Effect of Farm Income Risk on Smallholder Production Decisions in the Highlands of Machakos District, Kenya: The Case of Kauti Irrigation Scheme

By

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Declaration

I, **Elijah Nzula Muange**, declare that this thesis is my original work and has not been presented for a degree award in any university.

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Dedication

To my wife; Judy, and Children; Esther and David, for your love, support, inspiration and encouragement during my study period.

To my Mother Esther, and Late dad Muange, who introduced me to the academic world.

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List of Acronyms

EV	Mean-Variance combination of income associated with a farm plan
GAMS	General Algebraic Modelling System
Ksh	Kenya Shilling(s)
LP	Linear Programming
LU	Livestock Unit(s)
MVP	Marginal Value Product
QRP	Quadratic Risk Programming
SPSS	Statistical Package for Social Sciences
TFGM	Total Farm Gross Margin

Abstract

Raising agricultural productivity and incomes in the densely populated highlands of Machakos District is constrained by various risks which make farm income uncertain. Farmers diversify their activities to cushion themselves against risks but there is no empirical recommendation to guide them in selecting optimal enterprise combinations (farm plans). The farmers adopt own-preferred farm plans but it is not known whether such plans minimize risk. This study assessed the effect of farm income risks on production decisions in Kauti Irrigation Scheme, with a view to identifying farm plans that earn farmers higher incomes at existing or lower levels of income risk.

The study used crop and livestock production and marketing data covering 2007/08 and 2008 rain seasons, collected in March 2009 through a farm household survey involving 113 households. The data were analysed using linear and quadratic risk programming techniques. Results show that a typical farm plan in the study area features nine enterprises consisting of 0.96 acres of maize intercrop, 0.13 acres of French beans, 0.03 acres of kales and 0.04 acres of tomatoes in short rains season; 0.95 acres of maize intercrop, 0.02 acres of kales and 0.02 acres of tomatoes in long rains season; and 0.25 acres of coffee and 0.93 livestock units in both seasons. This farm plan is highly diversified compared to optimal farm plans developed in this study, but it is risk-inefficient. However, by adopting the optimal farm plans, a typical household can improve its income from the current KSh 36,049 to KSh 63,913, representing a 77 percent increase, under the current technological and resource constraints. This income can be further increased to KSh 75,339 – which is more than double and 31 percent less risky than the current income, if households' access to working capital is increased.

The study recommends that farmers abandon production of coffee and kales; allocate 1.018 acres to maize intercrop, 0.131 acres to French beans, and 0.119 acres to tomatoes in short

rains season; 0.761 acres to maize intercrop and 0.164 acres to tomatoes in long rains season; and keep 2.5 livestock units throughout the year. This farm plan earns farmers KSh 75,339, with a standard deviation of KSh 30,790. For this to happen, the government and development partners should develop farm input financing programmes that increase farmers' access to working capital by 67 percent, from the current KSh 9,915 to KSh 16,565. With this additional capital, farmers will particularly bring most of the idle irrigable land into production, reducing the proportion of income risks attributable to production risks. Notwithstanding these potential increases in farm incomes, the farm sizes in the study area are too small such that the optimal farm income is not sufficient to lift households out of poverty. This calls for policy makers to find ways of increasing off-farm employment.

Chapter 1: Introduction

1.1. Agricultural Sector in Kenya's Economic Development

Reduction of poverty and unemployment remain the two major development challenges facing Kenya. The government plans to reduce the proportion of its population living below the poverty line from 56 percent in 2000 to 26 percent by 2015, and the proportion of the food poor from 48.4 percent to below 10 percent by the year 2015, in line with the United Nations Millennium Development Goal number one (Republic of Kenya, 2004a). To achieve these objectives, the agricultural sector will play a pivotal role, particularly because the sector contributes about 22 percent of the country's gross domestic product (GDP), and is also the main source of livelihood for approximately 80 percent of the country's rural population (Republic of Kenya, 2008 and Kenya National Bureau of Statistics, 2009).

Kenya's agriculture sector is faced with a myriad of challenges including frequent droughts and floods, lack of farmer's access to credit, low adoption of modern technology, poor governance and corruption in major agricultural institutions, inadequate markets and market infrastructure and high costs of inputs, which slow down the performance of the sector (Republic of Kenya, 2004b). For the sector to perform its role in improving incomes and food security, efforts should therefore be geared towards raising productivity, commercializing agriculture, improving input and produce markets, encouraging diversification into high value enterprises and strengthening and reforming agricultural institutions (Eicher and Staatz, 1998, Fan and Chan-Kang, 2005 and World Bank, 2008).

Raising agricultural productivity is important in an agriculture-based country such as Kenya for a number of reasons. First, agriculture is the main food producing sector and therefore, increase in food productivity will improve food security in the country (Kinyua, 2004).

Secondly, the sector accounts for 80 percent of employment as mentioned above, 60 percent of export earnings and 45 percent of government revenue (Sikei et al, 2009), and these are likely to improve with increased productivity. Thirdly, agricultural productivity (particularly of staples) affects food prices and consequently wage costs and competitiveness of tradable sectors (World Bank, 2008). Kenya's economy depends on agriculture for its tradable sectors, which are basically primary industries such as agro-processing. Agricultural productivity is therefore crucial in determining the price of raw materials used in the tradable sectors and hence their competitiveness. This makes a case for improving agricultural productivity in the country.

1.2. Agricultural Productivity, Risk and Policy Issues

Agricultural output and productivity in Kenya is low in dry lowland regions such as Machakos, compared to the high rainfall areas (Kibaara et al, 2009). Key drivers of productivity in the country are well documented and they include high yielding varieties and animal breeds, use of inorganic fertilizers, access to rural financial services and reduced distances to agricultural extension services, input stockists and motorable roads (Kibaara et al, 2009). In the SRA (Republic of Kenya 2004b), the government outlines a number of measures that will ensure improvement of the above factors, but recent studies (Ariga et al, 2008 and Kibaara et al, 2009) show many of these factors are still unfavourable in the dryland areas.

One way of raising agricultural productivity in Kenya even under the existing technological, resource and institutional constraints is through proper planning of farm activities in order to enhance efficiency in utilization of the scarce productive resources. However, the farming environment, especially in the arid areas, is very risky and the risk aversive behaviour of farmers constrains adoption of optimal farm plans, leading to misallocation of resources

(Hardaker et *al*, 2004 and Msusa, 2007). Past studies (Owuor, 1999; Freeman and Omiti, 2003 and Kibaara et al 2009) show that adoption of productivity improving inputs and technologies is very low mainly due to risky farming environment occasioned by low and erratic rainfall. Thus, given that risks affect farm decisions, the extent to which risks and their effect on farmers' decision-making are understood can determine success of programs aimed at raising agricultural productivity and incomes, and consequently rural development (Olarinde, *et al*, 2008).

The distinction between risk and uncertainty was at first made by Frank Knight (quoted in Debertin, 2002). Knight postulated that in a risky environment, both event outcomes and their probabilities of occurrence are known; whereas in an uncertain environment, neither the outcomes nor their respective probabilities of occurrence are known. But Debertin (2002) puts a very thin divide between risk and uncertainty. He sees a risk-uncertainty continuum, with purely risky events on one extreme and purely uncertain events on the other extreme. In between the two extremes is an environment in which only some possible outcomes are known and only some outcomes have probabilities attached to them. It is in this mid-point that most farmers operate.

In Kenyan agriculture, risks are of several forms, as highlighted by (Kliebenstein and Scott JR., 1975, Hardaker *et al*, 2004, and Bhowmick, 2005).These include production risks, caused by extremities of weather elements like rainfall, humidity and temperature and biological organisms such as pests and diseases; market risks, caused by fluctuations in input and output prices, currency exchange rates and product demand; and institutional risks, emanating from unfavourable changes in government policies such as increases in taxes. If unabated, the above types of risk translate into farm income risks and consequently low agricultural productivity (Kuyiah *et al*, 2006).

Smallholder farmers are not unaware of risks and in their bid to cope with them; they adopt several mechanisms such as enterprise diversification, mixed cropping and irrigation (Kliebenstein and Scott JR., 1975, Rafsnider, *et al*, 1993, Bhowmick, 2005 and Umoh, 2008). Irrigation has the potential to reduce farming risks associated with stochastic rainfall, thereby increasing farm productivity, output and consequently incomes (FAO, 2003). In Kenya for example, available information (Republic of Kenya, 2009) shows that profitability (gross margins) of most crops grown in dryland areas can more than double if grown under irrigation compared to rainfed conditions (Table 1.2). Further, there is empirical evidence that irrigation improves lives of smallholder households, with irrigating farm households (especially in dry areas) reportedly being more food secure and having more incomes than those practicing rainfed farming (Neubert et al (2007).

Table 1.2: Gross Margins of Selected Crops under Rainfed and Irrigation Farming in Kenya

Crop	*Gross Margin (Ksh/ha)*		
	Rainfed	Irrigated	% Increase
Maize	10,621	34,289	223
Sorghum	9,684	21,802	125
Millet	718	10,436	1,353
Bean	12,283	39,827	224
Pigeonpea	11,341	28,430	151
Cassava	24,913	34,879	40
Cabbage	132,187	303,455	130
Kale	143,520	189,788	32
Onion	93,409	184,677	98
Tomatoes	164,129	251,547	53
Banana	50,612	137,718	172
Total	**653,417**	**1,236,848**	**89**

Source: Adapted from Republic of Kenya (2009)

Notwithstanding these potential benefits of irrigation, Kenyan agriculture is still largely rainfed, yet only about 20 percent of the country of the country has a high or medium potential for (rainfed) agricultural production according to the National Irrigation Board

(NIB)[1]. Out of the total potential irrigable land of 497,400 hectares, only about 183,900 hectares (37 percent) had been developed as at 2007, but the government plans to expand irrigated land to 300,000 hectares by 2012 in line with its *Vision 2030* goals (Republic of Kenya, 2009). However, irrigation development in Kenya faces numerous challenges including lack of a national irrigation policy, legal and institutional frameworks; inadequate investment in the sector by both public and private sector; inadequate development of irrigation infrastructure and water storage facilities; inadequate technical capacity for both the technical staff and farmers; inadequate farmers' organization and participation and inadequate support services such as credit, infrastructure and extension (Mbatia, 2006).

Machakos District has an irrigation potential of 10,000 hectares, but only about one third of this potential (3,000 hectares) is irrigated[2]. Most of the irrigation is practiced under small scale community irrigation schemes/projects managed by water user associations/groups. The projects source water from rivers, springs and dams and vary in size from about 2 to 800 hectares. Farmers in these schemes grow horticultural crops mainly for the market, but some also use irrigation water to supplement inadequate rainfall in subsistence crops. The main challenges experienced in the irrigation schemes are inadequate water, soil erosion problems due to steep slopes, high water losses due to seepage and evaporation during conveyance, crop pests and diseases that reduce quality and quantity of marketable produce, and poor marketing arrangements for farm produce.

In Kathiani, the study Division, there are ten small scale farmer-managed irrigation schemes, of which Kauti is the largest. Kauti Irrigation Scheme uses a gravity fed open furrow irrigation system. Irrigation water is sourced from Umanthi River and Muooni dam, built

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[1] http://www.nib.or.ke. Accessed on 30th August 2010

[2] According to various unpublished reports at the District Agricultural Office, Machakos.

along the same river, and is conveyed through four unlined canals. The estimated number of farmers in the scheme is 1,000. Although the initial purpose of the scheme was to introduce commercial farming, not all farmers practice irrigation in all seasons. The number of farmers irrigating during each season fluctuates depending on water availability and socioeconomic factors (Ministry of Agriculture 2005). Farmers are not formally restricted on the size of land or crops to irrigate. The choice of these depends on how well the farmer can manage the irrigation water allocated to him/her. The main irrigated crops grown are kales, tomatoes and French beans, while maize, beans, pigeon peas, cowpeas, coffee, bananas, mangoes and avocadoes are mainly rain-fed though some farmers irrigate to supplement rainfall when it is insufficient. The farmers also keep cattle, goats, sheep and chicken.

Several problems experienced in the scheme limit profitability of farming in the area. These include: reduced dam capacity due to siltation; canal degradation, which has reduced canal length from the initial 10 kilometres to less than 5 kilometres at present; high water losses through seepage and evaporation during conveyance; weak management system, with some farmers refusing to participate in management of the canals; lack of working capital; and poor marketing arrangements. These challenges expose farmers to many risks particularly due to the erratic nature of rainfall, irrigation water supply, and input and output prices. The scheme is currently being rehabilitated with funding from African Development Bank (ADB) to address most of these problems. But while these rehabilitation efforts go on, farmers face a key challenge of determining the type, number and level of enterprises that they must operate in their small farms in order to use the available irrigable land and other resources more efficiently and maximise their incomes while minimising risks[3].

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[3] Additional information from a focus group discussion with farmers and discussions with Ministry of Agriculture extension staff in Kathiani Division.

1.3. Statement of the Problem

Farmers in Kauti Irrigation Scheme are faced with numerous risks, which make farm incomes uncertain. In an attempt to cushion themselves against this income risk, the farmers resort to diversification of farm enterprises. However, no study has been carried out in the Scheme to determine optimal enterprise mixes (farm plans) that suits each farmer's degree of risk aversion. This is complicated by the small farm sizes which limit the degree of diversification, yet the farmers desire to operate as many enterprises as possible. In the absence of formally recommended optimal farm plans, farmers adopt own-preferred enterprise mixes, which reportedly misallocate resources and reduce farm incomes, as the farmers trade off expected income with risk (Bhende and Venkataram, 1994 and Kobzar, 2006). The low income levels in the Scheme call for improvement of the farming system in order to raise farm incomes and reduce income risks.

1.4. Objectives of the Study

The general objective of the study was to assess the effect of farm income risks on production decisions, with a view to identifying farm plans that earn farmers higher incomes at existing or lower levels of risk. Specific objectives were to:

i. determine optimal farm plans and compare them with the existing plans
ii. assess the effect of farm income risk on choice of optimal farm plans
iii. investigate risk mitigating strategies that would enable farmers increase incomes at the existing or lower levels of income risk.

The hypotheses tested were that existing farm plans are optimal; and secondly, that risk preference does not affect choice of optimal farm plans in the study area.

