DETERMINATION OF ECONOMIC COMPETITIVENESS OF DAIRY PRODUCTION IN SEMI-ARID AREAS:

"The Case of Smallholders in Kitui District"

BY

KITHALE, DAVID

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL

ECONOMICS OF THE UNIVERSITY OF NAIROBI

AUGUST 2007

DECLARATION

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

Signature: .... Date 16/08/2007

Kithale David

This thesis has been submitted for examination with my approval as the University supervisor.

Signature: .... Date 17/08/2007

Dr. J.T Karugia

ACKNOWLEDGEMENT

I am deeply indebted to various individuals and institutions whose assistance and guidance enabled me to complete this study. I may not mention all of them by their names but some deserve special vote of thanks for their direct contribution to the success of this work.

My special thanks go to my supervisor Dr. J.T. Karugia whose guidance and constructive criticisms enabled me to complete this thesis. I also extend my sincere gratitude to Dr. H. Ommeh who was one of my supervisors at the initial stages of the study. However, I am responsible for any errors and omissions that may be detected in the thesis.

I sincerely appreciate the generosity of the University of Nairobi for awarding me a scholarship and the Ministry of Agriculture for granting me study leave to undertake the course.

I also extend my gratitude to the staff of the Ministry of Livestock and Fisheries Development in Kitui district for their co-operation and assistance during the fieldwork. I must thank Munyao, Mrs Komu and Suleiman for devoting their time and resources during data collection. I am also grateful to all members of the Department of Agricultural Economics and my colleagues for their support and guidance.

Special thanks also go my dear wife Colletar and my son Daniel for their support and encouragement throughout the study period. Finally I extend my gratitude to my parents Mr Kithale Ngau and Mrs Kana Kithale for their support and counseling.

TABLE OF CONTENTS **Page**

List of Tables

List of Figures

List of Abbreviations and Acronyms.

ADC - Agricultural Development Corporation

AEZ-Agro-Ecological Zone.

ASAL-Arid and Semi-Arid Lands.

ECF-East Coast Fever

ERS-Economic recovery strategy.

GDP-Gross Domestic Product.

GM-Gross Margin.

GOK- Government of Kenya.

KCC- Kenya Co-operative Creameries.

LP-Linear Programming.

LRS- Long Rain Season

Lu – Livestock unit

MALDM- Ministry of Agriculture. Livestock Development and Marketing.

MOA- Ministry of Agriculture.

MoLFD- Ministry of Livestock and Fisheries Development.

MVP- Marginal Value Product.

SEAZ- Small East Africa Zebu.

SRS- Short Rain Season

TFGM - Total Farm Gross Margin.

TR-Total Revenue.

TVC-Total Variable Cost.

Abstract

This study was carried out in Kitui district in the year 2005 with the broad objective of determining the economic competitiveness of dairy production. In this study, the competitiveness of dairy production was assessed based on the contribution of the enterprise to total farm income and returns to land and capital resources.

Data were collected from dairy farmers and categorized into small, medium and large farms based on farm sizes. Gross margin, linear programming model and descriptive methods were used to analyse the data. Results of descriptive analysis revealed that the average farm size in the small, medium and large farm categories was 1.80 hectares, 4.90 hectares and 10.00 hectares respectively. The small farm category had 88% of the farmers who keep one or two dairy cows besides growing maize, beans, and pigeon peas for subsistence and commercial purpose. These results indicate that majority of the farmers within the area surveyed are smallholder producers.

Results of gross margin analysis showed that under the existing small, medium and farm plans, farmers earned Ksh 82,031 Ksh 91,844 and Ksh 109,075 respectively. The dairy enterprise contributes 61% to total farm income in the small farms while in the medium and large farms it contributes 71% and 59% respectively. The gross margins per hectare of the dairy enterprise in the small farms was estimated at Ksh 174,996 compared to Ksh 6,865 and Ksh 16,697 for maize/beans intercrop and beans respectively both produced during the short rain season. In the small farms, the return to operating capital from the dairy enterprise was Ksh 4.42 while it was Ksh1.41 and Ksh 3.54 for maize/beans intercrop and beans respectively. On the basis of enterprise contribution to total farm income, returns to land and capital it can be concluded that dairy production in Kitui district is profitable and competitive compared to crop production

Linear programming model was used to develop optimal farm plans with and without a subsistence constraint and to identify limiting resources to agricultural production. Results of linear programming analysis revealed that the optimal farm plans had few crop enterprises compared to the existing farm plans. The dairy enterprise was included in the optimal plans of the small and medium farms while it was excluded from the optimal plan of the large farm. The optimal plans developed from a linear programming model without subsistence constraints suggests that farmers with small, medium and large farms could earn Ksh 108,498, Ksh 107,004 and Ksh 158,807 respectively. Results of the linear programming model with subsistence constraints established that farmers with small, medium and large farms could earn Ksh 72,437, Ksh 69,978 and Ksh 137,253 respectively. The results show that farm plans developed from a linear programming model without subsistence constraints have higher income compared to the plans developed with the subsistence constraint.

Land and operating capital were found to be the most limiting resources in the small and medium farm categories. Labour was found to be a non- limiting resource in all the farm categories. Since land is a limiting resource farmers could improve farm income by producing few profitable crop enterprises (beans, maize and maize/pigeon peas intercrop) and keep one or two dairy cows under zero grazing production system.

CHAPTER ONE: INTRODUCTION

1.0 Background Information

1.1 Agriculture in the Context of National Development

Agriculture is the dominant sector of Kenya's economy as reflected by its contribution to income generation, employment creation, food security and industrial development (G.O.K. 2004). Agriculture directly contributes 26% to Gross Domestic Product (GDP) and indirectly a further 27% of GDP through linkages with manufacturing and distribution sectors. The sector contributes 60% of total export earnings and accounts for 60% of rural employment with women providing 75% of total labour force. It is estimated that 80% of Kenya's population lives in the rural areas and derive their livelihoods from subsistence crop production and livestock activities (G.O.K. 2004). The agricultural sector produces the bulk of the country's food requirement and it is a source of off-farm employment (Nyoro, 2002).

The agricultural sector is the engine that drives other sectors of the economy thus economic growth is dependent on the performance of the sector. The intermittent strength and overall weakness in Kenya's GDP, economic growth and development can be attributed to changes in the performance of agricultural sector. This is demonstrated by the close relationship between the performance of the agricultural sector and the national economy. During the first two decades after independence, Kenya's economy grew at an average rate of 6% per year (G.O.K, 2004). This tremendous economic growth is attributed largely to the high performance of the agricultural sector that registered a growth rate of 5.6 % per year. Between 1980 and 1990, the sector recorded an average annual growth rate of 3.5% while in the period 1990 to 2000; the sector grew at an average rate of 1.3% (G.O.K., 2004). The deterioration of the agricultural performance resulted in a sharp decline in the overall economic growth rate from 1.2% in the year 2002 to 1.1% in 2003 (G.O.K. 2004b).

The decline in the performance of the agricultural sector was attributed to unfavourable weather conditions, low and declining soil fertility, collapse of key institutions supporting agriculture (Kenya meat commission, Kenya co-operative creameries) and inadequate access to affordable financial credit, among other factors (G.O.K, 2004). Despite the declining trend in the performance of agriculture, it remains one of the key sectors to drive economic growth in Kenya. According to the Economic Recovery Strategy (ERS), agriculture was identified as the sector with the potential to achieve multiple objectives of food security, creation of employment and reduction of poverty (G.O.K, 2003b). Due to the close relationship between the performance of the agricultural sector and the national economy, emphasis should be on growth and development of the sector to enhance overall economic growth in Kenya (G.O.K, 2004).

1.2 Livestock Sub Sector and its Role in National Development

In Kenya, livestock production is an important sub sector of the agricultural sector. The livestock sub sector contributes 10% of the total national GDP and accounts for over 30% of agricultural GDP (G.O.K, 1997a). Livestock production earns the country foreign exchange through export of animals, hides and skin, and dairy products. The sub sector is a major source of household income through the sale of livestock and livestock products, and provides raw materials to agro-industries (G.O.K, 2002a). Livestock production accounts for over 50% of agricultural labour force. Livestock production is an important socio-economic activity in the high rainfall areas where dairy production is the main economic activity (Mutugi, 2003).

1.2.1 Dairy Industry in Kenya

1.2.1.1 Smallholder Dairy Development in Kenya

Kenya has one of the largest and well-developed dairy production and processing industries in Sub-Saharan Africa (G.O.K, 1993). The white settlers introduced commercial dairy production in Kenya in the 20th century when they brought exotic dairy breeds from South Africa and Europe (Bebe *et al.*, 2002). Before independence, commercial dairy production was the sole preserve of large scale settler farmers in the agricultural productive high and medium potential areas of Central, Rift valley and Eastern provinces (Reynolds *et al,* 1996; Muriuki *et al.*, 2003). Local people were not allowed to engage in commercial crop and dairy farming until the implementation of the Swynnerton plan of 1954 that introduced agricultural reforms and allowed non settler farmers to engage in commercial farming (Reynolds *et al.*, 1996; Muriuki *et al.,* 2003). The agricultural land reforms introduced consolidation of fragmented pieces of land into one piece under an individual's ownership with title deeds. After the reforms, indigenous farmers were encouraged to grow cash crops (coffee, tea and pyrethrum) for export markets. Income earned from the sales of the cash crop and other sources was use to purchase dairy cows from the settler farmers (Bebe *et al.*, 2002).

After independence, government development policies supported acquisition and sub division of the large-scale farms in the highlands into small farm units to facilitate settlement of indigenous farmers. The settler farmers who opted to leave the country sold their farms and dairy animals to smallholder farmers. This resulted into increased smallholder farms with crop and livestock activities (Bebe *et al.*, 2002). Currently smallholder farmers who keep one or two cows and grow crops on approximately one to two hectares of land dominate production in Kenya. The smallholder dairy farmers produce about 70% of the estimated 2.6 million metric tons of milk produced annually in Kenya (Staal *et al.*, 1998).

The government supported expansion and development of smallholder dairy production by initiating dairy breeding programmes and reforms in the milk market. Artificial Insemination and clinical services were subsidized and the operations of the Kenya cooperative creameries (KCC) were restructured to allow for the purchase of milk from smallholder producers. Artificial Insemination (A.I) services and bull schemes were established to ensure farmers had access to high quality dairy breeds (Muriuki *et al.*, 2003). Due to budget constraints, subsidization of smallholder dairy production was unsustainable hence the government revised its policies to enhance private sector participation in the provision of A.I and marketing services to the farmers. A major policy reform was done in 1992 when the dairy industry was liberalized to enhance competition and efficiency in resource allocation (G.O.K, 1993). The monopoly enjoyed by Kenya Cooperative Creameries in the marketing of milk was revoked and other private milk processors such as Spin Knit and Brookside emerged to compete with Kenya Cooperative Creameries in the delivery of services to farmers. The major impact of liberalization of the dairy industry has been the rapid growth of relatively efficient formal and informal private sector in the provision of AI and clinical services as well as marketing and processing services to the smallholder farmers (Waithaka *et al.*, 2005). However, access to these services is limited to the regions where commercial dairy production is the main economic activity especially in the high and medium potential areas (G.O.K, 1993).

1.2.1.2 Structure of Dairy Production in Kenya

In Kenya, dairy production is dominated by smallholder farmers who produce over 70% of the total milk output (Staal *et al.*, 1998). Dairy cattle population is estimated as over three million and about 660,000 smallholder farmers keep the dairy animals (Reynolds *et al.*, 1996). The main dairy cattle breeds include exotic breeds (Friesian, Ayrshire, Guernsey and Jersey) and various crossbreeds. The smallholder dairy producers are concentrated in the high potential highland areas that are characterized by favourable climate and high population density.

However due to population pressure on land in the high and medium potential areas, dairy production has been extend to semi arid areas such as Kitui district (Mutugi, 2003).

In Kenya, dairy farmers have adopted various production systems. Dairy production systems have changed from extensive to intensive systems as a result of increasing human population density and subsequent reduction in farm sizes and available grazing land (Reynolds *et al*, 1996; Waithaka *et al.*, 2003). The production systems are classified into two large scale and two small-scale systems based on agro-ecological zones (Wanyoike and Wahome, 2003; Waithaka *et al.*, 2005). Large-scale dairy production system is practiced in agro-ecological zones one to four by farmers with large farms and institutions such as Agricultural Development Corporation (ADC). Commercial large-scale dairy farms are found in the Rift Valley, and Central provinces. The average herd size is 20 animals but in some farms it may exceed 100 animals. The dominant breeds are Friesian and Ayrshire, and to a lesser extent Guernsey and Jersey. Fodder crops such as Napier grass; *Desmodium, Leuceana, Calliandra and Sesbania ses*ban are grown for the dairy animals (Muyekho and Wandera, 1996). In the large dairy production system, the average productivity per cow is 5,000 litres in a year with low calf mortality and high carving rate (Wanyoike and Wahome, 2003).

Large-scale dairy- meat production system is practiced in agro-ecological zones five to six in the Rift Valley, Coast and Eastern provinces where human population density is low (Mutugi, 2003; Waithaka *et al.*, 2005). The herd sizes vary from 30 to 150 cattle and the main breed are improved Boran and Sahiwal. In this system, milk is produced mainly for household consumption but surplus milk is sold to neighbours, hotels and schools. The average milk production per cow is about 200 litres in a year.

Small-scale dairy production system is practiced in agro-ecological zones two to four with a high concentration of small dairy herds in the peri-urban areas where market for milk is guaranteed. The small scale dairy production system holds about 80% of the total dairy cattle population in Kenya (Staal *et al.*, 1998). Farmers keep two to four dairy animals along with crop farming on farms of one hectare. The dairy animals are mainly kept for milk production but manure produced by the animal is used to improve soil fertility for crop production. The animals are confined in zero grazing units where they are fed on napier grass and other fodder crops produced in the farm. Supplement feeds such as dairy meal and mineral salts are fed to the animals to boost milk production. The average annual milk production per cow is about 2,500 litres.

Small scale dairy-meat production system is practiced in agro-ecological zones two to four in Nyanza and Western provinces. However this production system is also found also in some drier areas in Mwingi, Kitui, Mbeere and Tharaka districts that are in agro ecological zone four (Mutugi, 2003). The farm sizes range from 1 to 15 hectares and the main breeds are indigenous Zebu and Crossbreeds. This is a low input production system where the animals are grazed along roadsides and communal land. The productivity of cows in this system is about 600 litres per year.

1.2.1.3 Importance of Dairy Industry in Kenya

The dairy sub sector contributes 3.5 % to the national gross domestic product (GDP) and account for 14 % of the agricultural GDP (Staal, 2004c). The dairy industry plays an important role in the rural economy in terms of wealth and employment creation. Dairy production is a major source of livelihood to over 600,000 smallholder farmers and their families. The dairy industry offers approximately 365,000 employment opportunities along the milk marketing chain and over 500,000 jobs in the provision of support services (Staal, 2004b).

Smallholder dairy production is a source of manure that is used to improve soil fertility for crop production and this result in increased yields thereby contributing indirectly to household food security (Staal, *2004c*; SDP, 2005).

1.3 Constraints to Dairy Production in the Arid and Semi-Arid areas of Kenya

Constraints to dairy production in arid and semi arid are first and foremost climatic, particularly rainfall. In the arid and semi arid areas rainfall is erratic and unreliable, natural grasses grow rapidly for two to three months after which it becomes fibrous, indigestible and scarce. This results in irregular and inadequate natural pasture to ensure steady supply of livestock feed throughout the year. Lack of sufficient and high quality livestock feeds lead to under feeding of the dairy cattle and eventually to low productivity (Omore *et al.,* 1999; Karanja, 2003). Poor management of dairy cows is also a cause of low productivity. In farms where farmers have little experience in dairy farming, the animals are poorly managed and this is manifested by under feeding, low use of concentrate feeds, poor disease and parasite control programmes (G.O.K, 1997a). Farmers allocate small proportion of their land for the production of fodder crops and this result to inadequate supply of quality livestock feed during the dry seasons.

Access to veterinary and artificial insemination services (A.I.) is a limiting factor to dairy production in the arid and semi arid area. Following the liberalization of the dairy industry in the year 1992, provision of veterinary and A.I services were privatized with the anticipation that the private sector would fill the gap left by the government (Muriuki *et al.*, 2003; Karanja, 2003). However, majority of the private veterinary and A.I. services providers are found in areas with high dairy cattle density in the high and medium potential areas where dairy production is the main economic activity (Muriuki *et al.*, 2003). In the arid and semi arid areas where commercial dairy production is an emerging as an alternative source of livelihood, there is limited access to A.I services.

Relatively poor infrastructure (road network) and lack of cooling facilities are also major constraints to milk marketing (Staal, 2004c, Muriuki *et al.*, 2003). Milk is a high perishable commodity that requires proper handling and immediate transportation to processing plants and consumers. In Kitui district, most of the roads are impassable during the rain season (G.O.K, 2002). The state of the roads affects the delivery of vital services such as veterinary services and the marketing of farm produce. The existing road network covers a small proportion of the district and this makes most areas inaccessible during the rain season.

1.4 Problem Statement

Kitui district is classified among the semi-arid areas in agro-ecological zones 4 and 5 that are considered unsuitable for keeping of exotic dairy cattle due to unfavourable climatic conditions (Jaetzold and Schmidt, 1983). The semi arid areas are suitable for early maturing crops (Millets, Sorghum, Cowpeas, Maize and Green grams) and pastoral livestock production. However due to increasing human population farm sizes and grazing land have diminished and this has caused increased competition between crop and livestock activities for land (G.O.K, 2002). Farmers have responded to the problem of small farm sizes by shifting from extensive pastoral livestock production to small-scale dairy production as an alternative source of livelihood (G.O.K, 1997a). The main problem of dairy production in Kitui district is that there is increased competition between dairy and crop enterprises for the available land, labour and capital. Farmers are faced with the problem of how to allocate the scarce farm resources for the production of dairy and crop enterprises. Due to the scarcity of farm resources farmers have to select the combination of enterprises, which gives the better farm returns. Farmers consider dairy production as source of steady flow of income thus it is highly ranked when making decisions of what enterprises to include in the farm plan. However dairy production is a labour and capital-intensive activity that requires continuous supply of feed throughout the year (Staal, 2001). Pasture and fodder production in Kitui district is hampered by erratic and unreliable rainfall that is experienced in the district. There are two rain seasons with long rain season starting from April to May and short rain season from December to January. Annual rainfall in Kitui district ranges from 500mm to 1050mm (G.O.K, 2002). Pasture and water are available for a few months due to prolonged dry spell between the rain seasons. This result to water scarcity and inadequate feed supply for the dairy animals. During the dry period farmers crop residues preserved after harvest are the main sources of feed for the dairy animals. The smallholder dairy farmers often purchase maize stovers and pigeon peas husks from other farmers to feed to the dairy animals.

Incidences of tick borne diseases are common in Kitui district and they pose a major threat to dairy production. Exotic dairy cattle are more susceptible to tick borne diseases such as East Coast Fever (ECF) compared to Zebu cattle (G.O.K, 2003 b). Thus dairy production base on exotic dairy breeds could be a risky activity in Kitui district. Due to the unfavourable climatic conditions, small farm sizes and incidences of tick borne diseases it is probable that dairy production in Kitui district is not competitive compared to crop production. These constraints to dairy production form the basis of assessing the competitiveness of smallholder dairy production in Kitui district. The research question that this study sought to answer was "is it profitable to engage in dairy production in Kitui district?"

1.5 Objectives of the Study

The broad objective of the study is to assess the competitiveness of smallholder dairy production compared to crop enterprises.

Specific Objectives

i) To determine and compare the returns to farm resources from dairy and crop enterprises.

ii) To determine and compare the relative profitability of dairy and the competing crop enterprises.

iii) To determine the existing farm plans and then compare them to optimal farm plan.

iv) To assess the contribution of dairy enterprise to total farm gross margin in the existing and optimal farm plans in Kitui district.

