		Agro-Ecological Zones		
Factors affecting food security		Sunflower	Coffee	Tea
1	Farm size (ha)	Positive	Not significant	Positive
2	Household size (No.)	Negative	negative	Not significant
3	Wife's education level	Positive	Not significant	Not significant
4	Household head's education level	Positive	Not significant	Not significant
5	Adoption of tissue culture bananas	Positive	Not significant	Not significant
6	Access to agricultural extension	Not significant	Positive	Positive
7	Dependency ratio	Not significant	Negative	negative
8	Wife's age (years)	Not significant	Not significant	Positive
9	Head of household's age (years)	Not significant	Not significant	Negative
10	Adoption of improved coffee variety	Not significant	Positive	Not significant

Source: Field survey data, 2016

The effect of farm size and other key factors affecting food security in the Embu County varied across the three AEZs. Farm size was found to have a positive effect on food security in the Sunflower and Tea Zones, but was not significant in the Coffee Zone. The farm's access to agricultural extension had a positive effect on food security in the Coffee and Tea zones but its effect was insignificant in the Sunflower Zone. The levels of education for the head of household and the wife, and the adoption of tissue culture bananas were found to positively affect food security in the Sunflower Zone. The educational level and adoption of tissue culture bananas had no significant effect on food security in the Coffee and Tea Zones. The effect of Adoption of improved coffee varieties was found to be positive in the Coffee Zone. The wife's age was found to have a positive effect on food security in the Tea zone, but was insignificant in the Sunflower and Tea Zones

The household size was found to have a negative effect on food security in the Sunflower and Coffee Zones, but the effect was insignificant in the Tea Zone. The dependency ratio had a negative effect on food security in the Coffee and Tea Zones. The effect was however insignificant in the Sunflower Zone. The head of household's age was found to have a negative effect on food security in the Tea Zone but its effect was insignificant in the Sunflower and Coffee Zones.

The extent to which each of the 10 factors affects food security in each of the three AEZs was identified by examining and evaluating their marginal effects on food security. The marginal effect shows the extent to which the odds of a farm being in the lower food security category (or being food insecure) changes per unit change in the independent variable. This is given by the β-Coefficients provided by the multinomial logit regression. A negative marginal effect indicates that the odds of a farm being food insecure decreases per unit increase in the independent variable, that is, the variable has a positive effect on food security. An increase in the odds of a farm being food insecure as the independent variable increases, which shows a negative effect on food security, is indicated by a positive marginal effect.

Table 4.30 gives the marginal effect of farm size and other key factors affecting food security in the three AEZs. These marginal effects are discussed thereafter.

Table 4.30: The marginal effects of the factors affecting food security in different AEZs

		Agro-Ecological Zones		
Factors affecting food security		Sunflower	Coffee	Tea
1	Farm size (ha)	-2.890	-	-1.853
2	Household size (No.)	0.838	0.898	-
3	Wife's education level	-2.030	-	-
4	Household head's education level	-1.012	-	-
5	Adoption of tissue culture bananas	-2.220	-	-
6	Access to agricultural extension	-	-1.995	-3.317
7	Dependency ratio	-	3.725	6.726
8	Wife's age (years)	-	-	-0.238
9	Head of household's age (years)	-	-	0.288
10	Adoption of improved coffee varieties	-	-2.990	-

Source: Field survey data, 2016

As shown in Table 4.38, farm size was found to have the largest positive effect on food security in the Sunflower Zone (-2.890), and was followed by the adoption of tissue culture bananas (-2.220), wife's level of education (-2.030) and head of household's level of education. The household size was found to have the largest negative impact on food security in the Sunflower Zone (0.838).

In the Coffee Zone, the farm's access to agricultural extension was found to have the greatest positive effect on food security (-1.995), and was followed by adoption of improved coffee varieties. The dependency ratio was found to have the largest negative effect on food security in the Coffee Zone, and was followed by the household size (0.898).

In the Tea Zone, the farms access to agricultural extension was found to have the largest positive effect on food security (-3.317), and was followed by farm size (1.853) and age of the wife (-0.238). The dependency ratio had the largest negative impact on food security in the Tea Zone (6.726), and was followed by the head of household's age (0.288).

The existence of multicollinearity among the significant continuous variables was tested as described in Section 3.5.1 of this thesis. Table 4.31 gives the results of the multicollinearity test.

Table 4.31: Variance Inflation Factors (VIF) for Continuous Variables affecting food security

Variable	1/VIF	VIF
Farm-size (ha)	0.893	1.120
Household size (no.)	0.811	1.232
Dependency burden	0.668	1.497
Head of household age (years)	0.784	1.276

Source: Field survey data, 2016

Results presented in Table 4.31 show that the VIF for the continuous variables were less than 10; thus the existence of serious multicollinearity among these variables was ruled out.

The existence of multicollinearity among the significant discrete factors was ruled out using Contingency Coefficients as described in Section 3.5.1 of this thesis. The results of this test are given in Table 4.32.

Table 4.32: The Contingency Coefficient (CC) for discrete variables affecting food security

Variables	Wife's educational level	Household head's education level	Tissue culture banana adoption	Extension Access	Improved coffee variety adoption
Wife's educational level	1				
Household head's education level	0.345	1			
Tissue culture banana adoption	0.070	0.098	1		
Extension access	0.162	0.150	0.103	1	
Improved coffee variety adoption	0.093	0.202	0.202	0.200	1

Source: Field survey data, 2016

The results presented in Table 4.32 show that the CC for the discrete factors were less than 0.75 thus the existence of serious multicollinearty among these factors was ruled out.

4.5.2 Minimum Farm-Size for Attainment of Threshold HFSI

On the basis of the household food security index (HFSI), the minimum farm-size should be the farm-size category in which the average HFSI is equal to 1. In the Sunflower Zone, the minimum farm-size was found to be above 2 ha. In the Tea Zone, the minimum farm-size was found to be 0.5 ha. However, the minimum farm-size for a given agro-ecological zone, based on food security, is not static and may be expected to change with changes in farm productivity and other factors that affect food security in a particular agro-ecological zone.

The results in the Coffee Zone were not conclusive, since the variations in HFSI across the farm size categories in the coffee zone were not found to be significant. Among the three agro-ecological zones, the Coffee Zone is the closest to the three major towns in Embu County, namely Embu and Runyenjes. In addition, the main road from Nairobi to Meru town passes through the Coffee Zone. People living in the Coffee Zone therefore enjoy more opportunities for off-farm income, such as business and employment. The importance of the farm-size in determining the household food security in the Coffee Zone is thus reduced by these factors.

4.5.3 Effect of Farm Size and other Factors Affecting FE in the Three AEZs

The evaluation of the factors affecting farm efficiency in the three AEZs of the Embu County showed that a total of 11 factors significantly affect farm efficiency in the study area (Table 4.33). These factors are discussed hereafter.

Table 4.33: The effect of factors affecting farm efficiency in different AEZs

		Agro-Ecological Zones		
Narrative on the factors affecting farm efficiency		Sunflower	Coffee	Tea
1	Farm-size (ha)	-	Negative	Negative
2	Distance to market (km)	Negative	Negative	-
3	Education level (years)	Positive	Positive	-
4	Land tenure (yes/no)	-	-	Positive
5	Distance to all-weather road (km)	-	Negative	-
6	Access to credit (yes/no)	-		Positive
7	Off-farm occupation (yes/no)	-	Negative	
8	Off-farm income (Ksh)	Negative	-	-
9	Irrigation water access (yes/no)	Positive	-	-
10	Household head's age (years)	-	Positive -	-
11	Access to extension (yes/no)	-	-	Positive

Source: Field survey data, 2016

Farm size was found to negatively affect farm efficiency in the Coffee and Tea zones but was not found to be significant in the Sunflower Zone. Distance to the market was found to negatively affect farm efficiency in the Sunflower and Coffee Zones, but was insignificant in the Tea Zone. Farm efficiency was positively affected by household head's level of education in the Sunflower and Tea zones but was not significant in the Tea Zone. Increased tenure security for the land owned affected farm efficiency positively in the Tea Zone, but was insignificant in the Sunflower and Coffee zones.

Distance to all-weather road was found to negatively affect farm efficiency in the Coffee Zone but was insignificant in the Sunflower and Tea zones. The farmer's access to credit positively affected farm efficiency in the Tea Zone, but its effect was insignificant in the Sunflower and Coffee zones. The head of household's engagement in off-farm occupation and the level of off-farm income were found to have a negative effect on farm efficiency in the Coffee and Sunflower zones respectively, but their effects were insignificant in the Tea Zone. Access to irrigation water was found to have a positive effect on farm efficiency in the Sunflower Zone. Head of household's age and access to extension were found to have positive effects on farm efficiency in the Coffee and Tea zones respectively.

The marginal effects of the nine factors that were found to significantly affect farm efficiency in the three AEZs are given in Table 4.34. These marginal effects are discussed thereafter.

Table 4.34: The marginal effects of the factors affecting farm efficiency in different AEZs

Narrative on the factors affecting	Agro-Ecological Zones		
farm efficiency	Sunflower	Coffee	Tea
Farm-size (ha)	-	0.879	1.016
Distance to market (km)	0.676	1.853	
Education level (years)	-1.933	-1.075	
Land tenure (yes/no)			-1.865
Distance to all-weather road (km)		1.296	
Access to credit (yes/no)			-1.988
Off-farm occupation (yes/no)		3.834	
Off-farm income (Ksh)	0.618		
Irrigation water access (yes/no)	-1.390		
Household head's age (years)		-0.875	
Access to extension (contact no.)			-1.797

Source: Field survey data, 2016

The effect of farm size on farm inefficiency was not found to be significant in the Sunflower Zone. The level of education of the household head had the greatest negative effect on farm inefficiency (-1.933) in the Sunflower Zone, and was followed by access to irrigation water (-1.390). Distance to the market had the greatest positive effect on farm inefficiency in the Sunflower Zone (0.676), and was followed by off-farm income (0.618).

The effect of farm size on farm inefficiency was found to be positive in the Coffee Zone (0.879). The level of education of the household head had the greatest negative effect on farm inefficiency (-1.075) in the Coffee Zone, and was followed the household head's age (-0.875). The household head's engagement in off-farm occupation was found to have the largest positive effect on farm inefficiency (3.834), and was followed by distance to the market (1.853) and distance to an all-weather to credit (1.296).