1.5. Justification for the Study

Food security and poverty are major development challenges in Machakos District. Although about 70 percent of the population derive their livelihood from agriculture, low output and productivity and high farming risks threaten improvement of food security and farm incomes. With limited and decreasing per capita land, particularly in the densely populated highlands of the district, growth in agricultural output can hardly come from cultivating additional land, but rather from growth in productivity (Kibaara, *et al*, 2009). This productivity growth will result from improved efficiency in production as envisaged in the current Strategy for Revitalizing Agriculture (Republic of Kenya, 2004b) and by Adesiyan *et al,* (2007). One way of improving production efficiency in Machakos is by adoption farm plans that optimize risk, and this study contributes to the existing literature on how such plans can be generated.

Chapter 2: Literature Review

This chapter begins with a discussion on some of the main sources of farm income risks in the study area. It then introduces approaches to farm planning and enumerates some of the main risk programming techniques used in farm planning. The two farm planning techniques adopted in the study (linear programming and quadratic risk programming) are also discussed and in the final part of the chapter, summaries of some farm planning studies that have applied linear and quadratic programming techniques within and outside the country are reviewed.

2.1 Sources and Significance of Farming Risks in the Study Area

Among the main risks that affect agricultural production and incomes in Machakos District are erratic rainfall and input and output prices. The erratic nature of these factors has been presented in Figures 2.1(a), 2.1(b) and 2.1(c). Figure 2.1(a) shows rainfall pattern for the last 10 years before the study period (1997-2006), categorised by season[4]. The data shows that although an average figure for seasonal or annual rainfall may be quoted for the area, a high variability exists within the seasons and across the years[5]. This implies that farmers in the district, who practice mainly rain-fed agriculture, are exposed to a high risk of farm output fluctuation. When rains are good, farm output is high but output prices fall. On the contrary, poor rains result to low or no output, with a resultant high output prices. Hence, erratic rainfall is arguably the most important source of farm income risks in Machakos.

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[4] This data was recorded at Katumani Research Station of the Kenya Agricultural Research Institute (KARI).

[5] For instance, long-term rainfall data recorded at Katumani between 1957 and 2003 gave an annual rainfall figure that ranged between 330 and 1260 mm with a coefficient of variation of 28% (Rao and Okwach, 2005).

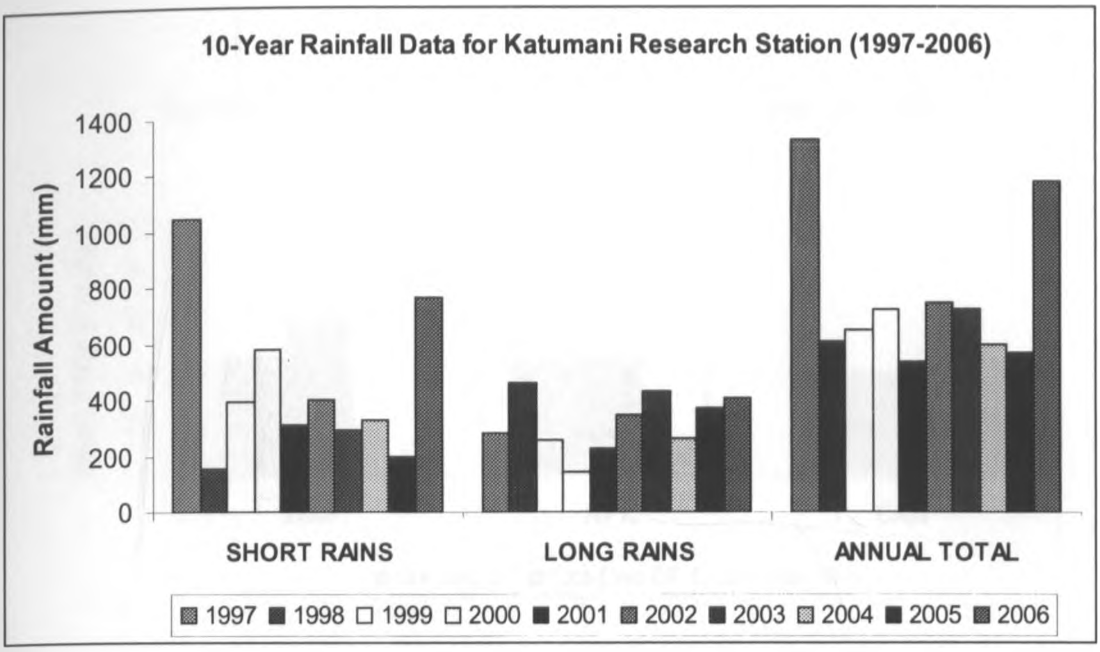

Figure 2.1(a): 10-year rainfall data for Katumani research station, Machakos

Data Source: District Agricultural Office, Machakos (2009)

Figure 2.1(b) illustrates quarterly prices of fertilizer at the main market in the Kathiani Division (Kathiani Town), while Figure 2.1(c) shows quarterly output prices of selected crops at farm gate prices, during the study period. The trends show that for most inputs and outputs, farmers face very uncertain prices, which also fluctuate within a very short time interval. This means that farmers' incomes will fluctuate directly or indirectly as a result of these price changes. It also means that farmers find it difficult to plan their production based on market prices, since they are uncertain about the prices they will face at the time they decide to buy inputs or sell their output.

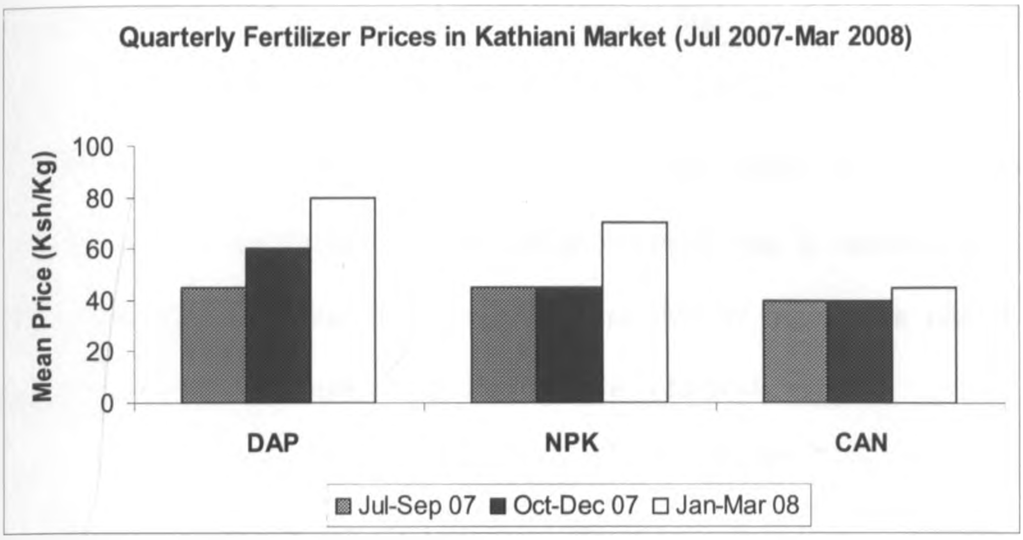

Figure 2.1(b): Quarterly fertilizer prices in Kathiani Market (July 2007– March 2008)

Data Source: Divisional Agricultural Office, Kathiani (2009)

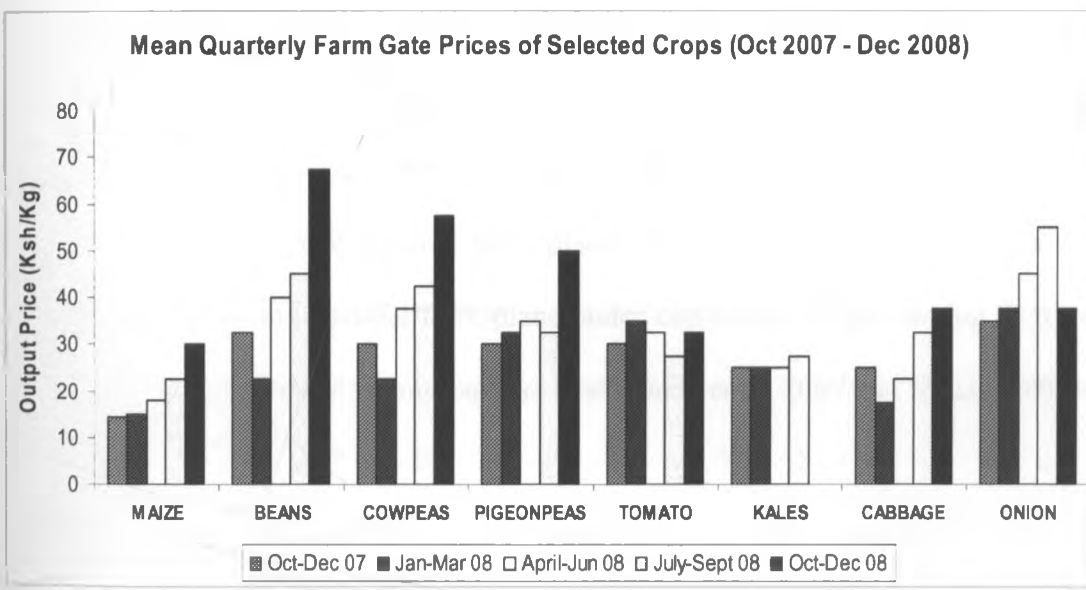

Figure 2.1(c): Quarterly farm gate prices of selected crops in Kathiani (Oct 2007– Dec 2008)
Data Source: Divisional Agricultural Office, Kathiani (2009)

Smallholder farmers in the study area have diversified their production as a risk coping strategy. However, in a bid to trade off expected income with risk, the more risk averse farmers reportedly diversify more and operate less risky enterprises which are also less profitable (Rafsnider, *et al*, 1993). In arid and semi-arid areas where rainfall is erratic, such strategies may be suitable during the low rainfall seasons, but they fail to capitalize on favourable opportunities presented by normal and high rainfall seasons (Rao and Okwach, 2005). On the other hand farmers with less risk aversion specialize in fewer but high income enterprises, which are also more risky (Kobzar, 2006). Since risk plays such an important role in smallholder farmers' decisions pertaining to resource allocation, production planning and enterprise selection as posited by Bhowmick (2005), it is imperative that risk considerations be at the very core of farm planning.

2.2 Farm Planning Techniques

A number of techniques are used in farm planning. Some of the most common are budgeting, programme planning, and marginal analysis (Adesiyan *et al,* 2007). Budgeting techniques can provide useful guide to most profitable enterprises, but their major limitation is the inability to provide optimal farm plans where diversification is desirable (Upton, 1996 and Alford *et al*, 2004). To overcome this limitation, linear programming is commonly used to generate optimal farm plans. However, this technique has a major weakness in determining optimal farm plans under conditions of the varying degrees of risk attitude that are inherent among farmers (Babatunde *et al*, 2007 and Msusa, 2007).

In an attempt to incorporate risk into a linear program, goal programming has been proposed as a technique that can be used to obtain optimal farm plans. A study by Sumpsi *et al* (1996) revealed that rather than pursuing a single objective of profit maximization, the actual behaviour of farmers is characterised by desire to optimise a blend of objectives (many of which conflict) such as profit maximization, minimization of working capital, minimization of hired labour, minimization of management difficulty and minimization of risk. The authors recommend that multi-objective programming models such as goal programming replace the classical single-objective optimizing mathematical programming techniques in farm planning. The main limitation of goal programming, however, is its difficulty in soliciting the relevant objectives from the farmers (Wallace and Moss, 2002).

To overcome this difficulty, researchers employ other techniques such as those documented by Sumpsi *et al* (1996), Just and Pope (2001); and Alford *et al* (2004). These are quadratic risk programming (QRP), minimisation of total absolute deviations (MOTAD) programming, direct expected utility maximization nonlinear programming (DEMP), direct expected utility maximization nonlinear programming with numerical quadrature (DEMPQ), semivariance (SV), chance constrained linear programming (CCLP), stochastic dynamic programming (SDP) and discrete stochastic programming (DSP). This study uses both linear and quadratic programming, and therefore only these two techniques are discussed in detail, in the next two sections.

2.2.1 Linear Programming

Linear programming (LP) has been a widely used technique in generating optimal farm plans (Alford *et al*, 2004). The model was formally conceived as a discipline in the 1940s following the work of Dantzig, Kantorovich, Koopmans and von Neumann, but its potential had been discovered much earlier (Dantzig, 1998 and Schrijver, 1998). Applications of the model were originally in the military, but later developments led to its widespread use in the fields of industry, finance and agriculture, among others (Dantzig, 1998).

LP simply involves maximization or minimization of a linear objective function, subject to a set of linear and non-negativity constraints (Schrijver, 1998 and Babatunde *et al*, 2007). It differs from classical optimization techniques in several ways as outlined by Debertin (2002). One, in classical optimization at least one of the functions must be nonlinear, whereas linear programming requires all functions to be linear. Two, all constraint equations in a classical optimization problem must have an equality sign. This means that for example, all resources available to a farmer must be utilized and all possible products must be produced. On the contrary, linear programming does not require strict equalities in constraint equations, allowing the use of less than maximum available resources and non-production of some of the possible products. Three, under classical optimization, isoquants and production functions must have continuously turning tangents, which is not the case with linear programming problems.

Linear programming operates under certain basic assumptions according to Debertin (2002) and Kitoo (2008). These are:

i. **Linearity**: the objective function and the constraints are linear.

ii. **Additivity**: this means that activities are additive – the total product of all activities should equal the sum of their individual products. Further, the sum of resources utilized by different activities should equal the total amount of resources used by each activity for all resources.

iii. **Divisibility**: all inputs and outputs are divisible – fractions of inputs can be used and fractions of output can be produced.

iv. **Non-negativity**: all inputs and outputs in the optimal solution must be either positive or zero, but never negative. A producer can neither use negative quantities of inputs nor produce negative quantities of outputs.

v. **Single-Valued Expectations**: requires that all model coefficients be known with certainty before the problem is set up. Such coefficients include levels of inputs/outputs and input/output prices.

vi. **Finiteness**: requires that there be a limit to the number of enterprises that a producer can engage in.