1.6 Justification

Dairy production is an important source of household income and food security in the high rainfall. However as a result of reduction in farm sizes caused by increasing human population in the high rainfall areas, smallholder dairy production has been extended to the semi arid areas such as Kitui district (Muhiyi *et al*; 2001; Mutugi, 2003). Despite the importance of dairy production in the semi arid areas, research and intervention programmes have been concentrated in the high and medium potential areas where dairy farming is the main economic activity. There is limited literature on the economics of dairy production in the semi arid areas of Kenya. Dairy production in the semi arid areas is a risky business due to factors such as unfavourable climatic conditions, incidences of livestock diseases, inadequate supply of feed, poor infrastructure, lack of milk cooling and processing facilities (Omore *et al.*, 1999). This is a justification for this study that sought to assess the profitability and competitiveness of dairy production in the semi arid areas.

1.7 Organization of the Thesis

The study is composed of five chapters. Chapter one presents background information, problem statement and objectives of the study. Chapter two reviews literature that is relevant for the study. Chapter three presents methodology of the study including theoretical framework, techniques used to analyse the data and data collection procedure. Chapter four presents the results and discusses the findings of the study. Chapter five gives summary, conclusions and recommendations of the study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Smallholder dairy production in the arid and semi arid areas is a risky business and farmers make decisions in a risky and changing environment (Kay, 1986). Climatic conditions, pest and disease are the major factors associated with risk and uncertainty that affect dairy production. These factors cannot be predicted accurately when making production decisions though they cause variability in milk yields. Rainfall seasonality and reliability affect natural pasture and fodder availability and consequently the productivity of dairy animals. Dairy cows are highly susceptible to unfavorable weather, pest and diseases. Arid and semi-arid areas are characterized by severe droughts and unreliable rainfall, irregular and inadequate natural pasture and fodder to ensure steady supply of feed for dairy production.

Marketing risks in dairy production arise from price (input, milk and milk product) fluctuations. Milk prices respond more rapidly to actual and anticipated changes in supply and demand for milk. Fluctuations in input and output prices cause income gains or losses (Patrick, 1998). Fluctuations of prices cause variability in the profitability and the competitiveness of farm enterprises (Schroeder and Goodwin, 1994).

Production and marketing risks exist in farming systems and they are interrelated. Price and yield variability determine profitability and competitiveness of farm enterprises. In view of the risky factors that have impact on dairy production, it was necessary to determine the competitiveness of smallholder dairy production in Kitui district. Farmers in Kitui district are investing in dairy production as a coping mechanism to the problems caused by crop failure and the risk of famine.

2.2 Indicators and Techniques of Assessing Competitiveness

Researchers have used different indicators and techniques to assess competitiveness of farm enterprises. Wanzala, (1993) carried out a study in Amukura division of Busia district to determine the economic competitiveness of rainfed rice and optimal resource allocation on smallholder farms. Data were collected from 50 farmers using a semi-structured questionnaire and three farm models namely small, large and aggregate rice farms were specified for the study based on the average farm sizes in each category. Gross margin analysis and linear programming techniques were used to assess the competitiveness of rainfed rice compared to maize, cassava, cotton, sorghum and finger millet. Sensitivity analysis was done to determine how changes in prices of products of rice, maize, cassava, cotton, sorghum and finger millet affect the optimal farm plans. Results of gross margin analysis showed that rice maize, cassava, cotton, sorghum and finger millet were profitable. Results of the linear programming analysis revealed that rice appeared in the optimal plan of the small farm model while it was excluded from the optimal plans of large and aggregate farm models. Although rice was included the optimal plans of the small farm model, it was at a relatively lower level of 0.8 hectares and its contribution to the total farm income was the least compared to maize, cassava, cotton, sorghum and finger millet. Sensitivity analysis revealed that rice could be included in the optimal plans of the large and aggregate farm models by increasing prices above ksh 8 per kilogram of rice. Based on the results of gross margin, linear programming and sensitivity analyses, the researcher concluded that rain fed rice production was not competitive to be produced under rainfed production. The current study also used gross margin analysis, linear programming model and sensitivity analysis to assess the competitiveness of dairy production in Kitui district. The study by Wanzala compared the gross margins between crop enterprises while the current study focused on crops and dairy enterprises.

Staal (2001) assessed the competitiveness of dairy production in Asia, Latin America and Sub-Sahara Africa. In the study, profit was used as an indicator of the competitiveness of dairy enterprise. Gross margin analysis was carried out to assess the performance of the dairy enterprise in terms of the profits realized by farmers. The study found that smallholder dairy production was profitable. However dairy production was competitive in areas where there were no alternative employment opportunities. In such areas, the opportunity cost of the farmer's labour is low as reflected by the casual wage rates observed in rural areas. Staal concluded that where wage rates were low, smallholder dairy production could be competitive because this is a labour intensive activity. The present study is different from that carried out by Staal in many aspects. While Staal used a partial farm budgeting approach with a focus on the performance of the dairy enterprise the present study focused on whole farm planning. In this study, the contribution of the dairy enterprise to total farm income was calculated and compared to the contribution from crop enterprises. Such an analysis was necessary because an enterprise might register positive profits but its contribution to total income is insignificant. Staal carried out gross margin analysis to assess the competitiveness of dairy production while this study combines gross margin analysis and linear programming model. Linear programming models are used to determine the most competitive enterprises, the levels at which they should be produced and the optimal resource use.

Ngategize (1989) used gross margin analysis and linear programming models to evaluate the competitiveness of small ruminants in sub-Saharan Africa. The main objective of the study was to assess whether small ruminant enterprises were competitive relative to other farm enterprises and the major constraint to small ruminant production systems. Relative profitability was used as an indicator of enterprise competitiveness. Gross margin analysis was carried out to assess the profitability of sheep and goats enterprises. Results of the gross margin analysis revealed that smallholder ruminant production was profitable. A linear programming model was used to assess whether sheep and goat production were competitive in a whole farm perspective and the levels (numbers and resource level) the ruminant enterprises could be produced if included in the optimal farm plans. Sensitivity analysis was carried out to determine the ranges within which the gross margins and price of enterprises in the optimal farm plans could change without affecting the net farm income. The study found that sheep and goat enterprises were among the basic enterprises in the optimal plans. Based on the results of gross margin and linear programming analysis, it was concluded that small ruminant production was competitive.

Baltenweck *et al.*, (1998) while analyzing intensification and competitiveness of smallholder dairy production system in Nairobi area used cash flow derived from dairy activities and returns to family labour as indicators of competitiveness. Net cash flow was calculated as the gross income from sales of milk, calves and culled cows minus costs of hired labour, feed expenditures and health services. The opportunity cost of milk consumed by the household and the livestock feed produced on farm were included in the analysis. In the current study, the amount of milk fed to the calves and consumed by the household was included in the calculation of the gross income of the dairy enterprise.

Ishuza (1994) used gross margin analysis and returns to land to evaluate the competitiveness of drought tolerant crops such as sorghum and millet, and non-drought tolerant food crops such as maize in Tanzania. In the study, profit was used as the proxy for competitiveness. According to Ishuza, relative profitability is a measure of competitiveness particularly with respect to efficient resource allocation and returns to resources. According to Ishuza, the concept of competitiveness in agricultural production considers the costs, product prices, profit margin and returns to resources used in production. Gross margin analysis was carried out to determine the profitability of maize, millet and sorghum and returns to land and labour. The results of the study showed that gross margins of sorghum and millet were 2.1 times higher than maize. The returns to labour for sorghum and millet were 1.4 times higher than for maize. The researcher concluded that the drought tolerant crops such as sorghum and millet were more competitive in terms of returns to land and labour compared to non-drought tolerant crops (maize).

Hanyani *et al.*, (1998) while analyzing the socio-economic aspects of smallholder dairying in Zimbabwe used gross margin analysis to evaluate the competitiveness of the dairy enterprise at the farm level. In the study, the performance of dairy enterprise was compared to maize, cotton, groundnuts and sorghum. The gross margin analysis involved estimation of gross margin per cow (GM/Cow) and gross margin per hectare (GM/Ha) for the crop enterprises. Returns to capital were calculated by expressing the gross margins of dairy, maize, cotton, groundnuts and sorghum per unit of variable cost (GM/VC). The gross margin per unit of variable cost was estimated at 1.12 for cotton and 0.2 for dairy. The researchers attributed the poor performance of the dairy enterprise to high establishment cost, high cost of transporting milk, lack of dairy management experience, inadequate feed and poor breeding practices. Based on the results of this study, the researchers concluded that smallholder dairy production in Zimbabwe was not profitable compared to the crop enterprises. The current study is similar to that carried out by Hanyani because gross margin analysis was used to determine the competitiveness dairy and crop enterprises by comparing their profits and returns to land and capital. Besides gross margin analysis, in the current study linear programming model was adopted to determined optimal farm plans and the most limiting resources to agricultural production in Kitui district.

Okoruwa *et al.*, (1996) used linear programming model to assess the competitiveness of crop and livestock enterprises in West Africa. Data were collected from 63 agro-pastoralists and 20 crop farmers. The sampled farmers were categorized into cattle owners, cattle owners and caretakers, caretakers and crop farmers. Gross margins analysis was carried out to assess and compare the performance of crop and livestock enterprises under different management systems. A Linear Programming model was used to determine optimal farm plans and efficiency in the allocation of land, labour and capital. Gross margin analysis found that for the cattle owner's the returns to family labour and management was 26,484 Naira (Nigerian currency), while for cattle caretakers and crop farmers it was 43,746 Naira and 37,027 Naira respectively. Results generated by the linear programming model showed that the expected gross margins from the optimum farm plans were 22% higher than those observed from the sampled farms. The optimum farm plan suggests that farmers with small farm holdings could maximize incomes by producing few enterprises and a small herd of cattle. Crop production should be allocated more land and labour to ensure household food security. The current study also used a linear programming model to develop optimal farm plans.

Barasa, (1989) used gross margin and linear programming techniques to analyze cotton production in Funyula division of Busia district. The objective of the study was to identify and analyse the main economic factors causing decline in the production of cotton. Data was collected from farmers growing cotton, maize, sorghum, bean, finger millet and cassava. The researcher specified small, medium, large and aggregate farm models based on farm sizes. The results of gross margin analysis revealed that cotton was the least profitable and has the least returns to labour and capital compared to maize, beans and sorghum. In the medium farms the returns to capital for cotton were Ksh 0.21 compared to Ksh 3.01, Ksh 1.36, and Ksh 0.84 for maize, sorghum and beans respectively

Results of the Linear Programming analysis showed that the optimal farm plan had maize, maize/sorghum intercrop and finger millet. Cotton was excluded from optimal farm plan and this suggested that it was not competitive compared to those enterprises in the optimal plan. Results of the Linear Programming analysis also revealed that labour was a limiting resource while operating capital was non-limiting factor to production. In addition to crop enterprises that Barasa analyzed, the current study considered livestock, which is an important enterprise to the livelihoods of many households living in the arid and semi arid areas such as Kitui district.

Mburu (1991) used gross margin analysis and linear programming techniques to evaluate the economics of simsim production in smallholder farms in Kwale district. Data were collected from 40 farmers producing simsim among other crops. The researcher specified three representative farm models namely small, medium and large farms on the basis of farm sizes. Results of the gross margin analysis showed that the average gross margins per acre of simsim was Ksh 271 and Ksh 207 in the small and large farm categories respectively. Linear programming model was used to estimate optimal farm plans for the three farm categories. Results of the linear programming analysis showed that in the small farm category, the optimal plan had coconut/cashew nut, maize/simsim intercrops, cassava and beans. Simsim was excluded from the optimal plan and this suggested that it is not competitive compared to other crop enterprises. However, simsim enterprise could enter the optimal plan if its price increased by 200%. A minimum food requirement constraint was incorporated in the linear programming model in terms of land that is sufficient to produce enough food crops for a household consumption. The average daily food requirement per person was estimated as 2709 calories and 68.09 grams of protein. The values of calories and proteins were used to determine the total food requirement for households of different sizes. The quantities of maize, cassava and beans required for provision of the required calories and protein were estimated and converted into land equivalent. In contrast the current study incorporated a subsistence constraint in the linear programming model expressed as the minimum land allocated to maize and beans production for subsistence.

Mukumbu (1997) adopted linear programming model and gross margin analysis to determine optimal enterprise mix and allocation of resources in the Kano pilot irrigation scheme. A sample of 40 farmers was collected randomly and analysed using gross margin and linear programming techniques. Two land constraints and a subsistence constraint were defined and incorporated in the linear programming model. The subsistence constraint was expressed in terms of the amount of money required for purchase of food per household. Gross margin analysis was carried out to assess and compare the performance of farm enterprises. Green gram was found to be the most profitable enterprise with a gross margin of Ksh 5,454 compared to Ksh 5,321 for rice. Results of the linear programming analysis showed that it was possible to double farm income from Ksh 9,033 earned from the existing cropping system to ksh 18,484 by adopting the optimal plans. Contrary in the current study, the subsistence constraint is incorporated in the programming model in terms of the minimum land allocated by farmers to maize and beans production for household consumption.

Bagazonzya (1980) used a linear programming model and gross margin analysis to assess the profitability of smallholder pig production in Nyeri district. In the study, gross margin of crop and livestock enterprises were calculated and expressed per acre and per livestock unit respectively. The gross margins of crop and livestock incorporated as coefficients of the linear programming model. Results of the linear programming analysis showed that optimal farm plans were superior to the existing farm plans. Pig and dairy enterprises were excluded from the optimal farm plans and the researcher concluded that they were not competitive to be included in the optimal farm plans. Bagazonzya expressed the dairy activity bases on a livestock unit while in the current study the gross margin of dairy enterprise is calculated per cow.

CHAPTER THREE: METHODOLOGY

3.1 Theoretical Framework

This study is based on the theory of the firm. The firm is the decision making unit in an industry (Barnard and Nix, 1979). The theory of the firm assumes that in the short run where planning is for a year, producers aim to maximize profits from the land, labour and capital resources available to them. The resources are scarce hence they should be allocated efficiently so that maximum outputs are realized. Due to scarcity of resources, producers make decisions on how to allocate the resources so as to meet their objectives. Profit maximization is regarded as the most important short-term objective but in farming other objectives may influence the farmer's decision of what enterprise to include in the farm plan (Barnard and Nix, 1979; Kay, 1986). The profit maximization objective is criticized on the bases that farmers also aim at other objectives that include adequate food supply, stable income and to minimize the risk of crop failure (Upton, 1987). These objectives should not be ignored in farm planning because they also have influence on choice of enterprise and net farm income.

Farm planning is the process of selecting a combination of enterprise and production methods that maximize profits and meets other objectives of the farmer (Mortenson and Lucening, 1979). Profit maximization and household food security are the main objectives of smallholder farmers. These objectives can be achieved by appropriate selection of crop and livestock enterprises. Resource availability, environmental factors, household food requirements and profitability are some of the factors that determine the enterprises to be included in a farm plan. Farmers are risk averse thus they may prefer enterprise with lower and stable income than those that give high income but they are risky to produce (Nyikal and Kosura, 2005).

3.2 Farm Planning Techniques

The farm planning techniques commonly used to analyse a farming situation include budgeting, gross margin analysis, linear and quadratic programming, and dynamic programming (Agrawal and Heady, 1972; Hezell and Norton, 1986; Kay, 1986). The farm planning techniques have advantages and limitations that determine their suitability in this study. Budgeting techniques are used for estimating future farm income and expenditures in order to assess the future position of the farm with regard to capital requirement and expected profitability (Norman et al., 1985). The budgeting techniques include partial and complete budgeting methods. Partial budgeting is used to analyse relatively small change in the existing farm plan. Complete farm budgeting is used to evaluate major changes in an existing farm plan. The advantage of budgeting techniques in farm planning is that they involve simple calculations and the results can be easily interpreted. The main limitation of budgeting techniques in farm planning is that they can not provide optimal farm plans thus they are not appropriate for this study because one of the objectives is to determining optimal farm plans for smallholder dairy farmers in Kitui district.

Gross margin analysis and linear programming techniques are used in farm planning to evaluate the profitability of enterprises and returns to factors of production (land, labour and capital). Gross margin of an enterprise is calculated as the difference between total revenue and total variable cost. The gross margins of crop enterprises are expressed per unit area (hectare or acre) while for dairy activities gross margins are calculated per cow (Norman *et al.*, 1985; Kay, 1986). Gross margin analysis form the basis of more advanced mathematical techniques such as linear programming (Alford *et al.*, 2003). The gross margins (per unit area and per cow) are incorporated as coefficients in linear programming models. Gross margin analysis can be used to determine competitiveness of farm enterprises based on returns to factors of production and the contribution of an enterprise to total farm income. Linear programming is used in farm planning to generate optimal farm plan and identify the limiting resources. Enterprises included in the optimal farm plans are considered to be competitive compared to those excluded from the plan. Linear programming and gross margin analysis are the main methods adopted in this study because of their advantages compared to other farm planning techniques.

3.3 Analytical Models

3.3.1 Gross Margin Model

Gross margin analysis is use in farm planning to evaluate the performance of farm enterprises (Makeham&Malcolm, 1986). Gross margins of crop and dairy enterprises are estimated and compared base on their profitability and returns to land, labour and capital. The gross margin of an enterprise is the difference between gross revenue and variable costs of production. A gross margin model can be written in equation form as shown by equation 1.

$$GM_j = \sum_{j=1}^{n} X_j P_{xj} - \sum_{j=1}^{n} U_j \quad (1)$$

Where:

GM_j = gross margin per unit of the j^{th} farm enterprise.

X_j = quantity of output per unit of the j^{th} farm enterprise.

P_{xj} = price per unit of output of the j^{th} farm enterprise.

U_j = total variable cost per unit of j^{th} farm enterprise.

n = number of farm enterprises.

j = 1, 2, 3…n.

The competitiveness of crop (maize, beans, maize/ beans and maize/pigeon peas intercrops) and dairy enterprises was assessed based on the contribution of an enterprise to total farm gross margin, gross margin per unit of land (GM/Ha) and gross margin per unit of variable cost (GM/Vc). Gross margin per unit of land and capital are measures of returns to factors of production. Enterprise with higher returns to resources and contribution to total farm gross margin are considered to be more competitive. This approach has been used by Bagazonzya (1980) to compare the performance of pig, dairy and crop enterprises in Nyeri district. Hanyani (1998) also used the same approach to assess the viability of smallholder dairy production in Zimbabwe.

Gross margin of the dairy enterprise was calculated as the difference between the total revenue from milk and the total variable cost of production. Milk consumed by the household was valued based on the market price and included in the total revenue of the dairy enterprise. The variable costs include expenditures on feeds (concentrates, mineral salts, by-products and fodder), veterinary services (drugs, acaricides Artificial Insemination and bull services) and hired labour. Gross margins of crop enterprises are estimate as the difference between total revenue and total variable cost. The variable costs include expenditures on inputs (seeds, fertilizers and pesticides), family and hired labour. Where family labour is used in production, its value is computed based on its opportunity cost of off-farm employment. Family labour is often considered as a fixed cost but when it is used in different farm activities it should be considered as a variable cost (Duffy and Darnell, 2007).

3.3.2 Linear Programming (LP) Model

Linear programming is a method used in farm planning to determine a profit maximizing combination of farm enterprises that is feasible with respect to a set of fixed farm constraints namely labour, land and capital (Hazell and Norton, 1986). Linear programming model has three components namely objective function, alternative activities for attaining the objectives and resource constraints (Agrawal and Heady, 1972; Hazell and Norton, 1986). A conventional linear programming model can be written as show by equation 2.

$$Max \quad Z = \sum_{j=1}^{n} C_j X_j \qquad (2)$$

$$subject \quad to:$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i$$

$$X_j \geq 0$$

$$j = 1,2 \ldots. n \quad ; \quad i = 1,2 \ldots.. m$$

Where Z –Total gross margin (TGM)

C_j = gross margin of the j^{th} activity (enterprise).

X_j = level of the j^{th} farm activity.

a_{ij} = quantity of the i^{th} resource required to produce a unit of the j^{th} activity.

b_i = amount of the i^{th} resource available.

n = number of activities (enterprises).