The effect of farm size on farm inefficiency was found to be positive in the Tea Zone (1.016). The farmer's Access to credit was found to have the greatest negative effect on farm inefficiency in the Tea Zone (-1.988), and was followed by land tenure (-1.865) and access to extension (-1.797).
The existence of serious multicollinearity among the continuous variables that were found to affect farm efficiency was ruled out as described in Section 3.5.1 of this thesis. The results of the test are presented in Table 4.35.

Table 4.35: Variance Inflation Factors (VIF) for Continuous Variables affecting farm efficiency

Variable	1/VIF	VIF
Farm-size (ha)	0.810	1.235
Distance to market (km)	0.424	2.358
Distance to all weather road (km)	0.425	2.532
Off-farm income	0.823	1.215
Household head's age	0.791	1.264
Education level	0.777	1.287

Source: Field survey data, 2016

Table 4.34 shows that the VIF for the continuous variables were less than 10; thus the existence of serious multicollinearity among these factors was ruled out.

The Contingency Coefficient was used to rule out the existence of serious multicollinearity among the significant discrete factors as described in Section 3.5.1 of this thesis. The results of the test are presented in Table 4.36.

Table 4.36: Contingency Coefficient (CC) for discrete variables affecting farm efficiency

Variables	Land tenure	Access to credit	Access to water	Access to extension	Off-farm occupation
Land tenure	1				
Access to credit	0.261	1			
Access to water	0.186	0.103	1		
Access to extension	0.361	0.397	0.478	1	
Off-farm occupation	0.028	0.052	0.177	0.014	1

Source: Field survey data, 2016

Table 4.36 shows that the CC for the discrete factors was less than 0.75; thus the existence of serious multicollinearty among these factors was ruled out.

4.5.4 Elasticity of Output in the three Agro-Ecological Zones

The following conclusions were made from the analysis of the farm output and input elasticity for land and other major farm inputs used in the study area:

1. The average farm output was found to be highest in the Tea Zone (163,554/year) and was lowest in the Sunflower Zone (91,855/year), implying that the status of household food security would be higher in the Tea and Coffee Zones than in the Sunflower Zone.
2. The land elasticity of production was found to be significant and positive in the Sunflower Zone but was not significant in the Coffee and Tea zones, implying that it is only in the Sunflower Zone where variations in farm output could partially be explained by variations in farm size

3. Labour was found to have the highest positive elasticity of production in all the three agro-ecological zones, implying that increased use of farm labour could greatly improve farm production and subsequently improve the status of household food security in the study area.
4. Fertilizer application was found to have a significant and positive elasticity of farm production in the Sunflower and the Tea zones, implying that increased use of fertilizer in the two zones would increase farm production and thus improve household food security.
5. Farm production in the Sunflower zones depicted constant returns to scale. In the Coffee and Tea zones, production depicted decreasing returns to scale

Based on the study results the null hypothesis that input elasticity of production for land and other key factors of production are not statistically significant in and across different agro-ecological zones in Embu County was rejected. The alternative hypothesis was not rejected.

CHAPTER FIVE: CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

1.1 Conclusions and Implications

The phenomenon of land fragmentation into small parcels, caused by increasing population pressure, is common in Kenya, especially in the high agricultural potential areas (GOK, 2016). The purpose of this current study was to evaluate the impact of land fragmentation and agro-ecological zones on food security and farm efficiency in Kenya, using data from Embu County in eastern Kenya. Specifically, this study identified and characterized the effects of farm size and other major factors affecting household food security, farm efficiency and farm output in three different agro-ecological zones (AEZs) in Embu County. The study determined the minimum farm size that could ensure attainment of threshold level of food security (HFSI=1) in three AEZs in Embu County. The results of the study were used to make recommendations for improving food security and farm efficiency in each AEZ and in other areas of similar AEZs in Kenya.

This study found the proportion of food secure households in the sample to be 34%. The proportion of food secure households varied across the 3 AEZs. The Tea Zone had the highest proportion at 44%, followed by the Coffee and Sunflower zones at 41% and 17% respectively. The most important study findings in relation to each of the study objectives are discussed under different subsections hereafter.

5.1.1 Effect of Farm Size and Other Factors Affecting Food Security

Based on the marginal effects found in this study, farm-size, technology adoption (tissue culture bananas) and the farm's distance to a passable road were the main factors found to positively affect household food security in the Sunflower Zone. In the Coffee Zone, extension access and technology adoption (improved coffee varieties) were the main factors which were found to positively affect household food security, but farm-size had no significant effect on food security. The main factors positively affecting household food security status in the Tea Zone were farm-size, extension access and the wife's age. The positive impact of farm size on household food security found in this study is consistent with previous findings by Abu and Soom (2016), Kessie *et al* (2014), Mitiku *et al* (2012), Osei Mensah *et al* (2013), Faridi and Wadood (2010) and Babatunde *et al* (2007). This study's finding that extension access and technology adoption have a positive impact on household food security is consistent with previous findings by Muche *et al* (2014), Taruvinga *et al (*2013), Kuwornu *et al* (2013), Saina *et al* (2012), Kessie *et al* (2012) and Haile *et al* (2005). In the reviewed literature, the number of studies that have examined the impact of land fragmentation on food security across different AEZs is limited. This study has made some contribution in that direction. However, this is an area that would require further research in future.

Based on the marginal effects found in this study, household size was found to be the main factor that had a negative impact on household food security in the Sunflower Zone. In the Coffee Zone, household size and dependency ratio were the main factors that were found to have a negative impact on household food security. In the Tea Zone, the main factors that were found to negatively influence household food security by this study were household head's age and dependency ratio.

These findings are consistent with those found by Gemechu et al (2015), Muche et al (2014), Sekhampu et al (2013), Osei Mensah et al (2013), Kessie et al (2012), Omotesho et al (2010) and Sidhua et al (2008). The current study contributes to knowledge by its findings that the factors affecting food security vary with the agro-ecological zones.

5.1.2 Minimum Farm Size for Attainment of Threshold Level of Food Security

The minimum farm-size that could ensure the minimum cut-off food security (mean HFSI = 1) in the Tea Zone was found to be 0.5-<1 ha farm size category. In the Sunflower Zone, none of the farm-size categories in the sample attained that minimum cut-off for food security status. The highest mean HFSI in the Sunflower Zone was found in the farm-size category 1- <2 ha, but the HFSI was below the threshold level. This study concluded that the minimum farm size for attainment of threshold food security status in the Sunfolwer Zone should be more than 2 ha. Since the effect of farm-size on food security was found to be insignificant in the Coffee Zone, the minimum farm size based on the food security status could not be determined. However, the minimum farm-size for a given agro-ecological zone, based on food security, is not static and may be expected to change with changes in farm productivity and other factors that affect food security in a particular agro-ecological zone. The current study contributes to knowledge by determining the minimum farm size for attainment of threshold level of household food security, and that the minimum cut-off farm-size, varies with the agro-ecological zones.

5.1.3 Effect of Farm-Size and Other Factors Affecting Farm Efficiency

This study found that farm efficiency varied across the three AEZs. The Tea Zone had the highest average level of farm efficiency (0.61), followed by the Sunflower Zone (0.50) and the Coffee Zone (0.43). The effect of farm-size on farm efficiency was found to be negative in the Coffee and Tea zones but was not significant in the Sunflower Zone. Based on the marginal effect of farm size, the effect of farm size on farm efficiency was highest in the Tea Zone (1.016), followed by the Coffee Zone (0.879).

The findings on the inverse relationship between farm size and efficiency are consistent with the findings from previous studies by Geta *et al* (2013), Ayalew and Deininger (2013), Sial *et al* (2012), Niringiye *et al* (2010), Tadesse and Krishnamoorthy (1997) and Byringiro and Reardon (1996). Other studies whose findings are consistent with the findings of the current study are Helfand and Levine (2004), Murthy et al (2009), Sharma and Bardha (2013), Dhehibi and Telleria (2012) and Enwerem and Ohajianya (2013). However, the current study contributes to the existing body of knowledge by its findings that the extent to which farm efficiency is negatively influenced by farm size varies with the agro-ecological zones.

Based on the marginal effects, the study identified and characterized other key factors affecting farm efficiency across different AEZS. The effect of these factors on farm efficiency was found to vary across the three AEZs. In the Sunflower Zone, the head of household's level of education and access to irrigation water were found to be the key factors that have a positive effect on farm efficiency. In the Coffee Zone, the key factors that were found to have a positive effect on farm efficiency were household head's level of education and age. The head of household's access to credit and extension, and land tenure security were the key factors that were found to positively affect farm efficiency in the Tea Zone. These findings are consistent with those from previous studies by Dhehibi *et al* (2014), Mapemba (2013), Bizimana *et al* (2004), Simonyan *et al* (2012), Seidu (2012), Khan *et al* (2010), Obare *et al* (2010), Smith *et al* (2011) Beshir *et al* (2012) and Rahman and Umar (2009)

Based on the marginal effects distance to market and off-farm income were identified as the key factors that negatively affect farm efficiency in the Sunflower Zone. In the Coffee Zone, farm-size and distance to market and all-weather road, and off-farm occupation were found to be the key factors that negatively affect farm efficiency. Farm-size was identified as the key factor that negatively affects farm efficiency in the Tea Zone. These findings are consistent with previous studies by Omondi and Shikuku (2013), Sial et al (2012), Fita et al (2011), Murthy (2009) Assuncao and Braido (2007), Dhehibi and Telleria (2012), Masterson (2007), Byringiro and Reardon (1996) and Llewelyn and Williams (1996). The current study contributes to knowledge by its findings that the extent to which farm efficiency is affected by the farm size and other factors vary with the agro-ecological zones

5.1.4 Elasticity of Output for land and Other Factors of Production

The average value of farm output was found to vary with the agro-ecological zones. The average farm output was found to be highest in the Tea Zone (163,554/year), followed by the Coffee Zone (143,554/year) and was lowest in the Sunflower Zone (91,855/year). The input elasticity of production for land and other key farm inputs were found to vary with agro-ecological zones. Land elasticity of production was found to be positive in the Sunflower Zone. Geta et al (2013), Khan et al (2010), Rahman and Umar (2009) and Dhehibi et al (2014) found results that are consistent with those from the current study. The land elasticity of production was not found to be significant in the Coffee and Tea zones.