The general formulation of an LP model is specified as follows:

Maximize: $$Y = \sum_{j=1}^{n} C_j X_j \qquad 2.2(a)$$

Subject to: $$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad i = 1, 2, \ldots, m \qquad 2.2(b)$$

$$X_1 \geq 0,\; X_2 \geq 0,\; \ldots,\; X_n \geq 0. \qquad 2.2(c)$$

Where: Y is variable to be maximized; n is the total number of activities, C_j is the contribution of each unit of activity i to Y; X_j is the number of units of activity j; m is the total number of resources, a_{ij} is quantity of resource i required by each unit of activity j; and b_i the total supply of the i^{th} resource. Equation *2.2(a)* represents the objective function, while equations *2.2(b)* and *2.2(c)* are resource and non-negativity constraints respectively.

In most farm planning problems where linear programming is used, it is assumed that the objective of the farmer is maximization of farm profits. Thus, the solution of an LP matrix gives the profit maximizing enterprise combination (farm plan) under the present farming system. This solution shows the level of each enterprise in the plan; value of the optimal farm plan (profit level); shadow costs (change in optimal profit if a unit of an enterprise excluded from the optimal plan is produced); shadow prices (value of an additional unit of a limiting resource); and underutilized or constraining resources (Alford *et al*, 2004 and Babatunde *et al*, 2007). However, the major weakness of this technique is its inability to account for risks, resulting in farm plans that do not represent a complete picture of the (risky) farming environment (Ateng, 1977 and Rafsnider *et al,* 1993).

2.2.2 Quadratic Programming

The quadratic programming or quadratic risk programming (QRP) technique is based on the expected utility and portfolio theories advanced by von-Neuman and Morgenstern (1944) and Markowitz (1952) respectively. The expected utility theory is invoked in the acknowledgement that risks inherent in agricultural production cause the income from a farm activity to be stochastic, in which case it has an expected value E, equal to its mean and a variance, V, which is a measure of risk. The portfolio theory, on the other hand explains the rationale for enterprise diversification: due to the stochastic nature of income from farm enterprises, farmers, being risk averse, diversify their enterprises in order to minimize the variation of the expected income (Adams *et al*, 1980 and Crisostomo and Featherstone, 1990).

QRP assumes that a farmer's attitude to risk while choosing a farm plan depends on an expected income-variance utility function (Thomson and Hazell, 1972 and Bhende, and Venkataram, 1994), which Freund (1956) equated to the utility of net revenue (money). QRP is therefore used to generate a set of efficient *EV* farm plans, which minimizes variances associated with increasing levels of expected income (Rafsnider *et al,* 1993). The *EV* set defines a utility maximizing frontier; on which each farmer's optimal farm plan could be found. The point on the frontier where utility is maximised is determined by the farmer's level of risk aversion (Rafsnider *et al,* 1993 and Bhende and Venkataram, 1994).

Following Stovall (1966) and Sharpe (1970), the procedure for obtaining the *EV* set is defined as follows:

i. The expected returns, *E*, is given by

$$E = \sum_{j=1}^{n} \bar{c}_j X_j \qquad 2.3(a)$$

Where *E* is the expected return of a portfolio; $\bar{c}_j$ is the expected return of investment *j*; and X_j is the weight of investment *j*.

ii. The variance of the return, *V*, is given by

$$V = \sum_{j=1}^{n} \sum_{k=1}^{n} X_j X_k \sigma_{jk} \qquad 2.3(b)$$

Where: X_j and X_k are the weighs of enterprises *j* and *k* respectively; and σ_{jk} the covariance between expected returns of investments *j* and *k*, (σ_{jk} becomes the variance of expected returns of an individual investment when $j=k$).

iii. To obtain the *EV* set, the following model is solved:

Minimize $V = \sum_{j=1}^{n} \sum_{k=1}^{n} X_j X_k \sigma_{jk}$ $\qquad$ 2.3(c)

Such that:

$$\sum_{j=1}^{n} \bar{c}_j X_j = \lambda \qquad 2.3(d)$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad 2.3(e)$$

And: $X_j \geq 0, \quad \forall j = 1,2,\ldots,n$ $\qquad$ 2.3(f)

Where: λ is a scalar equal to expected income, E, and represents the aspiration level of the investor. Other variables are as defined in equations *2.2(a)*, *2.2(b)*, *2.2(c)*, *2.3(a)* and *2.3(b)*.

The solution of the above QRP will give the levels of each investment in the portfolio that minimize the variance of expected returns (efficient portfolio) for the level of expected returns specified in the expected returns equation, and satisfy the other specified constraints.

The *EV* model is has some strengths as well as weaknesses. For example, Harwood *et al* (1999) find the expected utility theory advantageous in that it can accommodate a variety of utility functions and probability distributions. But the authors also find the theory to be weak in that utility functions are difficult to measure and the assumption that decision makers are highly rational is not always true. Similarly, Nyikal and Kosura (2005) identify a weakness in the portfolio theory in that not all investors can find their optimal enterprise mix in the *EV* set.

2.3 A Review of Some Farm Planning Studies

Both LP and QRP have been widely applied in farm planning studies, a few of which have been summarised in this section. In Pakistan, Ishtiaq *et al* (2005) studied cropping patterns in irrigated areas of Punjab to determine optimal crop combinations and found that the farmers were more or less operating at the optimal level. This was supported by the fact that in the optimal solution, although there were changes in resource allocation to the different crops, the overall cropped acreage decreased by only 0.37 percent; and income increased by a paltry 1.57 percent compared to the existing acreage. But Adesiyan *et al* (2007) studied the optimal maize-based enterprise combination of farmers in Orie Local Government Area of Nigeria using linear programming and reported different findings. The researchers concluded that farmers in the study area were not adopting optimal farm plans, based on existing level of resources. They also concluded that growing sole crops yielded more income than combining crops.

The results from these two studies imply that although farm planning may lead to reallocation of resources, this may not always translate into significant increases in the objective function (farm incomes). Further, according to these results, it cannot be generalized that farmers are always misallocating resources. The above studies have shown that some farmers are efficient, given the current level of resources and technology available to them, in which case productivity can only be increased through technological advancement and/or relaxation of resource constraints.

Among the early farm planning studies to incorporate risk was the one by Freund (1956). Freund used quadratic programming to determine the optimum crop combination for a representative farm in Eastern North Carolina under both 'risk' and 'no-risk' situations. His results show that the high risk enterprises comprising potatoes and fall cabbage accounted for 87.3 percent of the total net revenue in the 'no-risk' program, compared to 59.2 percent in the 'risk' program. Further, the less risky corn enterprise featured prominently in the 'risk' program, but was excluded in the 'no-risk' program. Overall, the expected net revenue in the 'no-risk' program was about 26.7 percent more than that of the 'risk' program.

Three decades later, Manos *et al* (1986) determined optimal farm plans for Central Macedonia. The study results showed that the risk-efficient farm plan suggested by the *EV* model generated using quadratic programming was different from the existing plan. The area allocated to corn, cotton to be picked by hand, sugar beet, and alfalfa increased in the optimal plan whereas the area allocated to cotton to be picked by machine, barley, tomatoes for processing, and beans decreased. In addition, *EV* model results suggested a better use of the available family labour and invested capital; and about 20 per cent increase profits.

Riaz (2002) used quadratic risk programming to determine optimal agricultural land use systems for northern Pakistan. Among his main findings were that with subsistence constraints, existing farm plans in the lower irrigated zone were equally as profit and risk-efficient as the optimal plans; but without subsistence constraints, resource reallocation could increase farmers' income by 8-10 percent. This, according to Riaz, implied that in the event of a disaster, farmers would be better-off having adopted the risk optimizing farm plan rather than the existing one. With subsistence constraint, the finding that existing farm plans are optimal concurs with the linear programming study by Ishtiaq *et al* (2005), quoted earlier. However, this finding contradicts those of risk studies by Freund (1956) and Manos *et al* (1986) above.

Closer home, recent studies in the Africa continue to underscore the significance of risk in farm planning. Fufa and Hassan (2006) used quadratic programming to assess income risk and crop production patterns of small-scale farmers in Eastern Oromiya, Ethiopia. They found out that as farmers become more risk averse, land allocated to maize was no more than just enough to meet the subsistent requirement, due to high level of maize income risk. On the other hand, the area allocated to sorghum production increased with risk aversion, due to stable yield and income from the crop. Further, the risk-neutral optimal farm plans (equivalent to those generated by linear programming) suggested the highest values of both expected returns and risk.

Most recently, Msusa (2007) used QRP to investigate the production efficiency of smallholder farmers in Malawi. His findings were that the variability of a crop enterprise's profitability, which is a measure of risk, significantly influenced the cropping pattern adopted by a farmer. He concluded that farmers should increase land allocated to groundnuts by about 198 per cent and decrease area under maize, tobacco and beans by about 47, 69 and 78 percent respectively, in order to optimize risk.

In Kenya, a number of earlier farm planning studies were carried out using linear programming, and provided insightful results on smallholder farmer resource allocation. The study by Mukumbu (1987) on enterprise mix and resource allocation in West Kano pilot irrigation scheme revealed that farmers could more than double their gross margins by adopting optimal plans. This implies that the farmers were misallocating resources through adoption of sub-optimal farm plans.

Similarly, Nguta (1992) studied resource allocation by smallholder irrigation farmers along the Yatta Canal of Machakos district and concluded that farmers were not efficient in allocating their resources. His study suggested that farmers' total gross margins could increase by between 28 and 121 percent, if they reallocated their resources and adopted the optimal farm plans. The study also found working capital to be limiting, with a marginal value product that exceeded the average credit lending rates. This implied that it was economically feasible for farmers to obtain credit to enable them invest in optimal enterprise combinations.

Furthermore, Wanzala (1993) assessed the economic competitiveness and optimal resource allocation among smallholder rain-fed rice producers in Busia district. The main finding was that rice was excluded from optimal farm plans, although farmers included it in their own cropping patterns. The implication was that farmers were misallocating their resources and could raise their incomes by adopting the optimal farm plans.

These studies showed that farmers in many parts of Kenya grossly misallocate their resources and could raise their productivity and farm incomes by adopting optimal farm plans. The shortcoming of these studies however, was their assumption that farmers are risk-neutral. The optimal plans generated did not allow farmers to choose plans that match their levels of risk preference.

Recent studies in the country are however acknowledging the need to incorporate risk in farm planning. Nyikal and Kosura (2005) used both linear and quadratic programming to assess risk preference and optimal enterprise combinations among smallholder farmers in Kahuro division of Murang'a district. The risk-neutral solution (produced using linear programming) revealed an optimal farm plan without subsistence requirement that featured 0.35 acres of coffee, 0.01 long rain sweet potatoes and 1.14 acres of banana; with total gross margin of 34,171 Kenya Shillings. On the other hand the optimal farm plans with subsistence requirement comprised of 0.31 acres of long rain maize and beans, 0.31 acres of short rain maize and beans, 0.34 acres of coffee, 0.38 acres of long rain sweet potatoes, and 0.47 acres of bananas; giving a total gross margin of 30,097 Kenya shillings. The conclusion was that the more risk aversive farm plans, which included maize for subsistence, resulted in lower farm incomes than the less risk averse farm plans which ignored a subsistence crop.

Further, the results of risk model (QRP) without subsistence constraint suggested that high risk enterprises enter the optimal farm plan at high levels of risk, while low risk enterprises dominated the farm plans at low risk levels. The optimal farm plans with subsistence constraint yielded lower incomes for a given level of risk than without the subsistence constraint. This notwithstanding, most farmers included the low income subsistence crops, resulting in inefficient farm plans. The conclusion was that farmers who are more risk averse allocated more resources to subsistence crop production and earned lower incomes than the less risk averse farmers. Hence, farmer-preferred cropping patterns were risk minimizing, not profit maximizing.

Similar findings were also reported by Diang'a (2006), who studied the effect of maize price risk on smallholder agricultural production in Kakamega District. In the risk-neutral model, the optimal farm plans yielded an income of Ksh 48,458 compared to existing plans, which earned farmers an income of Ksh 28,238. This shows that farmers could raise their incomes by 71.6 percent by adopting optimal production plans. On the other hand, the QRP model for the average farm suggested an optimal total gross margin of Ksh 72,121, which was 155.4 percent above that of the existing farm plans. He further found that farmers grew higher pay-off crops (which are also riskier to produce) only if their risk aversion was low.

In conclusion, results of the risk studies reviewed suggest that enterprise risk and farmers' risk attitude affect the efficiency of smallholder farmer resource allocation, and consequently expected returns. More often than not, farmers end up adopting farm plans that minimise risk, but also give them lower than optimal farm incomes for the level of risk assumed. It follows therefore, that smallholder farmers in Kenya and indeed other developing countries can increase their farm incomes by reallocating their resources to adopt risk-efficient farm plans. The studies have further demonstrated that despite its few weaknesses, QRP can be used to study how risks affect selection of optimal farm plans, justifying its use in this study.

Chapter 3: Methodology

This chapter presents the methodology used in the study. It covers the analytical framework (theoretical and empirical frameworks), a brief description of the study area, sources of data used, data collection methods, sample size and sampling procedures, and data analysis procedures.

3.1. Theoretical Framework

This study was anchored broadly on the theory of the firm. According to this theory, production decisions of a farmer are assumed to be driven by the desire to maximize expected utility (or expected profit), subject to availability of production constraints such as land, labour and capital (Feder *et al*, 1985). This profit is a function of the enterprises that a farmer chooses to operate and the technologies that a farmer employs in production of the selected enterprises.

To accommodate risk in the farmer's utility maximization venture, two economic theories specifically guided the study. These are the expected utility theory pioneered by von-Neuman and Morgenstern (1944) and the portfolio theory founded on the work of Markowitz (1952), as stated in Chapter 2. Under the expected utility theory, a farmer is assumed to derive some cardinal utility from returns of investing in farming activities. But given the risky nature of agriculture, the farmer will not always get the predicted value of returns: there will be deviations (variance) from this value. With this in mind, the farmer, being mostly risk averse, will invest in a combination of enterprises (called a portfolio or a farm plan), in order to minimize the risk. This is the gist of the portfolio theory, which presumes that the farmer is willing to choose among farm plans entirely on the basis of predicted income (mean) and uncertainty (variance) of that income (Sharpe, 1970; Crisostomo and Featherstone, 1990; and Fufa and Hassan, 2006).

The objective of portfolio analysis is to find out a set of efficient farm plans and the efficient frontier, which is the maximum mean return for a given level of variance, or the minimum variance for a given mean return (Barkley and Peterson, 2008). A farm plan is deemed more efficient than another if for the same expected return, its variance of return is smaller, or if for the same level of variance of expected return, its expected return is higher (Sharpe, 1970).