3.3.2.1 Assumptions of Linear Programming Model

The use of linear programming models as an analytical and planning tool is based on various assumptions that should be fulfilled if the results generated by the model are to be considered valid for decision-making. The basic assumptions of a conventional linear programming model include linearity, single value expect, additivity of resources and activities, and proportionality (Agrawal and Heady, 1972; Hazell and Norton, 1986).

a) Linearity

Linear programming is based on the assumption that the objective function and resource constraints are linear inequalities. This assumption implies that there is linear relationship between output and inputs. The economic implication of linearity in production economics is that constant returns to scale prevail and the net value of the objective function is independent of output of the various activities.

b) Single value expectation (deterministic)

The implication of this assumption is that a linear programming model use exact and not probabilistic or estimated data. The coefficients of objective function (C_j), input-output coefficients (a_{ij}), resource supplies (b_i) and prices of inputs and output are considered to be known with certainty. This assumption ignores risks common in any production system.

c) Additivity of resources and activities

According to this assumption, the total amount of resources used by different activities must be equal to total quantity of resources used by each activity. This implies there is no interaction between the activities.

d) Proportionality of activity level and resources

Proportionality assumption implies there is linear relationship between activities and resources. This assumption implies that output is directly proportion to level of input used in production. This assumption ignores the law of diminishing marginal returns that states that as equal increments of a variable resource are added to a fixed resource at some point output will decline (Ackello-Ogutu and Waelti, 1990).

3.3.2.2 Advantages of Linear Programming

Linear programming model has advantages over other farm planning methods such as budgeting, quadratic and dynamic programming (Alford *et al.*, 2003). Linear programming technique produces an optimal farm plan that shows combination of farm enterprises that maximizes income subject to resource constraints. Besides determining the optimal farm plan, a linear programming model provides additional information including marginal value products (shadow prices) of resources used in production. The marginal value products of resources are derived from the dual prices of the optimal solution (Barnard and Nix, 1979;Alford *et al.*, 2003). Marginal value product of resources shows the sensitivity of the optimal farm plan to changes in the gross margins of enterprise included in the plan. The marginal value products for resources indicate how much a farm manager could pay for using an additional unit of limiting resources. Linear programming can be used to distinguish limiting resources from non-limiting resources. This information is useful in suggesting how to allocate the available resources to the various farm activities (Barnard and Nix, 1979, Alford *et al.*, 2003).

Linear programming model can be used to analyse for risk through sensitivity analysis. Sensitivity analysis is a post-optimality analysis used to assess how changes in the gross margin of enterprises could affect the optimal farm plan. Risks in farm planning arise from unanticipated changes in input and output prices. and variability of crop and livestock yield. The assumptions of any economic model such as linear programming are subject to change and sensitivity analysis can investigate the impacts of the changes on the optimal solution (Pannell. 1997). Linear programming model can analyze complex situation common in farm planning (Barnard and Nix, 1979). Farmers are faced with the problem of selecting the most profitable combination of enterprises among the possible alternatives and how to allocate the available resources to the farm enterprises (Kay, 1986).

3.3.2.3 Limitations of Linear Programming Model

Although linear programming model has been used widely in farm planning it has limitations. The model is a relatively complex system that requires knowledge of matrix construction and interpretation of the results. Precise and accurate data is required for proper modeling of complex situations. In farms where records are not kept, it is unlikely to get data that can give reliable results (Barnard and Nix, 1979; Alford et al, 2003). However this is not a strong argument to disqualify the use of linear programming model since other methods of planning such as budgeting are also based on estimated data.

Limitations of linear programming technique are also related to the basic assumptions underlying the use of the model. Linear programming model assumes that there is one linear objective function to be maximized subject a set of linear constraints. However in actual farming situation, farmers aim at maximizing multiple objectives (Upton, 1987; Abdulkadri & Ajibefun, 1998). Profit maximization may be regarded as the most important short-term objective but farmers may aim at achieving adequate food supply and stable income. The problem of multiple objectives can be solved if one major objective is identified for maximization and the other objectives are specified as constraints (Loomba, 1978; Hazell and Norton, 1986).

Linear programming model are used in farm planning based on the assumption of single value expectation. This means that resource supplies, input-output coefficients, gross margins of enterprises are known constant (Hezell *et al.*, 1986). However changes in climatic conditions especially rainfall may cause variability of yield while government policies on marketing of commodities, changes in commodity supply and consumer preference cause price variability. Yield and price variability cause fluctuations in the coefficients (gross margins) of the objective function although they are expected to remain constant throughout the planning period. In this study, sensitivity analysis was carried to assess the ranges within which the optimal solution remained stable despite changes in gross margins of enterprises and resource supplies.

Specific Linear Programming Model

The specific linear programming model used for the study is specified as shown by equation 3.

$$\text{Max } Z = \sum_{j=1}^{n} C_j X_j \qquad (3)$$

Subject to: $\sum_{j=1}^{n} l_{sj} X_j \leq L_s$ Land constraint. S =1 or 2

$\sum_{j=1}^{n} K_j X_i \leq K$ Working capital constraint

$\sum_{j=1}^{n} M_{ij} X_i \leq M_i$ Labour constraint, i = 1, 2 . . . 12

$X_j \geq M_z$ Minimum area constraint for subsistence maize (Ha)

$X_j \geq B$ Minimum area constraint for subsistence beans (Ha)

$X_j, L_i, K, M_i, Mz, B \geq 0$

Where

Z - Total farm gross margin (TGM)

C_j - Gross margin per unit (cow or hectare) of the j^{th} enterprise

X_j - Units of resource required to produce a unit of the j^{th} enterprise.

L_s -Total available land (Ha) in seasons, S = 1 or 2 for short and long rain season respectively

M_i - Total labour available (man-hours) in the j^{th} month.

M_{ij} - Labour requirement per unit of the j^{th} enterprise.

l_{sj} . Land allocated to the j^{th} enterprise.

K_j - Working capital requirement per unit (cow or Ha) of j^{th} enterprise.

K- Total available capital available per year (Ksh).

M_z - Hectares allocated to maize for subsistence requirement.

B - Hectares allocated to beans for subsistence requirement.

Objective function

The objective function is specified as the maximization of total farm gross margin subject to land, labour, operating capital and minimum subsistence requirement constraints. The coefficients of the objective function are gross margins of crops and dairy enterprises expressed on the basis of per cow and per hectare of crop and dairy enterprises respectively. The total farm gross margin is the sum of gross margins of all enterprises in the farm plan.

Resource and non-resource constraints

The resource and non-resource constraints specified and incorporated in the linear programming model are land, labour, operating capital and minimum subsistence requirement.

a) Land constraint

Two land constraints are specified based on rainfall seasons in the study area. In Kitui district there are two rainfall seasons namely the short and long rainfall seasons (Jaetzold and Schimdt, 1983). The short rain season is from November to December while the long rain season is from April to May. The two constraints are land available for various farm uses during the short rain season and land available during the long rain season. Nguta (1992) also defined land constraints based on rainfall seasons in Machakos district.

b) Labour constraints

Twelve labour constraints were specified and incorporated in the linear programming model. The labour constraints were derived from the monthly labour requirements for crops and dairy enterprises. Farm labour is provided by family members, permanent and casual labourers. The amount of labour available in the farm depends on household size and structure, age and the number of hours worked in a day. Adults (persons who are 18 years and above) work for twenty-six days in a month. Children (those in school) provide their work for two days during the weekends while during the months of April, August and December they work for twenty-six days. Labour supplied by categories (children and adults) of people in the farm depends on their age (Robert, 1997). A weighting system developed by Norman (1973) as quoted by Wanzala, (1993) was used to discount labour supplied by people in different age brackets. The weights used to discount labour are presented in table 3.1.

Table 3.1 Weighting System for Farm Labour

Category	Age (years)	Man equivalent
Children	Below 18	0.5
Adult	18 – 55	1.0
Adult (aged)	More than 55	0.5

Source: Adopted from Norman (1973)

c) Operating capital

Operating capita was estimated as the total cash expenditure incurred in the purchase of inputs and other services required for crop and dairy production. The operating capital included expenditures on inputs (seed, fertilizer, chemicals, cost of artificial insemination services, purchase of concentrates) and casual labour. Nguta (1992) and Barasa (1989) have used the same approach to estimate total operating capital.

d) Subsistence constraint

Smallholder farmers strive to achieve household food security allocating a proportion of the available land for production of subsistence (Golam *et al.*, 2001). Maize and beans are the main subsistence crops in Kitui district. Two subsistence constraints for maize and beans were specified and incorporated in the linear programming model in terms of the minimum land size farmers allocate to these crops for household consumption. During the field survey farmers were asked to estimate the minimum land size allocated to maize and maize for subsistence. The constraint were included in the linear programming model to show how decision by farmers to include subsistence crops in the farm plan could affects enterprise combination and total farm income.

Other researchers (Nguta, 1992; Wanzala, 1993, Mukumbu, 1987; Nyikal, 2000; Golam *et al.*, 2001) have incorporated the subsistence constraint in linear programming mode but they have used different approaches to estimate and specify the constraint. Nguta (1992), Wanzala, (1993) and Nyikal, (2000) estimated the subsistence constraint based on land size required for the production of maize and beans for household consumption. Total food requirements of an average household are calculated base on number of people in a household and annual food requirement per person. The total food required by a household and the average crop yields are used to calculate the minimum land size required for production of adequate food for a household. This approach can be criticized because calculation of the minimum land size based on average yields and total food required could suggest land sizes that could be above the total land available to the farmer. Mukumbu (1987) estimated the subsistence constraint in terms of the amount of money required for the purchase of adequate food for an average household.

Technical coefficients for activities

The technical coefficients of activities refer to the input-output coefficients. The coefficients represent the amount of resources required per unit of activity. The coefficients K_i and (M_{ij}) represents the amount of variable cost and labour required per hectare of crop and per cow respectively.

3.4 Farm Model Specification

Farm models were specified after the field survey based on farm sizes because resource endowment and other socio-economic variables were found to vary considerably with farm sizes. The farm models specified for this study are small, medium and large categories. Data collected from the field was divided into three equal classes and the average value of the farm sizes in each category was calculated to determine the average farm model. The average farm model approach has been used by other researchers (Wanzala, 1993; Mburu, 1991; Barasa, 1989). The farm models specified for this study are presented and discussed in chapter four.

3.5 The Study Area

The field survey was carried in Kitui district of Eastern Province. The district borders Machakos and Makueni districts to the West, Mwingi, Tana- River and Taita- Taveta districts to the North, East and South respectively. The district is located between longitudes 37^0 45' and $39^0$0' East and latitudes $0^0$3.7' and $3^0$0' South. The district covers an area of approximately 20,402 square kilometers that include 609.30 square kilometres occupied by Tsavo national park. Kitui district has 10 administrative divisions namely Chuluni, Yatta, Matinyani, Mutonguni, Mutitu, Ikutha, Mwitika, Mutomo, Mutha and Central (G.O.K, 2002). According to Jaetzold and Schmidt, (1983) Kitui district is classified among the semi areas in agro ecological zones four (upper midland zones) and five (lowland zones). There are two distinct rain seasons namely short season between the months of November and December, and long rain season between April and May. The average annual rainfall is between 750mm and 1,150mm (Jaetzold and Schmidt, 1983; G.O.K. 2002).

The main economic activities in Kitui district are crop and livestock production. The major food crops grown are maize, beans, sorghum, pigeon peas, cowpeas, cassava, green grams and millet. Maize and beans production is concentrated in the central part of the district where rainfall is relatively high. Millet and cowpeas are the major crops grown for subsistence purpose in the lowlands where rainfall is unreliable. Cotton, mangoes, paw paws and tobacco are the major cash crops grown in the district. Coffee is grown by few farmers in Central and Mutonguni divisions where there are pockets of transitional marginal coffee zones (Jaetzold and Schmidt, 1983).

Livestock production activities are carried out in all divisions but the types and number depend on farm sizes and population densities (G.O.K. 2002). Majority of the farmers in the lowlands where rainfall is unreliable and population density is low, keep indigenous Zebu cattle, goat and sheep for meat and milk. The cattle main breeds include Small East African Zebu (SEAZ) and crosses of Boran and Sahiwal. The land carrying capacity in the lowlands is 5 hectares per livestock unit (G.O.K, 1997). Small scale intensive and semi-intensive dairy farming is practiced in Central, Matinyani, Chuluni and Mutonguni divisions where the rainfall is relatively higher, population density is high, farm size are small to medium scale and the land carrying capacities range from 2 hectares to 4.5 hectares per livestock unit (G.O.K, 1997). The dairy breeds kept include Friesian, Ayrshire, Jersey, Guernsey and their crosses. The dairy cattle herd contributed 20% of the total milk consumed in the district while the local

Zebu cattle account for 40%. Brookside, Premier Dairies, Spinknit, Masii and Wamunyu farmers Cooperative Societies supply 40% of the total milk consumed in Kitui (MOLFD, 2003).

3.6 Data Requirements and Sources

Primary data were required for the study and smallholder dairy farmers were interviewed to get the relevant information. The information required includes demographic characteristics (age, level of education, household size and structure, subsistence food requirement occupation) of farmers, resource (land, labour and operating capital) availability and utilization, main crops grown and production levels. The data on dairy production required include dairy production systems, breeds, milk production and marketing channels, qualities and cost of dairy feeds and minerals.

3.7 Sampling Procedure

Kitui district was purposively selected as a representative case of semi arid areas. The district has 10 administrative divisions but dairy production is practiced in four divisions namely Central, Chuluni, Matinyani and Mutonguni. A table of random numbers was used to select three out of the four divisions where dairy production is practiced. Central, Chuluni and Matinyani divisions were selected and a list of dairy farmers for each division was complied and used as the sampling frame. A sample of 40 farmers was selected from the list of farmers in each division using a table of random numbers. All farmers in the sampling frame had equal chances of being chosen. The number of farmers identified to be interviewed was 120 and this sample represents 13% of the 922 farmers practicing dairy production in Kitui district. Mugenda and Abel (1999) suggest that a sample that represents 10% of the population under investigation is adequate for any study. However when the population is large a sample of 100 to 1000 respondents is adequate (Pamela and Setter, 1985).

3.8 Data Collection

Field survey was conducted between October and November 2005. Data was collected is for the 2004/2005 cropping period (long and short rainfall seasons). Three enumerators were recruited and trained for two days on basic principles of data collection and how to administer questionnaires. Prior to actual data collection, the questionnaire was pre-tested by the researcher and the enumerators in five farms. The questionnaire was reviewed to fill the information gaps identified during pre-testing.

The enumerators visited and administered the questionnaires to all the farmers identified to be interviewed. The interviews were conducted on the farms and where farm records were available they were used to verify some of the information given by farmers. In farms where records were not available, the information collected was based on estimations made by the farmer. Errors of estimations were taken care of during data analysis by conducting sensitivity analysis. Although the survey targeted 120 farms, the response rate was 96% since farmers four failed to give information on the dairy activities. Data was analyzed for 116 farmers who successfully responded to the questionnaire.

3.9 Data Analysis

The data collected from the field survey were analysed by different methods so has to achieve the objectives stated for the study. The main analyses carried out include descriptive, gross margin, linear programming and sensitivity analyses.

3.9.1 Descriptive Analysis

Descriptive analysis was carried to give an overview of the characteristics of smallholder dairy farmers and also to describe the existing farming system of the area surveyed. The analysis involved calculation of average values, percentages and cross tabulation of the key variables. The variables subjected to descriptive analysis include education, household and farm sizes, labour, capital, crop and milk yields among others. Descriptive analyses form the basis for gross margin and linear programming analyses.

3.9.2 Gross Margin Analysis

Gross margin analysis was carried out to assess the competitiveness of dairy compared to crop enterprises. The analysis involved estimation of returns to land, labour and operating capital by individual enterprise and the relative profitability of the enterprises. Gross margin analysis was also used to determine and describe the existing farm plans. Contribution of dairy production to total farm income was also determined and compared to contribution from crop enterprises. The results from gross margin analysis were subsequently used in linear programming analysis. The average gross margins of crop and dairy enterprises (expressed per hectare and per cow) were used as coefficients in the objective function of linear programming model.

3.9.3 Linear Programming Analysis

Linear programming analysis was used to determine optimal farm plans and the most limiting resources to agricultural production. An optimal farm plan is the one that maximizes net farm income subject to specified constraints. Optimal plans were developed for a situation with subsistence constraint incorporated into the linear programming model and another analysis was carried out without the subsistence constraint. Such analysis was necessary because the study assumes that household subsistence needs influence production decisions.

3.9.4 Sensitivity Analysis

Sensitivity analysis is a post optimality analysis carried out after an optimal solution has been obtained from a linear programming model. Sensitivity analysis shows how changes in the parameters (C_j, a_{ij}, b_i) of the linear programming model affect the optimal solution (Loomba, 1978). In actual farming situation the gross margins (C_j) may change as a result of fluctuations in livestock and crop yields caused by adverse weather conditions. Prices of crop and livestock products may vary with season. Sensitivity analysis was carried out to establish the range (lower and upper limits) of the objective function coefficients and resource supply within which the optimal plans remained unchanged.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Results of Descriptive Analysis

Results of descriptive analysis are used to describe the socio-economic characteristics of smallholder farmers and existing farming systems in Kitui district. Farming system shows classification of farms based on sizes, cropping patterns and dairy production activities.

4.1.1 Socio-Economic Characteristics of Dairy Farmers in Kitui District.

4.1.1.1 Level of Education

Table 4.1 Level of Education of Dairy Farmers in Kitui District.

Education level	Number of respondents	Percentage
Never been to school	7	6
Primary school	24	21
Secondary school	36	31
College	45	39
University	4	3
Total	116	100

Source: Author's survey 2005

Table 4.1 shows that majority of the respondents interviewed have acquired formal education. About 94 % of the respondents have formal education while 6 % of respondents have never been to school. Farmers with formal education are more likely to adopt appropriate dairy production technologies such as zero grazing. Nyangito, (1986) found that adoption of new and improved technologies in agriculture was positively related to level of education.

4.1.1.2 Household Size and Structure

The study found that the average household size is 6 people and it is composed of four adults and two children. The structure of the household determines the supply of labour for the farming activities. Children are available for farm activities during the weekends and holidays while adults may work part time or full time depending on their other commitments. A household with many children in school may experience labour shortages because they are not available for farm activities. The average age of the respondents is 48 years with a range of 29 years to 84 years. The farmers have on average 6.6 years of experience in dairy production. This shows that dairy production base on exotic breeds in Kitui district is a relatively new venture.

4.1.2 Description of Existing Farming Systems

4.1.2.1 Farm Classification

The farms surveyed were classified into three categories namely small, medium and large categories based on farm sizes. Table 4.2 shows that 88 % of the farms were in the small farm category. In this category, the average farm size is 1.8 hectares within the range 0.2 hectares to 3.99 hectares. This is an indication that majority of farmers in Kitui have small farms for agricultural activities. Medium and large farm categories accounted for 9 % and 3 % of the surveyed farms respectively.

Table 4.2 Farm Classification

Category	Average farm size (Ha)	Size range (Ha)	Number of farmers	% of total sample
Small farm	1.80	0.20 to 3.99	102	88
Medium farm	4.90	4.00 to 7.99	10	9
Large farm	10.00	8.00 to 12.00	4	3
Total			116	100

Source: Author's survey 2005

4.1.2.2 Land Tenure Systems

In Kenya land tenure system is classified into three broad categories namely; communal land, government trust land and privately (freehold) land (G.O.K, 2003b). This study found that the land tenure systems in the area surveyed are communal and freehold ownership. Table 4.3 shows that 97% of the farmers are under freehold land tenure system while 3%

of the farmers are under communal land tenure system. Communal tenure system gives farmers the right to use the land but they have no title deeds for the land. The problem of communal land tenure system is that farmers have no incentives to conserve and use the land efficiently. Under freehold land tenure system, farmers have title deeds for the land that gives them incentives to invest in conservation of the land. Title deed can be used as collateral to secure loans from financial institutions for long-term investment in agricultural activities such as dairy farming.

Table 4.3 Land Tenure Systems in Kitui District

Land tenure system	Farm category			Number of farmers	Percentage
	Small	Medium	Large		
Communal	3	1	0	4	3
Freehold	99	9	4	112	97
Total	102	10	4	116	100

Source: Author's survey 2005

4.1.2.3 Subsistence Food Production

Maize and beans are the main staple food consumed in most of the households in Kenya (G.O.K. 2004). Table 4.4 shows how farmers allocate land to maize and beans for household consumption.

Table 4.4 Minimum Land Size Allocated to Maize and Beans for Subsistence in Kitui District

Farm category and size	Maize (Ha)	Beans (Ha)	Average area under Maize and Beans	% of total farm size
Small farm (1.80Ha)	0.65	0.42	1.07	59
Medium farm (4.90Ha)	1.46	0.56	2.02	41
Large farm (10.00Ha)	3.00	0.60	3.60	36

Source: Author's survey 2005

Table 4.4 indicates that the minimum land allocated to maize and beans production to meet the household subsistence needs vary with farm size. Farmers with small farms allocate 59% of the land to subsistence crops while those with large farms allocate 36% of their land to subsistence crops. Maize crop was allocated more land compared to beans in the three farm categories. Maize is the main staple food in Kenya (G.O.K, 2004).