The labour elasticity of production was found to be positive and significant in all the three agro-ecological zones. The results confirm other studies by Enwerem and Ohajiang (2013), Omondi and Shikuku (2013), Beshir et al (2012), Abur et al (2015) and Oyinbo (2015).

The fertilizer elasticity of production was found to vary with the AEZ. It was found to be significant in the Sunflower and the Tea zones. Similar results were obtained by Ngeno et al (2011), Ali and Samad (2013), Obare et al (2010), Vu et al (2012) and Ataboh (2014). The elasticity of fertilizer on farm output was not found to significant in the Coffee Zone. The current study contributes to knowledge by its findings that the input elasticity of production for land and other key farm inputs vary with the agro-ecological zones

1.2 Summary of the Study's Contribution to Knowledge

The current study has made the following contribution to knowledge by addressing some of the research gaps that were identified in Sections 2.4.4 and 2.5.3 of this thesis:

1. The study contributes to knowledge by its findings that the extent to which farm size and other factors affect food security vary with the agro-ecological zones.

2. The study contributes to knowledge by determining the minimum farm size for attainment of threshold level of household food security, and that the minimum cut-off farm-size varies with the agro-ecological zones.
3. The study contributes to the existing body of knowledge by its findings that confirm that farm size has a negative effect on farm efficiency. However, the extent to which farm efficiency is negatively influenced by farm size varies with the agro-ecological zones.
4. The study contributes to knowledge by its findings that the extent to which farm efficiency is affected by the farm size and other factors vary with the agro-ecological zones.
5. The study contributes to knowledge by its findings that the that the input elasticity of production for land and other key farm inputs vary with the agro-ecological zones

1.3 Recommendations for Improving Food Security and Farm Efficiency

Recommendations to improve farm efficiency and food security are made on the basis of the study findings in each AEZ and are presented on the basis of AEZs hereafter.

5.3.1 Improvement of Food Security and Farm Efficiency in the Sunflower Zone

The results of this study revealed that farm size category of 1- <2 ha in size was found to attain the highest level of household of food security in the Sunflower Zone. Policy should therefore be implemented to discourage subdivision of farms that are less than 1 ha in size in the Sunflower Zone. However, the policy should be reviewed as land productivity increases and makes it possible to support more people per ha.

Technology adoption was found to have a positive impact on food security in the Sunflower Zone. Public and private research institutions (including universities) should be facilitated to conduct and disseminate research on technologies that improve productivity in the Sunflower Zone. Technology development should be coupled with effective farmer training to ensure that the technologies generated are transferred to the farms.

The study revealed that household head's level of education and access to irrigation water had a positive effect on farm efficiency. The study therefore recommends for measures to encourage formal education for long term growth in farm efficiency. Access to irrigation water should be improved through provision of more and adequate piped water for irrigation. The effect of distance to market was found to have a negative effect on farm efficiency and the study recommended for establishment of more market centres in the area.

Land, labour and fertilizer elasticity of production were found to be significant and positive in the Sunflower Zone. The study therefore recommends for expansion of land under cultivation, and increased labour and fertilizer use in the Sunflower Zone

5.3.2 Improvement of Food Security and Farm Efficiency in the Coffee Zone

The study found a positive effect of access to agricultural extension and technology adoption on food security and farm efficiency. Support for improved public and private agricultural extension is recommended for the Coffee Zone. Formal education should also be supported for long-term improvement in food security and farm efficiency.

The study found a negative effect of household size and dependency ratio on food security in the Coffee Zone. These results call for education on the importance of family planning to the households in the Coffee Zone. Programmes targeting improvement of incomes for the economically productive age group (18-65 years should be initiated and supported. Other programmes targeting to assist the elderly, the physically challenged and the female-headed households should be initiated to reduce the dependency burden.

Distance to market and passable roads were found to have a negative effect on farm efficiency in the Coffee Zone. The study recommends for establishment of more market centres in the area and provision of passable roads to promote the marketing of agricultural produce in the Coffee Zone. Since off-farm occupation was found to have a negative effect on farm efficiency, the heads of households who are engaged in off-farm activities should be encouraged to devote more resources and attention to their farms

This study found the labour elasticity of production in the Coffee Zone to be significant and positive, and therefore recommends for increased labour use to increase farm production

5.3.3 Improvement of Food Security and Farm Efficiency in the Tea Zone

Farm size was found to have a positive effect on food security in the Tea Zone. The minimum farm size for attainment of the threshold level of food security in the Tea Zone was found to be in 0.5-<1 ha farm size category. A policy to discourage subdivision of farms that are less than 0.5 ha is therefore recommended. The policy should also encourage large farms to adopt measures that improve farm efficiency, such as training, access to agricultural extension and technology adoption.

Access to agricultural extension and technology adoption were found to have positive effect on food security. Public and private extension providers should be supported to extend improved technologies to farmers in the Tea Zone. Research on more productive cash crops in the Tea Zone region should be initiated and supported.

Access to credit was found to have a positive effect on farm efficiency. It is recommended that more micro-finance institutions be encouraged to extend affordable credit to the farming community in the Tea Zone. Farmers should be encouraged to form groups that serve as collateral and leverage in accessing credit.

The influence of household size and dependency ratio on food security was found to be negative in the Tea Zone. The study recommends for provision of family planning education to the households in the Tea Zone. Programmes targeting the improvement of incomes for the economically productive age group (18-65 years) should be initiated and supported. Programmes targeting the resource poor households, such as bursary funds and school feeding programmes, should also be encouraged to ease the dependency burden.

Farm efficiency was found to be negatively affected by the farm distance to a passable road infrastructure in the Tea Zone. The study therefore recommends a construction of more all-weather roads in the Tea Zone area. The existing roads should also be improved to make them more passable especially during the rainy seasons.

This study found the input elasticity of production for labour and fertilizer to be positive and significant in the Tea Zone, and therefore recommends for increased use of labour and fertilizer especially in tea production.

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APPENDICES

Appendix 1: Energy content of common food items per 100 grams edible portion

Food Items	Energy Content (kcal/100gm)	Food Items	Energy Content (kcal/100gm)
green maize	166	arrow roots	94
dry maize grain	345	Irish potatoes	97
maize flour	334	dried beans	320
millet flour	314	dried green grams	318
milled rice	333	dried cow pea	318
sorghum flour	343	cow milk	79
wheat flour	340	goat milk	84
white bread	240	beef (moderately fat)	140
brown bread	233	goat meat (moderately fat)	171
cassava	318	mutton (moderately fat)	257
banana (ripe, raw)	128	eggs (hen)	149
sweet potatoes	109	poultry	138

Source: CTA/ECSA (1987)

Appendix 2: Recommended daily energy requirement (kcal/day)

AGE	BOYS	GIRLS	AGE	BOYS	GIRLS
1	950	850	10	1825	1700
2	1125	1050	11	2000	1825
3	1250	1150	12	2175	1925
4	1350	1250	13	2350	2025
Average	1169	1075	14	2550	2075
5	1475	1225	Average	2180	1910
6	1350	1325	15	2700	2125
7	1450	1450	16	2825	2125
8	1550	1575	17	2900	2125
9	1675	1850	Average	2808.333	2125
Average	1500	1485			

Source: FAO (2001)

Appendix 3: Recommended daily energy requirement (kcal/day) for adults

	18 TO 29.9 YEARS		30 TO 59.9 YEARS		> 60 YEARS	
WEIGHT	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN
50	2100	1650	2100	1750	1700	1550
55	2200	1800	2200	1800	1950	1600
60	2300	1900	2250	1850	1850	1700
65	2400	2000	2350	1950	1950	1750
70	2550	2100	2450	2000	2050	1800
75	2650	2200	2500	2050	2150	1900
80	2750	2300	2600	2100	2200	1950
85	2850	2400	2700	2150	2300	2000
90	2950	2550	2750	2250	2400	2050
Averages	2528	2100	2433	1989	2061	1811

Source: FAO (2001)

Appendix 4: Household Food Intake Data

Key to Food Items

1. Maize grain
2. Maize flour
3. Rice
4. Wheat flour
5. Millet/sorghum
6. Beans
7. Sweet potatoes
8. Green bananas

			Major Food Items Consumed By Household Per Week in Kg							
HH S/NO	**Village**	**HH Size**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Kageri	5	4	2	3	0	1.75	2	2	0
2	Kageri	4	1	1.95	1.5	0	0	1.5	1	0
3	Kageri	1	1	1	0.25	0	0	1	0	0
4	Kageri	2	3	0	1.5	0	0	2.25	0	0
5	Kageri	9	6	4	1	0	1.75	4	3	0
6	Kageri	6	1	1	3	0	2.5	1.5	1	0
7	Kageri	2	0	0.5	1.5	1	0	0	0.5	0
8	Kageri	4	3	2	0	0	1.05	1.5	0	0
9	Kageri	5	1	0.5	4	0	0	1	0	0
10	Kageri	5	0	1	3	2	0	1	2	0
11	Kageri	4	1	1	3	0	0	1	1	1.5
12	Kageri	3	3	1	1.5	0	0.75	2.5	1.5	0
13	Kageri	4	0	1	2	1	1.0	0.5	1.5	0
14	Kageri	4	1	2	3	1	1.5	1	2	0
15	Kageri	9	8	3	4	3	2.1	8	0	0
16	Kageri	6	2	1	3	0	0	4	3.5	0
17	Kageri	2	1	0	2	1	0	0.5	2	0.7
18	Kageri	3	2	2	2	0	0	2	0	0
19	Kageri	6	6	2	1	0	2.1	4	0	0
20	Kageri	5	0	2.25	1.5	0	2	1	3	0.6