Following this efficiency criterion, a farmer's decision is based on the following rules according to Sharpe (1970):

1. The general rule is to choose the farm plan with a larger expected return and smaller variance of return than another.
2. If two farm plans have the same expected returns and different variances of return, the one with smaller variance of return is preferred.
3. If two farm plans have the same variance of return and different expected returns, the one with larger expected return is preferred

Figure 3.1 illustrates how a risk averse farmer chooses a risk-efficient enterprise mix as theorised by Harwood *et al* (1999) and Lien (2002). The farmer's preferences are represented by indifference curves U_1, U_2 and U_3. Each curve connects a locus of risk (represented by variance of expected income) and expected income levels that generate the same level of utility to the farmer. On the other hand, the *EV* efficient frontier connects locus of points that define the minimum variance associated with each level of expected income. The farmer desires a high level of expected net farm income and a low variance of the income, which involves moving upward along the Y-axis and/or to the left along the X-axis. The optimal enterprise mix for the farmer is found at the point on the *EV* frontier (point D) where the preferred income (E^*) and variance (V^*) intersect with the highest possible indifferent curve (U_2). Point C represents a risk-inefficient farmer with the potential of earning more income (E*) at the current risk level.

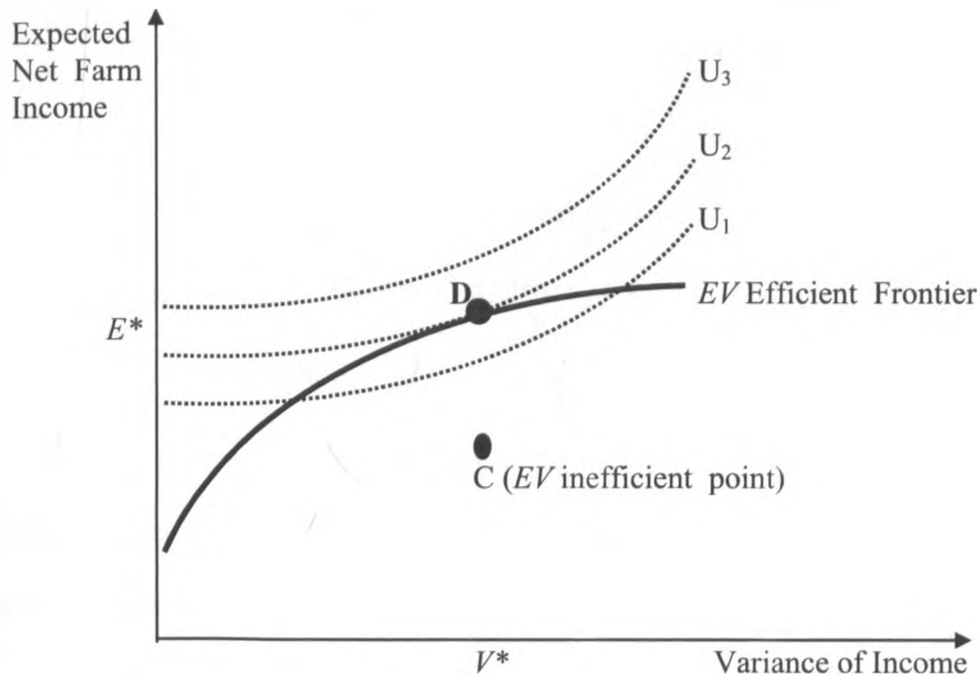

Figure 3.1: Process of Choosing a Risk-Efficient Enterprise Mix by a Farmer

Source: Adapted from Harwood *et al.* (1999) and Lien (2002)

3.2. Empirical Framework and Model Specification

3.2.1. The Linear Programming Model

The linear programming (LP) model was used to generate farm plans that reflect optimal allocation of resources under conditions of risk-neutrality. The model was run under two situations: one with subsistence restriction and the other without. The LP model used was specified as follows:

Maximise: $Y = \sum_{j=1}^{9} \bar{c}_j X_j$ Total farm gross margin (Ksh)

Subject to: $\sum_{j=1}^{9} a_{ij} X_j \le b_i$ Resource constraints,

$X_j \ge S$ Subsistence constraints, and

$X_1 \ge 0,\ X_2 \ge 0,\ \ldots,\ X_9 \ge 0.$ Non-negativity constraints

Where: Y = Total farm gross margin (TFGM) in Kenya Shillings (Ksh),

$\bar{c}_j$ = The gross margin per unit of enterprise j (Ksh),

X_j = level of investment in enterprise j (acres for crop enterprises, livestock units for livestock enterprise),

a_{ij} = quantity of resource i required to produce each unit of enterprise j,

b_i = total availability of the i^{th} resource, and

S = minimum subsistence requirement.

The model was run twice: first with the subsistence constraints and the second time without the subsistence restrictions.

3.2.2. The Quadratic Programming Model

Quadratic programming was used to generate a set of risk-efficient farm plans, the *EV* set. The procedure below was used to obtain the *EV* set.

Minimize $V = \sum_{j=1}^{n} \sum_{k=1}^{n} X_j X_k \sigma_{jk}$ Variance (risk)

Such that: $\sum_{j=1}^{n} \bar{c}_j X_j = \lambda$ Income (aspiration level)

$\sum_{j=1}^{n} a_{ij} X_j \le b_i$ Resource constraints

$X_j \ge S$ Subsistence constraints, and

$$X_1 \geq 0, X_2 \geq 0, ..., X_9 \geq 0 \quad \text{Non-negativity constraints}$$

Where:

V = Total variance associated with income level E (Ksh)

X_j, X_k = units of production allocated to enterprises j and k respectively

σ_{jk} = covariance between expected returns of enterprises j and k, (variance of expected returns of an individual enterprise when $j=k$).

All other notations are as defined in the LP equations in section 3.2.1.

Like the LP model, the QRP model was also solved with and without the subsistence constraints. The EV set was generated by setting λ at some arbitrary low level and successively raising it by Ksh 1,000, until the solution became infeasible. This approach has been adopted in a number of studies (see for example, Stovall, 1966, and Barkley and Peterson, 2008). The last feasible solution was deemed to give the maximum risk-efficient income, and risk-efficient farm plan.

3.2.3. Model Activities and Constraints

3.2.3.1. Real Activities (Enterprises)

Nine major activities were identified. These were:

1) Maize1 (Mze1) – maize grown in short rains. This enterprise consists mainly of maize, intercropped with beans and peas;
2) Maize2 (Mze2) – maize grown in long rains. This enterprise consists mainly of maize, intercropped with beans and peas;
3) Coffee (Coff) – coffee, grown in short and long rain seasons;
4) French Beans1 (Fbn1) – French beans grown in short rains;
5) Kales1 (Kal1) – Kales grown in short rains;

6) Kales2 (Kal2) – Kales grown in long rains;

7) Tomato1 (Tom1) – Tomatoes grown in short rains;

8) Totmato2 (Tom2) – Tomatoes grown in long rains;

9) Livestock (Lvst) – cattle and shoats, kept in both long and short rain seasons.

3.2.3.2. Model Constraints

A total of 12 constraints, summarized in table 3.2(b) were identified. The constraints were specified as follows:

i. Irrigable land – represents average irrigable land per household. Its calculation was based on quantity of water that farmers can comfortably use from the dam for irrigation during the dry spell when water is limiting. This land has two seasonal constraints of 0.250 acres each[6]. Irrigable land is assumed to be used for horticultural crops only (most farmers irrigate horticultural crops only).

ii. Non-irrigable land – this represents the average size of land that could not be irrigated due to water availability constraints. It was calculated as average cultivable land (1.268 acres) less irrigable land. Non-irrigable land had two seasonal constraints of 1.018 acres each.

iii. Family Labour – This was calculated using the number and availability of household members. Owing to differences in age among family members, the weights adopted by Nguta (1992) were used to convert household members into standard labour units (man equivalents), as presented in table 3.2(a). One man day was considered to consist of 8 working hours. Each month had 26 working days,

[6] Acres were used instead of hectares because land holdings in the study area are very small and also the acre is the most commonly used unit of land measurement in the area (2.5acres = 1 hectare).

except for December, which had 24 working days due to Christmas and Boxing Day holidays. Male labour was not distinguished from female labour, because there was no indication that farmers categorized labour on the basis of gender. Two family labour constraints of 397 man days in short rain season and 434 man days in long rain season were identified.

Table 3.2(a): Man equivalents of persons of different age categories

Class	*Age (years)*	*Man Equivalents*
Child	Under 7	0
Child	7-14	0.5
Adult	15-64	1
Adult	65-75	0.5
Adult	Over 75	0 (0.5 if active in farm activities)
Child/Adult	7 -75	0 if disabled).

Source: Adapted from Kamunge (1989)

iv. Capital – This constraint represents all cash expenditure on variable farm inputs such as rented land, seeds, fertilizers, pesticides, vet drugs, vet services, feeds, and casual labour. The constraint was divided into two seasonal constraints of Ksh 5,986 in the short rains and Ksh 3,929 in the long rains. This division was important since farmers do not get all the capital required in a year at once. Some products from the first season may have to be sold to finance farming activities in the second season. Further, in financing farm activities, many farmers also rely on off-farm income which they earn in a staggered fashion. These cash flow issues were hence the rationale for dividing the capital availability according to seasons; an approach also used by Mafoua-Koukebene *et al*, 1996.

v. Subsistence land – represents land allocated to maize intercrop in the models with subsistence restrictions. Food self sufficiency is the objective of most farmers and therefore they must allocate some minimum resources to certain crops for subsistence. Riaz (2002), Nyikal and Kosura (2005) and Kitoo (2008) link inclusion of subsistence crops in farmer plans to not only meeting subsistence needs but also reducing risk associated with food markets. For this reason, inclusion of some minimum resources for subsistence makes a farm plan more rational to smallholder farmers.

Maize is the main staple crop in the study area, while less than 20 percent of the main horticultural crops is used for home consumption (see Section 4.1.1), meaning that the crops are not grown primarily for subsistence. Maize was hence the only crop to which the subsistence constraint was allocated. The minimum subsistence land requirement was calculated using a per capita maize requirement of 103 kg per year (De Groote *et al*, 2002). This approach is also popular in Kenyan farm planning studies (see Nguta, 1992 and Nyikal and Kosura, 2005). The annual maize requirement for a 6-member household was 618 kg. With the mean maize yield in the study area being 406 kg per acre per season, each household had two subsistence land constraints, measuring 0.761 acres each.

vi. Subsistence carrying capacity – this represents livestock units required for 'subsistence'. Mostly, farmers in the area keep livestock for needs that seem to fulfil a complex subsistence objective. This objective covers subsistence demand for milk and manure, cultural value, store of wealth, and a quick source of cash for financing farm inputs and operations and other family needs, including emergencies. Hence, the livestock enterprise plays a crucial role not only for subsistence, but also in cushioning farmers against risks. To account for this objective, the existing mean stocking rate of 1.3 livestock units (LU) per acre of cultivable land was used to derive the livestock carrying capacity allocated for subsistence by the average farm, which translated to 1.65 LU.

Table 3.2(b): List of constraints used in the mathematical programming models.

Constraint	Description	Units	Limits
1. Irrigland1	Irrigable land available in short rains	Acres	≤ 0.250
2. Irrigland2	Irrigable land available in long rains	Acres	≤ 0.250
3. Nonirrland1	Non-irrigable land available in short rains	Acres	≤ 1.018
4. Nonirrland2	Non-irrigable land available in long rains	Acres	≤ 1.018
5. Labour1	Family labour available in short rains	Man-days	≤ 397
6. Labour2	Family labour available in long rains	Man-days	≤ 434
7. Capital1	Capital available in short rains	Ksh	≤ 5,986
8. Capital2	Capital available in long rains	Ksh	≤ 3,929
9. Subsland1	Land required for subsistence in short rains	Acres	≥ 0.761
10. Subsland2	Land required for subsistence in long rains	Acres	≥ 0.761
11. Subscc	Livestock carrying capacity for subsistence	LU	≥ 1.65
12. Totalcc	Total livestock carrying capacity	LU	≤ 2.50

Source: Computed form Survey Data (2009)

3.3. Area of Study[7]

The highlands of Machakos (before the recent subdivisions) comprise the hill masses of Central, Kathiani, Kangundo, and Matungulu divisions (see figures 3.3.1 and 3.3.2). These areas have high agricultural potential and high population densities. Land holdings average at 0.5 to 2 acres. The lands are on steep slopes and have been over-cultivated; resulting to soil degradation and erosion. The highlands lie in the Mixed farming (coffee, dairy and horticulture) livelihood zone. Despite the high agricultural potential in the highlands, poverty incidence is prevalent in most areas, ranging from 31 percent in Central Division to 65 percent in Kathiani and Matungulu Divisions. There is need to increase agricultural productivity in these areas order to increase farm incomes.

Kathiani Division covers an area of 213 square kilometres, and is divided administratively into 4 Locations and 21 Sub-locations. It has an estimated population of

[7] Information sources: Ministry of Agriculture. (2005). *Engineering Design for Rehabilitation and Expansion of Kauti Irrigation Scheme, Machakos District. Volume I: Design Draft Report;* Republic of Kenya (2005). *Machakos District Strategic Plan 2005- 2010;* District Officer's Office, Kathiani; and Divisional Agricultural Office, Kathiani.

122,347 persons in 24,471 households, and is the second most densely populated division in Machakos, with 574 persons per square kilometre. The main economic activity in the Division is Agriculture. Most of the farming is rain-fed, but a few farmers practice irrigation to supplement rainfall. The Division has 10 small scale farmer-managed irrigation schemes, most of which are currently being expanded or rehabilitated. Table 3.3.2 shows the administrative units and population data of Kathiani Division.