4.1.2.4 Resource Availability and Allocation

a) Land availability and allocation

Farmers allocate the available land for various uses such as crops, pasture, fodder and homestead. Figures 1 to 3 shows how land is allocated for the various use.

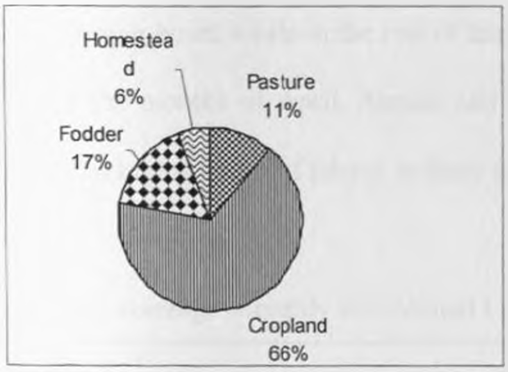

Figure 1: Land allocation in small farms.

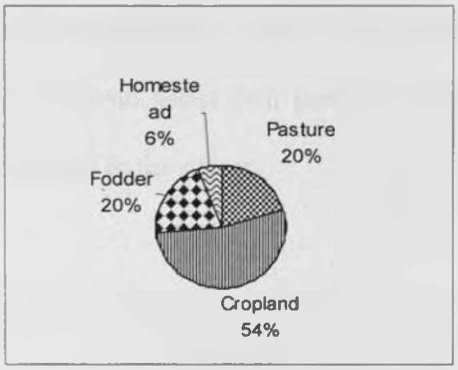

Figure 2: Land allocation in medium farm

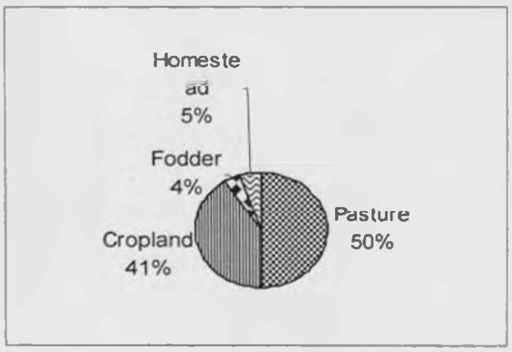

Figure 3: Land allocation in large farms

Figures 1 to 3 shows how farmers with different farm sizes allocate land for the various uses. Crop production is allocated 66%, 54% and 42% of the available land in the small, medium and large farms respectively. Figures 1 and 2 indicate that crop production is allocated more than half of the land in the small and medium farms. Fodder production occupied 17 %, 20 %

and 4 % of the land in the small, medium and large farms respectively. Fodder production is allocated large proportion of the land in the small and medium farms than in the large farms. Farmers in the small and large farm categories keep dairy animals under zero grazing system hence fodder crops such as Napier graze are grown to supply feed to the animals.

b) Labour availability

Labour for an average household was estimated for all the months and quantified to get the annual labour supply. Table 4.5 shows that the average annual labour supply for an average household is 9,657 man-hours. Labour supplies for the months of April, August and December are 999 man-hours while in the rest of the months of the year labour supply is 740 man-hours. During the months of April, August and December, children assist their parents in the farm hence the high amount of labour in those months compared to the others.

Table 4.5 Average Monthly and Annual Labour Supplies for Household, in Kitui District.

Month	Man-hours
January	740
February	740
March	740
April	999
May	740
June	740
July	740
August	999
September	740
October	740
November	740
December	999
Total annual labour supply (Man –hours)	9,657

Source: Author's survey 2005

c) Operating capital availability and allocation

Table 4.6 shows the total capital available to farmers with different farm sizes and the proportions of capital allocated to crop and dairy enterprises. The total operating capital available to farmers with small, medium and large farms is ksh 46,181, ksh 42,186 and ksh 42,574 respectively. Dairy production is allocated 52%, 59% and 67% of the available capital in the small, medium and large farm categories respectively. Dairy production requires more capital compared to crop production. Dairy feeds such as concentrates, mineral salts, de-wormers and acaricides are expensive.

Table 4.6 Capital Availability and Allocation in Different Farm Categories in Kitui District

Enterprise	Small farm (1.80 Ha)		Medium farm (4.90Ha)		Large farm (10.00Ha)	
	Capital allocated (kshs)	% of total capital	Capital allocated (kshs	% of total capital	Capital allocated (kshs	% of total capital
Maize -SRS	3,134	7	2,662	6	5452	13
Maize - LRS	2,519	5	1,925	5	3,432	8
Maize/pigeonpeas - SRS	2,957	6	3,723	9	-	-
Maize/pigeonpeas -LRS	2,010	4	1,666	4	-	-
Beans -SRS	1,864	4	2,262	5	2,755	6
Beans -LRS	1,733	4	1,573	4	2,493	6
Maize/beans -SRS	3,922	9	3,577	8	-	-
Maize/beans -LRS	4,238	9	-	-	-	-
Dairy	23,804	52	24798	59	28,442	67
Total	46,186	100	42,186	100	42,574	100

Source: Author's survey 2005

4.1.3 Dairy Production Activities

4.1.3.1 Dairy Production Systems

Table 4.7 show that 75% and 22% of the respondents practice zero grazing (stall feeding) and semi grazing production systems respectively while 3% of the respondents practiced extensive grazing. These results reveal that zero grazing is the most preferred dairy production system. Zero grazing dairy production system is a labour and capital intensive activity. The dairy animals are confined in stall where they are feed on Napier grass and supplementary feeds. Dairy feeds such as concentrates, de-wormers, mineral feeds and acaricides are expensive. Labour is required for cutting of grass and marketing of milk. Zero grazing system is an appropriate dairy production method where farm sizes are small.

Table 4.7 Dairy Production Systems in Kitui District.

Production system	Number of farmers	Percentage
Zero grazing	87	75
Semi-zero grazing	25	22
Extensive grazing	4	3
Total	116	100

Source: Author's survey 2005

4.1.3.2 Dairy Cattle Breeds

Figure 4 shows the distribution of breeds in a herd of dairy animals in Kitui district. Ayrshire and Friesian are the dominant breeds that account for 39% and 38% of the total cattle herd respectively while Guernsey, Jersey, Cross breed and Zebu combined account for 23% of the herd. This implies that Ayrshire and Friesian are the preferred breeds and this can be attributed to their milk production ability compared to the other breeds as shown in table 4.9. Staal *et al* (2001) also found that dairy farmers in Maragua, Machakos, and Nairobi districts prefer to keep Ayrshire and Friesian breeds.

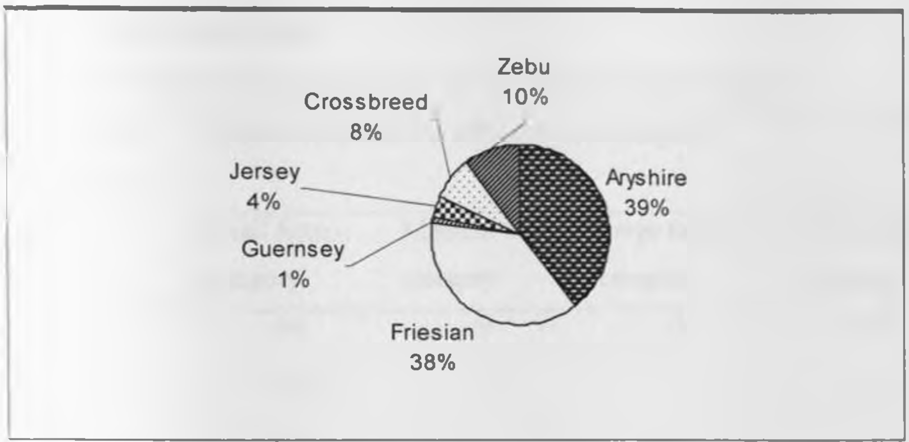

Figure 4: Dairy Cattle Breeds

4.1.3.3 Dairy Herd Structure

Figure 5 shows the structure of dairy animals kept by farmers in Kitui district. Herd structure refers to the different classes or categories of animals within the dairy herd. The dairy animals were classified into cows in milk, dry cows (in-calf), bulls and heifers (greater or less than one year). 46% of the herds were cows in milk while 5% were in-calf cows. Heifers and bulls (greater than one year) accounts for 17% and 14% of the herd respectively. Heifers are retained in the farm as replacement stock or for expansion of the dairy enterprise.

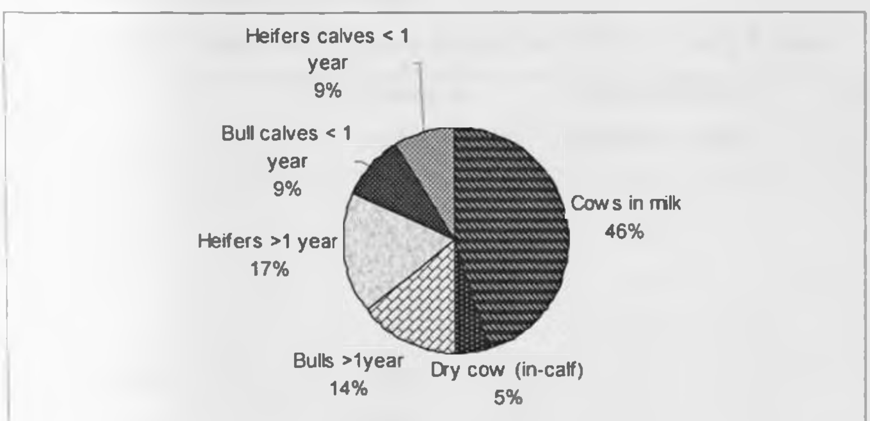

Figure 5: Herd Structure

4.1.3.4 Milk Production

Table 4.8 Distribution of Dairy Cows in Different Farm Categories

No.of cows per farmer	Number of farmers in different farm categories				Percentage
	Small farm category	Medium farm category	Large farm category	Total number of farmers	
1 or 2	90	9	3	102	88
3 or 4	11	0	1	12	10
5 or 6	1	1	0	2	2
Total	102	10	4	116	100

Source: Authors survey 2005:

Table 4.8 shows that 88% of the farmers interviewed keep 1 or 2 dairy cows while 2% of the farmers keep over 5 dairy animals. The small farm category has the highest number of farmers keeping 1 or 2 dairy cows. In the small farm category, the average farm size is 1.8 hectares and 66% of the land is allocated for crop production. Due to the small farm sizes, majority of the farmers keep few dairy animals. These results reveal small-scale producers dominate dairy production in Kitui.

4.1.3.5 Dairy Cattle Performance

Table 4.9 Milk Yield and Lactation Period for Different Dairy Breeds

Breed	No. of cows in milk	Average milk yield (litres/cow/ day)	Average lactation period (days)
Ayrshire	89	9	253
Friesian	69	10	285
Guernsey	1	13	200
Jersey	9	8	232
Cross breed	19	6	253
Zebu	10	3	231

Source: Author's survey, 2005

The performance of the dairy animals was assessed based on the productivity per cow and the lactation period. Lactation period is the duration that a cow produces milk. Table 4.9

shows the average daily milk production per cow and lactation period. Friesian produces 10 litres of milk per day and it has a lactation period of 285 days. Aryshire produces 9 litres of milk per day and it has a lactation period of 253 days. Farmers keeping Friesian and Aryshire breeds are assured of steady income for about 8 to 10 months from milk sales.

4.1.3.6 Milk Utilization and Marketing

Figure 6 shows that household consume 12% of the total milk produced and 88% of the milk is sold to neighbours, local schools and hotels. 61% of the milk is sold to neighbours, 22% and 5% to local hotels and schools respectively. The high proportion of milk sold to neighbours is an indicator of high local demand for milk. Staal *et al.*, (2001) also found that farmers in milk deficit areas of Machakos, Narok and Nairobi sell milk to neighbours. They also receive higher prices for their milk than those in Nyandarua and Nakuru districts where milk is surplus. The average price of milk in Kitui district is Ksh 35 per litre. These prices are high compared to of Ksh. 15.2 and 14.3 per litre of milk in Kiambu and Nyandarua districts respectively in the year 2000 (Staal *et al.*, 2003). The high prices of milk could be one of the driving forces toward dairy production in some parts of Kitui district.

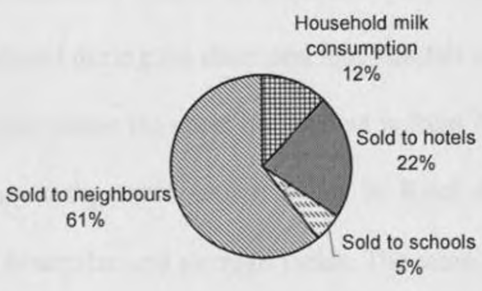

Figure 6: Milk Utilization and Marketing Channels in Kitui District

4.1.3.7 Other Types of Livestock

Besides cattle, other types of livestock kept by farmers in Kitui district are poultry, goats and sheep. Table 4.10 indicates that 93% of the farmers keep poultry while sheep and goats are kept by 2% and 65% of the farmers interviewed. Poultry production requires less land compared to other types of livestock (Isaboke, 1995). Small scale dairy farmers with small farm sizes can diversify farm activities by keeping poultry so as to improve farm income.

Table 4.10 Other Types of Livestock

Livestock type	Number of farmers	Percentage of total number of farmers	Average number of animals per farmer
Sheep	2	2	5
Goats	78	65	6
Poultry	111	93	24

Source: Author's survey 2005

4.1.4 Crop Production

Crop production is an important source of food and income for smallholder farmers in Kitui district. Crops are produced during the short and long rainfall seasons. The long rainfall season is between April and May while the short rain season is from November to December (G.O.K. 1997). Table 4.11 shows the main crops grown in Kitui district, the proportion of land allocated to each crop enterprise and average yields. The main crops grown in Kitui district are maize, maize/pigeon pea intercrop, beans, and maize/ beans intercrop. Maize and maize/beans intercrops are allocated more land compared to the other crops in all seasons. Maize and beans are the main staple food crops for most households in Kenya. The table also shows that crop yields vary with the rainfall season. Crops grown during the short rain season have higher yields compared to those produced during the long rain season. The short rain season is more reliable for crop production compared to the long rain season (Jaetzold and Schmidt, 1983). These results suggest that farmers could improve their livelihoods by devoting more resources and efforts to crop production during the short rain season.

Table 4.11 Major Crops and Average Yields, in Kitui District

Crop enterprise	Short rain season			Long rain season		
	No. of farmers	Average area (Ha)	Yield (bag/Ha)	No. of farmers	Average area (Ha)	Yield (bag/Ha)
Maize	74	1.13	10.80	67	1.03	3.10
Maize pigeon peas	28	0.64	1.30	28	0.64	6.30
Beans	88	0.38	7.20	70	0.36	1.50
Maize/beans	23	0.83	10.10	19	0.79	1.80

Source: Author's survey, 2005.

4.2 Results of Gross Margin Analysis

Gross margin analysis was carried out to determine the existing farm plans and subsequently the competitiveness of dairy compared to crop enterprises. The existing farm plans show the combination of enterprise in a farm and how resources are allocated to the enterprises. The competitiveness of the dairy enterprise was assessed based on the amount of income it contributes to the total farm gross margin and the returns to land and capital.

4.2.1 Returns to Land in the Existing Farm Plans

Returns to Land (Gross Margin per Hectare) in the Existing Small Farm Plan

Table 4.12 Existing Small Farm Plan, Kitui District (2004/2005 Production Period).

Enterprise	No. of farmers	Average area (Ha)	Gross margin (Ksh/Ha)	Contribution to total farm gross margin (ksh)
Maize -SRS	62	0.80	1,1351	9,051
Maize -LRS	58	0.73	1.080	789
Maize/pigeon peas -SRS	24	0.58	7,744	4,492
Maize/pigeon peas -LRS	24	0.58	7,727	4,482
Beans -SRS	75	0.35	16,697	5,844
Beans -LRS	61	0.34	-397	-135
Maize/beans- SRS	22	0.81	6,865	5,561
Maize/beans -LRS	19	0.79	-2,913	-2,302
Dairy	102	0.31	174,996	54,249
Total Farm Gross Margin (Ksh)				82,031

Source: Author's survey 2005

Note: a) SRS refer to Short rain season b) LRS refer to Long rain season

Table 4.12 shows the contribution of crop and dairy enterprises to total farm gross margin and the returns to land in the existing small farm plan. The annual total farm gross margin achieved from the existing farm plan is Ksh 82,031. The dairy enterprise contributes Ksh 54,249 to the total farm gross margin while maize and beans produced during the short rainfall season contributed Ksh 9,051 and Ksh 5.844 respectively. The dairy enterprise had a gross margin of Ksh 174,996 per hectare compared with Ksh 11,351 and Ksh 6,865 per hectare for maize and maize/beans intercrops. Based on enterprise contribution to total farm gross margin and returns to land, the dairy enterprise is the most profitable and competitive activity in the small farm plan.

Returns to Land in the Existing Medium Farm Plan

Table 4.13 Existing Medium Farm Plan, Kitui District (2004/2005 Production Period).

Enterprise	No. of farmers	Average area (Ha)	Gross margin (Ksh/Ha)	Contribution to total farm gross margin (ksh)
Maize - SRS	5	1.60	6875	11,000
Maize - LRS	4	1.20	1,137	1,365
Maize/pigeon peas- SRS	3	0.80	1,267	1,014
Maize/pigeon peas -LRS	3	0.80	4,791	3,833
Beans - SRS	7	0.51	14,531	7,411
Beans - LRS	5	0.34	6,441	2,190
Maize/beans SRS	2	1.20	7,787	9,345
Dairy	10	0.96	58,006	55,686
Total Farm Gross Margin (Ksh)				91,844

Source: Author's survey 2005

Note: a) SRS refer to Short rain season b) LRS refer to Long rain season

Table 4.13 shows that the existing medium farm plan is comprised of maize, beans, maize/beans intercrop, maize/pigeon peas intercrop and dairy enterprises. The total farm gross margin achieved in the existing medium farm plan is Ksh 91,844 of which the dairy enterprise contributed Ksh 55,686. Maize and Beans produced during short rainfall season contributed Ksh 11,000 and Ksh 7,411 respectively to the total farm gross margin. The gross margin per hectare for the dairy enterprise is Ksh 58,006 compared to Ksh 14,531 and Ksh 7,787 per hectare from beans and maize/beans intercrop respectively produced during the short rain season. Gross margin analysis of the medium farm plan show that dairy production is more profitable compared to crop enterprise. It has high contribution to total farm gross margin and returns to land. Despite the contribution of the dairy enterprise to total farm gross margin it is allocated 0.96 hectares of land compared to 1.60 hectares to maize during the short rain season.

Returns to Land in the Existing large Farm Plan

Table 4.14 show that in the existing medium farm plan, maize is allocated more land compared to beans and dairy enterprises. The total farm gross margin realized in the existing large farm plan is Ksh 109,075. The dairy enterprise contributed Ksh 67,300 to the total farm gross margin while maize and beans produced during the short rainfall season contributed Ksh 28,713 and Ksh 12,198 respectively. The gross margin per hectare from the dairy enterprise is Ksh 134,600 while the gross margin per hectare of beans produced during the short rainfall season is Ksh 15,247. Maize produced during the long rain season contributed negatively to the farm gross margin. This shows that it is not is not profitable to produce maize during the long rain season. This can be attributed low maize yield that is caused by inadequate rainfall received during the long rain season (Jaetzold and Schmidt, 1983). Farmers can improve the yield through water harvesting for crop production and timely planting of certified seeds.

Table 4.14 Existing Large Farm Plan, Kitui District (2004/2005 Production Period).

Enterprise	No. of farmers	Average area (Ha)	Gross margin (Ksh/Ha)	Contribution to total farm gross margin (ksh)
Maize-SRS	4	3.60	7,975	28,713
Maize -LRS	3	4.00	-325	-1,413
Beans-SRS	4	0.80	15,247	12,198
Beans - LRS	2	1.00	2,277	2,277
Dairy	4	0.25	134,600	67,300
Total Farm Gross Margin (Ksh)				109,075

Source: Author's survey 2005

Note: a) SRS refer to Short rain season b) LRS refer to Long rain season

4.2.2 Returns to Variable Cost (Operating Capital) in the Existing Farm Plan

The returns to variable cost were calculated by dividing gross margin per unit of enterprise by variable cost required to produce one unit of the enterprise. Table 4.15 shows the returns to variable cost in the existing small, medium and large farm plans.