21	Kageri	3	1	1.5	2.25	2	2	1.5	1.5	0
22	Kageri	3	2	6	1	2	0	2.25	0	1.5
23	Kageri	3	0	2	0.75	2	0	2	1.5	0
24	Managia	3	0	3	1.5	0	2	1	1	0
25	Managia	4	0	2.25	2.25	2	1	1	2.5	0.6
26	Managia	7	0	4	2	2	0	0	1	1
27	Managia	2	0	1.5	0.25	0	0	0.25	1.5	3
28	Managia	3	2	3	3	1	0	1.5	2	4.5
29	Managia	3	1	4	2	2	0	1.5	1	1.5
30	Managia	5	1	3	3	2	0	2	6	0
31	Managia	6	2	1	3.75	1.25	2.5	1.5	4	0
32	Managia	5	3	2	4.5	0	2.0	3	2	8
33	Managia	2	0.5	2.5	1.5	1	0	1	1	0
34	Managia	5	4.5	4	3	2	0	4	2	2
35	Managia	3	0.5	3	2	2	0	1.5	2	0.1
36	Managia	4	1	4	3	0	0.5	3	2	4.5
37	Managia	4	0.25	1	3.75	0	0	1.5	2	0
38	Managia	2	2	3	1	0	0.75	1.5	1	3
39	Managia	2	1	1	0.5	0	0	1.5	2	0.4
40	Managia	2	0	1.5	0.75	1	1.5	0.5	1	1.6
41	Managia	3	1	4	3	2	4.2	0.5	2	2.4
42	Managia	3	0.25	1	1	0	0	0.9	0	0
43	Managia	3	2	1.5	0.5	0	0	0	2	3
44	Managia	4	4	3	2	2	0	2	3	5
45	Managia	2	0.5	0.5	0.25	0	0	0.5	0	1
46	Managia	4	3	3	2	1	1	1.5	2	2.8
47	Managia	4	1	4	1	2	0.9	6	2	3.2
48	Managia	3	2	3	2	1	2.1	1	4	3.6
49	Managia	4	2	3	2	2	0.9	2	2	3
50	Managia	2	2	0	1	0	2.1	2	1	3
51	Managia	2	1	0.5	1.5	0	0	0.5	0.5	1.5
52	Managia	2	0	0	1.25	1	0	1.5	0	3
53	Managia	3	3	2	1	0	0	3	0	4
54	Managia	9	9	3	0	0	7	0	1	0
55	Managia	3	1	1	1.5	0	0	4	0	2
56	Managia	5	0.5	2	1.5	1	3.5	0.5	0	0
57	Managia	3	3	1.5	1	1	0	0.5	0	0

58	Managia	5	0.5	2	0.5	3	0	0.5	0.5	4
59	Managia	4	1.5	3	0.75	0	0	0.25	0	0.5
60	Managia	5	1	3	0.75	2	0	1	0.5	2
61	Managia	5	2	6.25	3	0	0.95	7	1	0.5
62	Managia	4	3	1.5	2	1.4	0	2	2	4
63	Managia	4	6	3	1	1	1.4	3	4	7.5
64	Managia	4	1	1.5	2	2	2.1	1	1	1
65	Managia	6	2	1	1	0	0	2	0	2
66	Managia	3	1.5	0.24	2.25	2	0.49	1.5	1.5	2
67	Kandete	5	3	3	1	0	0.5	3	1.5	1.5
68	Kandete	2	0	1.25	0.25	0	0	1	1	1
69	Kandete	2	0	0.5	1	1	0	0.25	3	1.5
70	Kandete	3	0	1.5	1	0.5	0	0.375	0.375	0
71	Kandete	5	0.75	1	0	0.5	3.5	1	0.875	10.5
72	Kandete	6	0	4	1.5	0	0	0.75	0.75	0
73	Kandete	4	0.375	1	1	0	2	0.375	0	8
74	Kandete	2	1	0.5	1	0	0	1.5	2	5
75	Kandete	4	1	4	3	2	0	1.5	0	0
76	Kandete	2	0.5	1	1	0	1	1.5	0.5	1.6
77	Kandete	5	2	3	1	0	1.5	3	0	1
78	Kandete	4	1	3	2	0	3.5	3	0	3
79	Kandete	2	0.75	0.5	0.5	0	1	1	0	0.5
80	Kandete	3	0.25	1.5	1	0	0.75	1.5	1.5	1.6
81	Kandete	5	0.5	4	2	4	0	1	4	2
82	Kandete	4	0.5	2.25	1	0	0	1.5	0.5	1.6
83	Kandete	2	2	2	0.5	1.2	0	1	0.8	1.6
84	Kandete	5	4	3	2	0	0	2	1	1.6
85	Kandete	3	1	1.5	1.5	1	2.5	1.5	0	1
86	Kandete	3	2	2	1	1	1.25	1	3	1.6
87	Kandete	4	1	5	2	2	2.5	1	4	3.2
88	Kandete	1	0.25	2	0.5	1	0	0.25	0.25	0.8
89	Kandete	3	1	1.5	2	1	0	0.5	2	1.6
90	Kandete	4	2	4	1	2	1.75	2	0	0.8
91	Kandete	6	6	3	1	2	0.5	3	2	2.4
92	Kandete	4	1	8	2	0	1.75	1	0	0
93	Kandete	5	1	4	2	0	1.75	1	2	3.6

94	Kandete	2	0.25	3	1	0	1	1	0.5	3
95	Kandete	2	0	2	0.25	0	1	1	0	4
96	Kandete	2	0.125	2	0.25	0	0	0.5	0.5	5
97	Kandete	1	0	0.5	0.25	0	0	0	0.5	2
98	Kandete	5	0.25	1.5	1	0	0	0.125	0.25	2.5
99	Kandete	4	3	1	2	1	0.9	0	2.5	1
100	Kandete	6	6	6	2	0	0	6	0	5
101	Kandete	2	0.25	0.25	0.875	0	0	0.75	0	2
102	Kandete	5	0.75	0.75	0.5	0	0.875	0.75	0.625	0
103	Kandete	5	0.25	4	1	0	7	2.5	0	3
104	Kandete	3	0.375	0	0.125	0	0	0.375	0.5	0
105	Kandete	6	0.25	0.75	0	0	0	0.25	0.25	3
106	Kandete	2	0.5	1.5	2	0	0	0.5	2	0.5
107	Kandete	4	2	3	1.5	0	0.5	2	0	1.6
108	Kandete	5	1	0	2	0	1.5	1	0	1
109	Kandete	5	0	3	4.5	0	4	2	2	4
110	Mwondu	2	0.5	1	0.5	0	0	0.75	0.5	2.4
111	Mwondu	6	1	2	2	2	3	1.5	4	3
112	Mwondu	8	1.5	3	0	0	7	3	2	1.6
113	Mwondu		2	2	1	0	0.5	3	0.5	1.2
114	Mwondu	2	1.5	1.5	1.5	1	2	1.5	1	4.5
115	Mwondu	4	1	1	2.25	0	7	1	1.5	2
116	Mwondu	8	4	2	1.5	0	0	5	0.25	1
117	Mwondu	6	1	0.5	1	0	1.75	1	1.75	2
118	Mwondu	4	1.5	6	0.5	0	0.5	2	0.8	1
119	Mwondu	3	0.5	0.25	1	0	0	0.375	2	1
120	Mwondu	8	3	1.5	1	0	0.875	3	0.5	1.1
121	Mwondu	4	0.375	0.375	1	0	0.5	0.375	0.75	6
122	Mwondu	3	1	1.5	1	1	0.75	1	7	2
123	Mwondu	4	0.5	1.5	3	2	1.5	1	1	1.2
124	Mwondu	5	2	3	2	0	1.75	0.5	36	1
125	Mwondu	4	3	2.5	1.5	0	0	3	1	1
126	Mwondu	5	1	1.5	2	2	3	1	2	1
127	Mwondu	2	0.125	0.625	0.125	0	0	0.25	3.5	0.5
128	Mwondu	3	0.125	0.375	1.5	0	0.875	0.375	0.375	0.9
129	Mwondu	5	0.25	0.75	3	0	0.875	1	1	0

130	Mwondu	5	0	1.75	0	0	1.75	0	3	2
131	Mwondu	7	0.25	0.375	2	2	1.75	0.25	3	2
132	Mwondu	5	2	0.375	0.5	0	0	1.5	0.3	1.5
133	Mwondu	6	6	8	1	0	0.5	2	1.5	5
134	Mwondu	4	0.75	0.75	0.5	0	1	0.75	0.5	1.6
135	Gatundur	1	0.8	0.4	3	0.125	0	1.8	0.5	2
136	Gatundur	3	2	3	3	2	1.5	3	1.5	2
137	Gatundur	3	2	3	0.5	0	0	2	6	1.6
138	Gatundur	6	3	2	0	0	4	0	2	5
139	Gatundur	3	1	1.5	2	1	1.2	2	1.5	3.6
140	Gatundur	3	0	1	3.75	0	0	0.75	0	0
141	Gatundur	4	1	4	2	4	1.75	3	2	2
142	Gatundur	1	0.48	0.75	0.5	0	0.875	0.5	0	1
143	Gatundur	4	3	1.5	2	0	2	3.75	1	0
144	Gatundur	6	4	5	3	1	1.75	5	2	1.8
145	Gatundur	1	1	0.75	0.5	0	0	1	0.5	1.8
146	Gatundur	5	5	5	1	0	0	4	0.25	3
147	Gatundur	2	0.5	1.5	1	0	4	0.5	0	2
148	Gatundur	3	2	1	1	7	0	1	2	2
149	Gatundur	2	0	1.2	0.5	0	0.5	0.75	0.9	1.2
150	Gatundur	4	0.5	5	0.5	1.75	0	2	0.75	0.75
151	Gatundur	5	0.5	3	1.5	0	0	0.5	0	6
152	Gatundur	6	8	2	1	1	0	4	0	3.2
153	Gatundur	3	2	3	2	0	0	1.5	0	6
154	Gatundur	6	3	4	1	0	0	3	3.5	1.2
155	Gatundur	3	5	2.5	1	0	1.75	5	1.5	2
156	Gatundur	2	0.5	1	1	0	0	1.5	0	4
157	Gatundur	5	1	3	3	2	2.1	2	5	4.5
158	Gatundur	2	1	2	0	0	0.3	0.75	0.4	3
159	Gatundur	4	4	3	1	0	0	3	3	3
160	Gatundur	6	2	4	1.5	0	0	2	0	3
161	Gatundur	2	0.5	2	1.5	1	2.5	1	1	0.8
162	Gatundur	2	0.5	1.5	1	1	1.75	1.5	1.5	1.6
163	Gatundur	5	4	3	3	2	0.25	3	5	3.6
164	Gatundur	3	1	2	4	2	1.75	3	2	2.4
165	Gatundur	5	1	3	2	2	0.25	3	4.5	3
166	Gatundur	4	1	1.5	1	0	0	0.75	1	2