Table 3.3: Administrative units and population data of Kathiani Division

Location	*No of Sub-locations*	*No. of Households*	*Population*
1. Mitaboni	6	7,189	35,943
2. Iveti	5	6,255	31,275
3. Kathiani	5	5,791	28,953
4. Kaewa	5	5,236	26,176
Total	**21**	**24,471**	**122,347**

Source: District Officer's Office, Kathiani (2009)

Kauti is the largest irrigation scheme in Kathiani Division, covering approximately 8 square kilometres. It is geographically located on the lower eastern slopes of Iveti hills, about 24 km by road from Machakos town. Administratively, the scheme is in Kathiani Sub-location (Kathiani Location) and Kauti Sub-location (Kaewa Location) as shown in figure 3.3.2.Altitude in the scheme ranges from 1,340 to 1,620 metres above sea level. The land generally slopes from the South to the North, allowing for gravitational flow of water in the scheme. The soils are well drained reddish brown sandy clay and loams with varying fertility status. Rainfall is bimodal, giving the area two distinct cropping seasons: the short rain season (more reliable) with rains falling between October and December; and the long rain season with rains falling between March and May. The mean annual rainfall is 1,000 mm, while average temperatures range from 12^0C (June-August) to 22^0C (January-March).

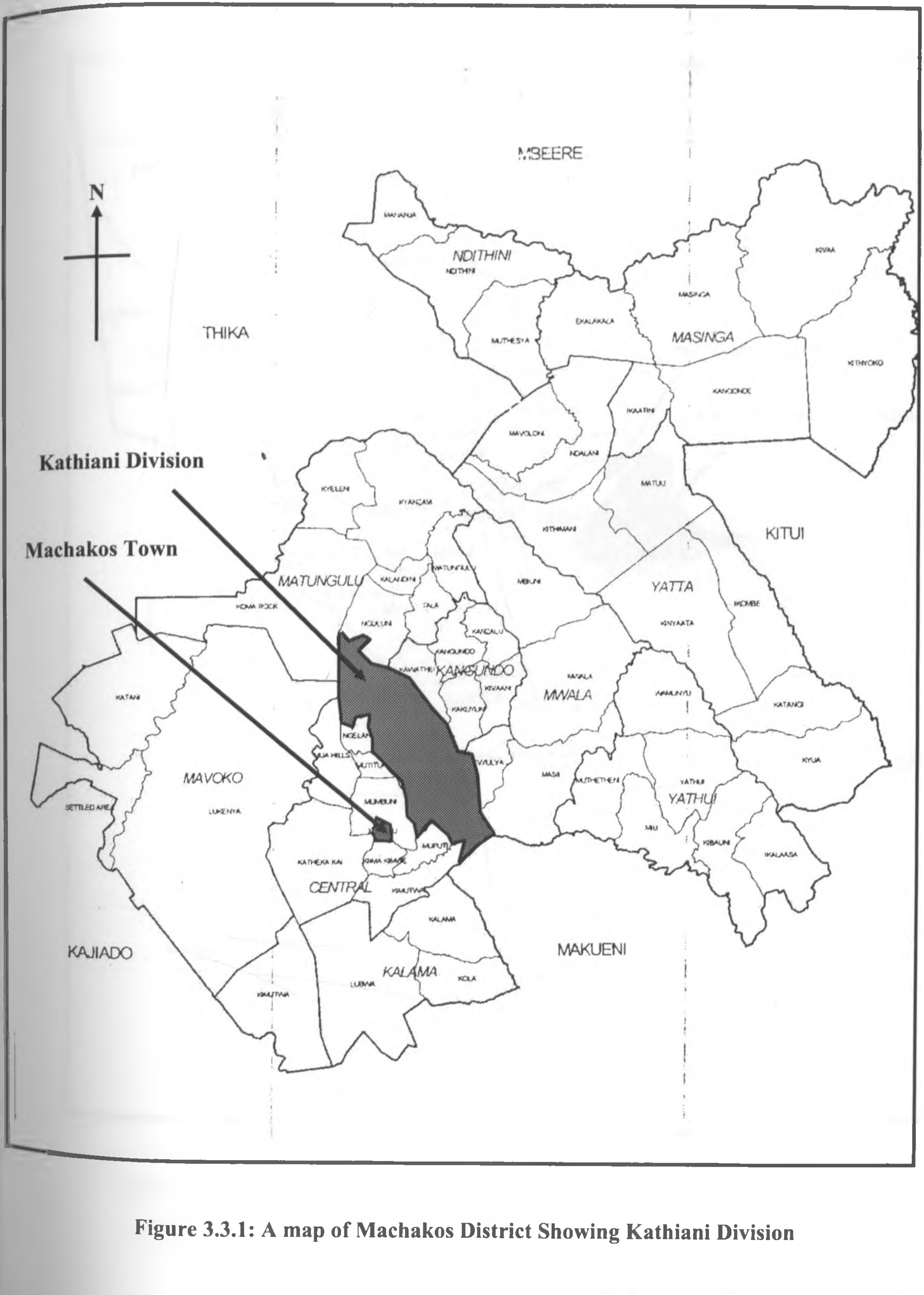

Figure 3.3.1: A map of Machakos District Showing Kathiani Division

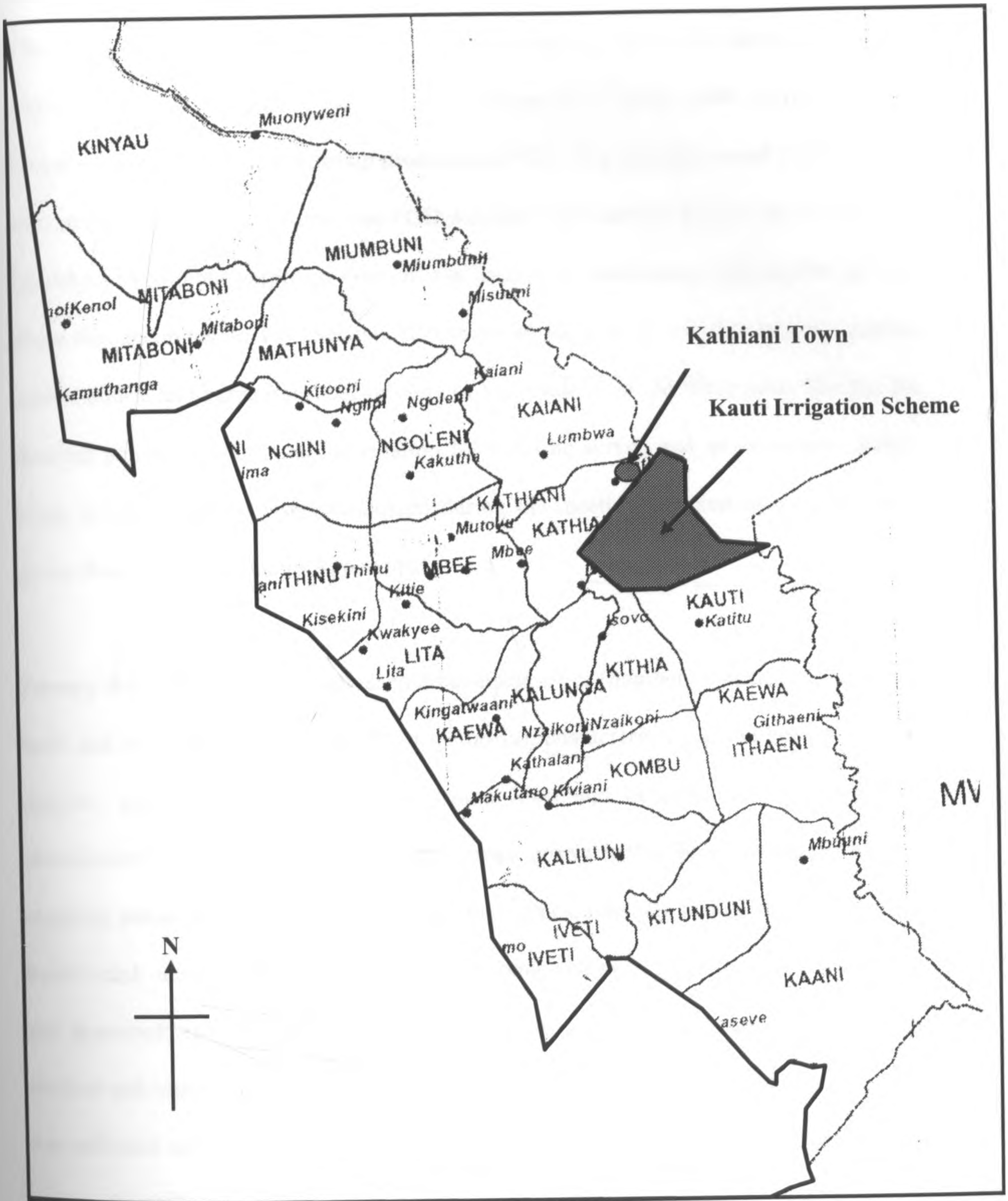

Figure 3.3.2: A map of Kathiani Division Showing Kauti Irrigation Scheme

3.4. Data Types, Sources and Collection

The study used primary data since secondary data of individual farmers were not available at a central place. The data were collected in March 2009, through a farm household survey and a focus group discussion (FGD). The survey covered 2007/08 short rain and 2008 long rain seasons. The FGD was held with farmers prior to the survey. The meeting served three purposes. First, it was used as a sensitization meeting for farmers about the upcoming survey. Second, it was a tool for gaining insights into the general socio-cultural and agricultural background of the residents of the study area. Thirdly, the meeting generated additional information for both the survey and questionnaire design. More details about the issues discussed during the meeting are contained in the focus group discussion schedule in Appendix 1.

Primary data were collected on household characteristics (number, gender, age, education level and occupation and of household members); characteristics of the household head (gender, age, farming experience, education level and occupation); farm enterprise characteristics (farm size and farm assets; crops grown including areas planted and the cropping patterns; livestock kept including their types, numbers and production systems; inputs used: manure, fertilizer, seed, feeds, labour and pesticides, including their types and quantities; crop and livestock outputs including their quantities and utilization; and product and input marketing including prices and marketing channels). The survey data was collected using a pre-tested, structured questionnaire (see appendix 2), administered to respondents by trained enumerators.

3.5. Sampling Procedure and Sample Size

Two main sampling methods were used in the study: purposive sampling and probability proportional to size (PPS) sampling. Purposive sampling was used to select the study site (district, division and the irrigation scheme). Machakos District was selected because it represents the semi-arid districts in Kenya with high agricultural potential. Kathiani Division was selected due to its high poverty incidence among the densely populated divisions of Machakos, while Kauti Irrigation scheme was selected due to its large size (in terms of number of farmers) compared to other schemes in the Division. An irrigation scheme was preferred since most high value enterprises and farming systems being promoted in the area require irrigation to supplement rainfall and there is deliberate government support in irrigation projects.

According to Yansaneh (2005), PPS is a preferred methodology in most rural household surveys due to its ability to improve the precision of the survey estimates. The method was used in this study to select households to be interviewed. However, its limitation is that it requires a prior knowledge of the population size in each primary sampling unit (village in this case); yet accurate population data at such levels is not available in many areas of Kenya.

Although the precise number of households or a list of all households in the Scheme was not available, the boundaries of the Scheme are well known. The help of local Assistant Chiefs and Village Headmen was enlisted to prepare a list of all households in the scheme, stratified by village. This list constituted the sampling frame.

One hundred and twenty seven households, distributed proportionately to the village sizes (in terms of population), were sampled as shown in Table 3.5. The sample size was determined using guidelines from the minimum sample size determination table developed by Bartlett *et al* (2001). According to the authors, with a population of 900 and confidence level of 5 percent, a minimum sample size of 105 is adequate for continuous data[8]. A 15 percent margin was also added to this minimum sample size to take care of non-responses and incorrect filling of questionnaires. Based on these considerations, the survey sample size *n* was set at 127, distributed among the 8 villages as shown in table 3.5.

Out of the 127 households sampled for interviews, 117 were interviewed. Four questionnaires were discarded due to errors; hence the final survey sample consisted of 113 households.

Table 3.5: Population and Sample Size per Village

Village	Population of Households	No. of Households Sampled
Kyuluni	170	25
Muuoni	167	25
Muthala A	81	13
Muthala B	111	17
Muthala C	63	10
Kitie	96	14
Kauti	98	15
Kyoimbi	49	8
Totals	**835**	**127**

Source: Computed from Survey Sampling Frame (2009)

3.6. Data Analysis

Data requirements for the optimization techniques are the mean returns for each enterprise, input-output coefficients, variance-covariance matrix of returns for each enterprise and other appropriate restrictions (Scott Jr and Baker, 1972). All the

[8] Although the study area had a household population of 835, a population of 900 was assumed to account for errors in preparing the sampling frame and for simplicity.

coefficients and resource constraints were entered into the models as averages of the sample data, having been calculated with the Statistical Package for Social Sciences (SPSS) software. The ideal coefficients would have been sourced from experimental stations, but Ateng (1977) notes that survey data are more reflective of actual smallholder farm situation than experimental data.

Enterprise gross margins were used to represent enterprise returns. The gross margins were calculated by subtracting total variable cost of production from value of total output produced by the enterprise[9]. For crop enterprises, the value of output was calculated for individual farmers by multiplying the total yields by average price faced by each farmer. Non-marketed output was valued using the average price of marketed output. Costs of production were also calculated using prices and quantities of inputs faced by individual farmers. For the livestock enterprise, the animals were treated as capital stock, hence only increases in their value together with physical outputs (milk and manure) were considered in calculating gross margins. The gross margin was calculated using guidelines proposed by Millear, *et al* (2005) as shown in appendix 3.

Gross margin for each enterprise was first calculated per farm then divided by land area (livestock units for livestock) allocated to the enterprise to get gross margin per unit. The per unit gross margins of each enterprise were then averaged over the number of farmers running the enterprise to obtain the mean gross margins for the enterprises. All outputs and inputs were valued in Kenya Shilling (Ksh). Input-output coefficients and subsistence restrictions were calculated as averages of survey data using SPSS, as discussed in section

[9] For each enterprise, the gross margin assumes that in the equation Gross Margin = Total Revenue (TR) – Total Variable Cost (TVC) – Total Fixed Cost (TFC). TFC are not attributable and thus ignored for convenience, hence, GM = TR-TVC.

3.2.3 above. The variance-covariance matrix of enterprise gross margins (table 4.1.3(b) was calculated using SPSS and entered into the QRP as a table.

To generate the optimal farm plans, a three situation analytical framework was used in generating the optimal plans. First, maximising farmers' total farm gross margin (TFGM) subject to resource constraints and subsistence requirements (Risk-neutral subsistence model); second, maximising TFGM subject to resource constraints (Risk-neutral non-subsistence model); and third, maximising farm income subject to risk and subsistence requirements (Subsistence model with risk). Situations one and two were analysed using an LP model, while situation three was analysed using a QRP model. The suitability of LP and QRP for this kind of analysis is also acknowledged by Thomson and Hazell, 1972 and Nyikal and Kosura, 2005).