Table 4.15 Gross Margin Per Unit of Variable Cost (Ksh) in Kitui district.

Enterprise	Small Farm (GM/Ksh)	Medium farm (GM/Ksh)	Large farm (GM/Ksh)
Maize- SRS	3.52	6.62	5.65
Maize - LRS	0.46	1.58	-0.02
Maize/Pigeon peas - SRS	4.04	6.14	-
Maize/Pigeon peas - LRS	3.82	1.58	-
Beans - SRS	3.54	4.20	4.53
Beans - LRS	0.04	0.85	1.01
Maize/Beans - SRS	1.41	6.38	-
Maize/Beans - LRS	-0.12	-	-
Dairy	4.42	2.6	1.40

Source: Author's field survey 2005

Table 4.15 shows that the dairy enterprise and maize planted during the short rain season have the highest returns to operating capital. Maize/beans intercrop and maize (pure stand) produced during the long rainfall season have negative gross margin per unit of operating capital in the small and large farm plans. The negative gross margin per unit of operating capital indicates for every shilling spent in maize/beans production during the long rain season farmers lose Ksh 0.12.

4.3 Results of Linear Programming Analysis

Linear Programming (LP) analysis was used to determine the optimal farm plan and the contribution of the dairy enterprise to the total farm gross margin of the optimal plan. Two sets of optimal farm plans were developed: one with a subsistence constraint incorporated in the linear programming model and the other without g the subsistence constraint. The optimal farm plans were compared to the existing farm plans based on the total farm gross margins, enterprise combinations and levels of resources used in production.

4.3.1 Comparison of Existing Farm Plans and Optimal Farm Plans (Without Minimum Subsistence Constraint)

Optimal farm plans were developed from a linear programming model without a subsistence constraint. The optimal farm plans were compared with the existing farm plans to determine whether they were different in terms of enterprise combination and total farm gross margin. The results of the optimal plans developed without the subsistence constraints and the existing farm plans are presented in tables 16 to 18.

Table 4.16.Comparison of existing small farm and optimal farm plan (without minimum subsistence constraint)

Enterprise	Existing small farm plan		Optimal small farm plan	
	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)
Maize -SRS	0.80 Ha	9051	0.00	0.00
Maize- LRS	0.73 Ha	789	0.00	0.00
Maize/pigeonpeas-SRS	0.58 Ha	4492	0.00	0.00
Maize/pigeonpeas-LRS	0.58 Ha	4482	0.00	0.00
Beans -SRS	0.35 Ha	5844	0.00	0.00
Beans -LRS	0.34 Ha	-135	0.00	0.00
Maize/beans- SRS	0.81 Ha	5561	0.00	0.00
Maize/beans - LRS	0.79 Ha	-2302	0.00	0.00
Dairy	1.00 cow	54249	2.00 Cows	108,498
Total Farm Gross Margin (TFGM)		82,031		108,498

Source: Author's field survey, 2005

NOTE: a) SRS refers to Short rain season b) LRS refers to Long rain season

Table 4.16 indicates that the existing farm plan has both crop and dairy enterprises while the optimal farm had only a dairy enterprise. The total farm gross margin that can be realized from the optimal farm plan is Ksh 108,498 compared to Ksh 82,031 achieved in the existing farm plan. The dairy enterprise account for 66% and 100% of the total farm gross margin in the existing and optimal farm plans respectively. The optimal farm plan show that farmers can maximize farm income by keeping two diary cows. Although the optimal farm plan has higher farm gross margin compared to the existing farm plan, it is unrealistic for farmers to rely on dairy production for their livelihood. Due to risks in agricultural production and imperfection of the markets, farmers opt for enterprise diversification as a coping mechanism against risk as reflected by the existing farm plan.

Table 4.17 Comparison f Existing Medium Farm and Optimal Farm Plans (Without Minimum Subsistence Constraint)

Enterprise	Existing medium farm plan		Optimal farm plan	
	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)
Maize -SRS	1.60 Ha	11,000	0.00	0.00
Maize- LRS	1.20 Ha	1,365	0.00	0.00
Maize/pigeon peas-SRS	0.80 Ha	1,014	0.00	0.00
Maize/pigeon peas-LRS	0.80 Ha	3,833	4.08 Ha	19,547
Beans -SRS	0.51 Ha	7,411	0.00	0.00
Beans -LRS	0.34 Ha	2,190	0.00	0.00
Maize/beans- SRS	1.20 Ha	9,343	4.08 Ha	31,771
Dairy	1.00 Cow	55,686	1.00 Cow	55,686
Total Farm Gross Margin (TFGM)		91,844		107,004

Source: Author's field survey, 2005

NOTE: a) SRS refers to Short rain season b) LRS refers to Long rain season

Table 4.17 show that optimal farm plan has few enterprises compared to the existing farm plan. The total farm income earned in the existing farm plan is ksh 91,844 compared to

Ksh 107,004 that would be achieved from the optimal plan. These results revealed that adoption of the optimal farm plan could increase farm income by 17%. The dairy enterprise accounts for 61% and 52% of the total income in the existing and optimal farm plans respectively. The optimal plan suggest that the total farm gross margin could be maximized by keeping a dairy cow, producing 4.08 hectares of maize/pigeon and 4.08 hectares of maize/beans intercrops. A comparison of the optimal and existing farm plans also reveal that there is inefficient allocation of land in the existing farm plan. Maize/beans and maize/pigeon peas intercrops are allocated 0.8 hectares and 1.20 hectares of land respectively but the optimal plan suggest that these crops should be allocated 4.08 hectares in order to maximize the farm income.

Table 4.18 Comparison of Existing Large Farm and Optimal Farm Plans (Without Minimum Subsistence Constraint)

Enterprise	Existing large farm plan		Optimal large farm plan	
	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)
Maize -SRS	3.60 Ha	28,713	0.00	0.00
Maize- LRS	4.00 Ha	-1,413	0.00	0.00
Beans -SRS	0.80 Ha	12,198	10.00	157,470
Beans -LRS	1.00 Ha	2,277	0.59	1,337
Dairy	2.00 cows	67,300	0.00	0.00
Total Farm Gross Margin (TFGM)		109,075		158,807

Source: Author's field survey, 2005

NOTE: a) SRS refers to Short rain season b) LRS refers to Long rain season

Table 4.18 shows that the existing farm plan has crop and dairy enterprises while the optimal farm plan has beans produced during the short and long rainfall seasons. The dairy enterprise has been excluded from the optimal farm plan and this was attributed to low gross margin per cow. The average gross margin per cow in the existing large farm is Ksh 33.650. The total farm gross of the existing large farm plan is Ksh 109.075 compared to Ksh 158.807 that could be earned by adopting the optimal plan. Dairy enterprise contributes 62% to the total farm gross margin in the existing farm plan. The optimal plan suggests that land under beans should be increased from the 0.8 hectares to 10 hectares.

4.3.2 Comparison of Existing Farm Plans and Optimal Farm Plans (With Minimum Subsistence Constraint)

Optimal farm plans were developed from a linear programming model with a subsistence constraint. This analysis was carried to show the effects of including household food requirements in the farm plan. The results generated by a linear programming model with subsistence constraints are presented in tables 4.19 to 4.21.

Table 4.19 Comparison of existing small farm plan and optimal farm plans (with minimum subsistence constraint)

Enterprise	Existing small farm plan		Optimal farm plan	
	Enterprise level (Ha or Cow)	Contribution to TFGM (Kshs)	Enterprise level (Ha or Cow)	Contribution to TFGM (Kshs)
Maize -SRS	0.80 Ha	9,051	0.64Ha	7,240
Maize- LRS	0.73 Ha	789	0.64Ha	691
Maize/pigeonpeas-SRS	0.58 Ha	4,492	0.00	0.00
Maize/pigeonpeas-LRS	0.58 Ha	4,482	0.42 Ha	3,245
Beans -SRS	0.35 Ha	5,844	0.42 Ha	7,012
Beans -LRS	0.34 Ha	-135	0.00	0.00
Maize/beans- SRS	0.81 Ha	5,561	0.00	0.00
Maize/beans - LRS	0.79 Ha	-2,302	0.00	0.00
Dairy	1.00 cow	54,249	1.00 cow	54,249
Total farm gross margin		82,031		72.437

Source: Author's field survey, 2005

NOTE: a) SRS refers to Short rain season b) LRS refers to Long rain season

Table 4.19 indicates that the optimal farm plan has maize produced during the short and long rain seasons, maize/pigeon pea intercrop and beans produced during the short and long rain seasons respectively and a dairy cow. The total farm gross margin that would be achieved in the optimal is Ksh 72,437 while the total farm gross margin earned in the existing farm plan is Ksh 82,031. The existing farm plans has higher total farm gross margin compared to the optimal plan. These results suggest that adoption of the optimal farm plan could lead to reduction of farm incomes by 12%.

Table 4.20 Comparison of Existing Medium Farm Plan and Optimal Farm Plans (With Minimum Subsistence Constraint)

Enterprise	Existing medium farm plan		Optimal farm plan	
	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)
Maize -SRS	1.60 Ha	11,000	1.46	10,037
Maize- LRS	1.20 Ha	1,365	1.46	1,660
Maize/pigeon peas- SRS	0.80 Ha	1,014	0.00	0
Maize/pigeon peas -LRS	0.80 Ha	3,833	1.10	5,270
Beans -SRS	0.51 Ha	7,411	3.40	49,405
Beans -LRS	0.34 Ha	2,190	0.56	3,606
Maize/beans- SRS	1.20 Ha	9,343	0.00	0
Dairy	1.00 Cow	55,686	0.00	0
Total farm gross margin (TFGM)		91,844		69,978

Source: Author's field survey, 2005

NOTE: a) SRS refers to Short rain season b) LRS refers to Long rain season

Table 4.20 show that the total farm gross margin achieved in the existing farm plan is Ksh 91,844 compared to Ksh 69,978 that could be achieved by adopting the optimal farm plan. The optimal farm plan has maize and beans crops produced to meet household food requirement. These results suggest that adoption of the optimal farm plan that exclude dairy enterprise results to a decrease of the total farm gross margin by 25%. Dairy contributes 61% to the total farm gross margin in the existing farm plan compared to 39% contributed by crops.

Table 4.21 Comparison of existing large farm and optimal farm plans (with minimum subsistence constraint)

Enterprise	Existing large farm plan		Optimal farm plan	
	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)	Enterprise level (Ha or Cows)	Contribution to TFGM (Kshs)
Maize -SRS	3.60 Ha	28,713	3.00	23,925
Maize- LRS	4.00 Ha	-1,413	0.00	0
Beans -SRS	0.80 Ha	12,198	7.00	106,729
Beans -LRS	1.00 Ha	2,277	2.90	6,603
Dairy	2.00 Cows	67,300	0.00	0
Total farm gross margin (TFGM)		109,075		137,257

Source: Author's field survey 2005

NOTE: a) SRS refers to Short rain season. b) LRS refers to Long rain season.

Table 4.21 shows that the dairy enterprise has been excluded from the optimal farm plan. The farm gross margin realized in the existing and optimal farm plans are Ksh 109,075 and Ksh 137,257 respectively. The results reveal that even when a subsistence constraint is incorporated into the linear programming model, the optimal farm plan is superior to the existing farm plan. The results of the optimal plan suggest that there is need to allocate more land in the production of beans while the land under maize production should be reduced from the current 3.6 hectares to 3 hectares. These results indicate that land is allocated at sub optimal levels. The farm income can improve through reorganization of the existing farm plan so that farm resources such as land are utilized efficiently.

4.3.3 Marginal Value Product (MVP) of Resources

Linear programming analysis generates optimal farm plan and gives the marginal value product of the resources used in production. Marginal value products of resources are derived from the dual (shadow) prices of the optimal solution as shown in appendices 3.1 to 3.6.

Marginal value product of a resource show the magnitude by which the net value of the objective function would change as a result of increasing the use of that resource by one unit assuming all other coefficients of the linear programming model are constant (Yadav and Rahman, 1994; Golam *et al.*, 2001). The marginal value products of fully utilize (limiting) resources and under utilized (surplus) resources in the optimum solution are positive and zero respectively (Chiang, 1984). MVP values are use to determine the most limiting resources in the optimal solution. The MVP of labour, land and operating capital of the optimal farm plans developed from a linear programming model without the subsistence constraint are presented in tables 4.22 to 4.24.

4.3.3.3.1 Marginal Value Product of Land

Table 4.22 Marginal Value Product of Land by farm category

Resource	Small farm (Ksh/Ha)	Medium farm (Ksh/Ha)	Large farm (Ksh/Ha)
Land (SRS)	46,522	5,709	12,610
Land (LRS)	7,727	649	0

Source: Author's field survey, 2005

NOTE: SRS refers to short rain season and LRS to long rain season.

Table 4.22 reveals that during the short rain season, land is a limiting resource in the three farm categories while during the long rain season it is a limiting resource in the small and medium farms. These results indicate that in the small farm category if land under production is increased by one hectare the farm gross margin could increase by Ksh 46,522 while in the large farm category the farm gross margin could increase by Ksh 12,601.In the large farm category, the marginal value product of land during the long rain season is zero. This implies that in the large farm category, land is not a limiting resource thus increasing area under production by one hectare will not change the farm gross margin.

4.3.3.2 Marginal Value Product Of Labour

Table 4.23 Marginal Value Product of Labour in Kitui District

Month	Small farm				Medium farm				Large farm			
	Available Labour (Mhrs)	Utilized Labour (Mhrs)	Surplus Labour (Mhrs)	MVP	Available Labour (Mhrs)	Utilized Labour (Mhrs)	Surplus Labour (Mhrs)	MVP	Available Labour (Mhrs)	Utilized Labour (Mhrs)	Surplus Labour (Mhrs)	MVP
January	740	274	466	0	740	124	616	0	740	152	588	0
February	740	274	466	0	740	173	567	0	740	330	410	0
March	740	274	466	0	740	124	616	0	740	152	588	0
April	999	274	725	0	999	186	813	0	999	277	722	0
May	740	274	466	0	740	206	534	0	740	23	717	0
June	740	274	466	0	740	206	534	0	740	23	717	0
July	740	274	466	0	740	124	616	0	740	641	99	0
August	999	274	725	0	999	182	817	0	999	281	718	0
September	740	274	466	0	740	124	616	0	740	152	588	0
October	740	274	466	0	740	218	522	0	740	100	640	0
November	740	274	466	0	740	202	538	0	740	300	440	0
December	999	274	725	0	999	202	797	0	999	300	699	0
Total	9657	3288	6369		9657	2071	7586		9657	2731	6926	

Source Author's survey, 2005

According to Chiang (1984) the marginal value product of under utilized (surplus) resource is zero while it positive for the limiting resources. Table 4.23 shows that there is surplus labour in all the three optimal farm plans as indicated by the marginal value product of zero. These results suggest that the optimal small farm plan provides for employment opportunities of 3.288 man-hours per year for the farm family while the available labour is 9,657 man- hours. Since there is surplus labour in all the months of the year some labour can be shifted to off farm activities without affecting the farm gross margin.

Marginal value product of capital

Table 4.24 Marginal value product of capital

Farm category	Available capital (Ksh)	Utilized capital (ksh)	Surplus (Ksh)	MVP (Shadow prices)
Small farm	49,439	42,848	6,591	0
Medium farm	46,840	46,840	0	2
Large farm	35,897	35,897	0	1

Source: Author's survey 2005

Table 4.24 shows that the marginal value product (shadow price) of operating capital is positive in the medium and large farm categories and zero in the small farm category. The shadow price of capital is Ksh 2 and Ksh 1 in the medium and large farm models respectively. In the medium and large farm models the optimal plans suggest that available capital is fully utilized. Operating capital is a limiting resource in the medium and large farm models while in the small farm models farmers have surplus operating capital.

4.3.4 Sensitivity Analysis

A linear programming model generate optimal farm plans and also show the Right –Hand – Side and objective ranging conditions which define the feasibility limits for the optimal plans. The feasibility limits of the optimal plans are determined by sensitivity analysis. Results of sensitivity analysis show the range of the objective function parameters (Cj) within which the basic variables (enterprise) remain in the optimal plan. The analysis also defines the range within which the resource constraints (Right – Hand- Side) could be relaxed without affecting the feasibility of basic variables and the value of the objective function. The results of sensitivity analysis of the optimal farm plans developed from a linear programming model with subsistence constraints are presented in tables 25 to 30.

4.3.4.1 Feasibility Limits of the Optimal Small Farm Plan

Table 4.25: Feasibility Limits of Enterprises in the Optimal Small Farm Plan

Enterprise	Lower limit	Current gross margin (GM/Cow)	Upper limit
Dairy	24,424	54,249	Infinity

Source: Linear programming printout (appedindix3.1)

Table 4.25 show that the lower limit of the gross margin per cow is Ksh 24.424 while the upper limit is infinity. These results suggest that if the gross margin per cow decreases below Ksh 24.424, the dairy enterprise will be excluded from the optimal plan. However the gross margin per cow can increase indefinitely without changing in the current production level of two cows since it is already at its maximum in the optimal plan.

Table 4.26: Feasibility Limits of Resource Constraints in the small farm plan

Resource	Lower limit of resources	Current resource level	Upper limit of resources
Land-SRS (Ha)	0.00	1.80	1.80
Land -LRS (Ha)	1.80	1.80	3.70
Operating capital (Ksh)	42,848.00	49,439.00	Infinity
January labour (Man-hours)	274.00	740.00	Infinity
February Labour (Man-hours)	274.00	740.00	Infinity
March labour (Man-hours)	274.00.00	740.00	Infinity
April labour (Man-hours)	274.00	999.00	Infinity
May labour (Man-hours)	274.00	740.00	Infinity
June labour (Man-hours)	274.00.00	740.00	Infinity
July labour (Man-hours)	274.00	740.00	Infinity
August labour (Man-hours)	274.00	999.00	Infinity
September labour (Man-hours)	274.00	740.00	Infinity
October labour (Man-hours)	274.00	740.00	Infinity
November labour (Man-hours)	274.00	740.00	Infinity
December labour (Man-hours)	274.00	999.00	Infinity

Source: Linear programming printout (Appendix 3.1)

Table 4.26 shows that if the land available during the long rain season decreases below 1.80 hectares the optimal solution will change. The upper limit for labour is infinity and this implies that labour can increased indefinitely without causing a change in the optimal plan. The lower limit for operating capital is Ksh 42,848 and the upper limit is infinity. In the small farm category capital was found to be a non-limiting resource.

4.3.4.2 Feasibility Limits of the Optimal Medium Farm Plan

The optimal farm plan has maize/pigeon peas intercrop, beans and dairy enterprises. Table 4.27 shows the range within which the gross margins of these enterprises can vary without changing the net value of the optimal plan.

Table 4.27: Feasibility Limits of Enterprises in the Optimal Medium Farm Plan

Enterprise	Lower limit	Current gross margin (GM/Ha or GM/Cow)	Upper limit (GM/Ha or GM/Cow)
Maize/ pigeon peas (LRS)	4,208	4,791	41,155
Beans (SRS)	12,214	14,531	39,033
Dairy	31,184	55,686	61,389

Source: Linear programming printout (Appendix 3.2)

Table 4.27 shows the lower and upper limits for the enterprises included in the optimal farm plan. The lower and upper limits within which the dairy enterprise will remain in the basis of the optimal farm plan are Ksh 31,184 and Ksh 61,389. The dairy enterprise can be excluded from the optimal plan if the gross margin per cow decreases by 44% below the current gross margin of Ksh 55,686 per cow. This is an indication that dairy production is competitive compared to crop enterprises because the gross margin per cow has to decrease by a big margin before the enterprise is pushed out of the plan to allow for other enterprise. Maize/pigeon peas will be excluded from the optimal plan if the gross margin per hectare decreases by Ksh 583. This is an indication that the optimal plan is sensitive to small changes in the gross margin of maize/pigeon peas.