167	Gatundur	2	0	0	1	0	0.375	1	0.6	0
168	Gatundur	2	1.5	0.75	0.5	0	0	0.75	1	1.5
169	Gatundur	1	3	0	0	0	0.75	2	0.4	1.5
170	Gatundur	8	6	6	3	0	0	2	0	3
171	Gatundur	3	1	0.9	1.5	0	1	2	0	0
172	Gatundur	3	0.5	1.2	0.5	2	0	1.2	0	1
173	Gatundur	3	1	1	0.25	0	0	2	0	0
174	Gatundur	4	2	5	2.5	0	0	2	1.25	2
175	Gatundur	3	10	1	0	0	0	5	2.5	3
176	Gatundur	5	1	2	3	2	0.5	1	4	3.6
177	Gatundur	3	1.5	0.25	2	1	0	1.5	5	1.2
178	Gatundur	2	0.25	0.5	1	0	2	0.5	1	1.2
179	Gatundur	6	2	2	3	0	4	4	0	0
180	Gatundur	1	0.5	1.5	1	0	0	0	0	1.5
181	Gatundur	5	1	3	1.5	1.25	0	1	1	2
182	Gatundur	5	3	2	1.5	0	1	1.5	0	0
183	Gatundur	3	2	2	1.5	0	2	2	0	4
184	Gatundur	4	2	2	1	0	1.75	1	3	2.25
185	Gatundur	4	5	2	1.5	0	1.75	2.4	3	2
186	Kirigi	4	2	3	1	2	0	2	1	4.2
187	Kirigi	5	1	2	2	4	0	2	4	3.6
188	Kirigi	2	1	1	1.5	1	0	2	1.5	2.4
189	Kirigi	3	4	2	1	2	0	4	2	3.6
190	Kirigi	5	8	2	1.5	0	0	4	0	0
191	Kirigi	2	0	1.5	0.75	0	0	0.75	1.5	1.6
192	Kirigi	2	0.25	0.5	0.5	1	0	0.5	0.5	1
193	Kirigi	3	2	4	2	2	0.75	2	1	2.4
194	Kirigi	3	1	2	0.5	0	0	1.5	3	4
195	Kirigi	5	0.75	4	1	2	1.25	1	2	3.2
196	Kirigi	3	2	3	1	0	0	3	1	4.5
197	Kirigi	3	0.5	1	0	0	0	1	0	0
198	Kirigi	2	0.5	3	0.5	0	0	1	10	1
199	Kirigi	5	2	2	2	2	0	2	4	3.6
200	Kirigi	3	0.5	1.5	1	1	2.1	2	2	3.6
201	Kirigi	3	2	0.75	1	1	0.85	3	1	4.5
202	Kirigi	5	2	3	2	0	0	3	2	5
203	Kirigi	2	0.25	0.5	0.75	0	1	0.75	2	2

204	Kirigi	3	1	2	1	0	0	1	2	1.6
205	Kirigi	10	2	4	4.5	2	0	1	0	4
206	Kirigi	5	0	2	3	0	3.5	1	3.5	7
207	Kirigi	5	8	3	2	0	1	5	2	1.5
208	Kirigi	7	2	2.5	3	0	4	3	2	6
209	Kirigi	2	2	4	2	1	0	3	1.5	2
210	Kirigi	2	1	0.5	2	1	0	2	0	1.4
211	Kirigi	4	2.7	4	0.5	0	1.75	5	1	1.5
212	Kirigi	4	2	7	0.5	0	0	1.5	0	2
213	Kirigi	5	1	4.5	3	4	1	3	4	3
214	Kirigi	4	1	3	2.25	0	0	1.5	0	4
215	Kirigi	2	2	2	2	0	1.75	3	3	5
216	Kirigi	5	2	2	1.5	0	2	4	2	2.8
217	Kirigi	3	4	0.5	0	0	0	2.5	0.5	4
218	Kirigi	3	1	2	4	1	0	1.5	3	3
219	Kirigi	3	1	3	1.5	0	2	2	0	2
220	Kirigi	4	2	3	3	0	1.5	3	2	7.5
221	Kirigi	3	1	4	1	0	1.05	4	1	1.4
222	Kirigi	4	0.5	3	4	0	0.5	1	2	0
223	Kirigi	4	4	2	4	2	0	1.5	1	1.5
224	Kirigi	6	3	3	3	0	0	2	2	6
225	Kirigi	4	4	6	2	2	1.75	3	3	3
226	Kirigi	3	4	4	2	2	0	2.5	1.5	4.2
227	Kirigi	3	1	3	2.25	1	0	1.5	2	1.4
228	Kirigi	4	2	2	2	1	1.75	3	1.5	8
229	Kirigi	4	2	4.5	1	1.5	1	4	3	4
230	Kyetheru	2	1	2	0	0	0	1.5	0	0
231	Kyetheru	2	0.5	1	1.5	1	0	0.75	2	2
232	Kyetheru	4	3	6	1	0	1	0	1	3
233	Kyetheru	5	1	0.75	2	0	0	3	4	3
234	Kyetheru	4	2	0.5	1	0.5	1.5	2	1	2
235	Kyetheru	3	2	3	3	2	0	0.75	0.5	2.4
236	Kyetheru	4	2	4.5	4.5	2	0	3	3	2.4
237	Kyetheru	2	2	1	1	0	0	4.5	0	4.5
238	Kyetheru	4	1	3	2.25	2	0	3	3	2.4
239	Kyetheru	3	1	1.5	3	2	1.5	3	4	1.2
240	Kyetheru	2	1	1.5	1	0	3.5	1.5	1	1.6

241	Kyetheru	2	1	3	1	1	3.5	2	1.5	0
242	Kyetheru	2	0.5	0.75	0.5	1.75	0	1.5	1.5	1.2
243	Kyetheru	4	3	1.5	1.5	3	1.75	1.5	1	2.8
244	Kyetheru	6	1.5	4	4.5	4	0.75	2	4	3.6
245	Kyetheru	3	1	1.5	2	1	0.5	1	2	2.4
246	Kyetheru	2	2	0.5	0.5	1	0.25	1	0	1.6
247	Kyetheru	2	0.5	1.5	1	0	0	0.75	1	2.4
248	Kyetheru	7	2	3	3	2	0	1	3	5.4
249	Nguui	3	1	5	3	0	1	2	4	3.2
250	Nguui	2	1	1	0.5	1	1.25	2	1.5	2.4
251	Nguui	5	50	2	1	1	0	1.5	1.5	2
252	Nguui	3	4	2	0	0	0	4	4	4
253	Nguui	7	0	5	2	0	2	2	0	4
254	Nguui	2	1	0.5	1	0	0	0	3.5	0
255	Nguui	5	0.5	3	3	0	0	0.75	0	4
256	Nguui	4	5	2.25	0	0	4	0.75	1.25	4.5
257	Nguui	3	0.5	1	1.5	0	0	0	0	4.5
258	Nguui	2	0.75	1	0	0	0	0.5	0.5	4
259	Nguui	3	0.75	1.5	1.5	0	0	1	1.5	2
260	Nguui	4	1	2	2	0	1	0.8	1.5	4
261	Nguui	3	0.5	2	1	0	1	0.5	6	12
262	Nguui	3	2	0.5	1	0	0	1.5	0.5	3
263	Nguui	5	3	2	1	0	2.5	3	2	3
264	Nguui	2	0.25	1	0.5	0	0	1	1	3
265	Nguui	6	2	2	1.5	2	1.75	3	2	3.6
266	Nguui	3	0.5	1.5	2	1	1	1	1	2.4
267	Nguui	6	1	1.5	4.5	0	1.75	0.75	0	14
268	Kathande	3	2	3	2	0	0	3	3	2.9
269	Kathande	5	1	3	3	2	0	2	3	1.6
270	Kathande	4	2	3	3	2	2.25	5	0	3
271	Kathande	2	0.5	1	0.5	0	0	0.5	0	0
272	Kathande	5	1	3	2	2	14	0.5	1.5	2
273	Kathande	3	0	1	1.5	0	0	0.5	0.5	2
274	Kathande	5	1	3	3	2	1.5	3	4.5	4.5
275	Kathande	5	1	3	3	0	2	2	1	6
276	Kathande	5	2	6	2	0	0	2	10	3.5
277	Kathande	2	3	0.5	1	1	1	1.5	4	2.4

278	Kathande	3	0.25	1.5	1	1	0.875	0.75	1	3.2
279	Kathande	2	0	0.5	0	0	1.75	0	2.5	10
280	Kathande	2	1	1.5	1.5	0	0	1	0	1.5
281	Kathande	3	1.5	4	0.5	0	0	1	0	0
282	Kathande	2	1	0.25	0.5	0	0	1	0.5	0.5
283	Kathande	5	4.5	2	1	2	0	6	3	1.5
284	Kathande	5	2	3	2	2	1	4	3	6.4
285	Kathande	3	1	2.25	2	0	0	0	0	2
286	Kathande	5	2	4	1	0	0.5	1	1.5	1
287	Kathande	3	2	2	2	2	2.5	1	7	4.2
288	Kathande	2	1	3	1	1	0	0	2	2
289	Kathande	2	2	0.5	0.5	0	0	2	2	1
290	Kathande	5	2	3	1	1.5	0	1.5	0.5	2
291	Kathande	5	1	3	1.5	2	0	1	0	4.5
292	Kathande	4	3	2	2	2	0.75	2	2	3.2
293	Kathande	4	0	3	3	2	1.75	1.5	7	1.2
294	Kathande	2	0	1	1	0	0	0	4	4
295	Kathande	4	1	2	2	0	0	0	1	2
296	Kathande	1	0	1	1.5	0	0	0.75	0.3	0
297	Kathande	4	3	3	2	1	0	2.5	0.4	3.6
298	Kathande	4	1	4	3	0	2	2	3	1.2
299	Kathande	3	1	1.8	1.25	0	0	1	1	1.5
300	Kathande	1	1	1.5	1	0	0	0.75	0	1
301	Kathande	2	0.5	0.25	0.5	0	0	0.25	0.375	4
302	Kathande	3	1	4	4	2	0.75	2	0	3.2
303	Kathande	4	2	4	2	1	0	3	4	6
304	Kathande	5	0.5	3	1	1	0	1	0	6
305	munyutu	4	2	3	1.5	0	0	1.5	0	2
306	munyutu	4	2	4	2	0	1.75	2	9	4.5
307	munyutu	2	0	1	1.5	0	0	1	0	4.5
308	munyutu	4	2	2	2	2	3.5	3	7	1.5
309	munyutu	4	1	1	3	2	0	4	1	2.8
310	munyutu	3	4	2	2	1	1.75	2	0.7	3
311	munyutu	3	1	1.5	1	0	2	1.5	0	3
312	munyutu	3	1	1.5	1	0.75	2	0	0	3.5
313	munyutu	2	1	0.5	1	0	0.30	1.5	2	4