The optimisation models were solved using the General Algebraic Modelling System (GAMS) computer program. The software is a powerful tool for formulating and solving mathematical programming models such as linear programming, mixed integer programming, quadratically constrained programming, mixed complementary and stochastic linear programming. GAMS has been used in a number of recent risk optimization studies[10] and was therefore deemed appropriate for this study.

3.7. Hypothesis Testing

The first hypothesis was tested using the one sample location test, an application of the student's t-test (Wikipedia, 2009). This test was used to compare the mean total gross margin from the existing farm plan to a 'known' constant, equal to the total gross margin of the optimal farm plan.

[10] See Nyikal and Kosura (2005); Diang'a (2006); Fufa and Hassan (2006); and Kitoo (2008).

The hypothesis was specified as follows:

$$\mathbf{H_0: Y_E = Y_O;\ \ H_1: Y_E \neq Y_O}$$

Where: H_0 = null hypothesis, H_1 = alternative hypothesis, Y_E = level of total farm gross margin (TFGM) from existing farm plans, Y_O; = level of TFGM from optimal farm plans

To test the hypothesis, a t-statistic was computed as follows, and tested at 5 percent level of significance:

$$t = \frac{Y_E - Y_o}{s/\sqrt{n}} \qquad (3.5.7)$$

Where: Y_E and Y_O are as defined above, s = sample standard deviation of existing TFGM and n = sample size.

The null hypothesis would be rejected if the absolute value of computed t exceeded the critical value, otherwise the null hypothesis would not be rejected. The second hypothesis was tested descriptively, by observing and comparing optimal enterprise combinations at different levels of risk. Changes in enterprise combinations would imply that risk preference affects choice of optimal farm plans. On the contrary, insensitivity of enterprise combinations to changes in risk would mean that risk does not affect choice of optimal farm plans.

Chapter 4: Results and Discussion

4.1. Characteristics of the Farming System and Sources of Risk

4.1.1. Crop production and marketing

Cultivated land in the Scheme ranged from 0.13 to 5.2 acres, averaging at 1.268 acres per household. The main crops grown were maize, beans, pigeonpeas, cowpeas, coffee, French beans, kales, and tomato. Others included spinach, cabbage, onion and fruits (mainly mangoes, avocadoes, bananas). Crop production was mainly rain-fed, but about 30 percent of the farmers supplemented rainfall with irrigation particularly in the vegetable enterprises. Farmers used both certified and non-certified seed, as illustrated in Table 4.1.1(a). Fertilizer adoption rate was high in all crops except coffee, but use of manure was mainly in maize. Except for French beans, other crops received less fertilizer amounts than recommended (see Ministry of Agriculture, 2007).

Table 4.1.1(a): Adoption of certified seed, manure and fertilizer in key crops

Adoption of certified seed/ manure/fertilizer	Crop*					
	Maize1	*Maize2*	*Coffee*	*French Beans*	*Kales*	*Tomatoes*
Certified seed adoption rate (%)	63	42	-	55	100	100
Certified Seed adoption intensity (%)	69	77	-	60	100	100
Manure adoption rate (%)	82	8.6	30	1	16	36
Manure use rate (Tons/acre)	1.14	0.52	1.82	-	0.72	0.91
Base dressing fertilizer adoption rate (%)	78	74	42	100	100	95
Base dressing fertilizer use rate (kg/acre)	21.5	13.7	47.8	71	32.3	25.0
Top dressing fertilizer adoption rate (%)	82	80	37	95	100	100
Top dressing fertilizer use rate (kg/acre)	17.9	11.5	66.7	63.5	31.7	25.6

*Maize1 – maize grown in short rains; Maize2 – maize grown in long rains
Source: Computed from Survey Data (2009)

Farmers faced different input prices as shown in Table 4.1.1(b). The prices varied widely with type and quantity of inputs purchased; and purchasing time and place[11]. Since input

[11] According to farmers, inputs purchased form big towns, friends, relatives and coffee cooperatives attracted lower prices. Conversely, farmers purchasing inputs in small quantities or during peak demand (e.g., seed at onset of rains) faced much higher prices.

price affects variable costs and consequently gross margins, the large variability observed in input prices was a source of farm income risk in the study area.

Table 4.1.1(b): Key input prices faced by farmers in 2007-08 short rains season

Input	Unit	Price (Ksh)			
		Mean	Standard Deviation	Minimum	Maximum
French Beans Seed	1kg	**761.4**	188.0	360	1,200
Maize Seed (Certified)	2kg	**369.0**	37.8	225	500
French Beans Seed (Non-certified)	1kg	**225.0**	48.3	150	300
Labour	1Man day	**106.2**	17.9	70	150
Base dressing Fertilizer	1kg	**67.7**	21.8	30	120
Beans Seed	1kg	**66.1**	16.9	40	120
Pigeonpea Seed	1kg	**54.9**	13.9	30	80
Cowpea seed	1kg	**52.3**	18.5	25	100
Top Dressing Fertilizer	1kg	**48.0**	15.6	18	86.8
Maize Seed (Non-Certified)	1kg	**24.8**	7.3	10	35
Manure	1kg	**1.17**	0.58	0.27	2.5

Source: Computed from Survey Data (2009)

There was a wide variability in yields of the different crops as shown in Table 4.1.1(c), with cash crops recording much higher yields than subsistence crops. Given that yield is a key variable in calculating gross margins, its variability was a source of farm income risk in the study area. An important observation is that most of the yields achieved were far below the estimated potential for the district; implying that farmers could raise their yields by increasing adoption of improved inputs (De Groote *et al*, 2002).

Table 4.1.1(c): Observed and potential yields of the main crops

Crop	Observed Yields (Kg/Acre)				Potential Yields[a] (Kg/Acre)
	Mean	Standard Deviation	Minimum	Maximum	
Tomato	**2,944**	2,528	429	8,267	*4,000 – 18,000*
Kales	**2,805**	2,445	240	9,600	*3,200 – 4,000*
French Beans	**2,177**	1,498	303	5,818	*2,000 – 4,000*
Coffee[b]	**776**	694	0	3,300	
Maize (Short rains)	**592**	405	0	2,200	*900 – 1,800*
Maize (Long rains)	**220**	226	0	1,080	*900 – 1,800*

[a] Source: Ministry of Agriculture (2007). [b] Yield refers to both fresh and dry cherries (*mbuni*) marketed

Source: Computed from Survey Data (2009)

Over 90 percent of output from the maize intercrop was consumed at home, implying that the enterprise was mainly for subsistence. Commercialization of coffee and French beans output was 100 percent, while kale and tomato output consumed at home was about 16 and 9 percent respectively, implying that the horticultural crops were grown primarily for sale. Crop output was marketed through open air markets, other farmers, middlemen, coffee factories and horticultural exporters. Output prices varied greatly with season, time of sale within the season, and the buyer. As with input prices, output prices are a key variable in computing farm incomes. Hence erratic output price, *ceteris paribus,* was a source of income risk in the study area. Output prices of major crops have been shown in Table 4.1.1(d).

Table 4.1.1(d): Output prices of major crops (2007-08)

Output	Output Prices (Ksh/Kg)			
	Mean	Standard Deviation	Minimum	Maximum
Beans (long rains)	49.2	12.10	25	80
Pigeonpea	47.0	15.67	30	70
Beans (short rains)	42.3	15.41	20	80
French Beans	35.5	9.37	25	53.9
Cowpeas (short rains)	25.7	3.94	22.2	30
Tomato	21.5	8.43	7.5	45
Maize (long rains)	20.9	12.14	12	50
Maize (short rains)	19.6	5.39	10	30
Coffee	19.1	6.92	5	32
Kales	9.7	2.43	5.98	15

Source: Computed from Survey Data (2009)

4.1.2. Livestock production and marketing

The main livestock kept in the study area were cattle, goats, sheep, indigenous chicken, and few donkeys. However, data on chicken production was hard for farmers to estimate or recall due to lack of records and hence chicken were excluded from analysis. Hereafter, livestock refers to cattle and shoats (sheep and goats). As shown in Table 4.1.2(a), 77 percent of the interviewed households had kept livestock, majority of which were of local breeds. The main production system was zero-grazing, but tethering and semi-grazing were also practised. Zero-grazed animals were fed mainly on dry maize stalks and Napier grass. Due to limited farming land in the area, negligible land was allocated for livestock grazing; implying that livestock farming depended almost entirely on the crop sector. Therefore, stocking rates were based on cultivable land.

Table 4.1.2(a): Main livestock kept, their production systems and stocking rate

	Cattle	*Goats*	*Sheep*	*Total*
Percentage of livestock farmers keeping	61	89	6	77
Percentage of farmers practicing zero-grazing	86	53	80	-
Percentage of farmers practicing tethering	0	41	20	-
Percentage of farmers practicing semi-grazing	14	7	0	-
Percentage of farmers growing Napier grass	-	-	-	69
Mean livestock kept per farm (Livestock Units)	-	-	-	1.25

Source: Computed from Survey Data (2009)

Since farmers kept different combinations of cattle and shoats, it was necessary to convert the livestock into comparable units as proposed by Millear *et al* (2005). All livestock were converted to Livestock Units (LU), following the weights used by Jaetzold, and Schmidt (1983), as shown in Table 4.1.5(b). Converting livestock into LU also made the enterprise divisible, which is a key requirement for activities entered in an LP problem. The mean livestock holding per household was 1.25 LU, translating to a stocking rate of about 1.3 LU per acre of cultivable land. This stocking rate is however lower than the recommended rate of 2 LU per acre, for the area (Jaetzold, and Schmidt, 1983), implying that there is potential for increasing livestock holding.

Table 4.1.2(b): Livestock unit equivalents of different categories of livestock

Livestock Unit Key	*Equivalent LU*			
	Under 1 year	*1-2 Years*	*Over 2 Years*	*Cows*
Improved stock	0.25	0.5	0.8	1
Unimproved stock	0.2	0.45	0.65	0.65
Goats/sheep/pigs	0.1	0.15	0.15	-

Source: Adapted from Jaetzold, and Schmidt (1983)

As illustrated in Table 4.1.2(c), the main livestock products were milk and manure. The mean quantity of milk produced per milk producing farm was 451 litres, (equivalent to

270 litres per LU per year), of which 52 percent was sold, at prices ranging from Ksh 25 to 40 per litre. The total quantity of manure produced averaged at 1.1 tons per farm (equivalent to 0.89 tons per LU). Almost all of the manure produced was used in the farm, as only 4.5 percent was sold.

Table 4.1.2(c): Main livestock products and their utilization

Product	Quantity produced per farm (kg)		Quantity produced per LU (kg)		% Utilized at home	(%)Sold
	Mean	*Standard Deviation*	*Mean*	*Standard Deviation*		
Milk	450.95	686.95	270.39	447.61	48.06	51.94
Manure	1131.24	1133.38	888.91	731.08	95.49	4.51

Source: Computed from Survey Data (2009)

4.1.3. Enterprise gross margins and risks

A summary of enterprise gross margins has been presented in Table 4.1.3(a). From the results, it can be noted that the high income enterprises also exhibited the large income variability as implied by their large standard deviations. The implication is that high income enterprises were also highly risky to produce compared to the low income enterprises.

Table 4.1.3(a): Gross margins of key enterprises (Figures in Ksh per unit)

Enterprise	Value of Outputs/Inputs		Gross Margin	
	Total Output	*Total Input*	*Mean*	*Std Deviation*
French Beans1	101,043	23,274	77,770	84,529.8
Totmato2	76,960	8,623	68,337	59,543.3
Tomato1	66,085	7,666	58,419	79,215.7
Kales2	30,934	7,824	23,110	26,899.5
Kales1	24,596	7,256	17,340	18,822.5
Livestock	13,843	1,746	12,097	14,972.0
Maize1	16,256	4,313	11,943	9,695.3
Coffee	14,417	3,078	11,339	12,591.3
Maize2	9,217	3,190	6,027	7,856.6

Source: Computed from Survey Data (2009)

The variance-covariance matrix shown in Table 4.1.3(b) gives the variances (**in bold**) of individual enterprise gross margins and covariance of any pair of enterprise gross margins. A mix of enterprises that gives a negative covariance implies that producing the mix will reduce overall income variance for a given farm plan, hence stabilizing the farm income. Enterprises with most negative income covariance will be included in the farm plan first, and then slowly be replaced by those with smaller negative covariance as risk aversion decreases (Riaz, 2002). Therefore in this study, long and short rain tomatoes and livestock were expected to feature prominently in the *EV* plans.

Table 4.1.3(b): Variance-covariance matrix for enterprise gross margins

Enterprise	***Variance-Covariance (x10^6)***								
	Maize1	*Maize2*	*Coffee*	*French Beans1*	*Kales1*	*Kales2*	*Tomato1*	*Tomato2*	*Livestock*
Maize1	**94.0**	55.3	35.0	-36.6	9.6	36.4	87.0	305.6	18.1
Maize2	55.3	**61.7**	-6.1	49.1	37.0	127.0	-143.7	-77.7	-5.0
Coffee	35.0	-6.1	**158.5**	577.5	-60.0	-24.4	395.7	118.0	-30.9
French Beans1	-36.6	49.1	577.5	**7,145.3**	2,013.0	3,608.5	-1,199.7	-13,180.7	-291.0
Kales1	9.6	37.0	-60.0	2,013.0	**354.3**	677.2	476.7	92.2	17.2
Kales2	36.4	127.0	-24.4	3,608.5	677.2	**723.6**	455.1	-273.9	-76.8
Tomato1	87.0	-143.7	395.7	-1,199.7	476.7	455.1	**6,275.1**	3,684.2	17.3
Tomato2	305.6	-77.7	118.0	-13,180.7	92.2	-273.9	3,684.2	**3,545.4**	-593.7
Livestock	18.1	-5.0	-30.9	-291.0	17.2	-76.8	17.3	-593.7	**224.2**

Source: Computed from survey data (2009)

4.2. Optimizing the Farm Plans

4.2.1. Risk-neutral farm plans

Results of the risk-neutral farm plans for the average farm with 1.268 acres of cultivable land have been presented in Tables 4.2.1(a) and 4.2.1(b). The results in Table 4.2.1(a) show that with subsistence constraints, the farmer should allocate 0.761 acres to maize intercrop each season, 0.165 acres to tomatoes in short rains, 0.007 acres to tomatoes in long rains season and keep 1.65 LU. Coffee, French beans and kales are excluded from the optimal farm plan, while area under maize intercrop in both seasons and long rain tomatoes reduces by about 20 and 63 percent respectively. The farmer should also triple the current area under long rain tomatoes and increase livestock units by 77 percent. This optimal farm plan earns the farmer an expected TFGM of Ksh 43,746, compared to the existing plan which gives the farmer an expected TFGM of Ksh 36,049, representing a 21.4 percent increase.