Table 4.28: Feasibility Limits of Resource Constraints in the Medium Farm

Resource	Lower limit	Current resource level	Upper limit
Land-SRS (Ha)	1.60	4.90	8.30
Land –LRS (Ha)	1.60	4.90	12.10
Operating capital (Ksh)	31,940.00	46.846.00	120,835.00
January labour (Man-hours)	124.00	740.00	Infinity
February Labour (Man-hours)	173.00	740.00	Infinity
March labour (Man-hours)	124.00	740.00	Infinity
April labour (Man-hours)	186.00	999.00	Infinity
May labour (Man-hours)	206.00	740.00	Infinity
June labour (Man-hours)	206.00	740.00	Infinity
July labour (Man-hours)	124.00	740.00	Infinity
August labour (Man-hours)	182.00	999.00	Infinity
September labour (Man-hours)	124.00	740.00	Infinity
October labour (Man-hours)	218.00	740.00	Infinity
November labour (Man-hours)	202.00	740.00	Infinity
December labour (Man-hours)	202.00	999.00	Infinity

Source: Linear programming printout (Appendix 3.2)

Table 4.28 show that the upper and lower limits of land and capital are defined while the upper limit of labour is infinity in all the months. According to Bagazonzya (1980) if a resource is non-limiting, a lower limit is defined beyond which some activities are excluded from the optimal solution while the upper limit is always infinity. Table 4.28 therefore shows that land and capital are limiting resources and while labour is not a limiting resource. If the available land in the short rain season decreases below 1.60 hectares the enterprises in the optimal plan will change.

4.3.4.3 Feasibility Limits of the Optimal Large Farm Plan

Table 4.29 Feasibility Limits of the Enterprises in the Optimal Large Farm Plan

Enterprise	Lower limit (GM/Ha)	Current GM/Ha (Ksh)	Upper limit (GM/Ha)
Beans (SRS)	10,864	15,749	Infinity
Beans (LRS)	1,789	2,277	10,067

Source: Linear programming printout (Appedindix3.3)

Table 4.29 show that the optimal farm plan has beans produced during the short and long rainfall seasons. The gross margin per hectare of beans produced during the short rain season is Ksh 15,749 but if the gross margin per hectare decrease below Ksh 10,864 beans will be excluded from the optimal plan. Beans produced during the long rain season is highly sensitive in the lower limit because if the gross margin per hectare decreases by Ksh 488, it will be excluded from the optimal plan.

Table 4.30: Feasibility Limits of Resource Constraints in the Optimal Large Farm Plan

Resource	Lower limit	Current resource level	Upper limit
Land-SRS (Ha)	3.17	10	10.43
Land –LRS (Ha)	0.59	10	Infinity
Operating capital	34430.00	35,897	59,410
January labour (Man-hours)	0.00	740	Infinity
February Labour (Man-hours)	330.00	740	Infinity
March labour (Man-hours)	9.00	740	Infinity
April labour (Man-hours)	18.00	999	Infinity
May labour (Man-hours)	24.00	740	Infinity
June labour (Man-hours)	24.00	740	Infinity
July labour (Man-hours)	0.00	999	Infinity
August labour (Man-hours)	22.00	740	Infinity
September labour (Man-hours)	22.00	740	Infinity
October labour (Man-hours)	0.00	740	Infinity
November labour (Man-hours)	100.00	740	Infinity
December labour (Man-hours)	300.00	999	Infinity

Source: Linear programming printout (appedindix3.3)

Table 4.30 shows that operating capital and land available during the short rain season have both lower and upper limits beyond which the enterprises in the optimal plan will change. The lower limit for labour and land available during the long rain season are defined but the upper limit is infinity. This is an indication that operating capital and land available during the short rain season are limiting resources. Land available during the short rain season is highly sensitive on the upper limit because an increase of the land by 0.43 hectares would change the enterprise in the optimal plan. The optimal plan is not sensitive to increase of land during the long rain season and labour because these resources are surplus as indicated by the upper limit.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

In Kitui district, mixed crop and pastoral livestock production has been the main source of income and food for majority of the households. However due to increasing human population farm sizes decreased and farmers are gradually shifting to small scale dairy production as an alternative source of livelihood. However Kitui district is in agro ecological zones four and five that are considered to be unsuitable for exotic dairy breeds due to harsh climatic conditions and threats of livestock diseases. This study was carried out with the broad of objective of assess whether dairy production in Kitui district is profitable (competitive) compared to crop enterprises.

To achieve the objective for this study a sample of 120 respondents was randomly selected to be interviewed but only 116 farmers responded to the questionnaire used to collect the required data. The surveyed farms were classified into small, medium and large categories base on farm sizes. Descriptive analysis, Gross Margin analysis and Linear Programming techniques were used to analysis the data. Descriptive analysis was carried out to generate statistics that include mean values, frequencies and percentages. Gross margin analysis was undertaken to assess the profitability of dairy and crop enterprises; and their contribution to total farm income. Linear programming model was used to develop optimal farm plans and to identify the most limiting resources.

The results of the descriptive analysis revealed that the average farm size in the small category is 1.80 hectares while in the medium and large categories it is 4.9 hectares and 10 hectares respectively. 88% of the farmers interviewed are in the small farm category while the medium and large farm categories have 9% and 3% of the farmers respectively. These results show that majority of dairy farmers in Kitui district are smallholder producers. Crop production is allocated 66%, 54% and 41% of the available land in the small, medium and large farm categories respectively. Fodder production is allocated 17%, 20% and 4% of the available land in the small, medium and large farms respectively. This shows that there is limited cultivation of fodder crop to sustain dairy production.

The main dairy production systems adopted by the farmers are zero grazing, semi-zero grazing and extensive grazing. 75% of the farmers have adopted zero grazing while 22% and 3% practice semi-zero and extensive grazing respectively. These results show that zero grazing is the preferred dairy production system within the study area and this can be attributed to the small farm sizes. Zero grazing is a land saving technology that is appropriate in the densely populated areas. The dairy breeds found in the farms surveyed include Friesian, Guernsey, Ayrshire, Jersey, Zebu and crossbreeds. Ayrshire and Friesian account for 38% and 39% of the dairy herd respectively and is an indication that these are the preferred dairy breeds within the in Kitui district. The performance of the breeds was assessed base on productivity per cow and. Friesian and Ayrshire produced 10 liters and 9 litres of milk per day respectively while Jersey, Crossbreeds and Zebu produced 8 litres, 6 litres and 3 litres of milk respectively. Although Friesian produces more milk compared to the other breeds, it requires high management and feeding to sustain the milk production. Milk production should not be the only factor to consider when selecting dairy breeds because other factors such as climatic, management and feeding will determine the performance of dairy animals.

Results of the Gross Margin analysis revealed that under the existing farming systems, the total farm gross margins earned in the small, medium and large farms is Ksh 82,031, Ksh 91,844 and Ksh 109,075 respectively. These results show that the total farm income varied with farm sizes. The dairy enterprise contributed 61%, 71% and 59% to the total farm income in the small, medium and large farms respectively. This is an indication that dairy production is the most profitable farm activity compared to crop production because more than half of the total farm income is generated from milk.

Linear Programming analysis was carried out to develop optimal farm plans and to determine the limiting resources. Results were obtained for a situation where a subsistence constraint was incorporated in the Linear Programming model and for a scenario without the subsistence constraint. The optimal plan developed from the linear programming model without the subsistence constraint showed that farmers with small, medium and large farms could earn a total gross margin of Ksh 108,498, Ksh 107,004 and Ksh 158,807 respectively. The dairy enterprise contributed 100% and 61% to the total farm income in the small and medium farms respectively. In the large farm, the optimal plan suggests that farm income could be maximised by producing crop enterprises. These results reveal that dairy production is an important enterprise in the small and medium farms. Based on the total farm gross margin the optimal farm plans are superior to the existing farm plans. The expected farm gross margins from the optimal farm plans in the small, medium and large farms are 32%, 17% and 46% respectively above what is earned under the existing farm plans. This is an indication that farmers can improve the farm income by adoption of the optimal farm plans. The optimal farm plans show the combination of enterprises that will give high farm income and the levels at which the enterprises should be produced.

Results obtained from the Linear Programming model when the subsistence constraint is incorporated in the model found that the existing farm plans were superior to the optimal plans. The total farm incomes earned from the existing farm plans in the small, medium and large farm categories are Ksh 82,031, Ksh 91,844 and Ksh 109,075 respective. The optimal plan suggests that farmers with small, medium and large farms could earn Ksh 72,437, Ksh 69,978 and Ksh 137,253 respectively. This shows that incorporating the subsistence constraint in the linear programming model reduces total farm income by 11% and 24% in the small and medium farms respectively. In the large farm model the farm income increases by 26% even when the subsistence constraint is incorporated in the linear programming model. This can be attributed to the fact that in the large farms land is not a constraint thus including the staple food crops in the farm plan does not affect the production of other farm enterprises.

Linear Programming analysis was carried out to determine the limiting resources with the view of advising the farmers on how they can allocate the scarce resources. The results of the LP analysis reveal that land and operating capital are the most limiting resources in small, medium and large farms. The Marginal Value Product (shadow price) of land during the short rain season is Ksh 46,522, Ksh 5,709 and Ksh 12,607 in small, medium and large farm categories respectively. During the long rain season, the shadow price of land was estimated as Ksh 7,727 and Ksh 649 in the small and medium land categories respectively while in the large farm category it was zero. This implies that the shadow price of land vary with farm sizes and season. Farmers with small farm sizes could be willing to pay more for an extra hectare of land than those with large farms. The MVP of land in the three farm categories was higher than the average land rent of Ksh 2,680 per hectare that prevailed in the study area in the year 2005. Thus farmers could increase incomes by renting land for agricultural production.

Operating capital was a limiting resource in the medium and large farms. The marginal value product of operating capital was found to be Ksh 2 and Ksh 1 in the medium and large farms respectively. Results of the study found that labour is not a limiting resource as indicated by a marginal value product of zero. The optimal farm plans generates more employment opportunities compared to the existing farm plans. In the small, medium and large farms the optimal farm plans generates 3288 hours, 2071 hours and 2731 hours of employment opportunities respectively. This is substantially higher than the employment opportunities of 2499 hours, 1920 hours and 2273 hours observed in the small, medium and farm categories under the existing plan. The small farm category provided higher employment opportunities than the medium and large farm categories. In the small farms, farmers practiced zero grazing production system that requires labour for cutting and transporting feed to the dairy animals.

5.2 Conclusions

From the results of this study it can be concluded that dairy production in Kitui district is profitable and competitive compared to crop production. Dairy production has high contribution to the farm income compared to crop production. The study found that farm sizes are small and crop production is allocated higher proportion of the available land compared to pasture and fodder. Farmers have adopted intensive dairy production in response to the small farm sizes. The dairy animals are kept under zero grazing system where the main feed sources are pasture and fodder produced in the farm. In order to maintain steady and adequate supply of feed for dairy production the land under fodder crops should be increased.

The optimal plans are superior to the existing farm plans based on total farm gross margin. Farm income could be increased above the current levels by adoption of the optimal farm plans. The enterprises that give high returns to the limiting resources should be allocated more resources. Land and capital are the most limiting resources to agricultural production in Kitui district and should be allocated efficiently.

5.3 Recommendations

The recommendations made out of this study are:

i. The study recommends adoption of the optimal farm plans because they suggest that higher farm income could be earned compared to what is earned from the existing farm plan. However the optimal farm plans should be reviewed annually because changes in climatic conditions, economic environment and resource supply may affect productivity of farm enterprise. Extension officers and other stakeholders in agricultural development can assist the farmers in the review of the farm plans.

ii. Due to the small farm sizes the study recommends that farmers should produce few crop enterprises and keep one or two dairy animals under the zero grazing system. Dairy production ensures steady flow of cash income and food (milk) throughout the year. Dairy and crop enterprises complement each other since crop residues are used as livestock feed while cow dung can be used to improve soil fertility for crop production.

iii. Farmers should allocate more land to the production of pasture and fodder crops so as ensure study supply of feed for dairy production. Manure from the dairy animals can be used to supply nutrients to the fodder crops so as to increase the amount of feed per unit area.

REFERENCES

Abdulkari, A.O, Ajibefun .I.A, (1998): Developing Alternative Farm Plans for Cropping System Decision Making. *Journal of Agricultural systems, vol. 56, No.4 pp.431 – 422, Elsevier science ltd.*

Ackello-Ogutu, C., Waelti, J.J., (1990): *Basic Concepts of Micro- Economic with Special Reference to Kenya.* Nairobi University Press, Kenya.

Agrawal, R.C., Heady, E.O., (1972): *Operation Research Methods for Agricultural Decisions.* The Iowa State University Press, USA.

Ahuja, H.I., (1977): *Principles of Microeconomics. A New Look At Economic Theory.* 13th edition. S.Chand & company limited.

Alford, A., Griffith, G., Cacho, A., (2003): *A Northen Tableland Whole Farm Linear Program For Economic Evaluation of New Technologies at the Farm Level.* Economoc Research Report No. 13NSW Agriculture, Armidale, October.

Bagazonzya, H.K., (1980): The Profitability of Small-Scale Pig Farms in Nyeri District Kenya. Unpublished MSc thesis, University of Nairobi.

Baltenweck, I.,Staal, S.J., Owango, M., Muriuki, H., Lukunyu, B., Gichungu, G., Kenyanjui, M., Njubi, D., Tanner, J., Thorpe, W., (1998): Intensification and Competitiveness of Smallholder Dairy Production System in the Greater Nairobi Milk-shed. Paper presented at: 'Marches urbains Development laitier en Afrique Sub-Saharienne Workshop', CIRAD Montpellier, France, 9-10 September 1998. 11p. www.smallholderdairy.org

Barasa T.N.;(1989): Economics of Cotton Production in Funyula Division, Busia District, Kenya. Unpublished Msc, Thesis, University of Nairobi.

Barnard, C.S., Nix, J.S., (1979): *Farm Planning and Control.* 2nd Edition, Cambridge University Press.

Bebe, B.O., (2003): Herd Dynamics of Smallholder Dairy in The Kenya Highlands. PhD Thesis Wageningen University.

Bebe, B.O., Udo, H.M.J., Jrowland. G., Thorpe, W., (2003): Smallholder Dairy Production Systems in The Kenyan Highlands: Breed Preference and Breeding Practices. *Journal of Livestock Production Science 82, Pp 117 -127, Elsevier BV 2003.*

Bebe, O., Udo H.M.J., Thorpe, W., (2002): Development of Smallholder Dairy Systems in The Kenya Highlands: *Outlook on Agriculture Vol.31 No 2.pp 113-120.*

Chiang, A.C., 1984: *Fundamental Methods of Mathematical Economics.* 3rd Edition. Mcgraw-Hill Book Co. Singapore.

Duffy,M., Darnell, S., (2007): Estimated Costs of Crop Production in Iowa. *http://www.extension.iastate.edu/agdm/crop/html/a1-20html.*

G.O.K., (1993): Kenya Dairy Development Policy, Government Printers, Nairobi. Kenya.

G.O.K., (2004b): Economic Survey 2004: Ministry Of Planning And National Development, Government Printers, Nairobi.

G.O.K., (1996): *Farm Management Training and Reference Manual.* 2nd edition. Ministry of Agriculture and Livestock Development and Marketing. Nairobi, Kenya.

G.O.K., (1997): Kitui District Development Plan 1997-2001. Government, Printers Nairobi,Kenya .

G.O.K., (1997a): National Development plan 1997- 2001: Government printers, Nairobi.

G.O.K., (2002a): National Development Plan, 2002-2008. “Effective Management for Sustainable Economic Growth and Poverty Reduction” Government Printers, Nairobi Kenya.

G.O.K., (2003): National Development plan 2002- 2008: Effective management for sustainable economic growth and poverty reduction: Government Printers, Nairobi.

G.O.K; (2003b): Economic Recovery Strategy (ERS) for wealth and employment creation: Government Printers. Nairobi.

G.O.K., (2004): Strategy for Revitalizing Agriculture 2004-2014: MoA/MoLFD. Government Printers.

G.O.K., (2005): Ministry of Agriculture Strategic plan 2005- 2008. Government, Printers, Nairobi.

G.O.K., 2002: Kitui District Development Plan 2002- 2008: Effective Management for Sustainable Economic Growth and Poverty Reduction. Government, Printer Nairobi,Kenya .

Golam, W., Sarker, F.M., Lingard .J, (2001): An Optimal Cropping Plan for Farmers in a ShallowTube Well Irrigation Area an Bangladesh. *Bangladesh Journal of Agricultural Economics (Xxiv) pp39-55.*

Hanyani, B.T., Sibanda, S., Ostergaard,V., (1998): Socio-Economic Aspects of Smallholder Dairy in Zimbabwe. *Livestock Research for Rural Development. Vol.10, Number.2.*

Hezell. P.B.R., Norton R.D., (1986): *Mathematical Programming for Economic Analysis in Agriculture.* Macmillan, New York.

Isaboke. M.J., (1995): An Economic Analysis of Dairy Production Systems in Nyamira District, Kenya. Unpublished Msc Thesis, University Of Nairobi

Ishuza. S.L.B., (1994): Competitiveness of Drought and Non-Drought Food Crop Staples In Tanzania: What Policy Direction?: In "Agricultural Competitiveness: Market Forces and Policy Choice". *International Conference Of Agricultural Economics August 22-29, 1994. Harare Zimbabwe*

Jaetzold, R., Schmidt, H., (1983): *Farm Management Handbook of Kenya Vol.11 Part C. (Eastern and Coast Provinces).* Ministry of Agriculture, Kenya, German Agricultural Team (GAT) of the German Technical Cooperation (GTZ).

Kamunge, J. N., (1989): The Role of Resource Optimization in Improving Farm Incomes in Small-Scale Irrigation Scheme. A Case Study of Mitunguu Project in Meru District, Kenya. Unpublished M.Sc.Thesis, University Of Nairobi.

Karanja, A.M., (2003): The Dairy Industry In Kenya: The Post-Liberalization Agenda. Working Paper No. 1, 2003.

Kay, R.D., (1986): *Farm Management, Planning Control and Implementation.* Mcgraw-Hill New York.

Loomba, N.P., (1978): *Management: A Quantitative Perspective.* Macmillan Publishing Co.Incl.,New York.

Makeham, J.P., Malcolm, L.R., (1986): *The Economics of Tropical Farm Management.* Cambridge University press.

Mburu B.N., (1991): Economics of Simsim Production Among Smallholder Farmers in Kwale District, Kenya. Unpublished Msc Thesis, University of Nairobi

M.O.A., (1998): Contribution to the Dairy Development Policy Review Committee's Working Papers. Ministry of Agriculture Kenya. Nairobi, Kenya.

MoFLD., (2003): Livestock Production Annual Report . Kitui District Livestock office.

MoLD., (1993): Kenya Dairy Development Project. Preparations Report No. 34/93 CP-Ken 3.

Mortenson, W.P., Luening, R.A., (1979): *The Farm Management Handbook.* 6th edition. The Interstate Printers And Publishers. Inc.

Mosi R.O.; (1997): Milk Production From Zebu Cattle, Camel, Goat And Other Milk Animals With Special Reference To Arid And Semi-Arid Areas.

Mugenda, O. M., Abel, G.M., (1999): *Research Methods: Quantitative and Qualitative Approaches.* Acts Press, Nairobi Kenya.

Muhiyi, W.B.,Wekesa, F.W., Mukisira, E.A., Mosi R.O., Isaka,M., Okero,C., Kirui, J., Makori .J., Lukibisi,F.B., (2001): Sustainability of Smallholder Dairy Production in the Semi-Arid Rongai Division of Nakuru District: In " The Challenges of Drought to Livestock Production in Kenya (2001): Abdulrazak, S.A., Mwangi, D., Mukisira, E.A., (Eds) .Proceedings of the Animal Production Society of Kenya. Symposium Held at Egerton University Njoro 7-Th March 2001. APSK.

Mukumbu.J.M., (1987): Determination of Optimal Enterprise Mix and Allocation of Resources For West Kano Pilot Irrigation Scheme. Unpublished Msc Thesis, University of Nairobi, Kenya.