314	munyutu	3	1	4	3	2	1.75	2	4	1.2
315	munyutu	4	0	4	3	2	0	3	2	2
316	munyutu	5	2	3	2	0	0	1.5	0	2.5
317	munyutu	2	0	3	1	0	1	2	2	1.6
318	munyutu	3	2	3	1.5	0	0	4	2	2
319	munyutu	5	2	3	1	0	0	1.5	0	1
320	munyutu	5	6	6	2	0	0	3	2	4
321	munyutu	5	5	3	2	0	0	4	4	0
322	munyutu	5	4	4.5	4.5	0	0	4	8	5.4
323	munyutu	3	0.5	1.5	2	0	2	1	1	1.5
324	munyutu	5	2	3	1	0	0	3	1	5
325	munyutu	4	3	3	2	1	0.5	4	4	1.2
326	munyutu	5	0	2	6	2	3.5	0	8	4.5
327	munyutu	2	1	2.25	1.5	0	0	1	0	1.5
328	munyutu	3	0.5	4	2	0	0	0.75	1.5	4
329	munyutu	3	1	5	1.5	0	1.75	4	0	4.2
330	munyutu	3	0.5	2	4	2	0	2	3	1.6
331	munyutu	4	2	3	0.5	0	0	1	1	2
332	munyutu	4	0.5	3	1.5	1	4	1	2	4
333	munyutu	2	1	1	1	0	0	1	2	4
334	munyutu	6	6	0	2	0	0	3	0	0
335	munyutu	7	6	4	4	0	1	3	2	2
336	munyutu	4	2	3	3	0	0.75	1.5	1.25	1
337	munyutu	4	0.6	3	4	0	0.5	1	1	1
338	munyutu	5	0.5	3	2	0	0	0.75	0	0
339	munyutu	5	2	2	2	2	1.75	1	3	3
340	munyutu	4	0.4	0.75	1	1	1.75	0.75	3	2.4
341	munyutu	4	1	3	2	1	3.5	3	6	1.2
342	munyutu	4	1	2	4	4	1.75	4	1	1.6
343	munyutu	3	0.5	1.5	2	1	1.2	2	2	3.6
344	Rukuriri	3	1	0.75	1.5	1	0	2	2	4
345	Rukuriri	6	2	3	3	0	0	1	2	6
346	Rukuriri	3	1	4	3	1	1	3	2	2.4
347	Rukuriri	6	6	5	3	0	0	4	4	1.6
348	Rukuriri	2	1	2	2	0	0	2	1	1.6
349	Rukuriri	1	0	0.25	1.25	1	0	0.25	0.5	0.6
350	Rukuriri	8	1	4.5	3	0	28	1	2	8

351	Rukuriri	4	1.25	2	2	0	0	1	0	0
352	Rukuriri	7	1	4.5	3	0	0	1	0	6
353	Rukuriri	4	1	3	1	0	0	2	2	4
354	Rukuriri	3	2	3	2	0	1.75	3	4	4.5
355	Rukuriri	5	1	0	6	6	1.75	5	2	3.6
356	Rukuriri	3	4	6	3	0	1.75	2	0	2
357	Rukuriri	3	0	1.5	0.5	3	1.25	3	0	0
358	Rukuriri	3	0	5	3	4	0	3	0.5	1.5
359	Rukuriri	7	1	1	0	4	0	2	1	21
360	Rukuriri	3	0.5	4	3	0	1	0.5	3.5	3
361	Rukuriri	3	4	1.5	2	0	0	3	0.5	2
362	Rukuriri	5	2	3	4	2	0.9	1.5	1	1.6
363	Rukuriri	4	2	2	2	2	0	3	2	1.5
364	Rukuriri	4	1	2	2	0	2	1	0.5	5
365	Rukuriri	2	0.5	5	1	0	4	0.5	1.5	2
366	Rukuriri	4	3	4	4.5	0	0	2	1.5	6
367	Rukuriri	3	1	4	4	0	0	4	4	2.8
368	Rukuriri	3	3	5	2	2	0.25	4	0	1.5
369	Rukuriri	4	2	3	2	0	0	3	2	4
370	Rukuriri	5	2	4	2	2	0	2	3	3
371	Rukuriri	3	1	3	2	0	0	1	2	4
372	Rukuriri	5	0.5	4	5	2	1.75	1.5	7	3.5
373	Muvandor	2	0.5	2	1	0	0	1	0.4	2
374	Muvandor	4	0	3	0.5	0	0	0.75	2	0.6
375	Muvandor	4	3	4	1	0	0	1.5	1	3.2
376	Muvandor	5	1	3	2	2	0.25	1	4	2
377	Muvandor	3	0.75	5.25	1.5	0	0	0.75	3	1.5
378	Muvandor	2	0	1	1	1	0	0	1	2
379	Muvandor	4	2	1	3	3.5	0	3	0	0
380	Muvandor	4	1	5	3	4	0	2.5	0	2.4
381	Muvandor	4	3	5	1	1	0.6	1.5	4	3.2
382	Muvandor	5	6	4	4	2	0	3	1	1.5
383	Muvandor	3	3	3	5	2	0	3	0	0
384	Muvandor	3	2	1	1.5	0	0.75	1.5	1	2.4

Appendix 5: Farm Efficiency Data

HH S/NO	VILLAGE	AEZ	FARM SIZE	FARM EFFICIENCY
1	Kageri	sunflower	0.8	0.53
2	Kageri	sunflower	1.2	0.56
3	Kageri	sunflower	0.8	0.52
4	Kageri	sunflower	0.6	0.49
5	Kageri	sunflower	1	0.53
6	Kageri	sunflower	0.8	0.59
7	Kageri	sunflower	1.8	0.65
8	Kageri	sunflower	0.4	0.58
9	Kageri	sunflower		0.46
10	Kageri	sunflower	0.4	0.58
11	Kageri	sunflower	0.8	0.72
12	Kageri	sunflower	0.9	0.51
13	Kageri	sunflower	0.5	0.52
14	Kageri	sunflower	1.68	0.66
15	Kageri	sunflower	0.8	0.28
16	Kageri	sunflower	0.4	0.66
17	Kageri	sunflower	0.5	0.36
18	Kageri	sunflower	1.2	0.58
19	Kageri	sunflower	0.4	0.43
20	Kageri	sunflower	0.4	0.77
21	Kageri	sunflower	1.2	0.53
22	Kageri	sunflower	1.6	0.47
23	Kageri	sunflower	1	0.52
24	Managia	sunflower	0.8	0.54
25	Managia	sunflower	0.8	0.58
26	Managia	sunflower	0.8	0.45
27	Managia	sunflower	4.8	0.27
28	Managia	sunflower	1.4	0.38
29	Managia	sunflower	0.4	0.82
30	Managia	sunflower	1.2	0.6
31	Managia	sunflower	0.4	0.73

32	Managia	sunflower	1.2	0.56
33	Managia	sunflower	1	0.39
34	Managia	sunflower	0.4	0.8
35	Managia	sunflower	0.4	0.47
36	Managia	sunflower	0.4	0.52
37	Managia	sunflower	0.8	0.43
38	Managia	sunflower	4	0.48
39	Managia	sunflower	2	0.74
40	Managia	sunflower	1.2	0.47
41	Managia	sunflower	1.2	0.45
42	Managia	sunflower	0.2	0.51
43	Managia	sunflower	0.52	0.7
44	Managia	sunflower	0.8	0.42
45	Managia	sunflower	0.9	0.66
46	Managia	sunflower	2.4	0.57
47	Managia	sunflower	0.8	0.5
48	Managia	sunflower	1.6	0.63
49	Managia	sunflower	0.8	0.49
50	Managia	sunflower	0.8	0.53
51	Managia	sunflower	0.8	0.49
52	Managia	sunflower	0.4	0.6
53	Managia	sunflower	0.8	0.55
54	Managia	sunflower	1.2	0.35
55	Managia	sunflower	2.4	0.49
56	Managia	sunflower	0.8	0.15
57	Managia	sunflower	1.8	0.59
58	Managia	sunflower	1.6	0.01
59	Managia	sunflower	0.8	0.43
60	Managia	sunflower	4	0.05
61	Managia	sunflower	1	0.52
62	Managia	sunflower	0.8	0.2
63	Managia	sunflower	0.8	0.4
64	Managia	sunflower	0.2	0.04
65	Managia	sunflower	1.6	0.53
66	Managia	sunflower	3.6	0.22
67	Kandete	sunflower	3.2	0.58
68	Kandete	sunflower	1.6	0.71

69	Kandete	sunflower	2.4	0.7
70	Kandete	sunflower	0.8	0.41
71	Kandete	sunflower	1.2	0.63
72	Kandete	sunflower	0.8	0.71
73	Kandete	sunflower	0.4	0.42
74	Kandete	sunflower	1.2	0.39
75	Kandete	sunflower	3.2	0.55
76	Kandete	sunflower	0.8	0.58
77	Kandete	sunflower	0.3	0.47
78	Kandete	sunflower	0.4	0.26
79	Kandete	sunflower	0.8	0.61
80	Kandete	sunflower	2.4	0.72
81	Kandete	sunflower	0.4	0.7
82	Kandete	sunflower	0.8	0.49
83	Kandete	sunflower	2	0.77
84	Kandete	sunflower	1	0.57
85	Kandete	sunflower	2	0.57
86	Kandete	sunflower	0.8	0.62
87	Kandete	sunflower	0.4	0.28
88	Kandete	sunflower	0.8	0.48
89	Kandete	sunflower	0.4	0.44
90	Kandete	sunflower	0.3	0.58
91	Kandete	sunflower	4	0.71
92	Kandete	sunflower	0.2	0.67
93	Kandete	sunflower	4.6	0.57
94	Kandete	sunflower	0.4	0.3
95	Kandete	sunflower	1.2	0.76
96	Kandete	sunflower	0.3	0.36
97	Kandete	sunflower	1	0.73
98	Kandete	sunflower	0.6	0.56
99	Kandete	sunflower	1.6	0.79
100	Kandete	sunflower	0.6	0.39
101	Kandete	sunflower	1	0.54
102	Kandete	sunflower	2.2	0.42
103	Kandete	sunflower	2	0.65
104	Kandete	sunflower	2.4	0.41
105	Kandete	sunflower	0.4	0.44