On the other hand, the optimal farm plan without subsistence constraints suggests an allocation of 0.438 acres to maize intercrop in short rain season, 0.25 acres to tomatoes in short rain season, 0.203 acres to tomatoes in long rain season and 2.5 LU. In this farm plan, coffee, French beans, kales and long rain maize are excluded from the optimal farm plan, while area under short rain maize decreases by 54 percent. The farmer ought to increase area under short rain tomatoes and long rain tomatoes by about 5 and 10 times respectively, and increase LU by 169 percent. This plan gives the farmer an expected TFGM of Ksh 63,913, which is 77.3 percent more than the existing TFGM, and 46.1 percent above the optimal subsistence TFGM described above.

These results indicate that by having highly diversified farm plans, farmers compromise on expected income. The typical farm plan in the irrigation scheme features about 9 enterprises, yet the optimal farm plans, featuring 4-5 enterprises generate 21.4 – 77.3 percent more income. In addition, as farmers insist on growing less profitable food crops for subsistence, farm incomes reduce; a conclusion reached by other studies (see Nyikal and Kosura, 2005 and Kuyiah *et al*, 2006).

Table 4.2.1(a): Comparison between current and risk-neutral optimal farm plans

	Current farm Plan	*Optimal farm plan with subsistence constraints*			*Optimal farm plan without subsistence constraints*		
	Current Level	**Optimal Level**	**% Change**	**Marginal Value**	**Optimal Level**	**% Change**	**Marginal Value**
Maize1	*0.962*	0.761	-21	-	0.438	-54	-
Maize2	*0.953*	0.761	-20	-	-	*-100*	-19,253.6
Coffee	*0.248*	-	*-100*	-12,300	-	*-100*	-393.6
French beans1	*0.018*	-	*-100*	-99,590	-	*-100*	-23,868.6
Kales1	*0.026*	-	*-100*	-37,950	-	*-100*	-39,943.7
Kales2	*0.018*	-	*-100*	-38,890	-	*-100*	-38,895.0
Tomatoes1	*0.041*	0.165	302	-	0.250	510	-
Tomatoes2	*0.019*	0.007	-63	-	0.203	968	-
Livestock	*0.930*	1.650	77	-	2.500	169	-
TFGM	***36,049.2***	**43,745.8**	***21.4***	**-**	**63,913.4**	***77.3***	**-**

TFGM = Total Farm Gross Margin. Figures are in acres for crop enterprises and LU for livestock enterprise
Source: Survey Data (2009): Linear Programming Output

Marginal analysis presented in the above table indicates that in the subsistence model, income will decrease most (by Ksh 99,590) from production of an additional acre of French beans, and least (by Ksh 12,300) from an additional acre of coffee. But in the non-subsistence model, income will decrease most (by Ksh 39,940) from an additional acre of short rain kales and least (by Ksh 393.5) from an additional acre of coffee.

The optimal TFGMs were subjected to a t-test to ascertain whether they were significantly different from existing TFGM. As presented in Table 4.2.1(b), the computed t-value was -2.154, which is greater than the critical t-value at 5 percent level of significance (as implied by the p-value of 0.033). The null hypothesis of equal farm gross margins was hence rejected, meaning that the TFGM from existing farm plan was significantly lower than that from the optimal plans. The optimal farm plans generated in this study are hence superior to the current plans under existing technology and resource endowment, implying that farmers can earn more income by reallocating their resources and adopting them.

Table 4.2.1(b): t-test results for equality of existing and optimal TFGM

Variable	Test Value = 43,745			
	t	Df	Sig. (2-tailed)	Mean Difference
Total farm gross margin (Ksh)	-2.154	106	0.033	-7,695.8

Source: Computed from survey data (2009)-SPSS output

The analysis of resource use presented in Table 4.2.1(c) shows that in the subsistence model, both land and family labour are non-constraining, whereas working capital is constraining in both seasons. In the short rains, unutilized irrigable and non-irrigable lands are 0.085 and 0.257 acres respectively, while family labour is in surplus by 301.7 man-days. In the long rain season, almost all the irrigable land (0.243 acres), 0.257 acres of non-irrigable land and 353.4 man-days of family labour are surplus. Unused livestock carrying capacity in this model is 0.85 LU.

The non-subsistence model on the other hand suggests that irrigable land, livestock carrying capacity and working capital were constraining; whereas non-irrigable land and family labour were in surplus. In the short rain season, 0.580 acres of non-irrigable and 277.4 man-days of family labour are idle. But in the long rains, 0.047 acres of irrigable land, all of the non-irrigable land and 334.4 man-days of family labour are unutilized.

These results show that by adopting the optimal farm plans, farmers will not only increase farm incomes, but they will also increase employment of farm family labour. The subsistence model uses 19 percent more family labour in 41 percent more irrigable land than the current plan. On the other hand, the non-subsistence model employs 49 percent more family labour than the current plan and 25 percent more family labour than the optimal subsistence model respectively. It further utilizes 91 percent of all irrigable land, an increase of 271 percent over the current plan.

Table 4.2.1(c): Optimal resource allocation and marginal values

Constraint	*Existing Plan*		*Subsistence Model*			*Non- subsistence Model*		
	Level	Surplus	Optimal Level	Surplus	Marginal Value	Optimal Level	Surplus	Marginal Value
Irrigland1	0.085	*0.165*	0.165	*0.085*	-	0.250	-	37,191.3
Irrigland2	0.037	*0.213*	0.007	*0.243*	-	0.203	*0.047*	-
Nonirrland1	1.018	-	0.761	*0.257*	-	0.438	*0.580*	-
Nonirrland2	1.018	-	0.761	*0.257*	-	-	*1.018*	-
Subsland1			0.761	-	-20,920.0	-	-	-
Subsland2			0.761	-	-19,250.0	-	-	-
Subscc			1.650	-	-1,474.2	-	-	-
Totalcc	0.930	*1.570*	1.650	0.85	-	2.50	-	2,761.1
Labour1	75.7	*321.3*	95.3	*301.7*	-	119.6	*277.4*	-
Labour2	71.8	*362.2*	80.6	*353.4*	-	99.6	*334.4*	-
Capital1	5,986	-	5,986.0	-	7.621	5,986.0	-	2.769
Capital2	3,929	-	3,929.0	-	7.925	3,929.0	-	7.925

Figures are in acres for crop enterprises, LU for livestock enterprise, man-days for labour and Ksh for capital
Source: Survey Data (2009): Linear Programming Output

Results in Table 4.2.1(c) further show that if an additional acre of irrigable land was available in short rains, cultivating it will increase a non-subsistence farmers' income by Ksh 37,191; while relaxing the total livestock carrying capacity of the farmers' land by one LU will increase farm incomes by 2,761. In addition, relaxing working capital by one unit (Ksh 1) would increase the TFGM by between Ksh 2.77 and 7.93. The commercial bank lending rates as at March 2007, ranged between 15.5 and 19.0 percent (Central Bank of Kenya, 2008), implying that the cost of capital was Ksh 0.155 – 0.19 per unit, and therefore it was economically feasible for farmers to use commercial credit if they had access to it. Overall, the non-subsistence model is more efficient in allocating farm resources than the subsistence model.

4.2.2. Effect of risk on optimal farm plans

Effect of risk on optimal farm plans has been summarised in Tables 4.2.2(a) and 4.2.2(b). As mentioned earlier, this risk is measured in terms variance (V) of expected income (E) and therefore, taking the square root of the given variance gives the standard deviation of the expected income from its mean. The results show that the composition of enterprises in optimal farm plans changes at each level of income risk, implying that farmers' attitudes to this risk would affect the kind of farm plan they adopt. The subsistence model presented in Table 4.2.2(a) shows that the land allocated to subsistence crops does not exceed the minimum requirement of 0.761 acres per season, nor does the allocation of available livestock carrying capacity exceed the minimum required for subsistence (1.65 LU), regardless of the risk preference level. Further, while coffee and kales do not feature in any optimal farm plan, the amount of land allocated to long rain tomatoes remains constant at 0.007 acres, at all levels of risk. The results also show that as risk aversion decreases, the allocation of land to short rain French beans must decrease (because of its high risk), while land allocated to short rain tomatoes increases.

Table 4.2.2(a): Risk-efficient farm plans for the subsistence model

EV Set (Figures in Ksh)		*Optimal Enterprise Levels (Acres for crops, LU for livestock)*								
Income	**Variance (10^6)**	**Mze1**	**Mze2**	**Coff**	**Fbn1**	**Kal1**	**Kal2**	**Tom1**	**Tom2**	**Lvst**
44,340	Infeasible									
43,745	960.5	0.761	0.761	-		-	-	0.165	0.007	1.65
43,340	929.6	0.761	0.761	-	0.004	-	-	0.152	0.007	1.65
42,340	863.8	0.761	0.761	-	0.014	-	-	0.122	0.007	1.65
41,340	812.5	0.761	0.761	-	0.024	-	-	0.091	0.007	1.65
40,340	775.7	0.761	0.761	-	0.034	-	-	0.061	0.007	1.65
39,340	753.7	0.761	0.761	-	0.044	-	-	0.030	0.007	1.65
38,340	746.1	0.761	0.761	-	0.054	-	-	-	0.007	1.65
36,049	**1,365.0**	**0.962**	**0.953**	**0.248**	**0.018**	**0.026**	**0.018**	**0.041**	**0.019**	**0.93**

Mze=Maize, Coff=Coffee, Fbn=French beans, Kal=Kales, Tom=Tomatoes, Lvst=Livestock

Source: Survey Data (2009): QRP Output

Generally, the variance associated with the current farm plan (bottom row in the above table) is higher than that associated with the risk-efficient farm plans generated in the subsistence model. Figure 4.2.2(a) shows that the existing farm plan is below the efficient

EV frontier. The implication is that the current farm plan is highly risky, yet farmers diversify with the aim of reducing risk. The most risk-averse farmer can optimize risk by dropping coffee, kales and short rain tomatoes from the current farm plans, growing 0.761 acres of maize intercrop in both seasons, 0.054 acres of French beans in short rains and 0.007 acres of tomatoes in long rains, and keeping 1.65 LU. This farm plan will earn the farmer an expected income of Ksh 38,340, which has a variance of 746 million (equal to a standard deviation of KSh 27,315).

On the other hand, the subsistence-oriented farmer with least risk-aversion can earn an expected income of Ksh 43,745, with a variance of 960.5 million (standard deviation of KSh 30,992), by growing 0.761 acres of maize intercrop in both short and long rain seasons; 0.165 acres of tomatoes in the short rains and 0.007 acres of tomatoes in long rain season; and keeping 1.65 LU. This farm plan can be recommended for adoption under current level of resource availability because the variance associated with it is 30 percent less than that of the existing farm plan, yet it earns farmers 21 percent more income, utilises 41 percent more irrigable land and increases employment of family labour by 19 percent. Detailed information on resource requirement/allocation for this model can be obtained from Appendix 6 (plan VII).

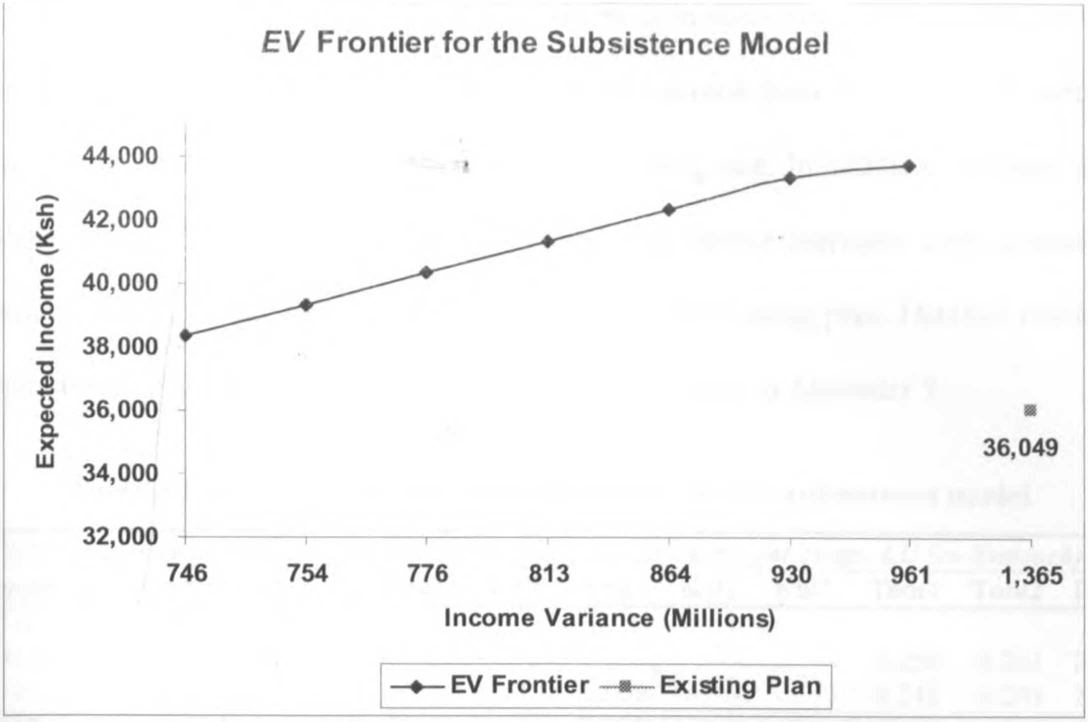

Figure 4.2.2(a): ***EV*** **Frontier for the Subsistence model**

Source: Survey Data (2009): QRP Output

The non-subsistence model illustrated in Table 4.2.2(b) shows that like in the subsistence model, risk affects enterprise composition in optimal farm plans. In this model, whereas the land allocated to short rain maize intercrop and tomato enterprises increases with level of risk, land allocated to the highly profitable short rain French beans decreases due to its high risk. Furthermore, land allocated to long rain tomatoes and carrying capacity allocated to livestock show only a slight change as risk level changes. Long rain maize, coffee, and kales are excluded from optimal farm plans at all levels of risk preference.