Muriuki, H., Omoro, A., Nooton, N., Ouma, R., Staal, S.J., Odhiambo P., (2003): The Policy Environment in the Kenya Dairy Sub-Sector: A Review of SDP Research And Development Report 2. Smallholder Dairy (R&D) Project. *MOA/KARI/ILRI.*

Muriuki, H.G., Mwangi, D.M., Thorpe, W., (2001): How Smallholder Dairy Systems in Kenya Contribute to Food Security and Poverty. Paper Presented at The 28th Tanzania Society of Animal Production Conference, Morogoro 7th-9th August, 2001. Theme: Contribution of Livestock to Food Security and Poverty Alleviation.

Mutugi J.J.; (2003): A Review of Major Infectious Diseases of Cattle and their Control Measure so as to Enhance Cattle Health and Productivity. In: "KARI (2003); Cattle Production In Kenya". Strategies for Research Planning and Implementation. (Workshop Proceedings 15th To 16th December 2003)

Muyekho,F.N, Wandera J.L, (1996): Forage Legume Seed Production: Opportunities and Challenges for Research and On-Farm Production in Kenya. In Fungoh, P.O., Mbadi, G.C.O., (eds) "Focus On Agricultural Research for Sustainable Development in a Changing Environment. Proceedings of The 5th KARI Scientific Conference.

Ngategize, P.K., (1989): Constraint Identification and Analysis in African Small Ruminant Systems. In: Wilson R.T., Azeb, M., (eds), African Small Ruminants Research and Development. Proceedings of A Conference Held At Bamanda , Cameroon 18th- 25th January, 1989. ILCA (International Livestock Centre for Africa) Addis Ababa Ethiopia, Pp 7 – 22.

Nguta S.M., (1992): Optimal Farm Plans for Smallholder Farmers Practicing Irrigation Along Yatta Canal of Machakos District, Kenya: A Linear Programming Approach. Unpublished Msc Thesis, University of Nairobi, Kenya.

Norman, L., Turner, R., Wilson, K., (1985): *The Farm Business*. Longman Incl., New York.

Nyangito, H.Z., (1986): A Socio-Economic Analysis of the Factors that Determine the Effect of Potato Post Harvest Practices and Storage Technologies in Kinangop, Kenya. A Case Study. Unpublished Msc Thesis, University of Nairobi, Kenya.

Nyikal R.A., (2000): Financing Smallholder Agricultural Production in Kenya. An Economic Anaysis of the Credit Market. Unpublished PhD Thesis, University of Nairobi

Nyikal R.A. Kosura W.O, (2005): Risk Prefernce and Optimal Enterprise Combination in Kahuro Division of Murang'a District, Kenya. *Agricultural Economis 32 (2005) 131 – 140*

Nyoro, J.K., (2002): Agriculture and Rural Development in Kenya: Tegemeo Institute,Egerton University.

Okoruwa. V., Jabbar.M.A, Akinwumi. J.A., (1996): Crop-Livestock Competition in the West African Derived Savanna: Application of a Multiple Objective Programming Model. *Agricultural System Journal Vol. 52 Pp 439-453. Elsevier Science Ltd.*

Omore .A., Muriuki .H., Kenyanjui .M., Owango .M., Staal .S., (1999): The Kenya Dairy Sub Sector: A Rapid Appraisal Smallholder Dairy (Research and Development) Project Report. MOA/KARI/ILRI. Nairobi, Kenya.

Pannell. D.J., (1997): Sensitivity Analysis of Normative Economic Models: Theoretical Framework and Practical Strategies. *Agricultural Economics* 16: 139-152.

Patrick G.F., (1998): Managing Risk in Agriculture, NCR 406, Co operative Extension Services, Purdice University, West Cafayette, in 47907.

Pemela. A.L., Setter, R.B., (1985): *The Survey Research Handbook*: Richard D Irwin incl.

Reynolds L., Metz T, Kiptarus J, (1996): Smallholder Dairy Production in Kenya. *Journal of World Animal Review 87- 1996/2.*

Robert .F., (1997): Farm Management for Asia: A Systems Approach. FAO farm systems Management series 13.

Schroeder T.C., Goodwin B.K., (1994): Risk Unique to Agricultural Markets Brings Changes in Producer Marketing Practices. *East African Agriculture and Forest journal.*

SDP, (2004a): Kenya's Dairy Sector: The Potential for Change: New Agriculturist on Line, 1, July 2004: www.new.agric.co.uk.

SDP, (2005): Multiple Benefits of Smallholder Dairy production: SDP Policy Brief 7. www.smallholder.org

Staal S., Chege L., Kimari A., Lukuyu B., Njubi D., Owango M., Tanner J., Thorpe W., Wambugu M.; (1998): Characteristics of Dairy Systems Supplying the Nairobi Milk Market: Collaborative Dairy Research Programme. KARI/MOA/ILRI, N airobi, Kenya.

Staal, S.J., Muriuki, H.,Owango, M., Kenyanjui, M., Lukuyu, B., Njoroge L., Njubi, N.,Baltenweck, I., Musembi F., Bwana O., Muriuki, K., Gichungu, G., Omore, A. Thorpe, W., 2001: Dairy Systems Characteristics of the Greater Nairobi milk Shed. SDP Research Report: MoARD/KARI/ILRI/DFID

Staal, S.J., (2001): Competitiveness of Smallholder Dairy Production: Evidence from Sub-Saharan Africa, Asia and Latin America. In: Rangnekar D & Thorpe W (eds), Smallholder Dairy Production and Marketing-Opportunities and Constraints. Proceedings of a South-South workshop held at NDDB, Anand,India,13th-16th March 2001. NDDB &ILRI, Nairobi, Kenya, 538pp. http://www.ilri.cigiar.org

Staal, S.J., (2004b): Employment Generation in the Kenya Dairy Industry: Smallholder Dairy Project Policy Brief 2. Smallholder Dairy (R&D) Project Research Report *www.smallholderdairy.org*

Staal, S.J., (2004c): Competitiveness of the Smallholder Dairy Enterprise in Kenya: Smallholder Dairy Project Policy Brief 3. Smallholder Dairy (R&D) *Project.*

Staal S.J., Waithaka M., Njoroge L., Mwangim D.M., Njubi D., Wakobi A., (2003): Cost of Milk production in Kenya: Estimates from kiambu, Nakuru and Nyandarua. S.D.P Research and Development report 1: Smallholder dairy (R &D) Project.

Upton, M., (1987): *Farm Management in Africa: "The Principles of Production and Planning*": Oxford University Press.

Waithaka, M., Nyangaga J., Mwangi, D.M., Muriuki, H.G., Staal, S., (2005): The Kenya dairy sub sector: A Rapid Appraisal Smallholder Dairy (R&D) Project. SDP Collaborative Research Report,MoLFD/KARI/ILRI/DFID, Nairobi, Kenya.

Wanyoike, M.M., Wahome, R.G., (2003): Cattle Production Systems in Kenya. In "KARI (2003), Workshop Proceedings 15th to 16th December 2003

Wanzala.R.A, (1993): Determination of Economic Competitiveness of RainFed Rice and Optimal Resource Allocation on Smallholder Farms: A Case of Amukura Division, Busia District Kenya. Unpublished Msc Thesis, University of Nairobi.

Yadav D.P., Rahman A.A.; (1994): Credit Technology and Paddy Farm Production: A case Study of Tonjong Karang and Beranang, Malaysia. *Journal of the Developing Economies. Vol. 32/1 pp 66 – 85.*

Appendices

APPENDIX 1: SURVEY QUESTIONNAIRE

DETERMINATION OF THE ECONOMIC COMPETITIVENESS OF SMALLHOLDER DAIRY PRODUCTION IN ARID AND SEMI- ARID AREAS: "A CASE STUDY OF KITUI DISTRICT."

Division---------------------------------------.

Enumerator's name-------------------------.

Date ---.

Serial number of questionnaire---------------

1: General information

1.1. Name of respondent --

1.2. Are you the owner of the farm? *(Tick one)*

Yes ----   No -----

1.3. If the answer in (1.2) above is NO how are you related to the owner? (*Tick one*)

Spouse---------------

Son----------------

Daughter----------

Employee--------

1.4 a) Are you the one who manages the farm? (*Tick one*)

Yes------   No-------

b) If yes then answer the following questions.

1.5. What is your age? --------- Years. Date of birth -------

1.6. Sex of respondent: male ------Female ----

1.7. What level of education did you reach in school? (*Tick one*)

Never been to school---------

Primary level ------------------

Secondary level ---------------

College-----------------------

University---------------------

1.8. What is the size of your family?

Sex	Age (years)			Total
	<18 yrs	18-55 yrs	>55 yrs	
Male				
Female				
Total				

1.9. What is your occupation?

Self employed on the farm (farmer) ------

Self employed outside the farm (business) ------

Salaried employee ---------------------------------

Other (specify) ---

1.10. Do you keep farm records?

Yes----- No-----

1.11a) If the answer in 1.10 is YES what kind of records do you keep?

Crop yields--- Milk yields---- cost of inputs ---- farm assets --

Others (specify)----------------------------------

b) Can I see the records? Records shown------. Records not seen ------

1.12. If the answer in 1.11 above is NO would you be willing to start keeping records?

Not willing -------- Willing -------- Highly willing---------

2: Farm characteristics

2.1 a) What is the size of land owned by the household? --------------- Areas.

b) What area is under the following land uses?

Cropland -------- acres. Pasture (uncultivated) ---------- acres. Homestead------- acres.

2.2 Under which tenure is the land owned?

Communal .... Privately owned ---- Others (specify)--------

2.3 Is the land you own enough for all farming activities? (*Tick one*)

Yes----- No-----

2.4 Did you rent land last year? (*Tick one*)

Yes----- No-----

2.5 If the answer in 2.4 is YES how many acres? ----------------Acres.

2.6 What was the rental fee? ------------Ksh/acres.

3: Crop enterprise details

3.1 Which crops /crop mixtures did you grow last year? (*Tick the main crops only)*

Maize/ Pigeon peas intercrop	
Beans	
Maize/beans	
Cowpeas	
Maize/cowpeas	
Mangoes	
Tobacco	
Other (specify)	

3.2 What was the area under the crops?

Crop	1st season		2nd season	
	Area (acres)	Yield (state units)	Area (acres)	Yield (state units)
Maize/pigeon peas				
Beans				
Maize/beans intercrop				
Cowpeas				
Maize/cowpeas intercrop				
Mangoes				
Tobacco				
Others (specify)				

3.3. a) How much of the total output of the crop produced was either consumed at home or sold?

Crop enterprise	Total output (Specify units)	Home consumption	Sold (specify units)	Unit price (Ksh)	Total value (Ksh)
Maize					
Beans					
Pigeon peas					
Mangoes					
Tobacco					
Cowpeas					

3.3 b) what quantity of the following food items did you purchase and at what price last year?

	Quantity purchased	Unity price	Total value (ksh)
Maize			
Beans			
Pigeon peas			
Cow peas			

3.4 What inputs did you purchase in the 1st season?

Crop	Seed			Fertilizer			Insecticides		
	Qty used	Unit price	Total cost (ksh)	Qty used	Unit price	Total cost (ksh	Qty used	Unit price	Total cost (ksh
Maize									
Beans									
Pigeon peas									
Cowpeas									
Tobacco									

3.5. What inputs did you purchase in the 2nd season?

Crop	Seed			Fertilizer			Insecticides		
	Qty used	Unit price	Total cost (ksh)	Qty used	Unit price	Total cost (ksh	Qty used	Unit price	Total cost (ksh
Maize									
Beans									
Cowpeas									
Pigeon peas									
Cowpeas									
Tobacco									

3.6. a)What did you use to perform the following farm activities? (*Tick the option*).

Planting- Oxen ☐ Tractor ☐ Hand hoeing ☐

Weeding - Oxen ☐ Tractor ☐ Hand hoeing ☐

Harvestig - Oxen ☐ Tractor ☐ Hand hoeing ☐

b) What was the cost of tractor per acre of operation? (*Use the rate in question 3.9)*

------------ Ksh / acre.

c) What was the cost of hand hoeing per acre? Use the rate in question 3.9)

---------------- Ksh / acre

3.7. If oxen were used do you own them?

Yes ---- No -------------

3.8. If the answer in 3.7 above is NO how much money did you pay for oxen per acre of farm operation? ----------------------- Kshs/acre.

3.9. How much money did you spend on the following operations in each enterprise?

		Planting		Weeding		Harvesting	
Crop	Acres	Cost/acre	Total cost (ksh)	Cost /acre	Total cost (ksh)	Cost /acre	Total cost (ksh)
Maize							
Maize/pigeon peas							
Beans							
Maize/beans							
Mangoes							
Tobacco							
Maize/cowpeas							

Labour availability and utilization

3.10. How many family members are available to work in the farm?

Family member	Number	Number of hours worked per day	Number of days available for work/week	Total number of hours worked/year
Children <18 years				
Adults 18-55 years				
Adults >55 years				
Totals				

3.11. How many permanent workers did you have last year? Number --------------------.

3.12. How many hours did the permanent employees work per day? ------------------. Hours.

3.13. What is the monthly pay for the permanent employees? ----------------------. Kshs/month.

3.14. Did you employ casuals to work on crop enterprises?

Yes ---- No -----------

3.15. If the answer in 3.14 above is YES how much did you pay the casuals per day?

--------------- Kshs/day.

3.16. Approximate how long it takes a man working 5 hours a day to do the following activities per acre in your farm?

Enterprise	Operation	Days required
Maize/pigeon peas	Planting	
	Weeding	
	Harvesting	
Beans	Planting	
	Weeding	
	Harvesting	
Tobacco	Planting	
	Weeding	
	Harvesting	
Mangoes	Planting	
	Weeding	
	Harvesting	
Others (specify)	Planting	
	Weeding	
	Harvesting	

3.17 In which months did you employ casual labour and for what farm operation?

Month	Operation
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

Subsistence food requirement

3.18. Are there crops that you must grow to reduce the possibility of food shortage for the family?

Yes ---- No ---------

3.19. How many acres must you put under these crops?

Maize ------------ acres

Beans ------------ acres

4: Details of livestock enterprises

4.1. How long have you been in dairy farming? -------- Years.

4.2. What was your initial cost of starting the dairy enterprise?

Purchase of dairy cow(s) ---------------- ksh.

Building of structures ----------------- ksh.

Total cost ------------------ kshs.

4.3. What was the source of the starting capital?

Own savings -------------

Loan from bank --------

Assisted by NGO-------

Others (specify) --------------------------------

4.4. If NGOs name them and the assistance given.

Name of NGO kind of assistance

4.5. How many dairy cattle did you have last year in the different class and breeds?

Class	Breed						
	Ayrshire	Friesian	Guernsey	Jersey	Upgrade (Cross breed)	Zebu	Total
Cows in milk							
Dry cows							
Bulls > 1 yr							
Heifers > 1yr							
Male calves < 1 yr							
Female calves < 1 yr							
Total							

4.6 How much milk did the cows produce in the last 12 months?

Breed	Number of Cows in milk	Average milk output/cow/day (Litres)			Average number of days cows were milked	Total milk output /year (litres)
		Morning	Evening	Total milk output/day		
Ayshire						
Friesians						
Guernsey						
Jersey						
Upgrade (cross breed)						
Zebu						
Total						

4.7 How much milk is consumed at home?

---------- Lts/day ----------- lts/month ------------lts/years

4.8 a) Did you sell milk in the last 12 months?

Yes ---   No ----------

b) If the answer in (a) above is YES, how much milk did you sell and at what price?

Market	Total amount of milk sold (litres)	Unit price (ksh)	Total value (ksh)
Schools			
Hotels			
Neighbors			
Others (specify)			

4.9 Did you sell dairy calves, culled dairy cows and bulls last year? (Tick one option)

Yes --   No ----

4.10 If the answer in 4.9 above is yes provide the following in formation.

Type of animal	Number sold	Unit price (ksh)	Total value (ksh)
Dairy calves			
Bulls			
Culled dairy cows			
Total			

4.11 What other livestock do you keep?

Type of livestock	Number
Poultry	
Sheep	
Goats	
Cattle	

5: Resource use in dairy production

a). Land

5.1.How much land did you allocate to the following activities?

Activity Acres

Pasture --------

Fodder --------

b) Operating capital

5.2. Who treats your animals when they fall sick?

a) Self -----------------------

b) Veterinary officer ------

c) Both (a & b)------------

5.3.What diseases were the cows treated for and what was the cost?

Disease	Cost/cow (ksh)	Number of cows treated	Total cost (ksh)

5.4. How much money did you spend on purchasing of acaricides and de-wormers last year?

Type of medicine	Units purchased	Unit cost (ksh)	Total cost (ksh)
Acaricides			
De-wormers			
Total (kshs)			

Concentrates and mineral salts

5.5. Did you feed supplements (concentrates) to the cows last year? (*Tick one option.*)

Yes --- ---- No --- ----

5.6. How much feed/mineral salt did you purchase?

Type of feed/mineral salt	Units	Amount purchased	Unit cost (ksh)	Total cost (ksh)

5.7. How much feed did you give the cows?

Type of feed	Kg/cow/day	Number of cows fed	Number of days fed	Total amount in a year

5.8. Are the feeds available in the local markets? *(Tick one option)*

Yes ---   No ---

5.9. If the answer in 5.8 above is NO, where did you purchase the feed?----------------------

c) Farm by- products (crop residues)

5.10. Did you feed crop residues to the cows last year? (*Tick one option*)

Yes ----   No ---------

5.11. If the answer in 5.10 above is YES which are the main crop residues?

Maize stovers ----- ----------

Beans residues ---------------

Pigeon peas residues -------

Others (specify)----------------------

5.12 Which was the source of the crop residues?

a) Own production -------

b) Purchased --------------

c) Both (a & b) ------------

d) Others (specify) ---------------------------------

5.13. If the crop residues fed to cows were purchased estimate the amount of money you spent on them last year.

Type of crop residues	Total amount purchased (state units i.e. bundles or pick-ups)	Unit cost (kshs)	Total cost
Maize stovers			
Beans residues			
Pigeon peas residues			
Others (specify)			

e) Labour utilization

5.14 Are there members of your family who work on dairy enterprises?

Yes ---------   No ------------

5.15. If the answer in 5.4 above is YES give the following information.

Family member	Number	Average hours worked per day	Number of days available /week	Total number of hours worked
Adults 18-55 years				
Adults >55 years				
Children <18 years				
Totals				

5.16. Did you employ permanent worker(s) specifically for the dairy enterprise?

Yes ---   No ----------

5.17. If 5.13 above is YES how many people did you employ and what was the salary per person per month?

Number -------------. Ksh/month.----------------. Ksh/ year (12 months) ---------------

5.18 How many hours does the permanent employee work per day on the dairy enterprise?

Number employed	Hours worked /day	Days worked/week	Weeks worked/month	Total man hours/year

6. Dairy production systems

6.1 (a) Which livestock production system have adopted?

Zero-grazing --- -- Semi-zero grazing ----- Free range ---------

(b) How is the cow dung disposed?

Used as manure for crops---- Sold to neighbours ---- Other (specify) ------

6.2.(a) If you sold the cow dung estimate the quantity sold.------- (specify units e.g. bags, debe)

(b) What was the unit price of cow dung? -------------- Ksh/unit

6.3. Do you have any established fodder crops that you cut and feed the cows?

Yes ---- No --------

6.4. If the answer in 6.2 is YES which fodder crops did you grow last year?

Fodder crop	Area (acres)	Number of harvests last year

7.A.I and bull services

7.1 How are the cows serviced once on heat?

a) By A. I ----------

b) By Bull --------

c) Both (a & b) ------

7.2. If bull service was used where did you get the bull?

Own bull ----------------------

Neighbor's bull ---------------

7.3 How much did you pay for AI and bull service last year?

Type of service	Number of cows serviced	Number of services	Cost/service (ksh)	Total cost (ksh)
A. I				
Bull service				
Total cost (kshs)				

8. Housing of the dairy cows

8.1. Do you have houses for the dairy cows?

Yes ---- No -----

8.2. What was the cost of building the houses? ------------------ Kshs.

9 Extension

9.1 Did you get advice from extension officers?

Yes --- No ---

9.2. If the answer in 9.1 above is yes how many times did the extension officers visit you per month?

----------- Times/month.

9.3. Have you been trained on crop and livestock production?

Yes --- No ---

9.4. If the answer in 9.3 above is yes what kind of training?

Type of training	Venue	Year	Organized by

10. Problems experienced by farmers

10 What problems do you experience in farming?

i) --

ii) --

iii) --

iv) --

v) --

vi) --

vii) --

End of interview.

Thank the farmer for sparing time to respond to questionnaire.