106	Kandete	sunflower	1.2	0.52
107	Kandete	sunflower	5.6	0.28
108	Kandete	sunflower	0.04	0.44
109	Kandete	sunflower	1.8	0.46
110	Mwondu	sunflower	1.6	0.63
111	Mwondu	sunflower	2.4	0.68
112	Mwondu	sunflower	0.2	0.43
113	Mwondu	sunflower	1.2	0.3
114	Mwondu	sunflower	0.4	0.54
115	Mwondu	sunflower	2.4	0.52
116	Mwondu	sunflower	0.4	0.48
117	Mwondu	sunflower	0.4	0.37
118	Mwondu	sunflower	0.2	0.21
119	Mwondu	sunflower	0.1	0.64
120	Mwondu	sunflower	0.4	0.34
121	Mwondu	sunflower	0.8	0.59
122	Mwondu	sunflower	0.2	0.55
123	Mwondu	sunflower	0.8	0.45
124	Mwondu	sunflower	0.6	0.62
125	Mwondu	sunflower	1.6	0.21
126	Mwondu	sunflower	1.8	0.65
127	Mwondu	sunflower	0.8	0.23
128	Mwondu	sunflower	1.2	0.28
129	Mwondu	sunflower	0.8	0.51
130	Mwondu	sunflower	4	0.23
131	Mwondu	sunflower	2	0.42
132	Mwondu	sunflower	0.8	0.46
133	Mwondu	sunflower	0.8	0.51
134	Mwondu	sunflower	1.6	0.6
135	Gatundur	coffee	0.8	0.14
136	Gatundur	coffee	0.6	0.44
137	Gatundur	coffee	0.05	0.56
138	Gatundur	coffee	0.1	0.6
139	Gatundur	coffee	0.3	0.44
140	Gatundur	coffee	0.8	0.65
141	Gatundur	coffee	0.2	0.62
142	Gatundur	coffee	0.2	0.31

143	Gatundur	coffee	1.2	0.73
144	Gatundur	coffee	0.2	0.44
145	Gatundur	coffee	0.3	0.38
146	Gatundur	coffee	0.5	0.04
147	Gatundur	coffee	1	0.14
148	Gatundur	coffee	1.2	0.12
149	Gatundur	coffee	0.1	0.53
150	Gatundur	coffee	0.4	0.48
151	Gatundur	coffee	1.2	0.72
152	Gatundur	coffee	1	0.56
153	Gatundur	coffee	0.4	0.24
154	Gatundur	coffee	0.2	0.63
155	Gatundur	coffee	0.4	0.41
156	Gatundur	coffee	0.4	0.29
157	Gatundur	coffee	0.3	0.19
158	Gatundur	coffee	0.3	0.27
159	Gatundur	coffee	0.05	0.46
160	Gatundur	coffee	0.4	0.76
161	Gatundur	coffee	0.8	0.77
162	Gatundur	coffee	0.3	0.63
163	Gatundur	coffee	1.6	0.55
164	Gatundur	coffee	0.3	0.3
165	Gatundur	coffee	1.6	0.22
166	Gatundur	coffee	0.2	0.28
167	Gatundur	coffee	0.2	0.15
168	Gatundur	coffee	0.2	0.31
169	Gatundur	coffee	0.6	0.29
170	Gatundur	coffee	0.2	0.29
171	Gatundur	coffee	4.8	0.34
172	Gatundur	coffee	0.4	0.55
173	Gatundur	coffee	0.3	0.42
174	Gatundur	coffee	1.2	0.64
175	Gatundur	coffee	0.45	0.19
176	Gatundur	coffee	0.1	0.77
177	Gatundur	coffee	0.4	0.31
178	Gatundur	coffee	0.3	0.63
179	Gatundur	coffee	0.3	0.83

180	Gatundur	coffee	0.2	0.62
181	Gatundur	coffee	0.3	0.46
182	Gatundur	coffee	0.2	0.74
183	Gatundur	coffee	0.2	0.68
184	Gatundur	coffee	0.2	0.51
185	Gatundur	coffee	0.4	0.42
186	Kirigi	coffee	0.4	0.59
187	Kirigi	coffee	0.8	0.37
188	Kirigi	coffee	0.4	0.25
189	Kirigi	coffee	0.6	0.28
190	Kirigi	coffee	0.8	0.31
191	Kirigi	coffee	0.6	0.44
192	Kirigi	coffee	0.4	0.33
193	Kirigi	coffee	0.8	0.23
194	Kirigi	coffee	2.4	0.36
195	Kirigi	coffee	1.6	0.3
196	Kirigi	coffee	0.05	0.09
197	Kirigi	coffee	1.4	0.77
198	Kirigi	coffee	0.5	0.23
199	Kirigi	coffee	0.4	0.6
200	Kirigi	coffee	0.3	0.55
201	Kirigi	coffee	0.3	0.52
202	Kirigi	coffee	2	0.23
203	Kirigi	coffee	1.2	0.77
204	Kirigi	coffee	1.2	0.82
205	Kirigi	coffee	1.2	0.6
206	Kirigi	coffee	0.4	0.43
207	Kirigi	coffee	0.05	0.62
208	Kirigi	coffee	0.9	0.09
209	Kirigi	coffee	2.4	0.37
210	Kirigi	coffee	0.6	0.21
211	Kirigi	coffee	0.2	0.16
212	Kirigi	coffee	0.1	0.18
213	Kirigi	coffee	0.1	0.46
214	Kirigi	coffee	0.2	0.25
215	Kirigi	coffee	0.8	0.47
216	Kirigi	coffee	0.8	0.23

217	Kirigi	coffee	0.2	0.41
218	Kirigi	coffee	0.05	0.58
219	Kirigi	coffee	0.3	0.29
220	Kirigi	coffee	0.6	0.82
221	Kirigi	coffee	0.4	0.2
222	Kirigi	coffee	0.1	0.32
223	Kirigi	coffee	0.4	0.64
224	Kirigi	coffee	0.8	0.47
225	Kirigi	coffee	0.4	0.41
226	Kirigi	coffee	0.2	0.34
227	Kirigi	coffee	1.6	0.38
228	Kirigi	coffee	0.2	0.68
229	Kirigi	coffee	0.1	0.46
230	Kyetheru	coffee	0.8	0.22
231	Kyetheru	coffee	1	0.35
232	Kyetheru	coffee	1.6	0.61
233	Kyetheru	coffee	0.2	0.09
234	Kyetheru	coffee	0.3	0.2
235	Kyetheru	coffee	0.8	0.4
236	Kyetheru	coffee	0.4	0.16
237	Kyetheru	coffee	0.4	0.61
238	Kyetheru	coffee	0.1	0.56
239	Kyetheru	coffee	0.3	0.79
240	Kyetheru	coffee	0.4	0.22
241	Kyetheru	coffee	0.2	0.21
242	Kyetheru	coffee	0.8	0.49
243	Kyetheru	coffee	0.6	0.43
244	Kyetheru	coffee	0.1	0.68
245	Kyetheru	coffee	2	0.45
246	Kyetheru	coffee	0.8	0.49
247	Kyetheru	coffee	0.4	0.35
248	Kyetheru	coffee	1.2	0.41
249	Nguui	coffee	0.1	0.46
250	Nguui	coffee	0.6	0.22
251	Nguui	coffee	0.4	0.62
252	Nguui	coffee	0.8	0.37
253	Nguui	coffee	0.1	0.26

254	Nguui	coffee	0.4	0.46
255	Nguui	coffee	0.2	0.45
256	Nguui	coffee	0.1	0.32
257	Nguui	coffee	0.08	0.56
258	Nguui	coffee	0.1	0.66
259	Nguui	coffee	0.1	0.62
260	Nguui	coffee	0.2	0.1
261	Nguui	coffee	0.2	0.61
262	Nguui	coffee	0.2	0.54
263	Nguui	coffee	0.4	0.33
264	Nguui	coffee	0.3	0.24
265	Nguui	coffee	0.3	0.32
266	Nguui	coffee	0.2	0.44
267	Nguui	coffee	0.4	0.39
268	Kathande	tea	0.8	0.57
269	Kathande	tea	2.4	0.46
270	Kathande	tea	1.2	0.6
271	Kathande	tea	0.2	0.67
272	Kathande	tea	1.2	0.57
273	Kathande	tea	1.8	0.81
274	Kathande	tea	0.05	0.85
275	Kathande	tea	0.8	0.63
276	Kathande	tea	0.8	0.58
277	Kathande	tea	0.6	0.56
278	Kathande	tea	0.6	0.42
279	Kathande	tea	0.7	0.46
280	Kathande	tea	0.8	0.51
281	Kathande	tea	0.1	0.52
282	Kathande	tea	0.3	0.68
283	Kathande	tea	0.2	0.77
284	Kathande	tea	0.4	0.48
285	Kathande	tea	0.3	0.74
286	Kathande	tea	0.5	0.59
287	Kathande	tea	0.4	0.66
288	Kathande	tea	1.4	0.49
289	Kathande	tea	0.1	0.81
290	Kathande	tea	0.4	0.38

291	Kathande	tea	0.8	0.55
292	Kathande	tea	0.3	0.67
293	Kathande	tea	2.4	0.47
294	Kathande	tea	0.5	0.62
295	Kathande	tea	1.8	0.48
296	Kathande	tea	0.4	0.65
297	Kathande	tea	0.8	0.84
298	Kathande	tea	0.8	0.52
299	Kathande	tea	0.4	0.71
300	Kathande	tea	1.4	0.51
301	Kathande	tea	0.4	0.61
302	Kathande	tea	0.2	0.66
303	Kathande	tea	1.2	0.7
304	Kathande	tea	1.6	0.6
305	munyutu	tea	0.2	0.78
306	munyutu	tea	0.4	0.49
307	munyutu	tea	0.7	0.74
308	munyutu	tea	0.4	0.6
309	munyutu	tea	0.4	0.46
310	munyutu	tea	0.7	0.49
311	munyutu	tea	0.8	0.31
312	munyutu	tea	0.3	0.4
313	munyutu	tea	0.8	0.56
314	munyutu	tea	1.6	0.47
315	munyutu	tea	0.9	0.52
316	munyutu	tea	0.8	0.72
317	munyutu	tea	0.3	0.58
318	munyutu	tea	0.3	0.5
319	munyutu	tea	0.6	0.65
320	munyutu	tea	0.4	0.62
321	munyutu	tea	0.6	0.4
322	munyutu	tea	0.2	0.81
323	munyutu	tea	0.1	0.82
324	munyutu	tea	0.3	0.69
325	munyutu	tea	0.2	0.6
326	munyutu	tea	0.4	0.68
327	munyutu	tea	4	0.37

328	munyutu	tea	0.4	0.65
329	munyutu	tea	1	0.52
330	munyutu	tea	0.4	0.69
331	munyutu	tea	0.4	0.6
332	munyutu	tea	0.8	0.35
333	munyutu	tea	0.8	0.61
334	munyutu	tea	0.4	0.67
335	munyutu	tea	0.8	0.4
336	munyutu	tea	0.4	0.66
337	munyutu	tea	10	0.91
338	munyutu	tea	0.6	0.52
339	munyutu	tea	0.2	0.73
340	munyutu	tea	0.4	0.62
341	munyutu	tea	0.4	0.55
342	munyutu	tea	0.2	0.63
343	munyutu	tea	1.2	0.58
344	Rukuriri	tea	0.4	0.65
345	Rukuriri	tea	0.4	0.62
346	Rukuriri	tea	1.6	0.48
347	Rukuriri	tea	0.2	0.31
348	Rukuriri	tea	0.3	0.78
349	Rukuriri	tea	2.4	0.51
350	Rukuriri	tea	0.4	0.92
351	Rukuriri	tea	1	0.54
352	Rukuriri	tea	0.4	0.7
353	Rukuriri	tea	0.4	0.49
354	Rukuriri	tea	0.3	0.55
355	Rukuriri	tea	0.2	0.45
356	Rukuriri	tea	0.2	0.55
357	Rukuriri	tea	0.2	0.36
358	Rukuriri	tea	0.3	0.59
359	Rukuriri	tea	0.2	0.61
360	Rukuriri	tea	0.1	0.78
361	Rukuriri	tea	0.3	0.84
362	Rukuriri	tea	0.2	0.52
363	Rukuriri	tea	0.2	0.53
364	Rukuriri	tea	0.2	0.74

365	Rukuriri	tea	0.2	0.53
366	Rukuriri	tea	0.3	0.61
367	Rukuriri	tea	2	0.64
368	Rukuriri	tea	2	0.67
369	Rukuriri	tea	0.2	0.91
370	Rukuriri	tea	0.4	0.71
371	Rukuriri	tea	0.3	0.81
372	Rukuriri	tea	0.3	0.7
373	Muvandor	tea	0.4	0.53
374	Muvandor	tea	0.8	0.66
375	Muvandor	tea	0.2	0.68
376	Muvandor	tea	0.2	0.64
377	Muvandor	tea	0.2	0.83
378	Muvandor	tea	1.2	0.92
379	Muvandor	tea	0.3	0.7
380	Muvandor	tea	1.2	0.5
381	Muvandor	tea	0.8	0.6
382	Muvandor	tea	0.7	0.59
383	Muvandor	tea	0.4	0.63
384	Muvandor	tea	0.4	0.63

Appendix 6: Questionnaire for Collecting Food Security and Farm Efficiency Data

A) General Information

	Name of Farmer				
	Mobile telephone No.				
	Village				
	Farm size in acres				
	Agro-ecological zone				
	Season (tick)	Long rains (LR)		Short rains (SR)	

1) Gender of head of household (tick as appropriate)

Male	
Female	

2)

3) Highest level of education of adult family members (above 18 years)

Level	No Formal Education	Primary Education	Secondary Education	College Education	University Education
Father					
Mother					
Others (specify)					

4) Number of Household members (only those who take meals in the household)

5) Head of households farming experience in years

6) Ages of household members in years:

Gender	No. in the category	Age(s) in years
Head of household		
Spouse		
Male children		
Female children		
Others (specify)		

7) Which of the following food items have you used to prepare meals for your family in the last 7 days (1 week)?

Types of foods consumed in last 7 days	Number of times prepared last 7 days	Unit of measure	Total quantity consumed last 7 days	How acquired (purchased or produced in the farm)	Price per unit of measure
Cereals & Legumes					
Maize (grains)					
Maize flour					
Rice					
Wheat flour					
Bread					

Sorghum					
Millet					
Green grams					
Beans					
Others (specify)					
Roots & tubers					
Irish potatoes					
Sweet potatoes					
Arrow roots					
Other roots & tubers (specify)					
Other starchy foods					
Cooking bananas					
Maize (green)					
Others (specify)					
Fruits & vegetables					
Mangoes					
Ripe bananas					
Water melons					
Oranges					
Others (specify)					
Tomatoes					
Onions					
Carrots					
Kales					

Cabbages					
Others (specify)					
Animal products					
Cow Milk					
Goat milk					
Beef (cow meat)					
Goat/sheep meat					
Chicken					
Eggs					
Others (specify)					
Other purchased products					
Oil /cooking fat					
Sugar					
Tea					
Coffee					
Others (specify)					

8) How much of the following food crops or animal products did you produce in your farm during the last one season (December 2015 to May 2016)?

Food crop/animal product	**Amount produced**	**Amount sold**	**Price per unit**
Maize			
Beans			
Green bananas			
Cow milk			
Goat milk			
Eggs			

Others (specify)			

9) How much of the following cash crops did you produce in the farm in the last one season (December 2015- May 2016?

Cash crop	**Amount produced**	**Price per unit (including bonus)**
Coffee (parchment)		
Coffee (mbuni)		
Tea		
Macadamia		
Mangoes		
Others (specify)		

10) What is the estimated value of livestock owned by the farm?

Type of Livestock	**No.**	**Estimated Value /Animal**
Cows		
Adult Cows (Females)		
Adult Bulls		
Heifer Calves		
Bull Calves		
Goats		
Adult Females		
Adult Males		
Young Females		
Young Males		
Poultry		
Adult Birds		
Young Birds		
Others (Specify)		

11) Are any of the adult members of the household (husband, wife, or guardian) engaged in off-farm employment?

Yes	
No	

12) If yes in 10 above, specify the form of off-farm employment

Formal employment	Business	Casual farm labour	Casual domestic labour	Others (specify)

13) What is the total amount of off-farm income generated per month?

14) Does the farm or any adult family members have access to credit in cash or in kind?

Yes	
No	

15) If yes in 12 above, specify the main source(s) of that credit

Banks	SACCO	Cooperative society/crop factories	Self-help group	Others (specify)

16) What is the distance from the farm to the nearest major marketing centre or town in Km?

17) What is the distance from the farm to the nearest tarmac road in Km?

18) Does the farm have access to agricultural information or advice?

Yes	
No	

19) If yes in 17 above, specify the source of agricultural information

Mass media	County Extension office	Other farmers	NGOs	Cooperatives/crop factories	Others (Specify)

20) Does the farm have access to electricity?

Yes	
No	

21) Nature of land ownership (tick appropriately)

Owned with title	Owned without title	Rented land

22) Amount of land rented

a.	Any land rented elsewhere (specify acreage)?	
b.	Land rental rate per acre per year	
a.	Land rental rate per acre per year	
b.	Estimated amounts of food products from rented land	
c.	Estimated farm income per year including from rented land(Ksh)	

23) Which of the following innovations are currently being used in the farm?

Fish farming		Modern bee-hives	
Irrigation		Zero-grazing technology	
Dairy goats		Purple tea	
Tissue culture bananas		Contract farming	

Machine milking		Green house production	
Ruiru 11, Batian coffee and others		Improved local chicken	
Certified seeds (maize,beans, etc)		Grafted fruits (mangoes, avocado, citrus, etc)	

24) Annual Crop Production

Provide the following information concerning the major annual crops grown in the current long-rain season:

Types and Varieties

Type	Variety	Acreage	seeds (kg)	Output
Maize- purestand				
Maize-intercrop				
Beans -purestand				
Beans-intercrop				
Others (specify)				

Product Prices

Item	**Price**
Maize per bag	
Beans per bag	
Maize seeds per kg	
Bean seeds per kg	

Fertilizer Application- planting and topdressing

Type	DAP (Kg)	23:23: (Kg)	CAN (kg)	Others (specify)
Maize- purestand				
Maize-intercrop				
Beans -purestand				
Beans-intercrop				
Others (specify)				

Fertilizer prices

Fertilizer	**Price**

DAP	
23:23	
CAN	
Others (specify)	

Labour Application

Cost per man-day of labour plus other costs: ……………………………………………

Crop Type	Land preparation (man-days)	Planting (man-days)	Weeding (man-days)	Harvesting (man-days)	Shelling/threshing (man-days)
Maize- pure stand					
Maize-intercrop					
Beans -pure stand					
Beans-intercrop					
Others (specify)					

25) Perennial crop production

Types and Varieties

Type	Variety	Acreage	No. of trees or bushes	Amount harvested in last 6 months	Prices
Coffee					
Tea					
Bananas					
Mangoes					
Macadamia					

Others (specify)					

Fertilizer and manure application-topdressing (last 6 months)

Type	**DAP (kg)**	**CAN (kg)**	**23:23**	**Manure (carts)**	**Others (specify)**
Coffee					
Tea					
Bananas					
Mangoes					
Macadamia					
Others (specify)					

Prices

Input	**Price**
DAP	
CAN	
23:23	
Manure per cart	
Others (specify)	

Labour application (last 6 months)

Crop-type	**Weeding (man-days)**	**Harvesting (man-days)**	**Fertilizer application (man-days)**	**Manure application (man-days)**	**Chemical application**