Appendix 2.0: Linear programming equations

Appendix 2.1: Small farm model

Max z = 11351 x1+ 1080X2 + 7744X3 + 7727X4 + 16697X5 + 6865X6 + 54249X7

Subject to

X1 + X3 + X5 + X6 +X7 <= 1.8 Land constraint (short rain season)

X2 + X4 + X6 + X7 <= 1.8 Land constraint (long rain season)

X1 >= 0.64 minimum area under maize for subsistence (short rain season)

X2 >= 0.64 minimum area under maize for subsistence (long rain season)

X5 >= 0.42 minimum area under beans for subsistence

152X7 <= 740	January labour constraint
24X1 + 18X3 + 9X5 + 30X6 + 152X7 <= 740	February labour constraint
152X7 <= 740	March labour constraint
29X4 + 28X4 + 152X7 <= 999	April labour constraint
46X2 - 31X4 + 152X7 <= 740	May labour constraint
46X2 + 31X4 + 152X7 <= 740	June labour constraint
152X7 <= 740	July labour constraint
21X2 + 18X4 + 152X7 <= 999	August labour constraint
152X7 <= 740	September labour constraint
31X1 + 28X3+ 14X5 + 37X6 + 152X7 <= 740	October labour constraint
46X1 + 31X3 + 19X5 + 61X6 + 152X7 <= 740	November labour constraint
46X1 + 31X3 + 19X5 + 61X6 + 152X7 <= 999	December labour constraint

3200X1+3450X2+5098X +3465X4 +5325X5 +5097X6 +23804X7<= 49439 capital constraint

X1, X2, X3, X4, X5, X6, X7, >=0 non- negativity constraint

Where; X1—maize (short rain season)

X2 –maize (long rain season)

X3—maize/ pigeon peas (short rain season)

X4 – maize/ pigeon peas (long rain season)

X5 – beans (short rain season)

X6 – maize/ beans (short rain season)

X7 – dairy enterprise

Appendix 2.2: Medium farm model

MAX Z = 6875 X1 + 1137 X2 + 1267 X3 + 4791 X4 + 14531X5 + 6441 X6 + 7787 X7 + 55686 X8

Subject to

X1 + X3 + X5 + X7 + X8 <= 4.9

X2 + X4 + X6 + X8 <= 4.9

X1 >= 1.46 minimum area under maize for subsistence (short rain season)

X2 >= 1.46 minimum area under maize for subsistence (long rain season)

X5 >= 0.56 minimum area under beans for subsistence (short rain season)

X6 >= 0.56 minimum area under beans for subsistence (long rain season)

152X8 <= 740 — January labour constraint

46X1 + 18X3 + 12X5 + 39X7 + 152X8 <= 740 — February labour constraint

152X8 <= 740 — March labour constraint

38X2 + 15X4 + 13X6 + 152X8 <= 999 — April labour constraint

12X2 + 20X4 + 13X6 + 152X8 <= 740 — May labour constraint

12X2 + 20X4 + 13X6 + 152X8 <= 740 — June labour constraint

152X8 <=740 — July labour constraint

30X2 + 18X4 + 10X6 + 152X8 <= 999 — August labour constraint

152X8 <= 740 — September labour constraint

15X1 + 15X3 + 23X5 + 45X7 + 152X8 <= 740 — October labour constraint

12X1 + 20X3 + 19 X5 + 37X7 + 152X8 <= 740 — November labour constraint

12X1 + 20X3 + 19 X5 + 37X7 + 152X8 <= 999 — December labour constraint

1663X1+1604X2+4653X3+2082X4+ 4435X5+ 4625X6+2980X7+24798X8 <= 446840 capital constraint

X1, X2, X3, X4, X5, X6, X7, X8, >=0 non- negativity constraint

Where; X1—maize (short rain season)

X2 -maize (long rain season)

X3—maize/ pigeon peas (short rain season)

X4 – maize/ pigeon peas (long rain season)

X5 – beans (short rain season)

X6—beans (long rain season)

X7-- maize/ beans (short rain season)

X8 – dairy enterprise

Appendix 2.3: Large farm model

MAX $Z = 7975X1 + 15247X2 + 2277X3 + 33650X4$

Subject to

$X1 + X2 + X4 <= 10$

$X3 + X4 <= 10$

$X1 >= 3$ minimum area under maize for subsistence (short rain season)

$X2 >= 0.6$ minimum area under beans for subsistence (long rain season)

$152X4 <= 740$ January labour constraint

$45X1 + 33X2 + 152X4 <= 740$ February labour constraint

$152X4 <= 740$ March labour constraint

$30X3 + 152X4 <= 999$ April labour constraint

$40X3 + 152X4 <= 740$ May labour constraint

$40X3 + 152X4 <= 740$ June labour constraint

$152X4 <= 740$ July labour constraint

$37X3 + 152X4 <= 999$ August labour constraint

$152X4 <= 740$ September labour constraint

$25X1 + 10X2 + 152X4 <= 740$ October labour constraint

$75X1 + 30X2 + 152X4 <= 740$ November labour constraint

$75X1 + 30X2 + 152X4 <= 740$ December labour constraint

$1514X1 + 3443X2 + 2498X3 + 28442X4 <= 35897$ capital constraint

$X1, X2, X3, X4, >= 0$ non- negativity constraint

Where; X1------ maize (short rain season)

X2 ---- beans (short rain season)

X3----Beans (long rain season)

X4---- Dairy enterprise

APPENDIX 3.0: LINEAR PROGRAMMING COMPUTER OUTPUTS

APPENDIX 3.1: LINEAR PROGRAMMING COMPUTER PRINT OUTPUT OF SMALL FARM MODEL (WITHOUT SUBSISTENCE CONSTRAINT)

Number of Iterations=2

Objective Function Value Ksh 108,498

Variable	Value	Reduced cost
X1	0.00	35,171.00
X2	0.00	6,647.00
X3	0.00	38,778.00
X4	0.00	0.00
X5	0.00	29,825.00
X6	0.00	39,657.00
X7	2.00	0.00

Row	Slack/Surplus	Dual Prices (Marginal Value Product)
2	0.00	46,522.00
3	0.00	7,727.00
4	466.40	0.00
5	466.40	0.00
6	466.40	0.00
7	725.40	0.00
8	466.40	0.00
9	466.40	0.00
10	466.40	0.00
11	725.40	0.00
12	466.40	0.00
13	466.40	0.00
14	466.40	0.00
15	725.40	0.00
16	6591.80	0.00
17	0.00	0.00
18	0.00	0.00
19	0.00	0.00
20	0.00	0.00
21	0.00	0.00
22	0.00	0.00
23	2.00	0.00

SENSITIVITY (RANGE) ANALYSIS OF SMALL FARM MODEL (WITHOUT SUBSISTENCE CONSTRAINT)

OBJECTIVE COEFFICIENT RANGES			
Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X1	11,351	35,171	Infinity
X2	1,080	6,647	Infinity
X3	7,744	38,778	Infinity
X4	7,727	29,825	6,647
X5	16,697	29,825	Infinity
X6	6,865	39,657	Infinity
X7	54,249	Infinity	29,825

RIGHT-HAND SIDE -RANGES			
Row	RHS	Allowable increase	Allowable decrease
2	1.80	0.00	1.80
3	1.80	1.90	0.00
4	740.00	Infinity	466.40
5	740.00	Infinity	466.40
6	740.00	Infinity	466.40
7	999.00	Infinity	725.40
8	740.00	Infinity	466.40
9	740.00	Infinity	466.40
10	740.00	Infinity	466.40
11	999.00	Infinity	725.40
12	740.00	Infinity	466.40
13	740.00	Infinity	466.40
14	740.00	Infinity	466.40
15	999.00	Infinity	725.40
16	49439.00	Infinity	6591.80
17	0.00	0.00	Infinity
18	0.00	0.00	Infinity
19	0.00	0.00	Infinity
20	0.00	0.00	Infinity
21	0.00	0.00	Infinity
22	0.00	0.00	Infinity
23	0.00	1.80	Infinity

APPENDIX 3.2: LINEAR PROGRAMMING COMPUTER PRINT OUT OF MEDIUM FARM MODEL (WITHOUT SUBSISTENCE CONSTRAINT)

Number of iterations= 3

Objective function value Ksh107, 004

Variable	Value	Reduced cost
X1	0.00	31,915.00
X2	0.00	2,703.00
X3	0.00	2,289.00
X4	4.08	0.00
X5	4.08	0.00
X6	0.00	3,408.00
X7	0.00	3,848.00
X8	1.00	0.00

Row	Slack/Surplus	Dual Prices (Marginal Value Product)
2	0.00	5709.00
3	0.00	649.00
4	616.00	0.00
5	567.00	0.00
6	616.00	0.00
7	813.00	0.00
8	534.00	0.00
9	534.00	0.00
10	616.00	0.00
11	817.00	0.00
12	616.00	0.00
13	522.00	0.00
14	538.00	0.00
15	797.00	0.00
16	0.00	1.98
17	0.00	0.00
18	0.00	0.00
19	0.00	0.00
20	4.08	0.00
21	4.08	0.00
22	0.00	0.00
23	0.00	0.00
24	1.00	0.00

SENSITIVITY (RANGE) ANALYSIS OF MEDIUM FARM MODEL (WITHOUT SUBSISTENCE CONSTRAINT)

OBJECTIVE FUNCTION RANGES			
Variable	Current Coefficients	Allowable Increase	Allowable Decrease
X1	6,875	31,915	Infinity
X2	1,137	2,703	Infinity
X3	12,675	2,289	Infinity
X4	4,791	36,364	583
X5	14,351	24,502	2,317
X6	6,441	3,408	Infinity
X7	21,480	3,849	Infinity
X8	55,686	5,703	24,502

RIGHT HAND SIDE RANGES			
Row	RHS	Allowable increase	Allowable decrease
2	4.90	3.36	3.28
3	4.90	7.15	3.66
4	740.00	Infinity	616.00
5	740.00	Infinity	567.00
6	740.00	Infinity	616.00
7	999.00	Infinity	813.00
8	740.00	Infinity	534.00
9	740.00	Infinity	534.00
10	740.00	Infinity	616.00
11	999.00	Infinity	817.00
12	740.00	Infinity	616.00
13	740.00	Infinity	522.00
14	740.00	Infinity	538.00
15	999.00	Infinity	797.00
16	46846.00	73989.00	1409.00
17	0.00	0.00	Infinity
18	0.00	0.00	Infinity
19	0.00	0.00	Infinity
20	0.00	4.08	Infinity
21	0.00	4.08	Infinity
22	0.00	0.00	Infinity
23	0.00	0.00	Infinity
24	0.00	1	Infinity

APPENDIX 3.3: LINEAR PROGRAMMING COMPUTER PRINT OUT OF LARGE FARM MODEL (WITHOUT SUBSISTENCE CONSTRAINT)

Objective Function Value Ksh158, 807

Variable	Value	Reduced Cost
X1	0	6,015.00
X2	10.00	0.00
X3	0.59	0.00
X4	0	4,885.00

Row	Slack/surplus	Dual Prices (Marginal Value Product)
2	0.00	12,610.00
3	9.40	0.00
4	740.00	0.00
5	410.00	0.00
6	990.00	0.00
7	722.00	0.00
8	716.00	0.00
9	716.00	0.00
10	99.00	0.00
11	718.00	0.00
12	740.00	0.00
13	640.00	0.00
14	440.00	0.00
15	699.00	0.00
16	0.00	0.90
17	0.00	0.00
18	0.00	0.00
19	0.59	0.00
20	0.00	0.00

SENSITIVITY (RANGE) ANALYSIS OF LARGE FARM MODEL (WITHOUT SUBSISTENCE CONSTRAINT)

OBJECTIVE FUNCTION RANGES			
Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X1	7,975	6,015	Infinity
X2	15,749	Infinity	4,885
X3	2,277	7,790	488
X4	33,651	4,885	Infinity

RIGHT HAND SIDE RANGES			
Row	CURRENT RHS	Allowable Increase	Allowable Decrease
2	10.00	0.43	6.83
3	10.00	Infinity	9.41
4	740.00	Infinity	740.00
5	740.00	Infinity	410.00
6	999.00	Infinity	990.00
7	740.00	Infinity	722.3.00
8	740.00	Infinity	716.51
9	740.00	Infinity	716.52
10	999.00	Infinity	999.00
11	740.00	Infinity	718.27
12	740.00	Infinity	740.00
13	740.00	Infinity	640.00
14	740.00	Infinity	440.00
15	999.00	Infinity	699.00
16	35,897.00	23,513.00	1,467.00
17	0.00	0.00	Infinity
18	0.00	10.00	Infinity
19	0.00	0.59	Infinity
20	0.00	0.00	Infinity

APPENDIX 3.4: LINEAR PROGRAMMING COMPUTER PRINT OUT OF SMALL FARM MODEL (WITH SUBSISTENCE CONSTRAINT)

Number of Iterations=5

Objective Function Value Ksh 72,437

Variable	Value	Reduced cost
X1	0.64	0.00
X2	0.64	0.00
X3	0.00	38,778.00
X4	0.42	0.00
X5	0.42	0.00
X6	0.00	39,657.00
X7	1.00	0.00

Row	Slack/Surplus	Dual Prices (Marginal Value Product)
2	0.00	46,522.00
3	0.00	7,727.00
4	0.00	-35171.00
5	0.00	-6,647.00
6	0.00	-2982.00
7	627.57	0.00
8	608.38	0.00
9	627.52	0.00
10	850.32	0.00
11	585.06	0.00
12	585.06	0.00
13	627.52	0.00
14	865.52	0.00
15	627.52	0.00
16	601.80	0.00
17	590.10	0.00
18	849.16	0.00
19	23,876.24	0.00
20	0.64	0.00
21	0.64	0.00
22	0.00	0.00
23	0.42	0.00
24	0.42	0.00
25	0.00	0.00
26	1.00	0.00

SENSITIVITY (RANGE) ANALYSIS OF SMALL FARM MODEL (WITH SUBSISTENCE CONSTRAINT)

OBJECTIVE FUNCTION RANGES			
Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X1	11,351	35,171	Infinity
X2	1,080	6,647	Infinity
X3	7,744	38,778	Infinity
X4	7,727	29,825	6,647
X5	16,697	29,825	Infinity
X6	6,865	39,657	Infinity
X7	54,249	Infinity	29,825

RIGHT HAND SIDE RANGES

Row	RHS	Allowable Increase	Allowable Decrease
2	1.80	0.42	0.74
3	1.80	6.89	0.42
4	0.64	0.74	0.42
5	0.64	0.74	0.64
6	0.42	0.74	0.42
7	740.00	Infinity	627.00
8	740.00	Infinity	608.00
9	740.00	Infinity	627.00
10	999.00	Infinity	850.00
11	740.00	Infinity	585.00
12	740.00	Infinity	585.00
13	740.00	Infinity	627.00
14	999.00	Infinity	865.00
15	740.00	Infinity	627.00
16	740.00	Infinity	601.00
17	740.00	Infinity	590.00
18	999.00	Infinity	849.00
19	49,439.00	Infinity	23,876.00
20	0.00	Infinity	Infinity
21	0.00	Infinity	Infinity
22	0.00	Infinity	Infinity
23	0.00	Infinity	Infinity
24	0.00	Infinity	Infinity
25	0.00	Infinity	Infinity
26	0.00	Infinity	Infinity

APPENDIX 3.5: LINEAR PROGRAMMING COMPUTER PRINTOUT OF MEDIUM FARM MODE (WITH SUBSISTENCE CONSTRAINT)

Number of Iterations= 3
Objective Function Value KSH 69,978

Variable	Value	Reduced cost
X1	1.46	0.00
X2	1.46	0.00
X3	0.00	2,357.00
X4	1.10	0.00
X5	3.40	0.00
X6	0.56	0.00
X7	0.00	3,395.00
X8	0.00	5,703.00

Row	Slack/Surplus	Dual Prices (Marginal Value Product)
2	0.00	4,325.00
3	1.74	0.00
4	0.00	-35,720.00
5	0.00	-2,554.00
6	2.90	0.00
7	0.00	-420.00
8	740.00	0.00
9	631.56	0.00
10	740.00	0.00
11	919.16	0.00
12	692.42	0.00
13	692.42	0.00
14	740.00	0.00
15	933.66	0.00
16	740.00	1.98
17	638.98	0.00
18	657.12	0.00
19	916.12	0.00
20	0.00	2.30
21	1.46	0.00
22	1.46	0.00
23	0.00	0.00
24	1.14	0.00
25	3.44	0.00
26	0.56	0.00

SENSITIVITY (RANGE) ANALYSIS OF MEDIUM FARM MODE (WITH SUBSISTENCE CONSTRAINT)

Objective Function Ranges			
Variable	Current Coefficients	Allowable Increase	Allowable Decrease
X1	6,875	35,720	Infinity
X2	1,137	2,554	Infinity
X3	12,675	2,357	Infinity
X4	4,791	2,030	583
X5	14,351	Infinity	2,357
X6	6,441	420	Infinity
X7	21,480	3,395	Infinity
X8	55,686	5,703	Infinity

RIGHT HAND SIDE RANGES			
Row	RHS	Allowable increase	Allowable decrease
2	4.90	0.53	0.81
3	4.90	0.19	1.74
4	1.46	1.47	0.29
5	1.46	2.88	0.46
6	0.56	0.51	Infinity
7	0.56	Infinity	0.56
8	740.00	Infinity	740.00
9	740.00	Infinity	631.00
10	740.00	Infinity	740.00
11	999.00	Infinity	919.00
12	740.00	Infinity	692.00
13	740.00	Infinity	740.00
14	740.00	Infinity	933.00
15	999.00	Infinity	740.00
16	740.00	Infinity	638.00
17	740.00	Infinity	657.00
18	740.00	Infinity	657.00
19	999.00	Infinity	916.00
20	46,840.00	3,625.00	2,370.00
21	0.00	1.46	Infinity
22	0.00	1.46	Infinity
23	0.00	0.00	Infinity
24	0.00	1.13	Infinity
25	0.00	3.44	Infinity
26	0.00	0.56	Infinity
27	0.00	0.00	Infinity
28	0.00	0.00	Infinity

APPENDIX 3.6: LINEAR PROGRAMMING COMPUTER PRINT OUT OF LARGE FARM MODEL (WITH SUBSISTENCE CONSTRAINT)

Objective Function Value Ksh 137,257

Variable	Value	Reduced Cost
X1	3.00	0.00
X2	7.00	0.00
X3	2.90	0.00
X4	0	4,885.00

Row	Slack/Surplus	Dual Prices (Marginal Value Product)
2	0.00	12,610.00
3	7.09	0.00
4	0.00	-6,015.00
5	6.40	0.00
6	740.00	0.00
7	374.00	0.00
8	740.00	0.00
9	911.00	0.00
10	623.00	0.00
11	623.00	0.00
12	740.00	0.00
13	891.00	0.00
14	740.00	0.00
15	595.00	0.00
16	305.00	0.00
17	564.00	0.91
18	0.00	0.00
19	3.00	0.00
20	7.00	0.00
21	2.90	0.00
22	0.00	0.00

SENSITIVITY (RANGE) ANALYSIS OF LARGE FARM MODEL (WITH SUBSISTENCE CONSTRAINT)

OBJECTIVE FUNCTION RANGES			
Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X1	7,975.00	6,015.00	Infinity
X2	15,749.00	Infinity	4,885.00
X3	2,277.00	7,790.00	488.00
X4	33,651.00	4,885.00	Infinity

RIGHT-HAND SIDE RANGES			
Row	Current RHS	Allowable Increase	Allowable Decrease
2	10.00	2.10	5.10
3	10.00	Infinity	7.09
4	3.00	6.40	3.00
5	0.60	6.40	Infinity
6	740.00	Infinity	740.00
7	740.00	Infinity	374.00
8	740.00	Infinity	740.00
9	999.00	Infinity	911.00
10	740.00	Infinity	623.00
11	740.00	Infinity	623.00
12	740.00	Infinity	740.00
13	999.00	Infinity	891.00
14	740.00	Infinity	740.00
15	740.00	Infinity	595.00
16	740.00	Infinity	305.00
17	999.00	Infinity	564.00
18	35.897.00	17,726.00	2,254.00
19	0.00	3.00	Infinity
20	0.00	7.00	Infinity
21	0.00	2.90	Infinity
22	0.00	0.00	Infinity