The maximum feasible income of Ksh 63,913.4 is achieved by producing 0.438 acres of maize intercrop and 0.25 acres of tomatoes in the short rain season; 0.203 acres of long rain tomatoes; and 2.50 LU. This farm plan, despite being more profitable, is also more risky than the existing plan. The average farmer who is not willing to take more risks can adopt the *EV* set which provides an income of Ksh 62,730, with a variance of Ksh 1,240 million (standard deviation of KSh 35,214). The farm plan features 0.258 acres of maize, 0.05 acres of French beans and 0.2 acres of tomatoes in short rain season; 0.203 acres of tomatoes in long rain season; and 2.5 LU. Income earned from the plan is 73 percent more and is slightly less prone to risk than the existing one. In addition, the farm plan utilises about 271 percent more irrigable land and further increases employment of available family labour by 47 percent, compared to the existing plan. Detailed resource requirements/allocations for each *EV* set have been provided in Appendix 7.

Table 4.2.2(b): Risk-efficient farm plans for the non-subsistence model

EV Set (Figures in Ksh)		***Optimal Enterprise Levels (Acres for crops, LU for livestock)***								
Income	**Variance(10^6)**	**Mze1**	**Mze2**	**Coff**	**Fbn1**	**Kal1**	**Kal2**	**Tom1**	**Tom2**	**Lvst**
63,730.0	Infeasible									
63,913.4	1,863.1	0.438	-	-	-	-	-	0.250	0.203	2.500
63,730.0	1,760.8	0.410	-	-	0.008	-	-	0.242	0.203	2.500
62,730.0	1,240.4	0.258	-	-	0.050	-	-	0.200	0.203	2.500
61,730.0	783.0	0.106	-	-	0.091	-	-	0.159	0.203	2.500
60,730.0	379.8	0.014	-	-	0.122	-	-	0.128	0.212	2.406
59,730.0	1.2	-	-	-	0.139	-	-	0.111	0.235	2.183
43,745.0	***960.4***	***0.761***	***0.761***	-	-	-	-	***0.165***	***0.007***	***1.650***
36,049.2	**1,365.0**	**0.962**	**0.953**	**0.248**	**0.018**	**0.026**	**0.018**	**0.041**	**0.019**	**0.930**

Mze=Maize, Coff=Coffee, Fbn=French beans, Kal=Kales, Tom=Tomatoes, Lvst=Livestock
Source: Survey Data (2009): QRP Output

Similar to what has been shown in the subsistence model, the existing farm plan is not risk-efficient compared to the non-subsistence model. Figure 4.2.2(b) illustrates that the income-variance combination of the existing plan is below the risk-efficient *EV* frontier. The same conclusion can also be made by comparing the risk-efficient subsistence model with the risk-efficient non-subsistence model. All levels of risk in the subsistence model are associated with a much lower level of income than in the non-subsistence model. Further, the slope of the *EV* frontier for the non-subsistence model is steeper than that of the subsistence model, implying that the former model is more prone to risk than the latter, and confirming earlier observations and literature that farm plans with higher expected returns are also more risky.

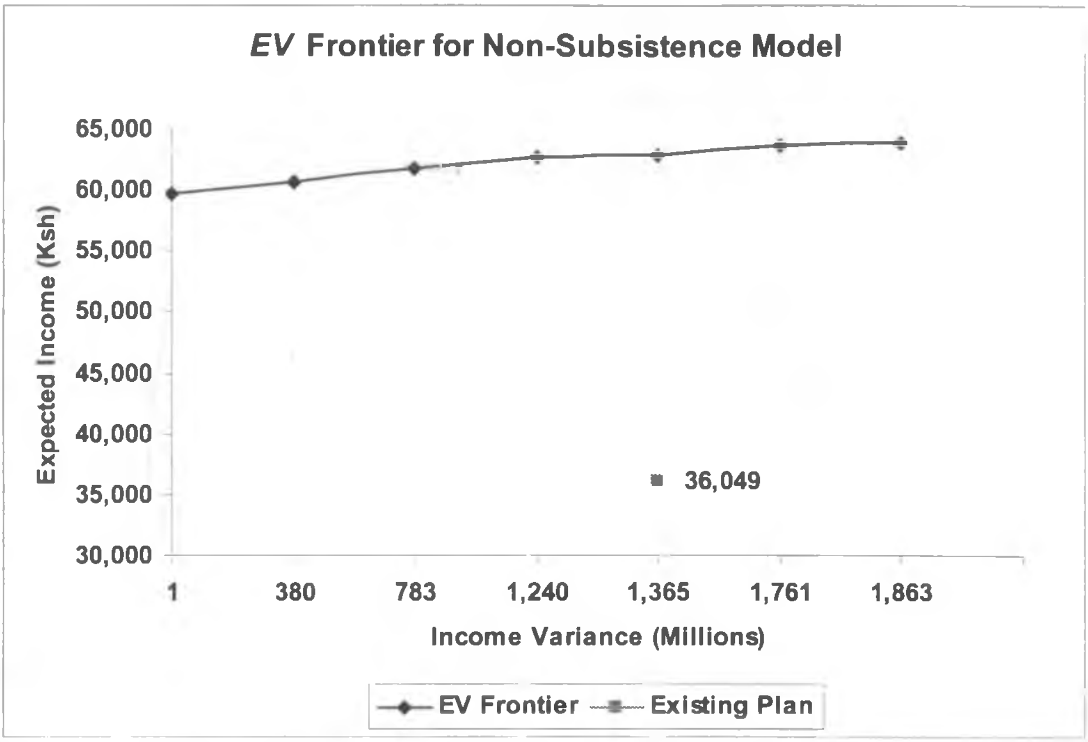

Figure 4.2.2(b): ***EV*** **Frontier for the Non-subsistence Model**

Source: Survey Data (2009): QRP Output

These findings also imply that if economic efficiency (profit maximisation) is the sole criterion for choosing optimal farm plans, then the non-subsistence model provides the best set of farm plans at each level of farmer's risk preference. But the subsistence objective is critical for food security of smallholder farmers and must therefore be included in any optimal farm plan, for it to be accepted by them (Ateng, 1977).

The results presented in this section have demonstrated that the number, type and levels of enterprises in optimal farm plans were affected by income variance (risk). These observations imply therefore, that farmers' risk preference would indeed affect enterprise composition in optimal farm plans and hence the second hypothesis that risk does not affect choice of optimal farm plans was rejected.

4.2.3. Mitigating risk: relaxing the working capital constraint

The results presented in sections 4.2.1 and 4.2.2 have shown that the subsistence model provides optimal farm plans with lower expected income that the non-subsistence models. However, subsistence model is deemed more realistic to farmers' conditions and hence more likely to be accepted by farmers. In view of this, it became necessary to subject the subsistence model to some sensitivity analysis[12] to assess possibility of lowering income risk associated with this model.

In this study, varying the maximum available working capital was preferred, because working capital was the only constraining resource in optimal farm plans for the subsistence model, as illustrated in Table 4.2.1(b). In addition, farmers in the study area had in the focus group discussion identified working capital as their most limiting farming constraint[13]. It has also been established that while farmers in Machakos District invest low levels of capital and land as a strategy for mitigating farming risks associated with erratic rainfall, such a strategy makes the farmers not to exploit opportunities presented by good seasons (Rao and Okwach, 2005). Investigating the effect of easing working capital on optimal farm plans would therefore provide guidelines on how the farmers can invest the additional capital to minimize farm income risk. *EV* sets were generated and analysed under unconstrained capital in season 1; unconstrained capital in season 2; and unconstrained capital in both seasons[14]. The results of each capital availability regime were compared with those in which capital was constrained in both seasons (baseline plans), and the existing plans. The results have been presented below.

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12 Sensitivity analysis evaluates how a model's results will be affected by changes in input values or assumptions (Pasky et al, 2003), and it should concern itself only with changes in inputs (or assumptions) that will lead to different decisions (Frey, 2002). To do this, Pannell (1997) suggests that one could vary the contribution of an activity to the objective; the objective function; a constraint limit; the number of constraints; the number of activities; or technical parameters; and observe the changes for instance in values of objective function or decision variables.

13 Some studies also report that most farmers lack access to capital (see for example, Place *et al,* 2006).

14 Season1 refers to short rains season, while season2 refers to long rains season.

(a) Risk-efficient subsistence model with unconstrained capital in season 1

Results of the sensitivity analysis show that it would require an additional Ksh 731 (7.3 percent) to completely relax the capital constraints in the short rains season. This would result in risk-efficient farm plans that earn the farmer maximum expected returns of Ksh 49,134. The total expected returns earned exceed those provided by the baseline plans by Ksh 5,389 (12.3 percent), but also increase income variance by 29 percent. However, the risk level associated with this farm plan is still 10 percent less, while the income earned would be 36 percent more, compared to the existing plan. This means that by relaxing working capital constraints, income risks would reduce and farmers would improve their efficiency, as shown in the *EV* frontier map in Figure 4.2.3.

As shown in Table 4.2.3(a), the land allocated to subsistence crops does not exceed the minimum requirement. French beans features in lower risk farm plans but is excluded in the most profitable farm plan. The best feasible farm plan features 0.761 acres of maize intercrop in both seasons; 0.25 acres of tomatoes in season 1; and 1.72 LU. This farm plan utilises about 111 percent more irrigable land than the current plan. It also increases returns to working capital from KSh 3.6 to KSh 4.6 per shilling invested, representing a 27 percent increase, and increases employment of family labour by 27 percent. Assuming that the farmers' risk preference remains at the level depicted in the existing farm plan, farmers with access to adequate capital in short rains season only can be advised to adopt this farm plan. Detailed resource requirements and allocations for each *EV* set are provided in Appendix 8.

Table 4.2.3(a): Risk-efficient farm plans for a subsistence model with unconstrained capital in season 1

EV Set (Figures in Ksh)		*Optimal Enterprise Levels (Acres for crops, LU for livestock)*								
Income	**Variance(10^6)**	**Mze1**	**Mze2**	**Coff**	**Fbn1**	**Kal1**	**Kal2**	**Tom1**	**Tom2**	**Lvst**
50,234.5	*Infeasible*									
49,133.6	***1,238.5***	**0.761**	**0.761**	-	-	-	-	**0.250**	-	**1.72**
48,234.5	*1,097.7*	0.761	0.761	-	0.011	-	-	0.227	0.007	1.65
47,234.5	*1,003.0*	0.761	0.761	-	0.021	-	-	0.197	0.007	1.65
46,234.5	*922.8*	0.761	0.761	-	0.031	-	-	0.166	0.007	1.65
45,234.5	*857.2*	0.761	0.761	-	0.041	-	-	0.136	0.007	1.65
44,234.5	*806.2*	0.761	0.761	-	0.051	-	-	0.105	0.007	1.65
43,234.5	*769.8*	0.761	0.761	-	0.061	-	-	0.075	0.007	1.65
42,234.5	*747.9*	0.761	0.761	-	0.071	-	-	0.044	0.007	1.65
41,234.5	*740.7*	0.761	0.761	-	0.081	-	-	0.014	0.007	1.65
43,745.0	***960.4***	***0.761***	***0.761***	-	-	-	-	***0.165***	***0.007***	***1.65***
36,049.2	**1,365.0**	**0.962**	**0.953**	**0.248**	**0.018**	**0.026**	**0.018**	**0.041**	**0.019**	**0.930**

Source: Survey data (2009): Optimization Results
Last and second last rows represent the existing and baseline plans respectively

(b) Risk-efficient subsistence model with unconstrained capital in season 2

Relaxing the capital constraints in season 2 would require an additional capital of Ksh 2,095 (21.1 percent) and result in risk-efficient farm plans that earn the farmer a maximum expected return of Ksh 60,347, with a variance of Ksh 1,085 million (standard deviation of KSh 32,939) as shown in Table 4.2.3(b). This farm plan features 0.761 acres of maize intercrop in both seasons; 0.165 acres of tomatoes in season 1; 0.25 acres of tomatoes in Season 2; and 1.65 LU. The returns earned exceed those provided by the baseline plans by Ksh 16,601 (38 percent), but also have an income variance that is 13 percent above that of the baseline plan. Nevertheless, this variance is still 20 percent less than that of the existing farm plan, implying that at the current level of risk preference, farmers would be better-off by adopting this farm plan.

The results further imply that if capital was not limiting in the long rain season, farmers would not only earn higher incomes, but they would also face less fluctuations in the farm incomes. By adopting the farm plan described above, farmers will increase their use of irrigable land by 240 percent and family labour employment by 32 percent compared to the existing plan. This farm plan also increases returns to working capital by 38 percent from the current KSh 3.6 to KSh 5.0 per shilling invested. Detailed resource requirements and allocations for each *EV* set have been provided in Appendix 9.

Table 4.2.3(b): Risk-efficient farm plans for a subsistence model with unconstrained capital in season 2

EV Set (Figures in Ksh)		*Optimal Enterprise Levels (Acres for crops, LU for livestock)*								
Income	**Variance(10^6)**	**Mze1**	**Mze2**	**Coff**	**Fbn1**	**Kal1**	**Kal2**	**Tom1**	**Tom2**	**Lvst**
60,940.0	*Infeasible*	-	-	-	-	-	-	-	-	
60,346.9	**1085.2**	**0.761**	**0.761**	**-**	**-**	**-**	**-**	**0.165**	**0.25**	**1.65**
59,940.0	1005.9	0.761	0.761	-	0.004	-	-	0.152	0.25	1.65
58,940.0	821.2	0.761	0.761	-	0.014	-	-	0.122	0.25	1.65
57,940.0	651.0	0.761	0.761	-	0.024	-	-	0.091	0.25	1.65
56,940.0	495.5	0.761	0.761	-	0.034	-	-	0.061	0.25	1.65
55,940.0	354.5	0.761	0.761	-	0.044	-	-	0.030	0.25	1.65
54,940.0	228.2	0.761	0.761	-	0.054	-	-	-	0.25	1.65
43,745.0	***960.4***	***0.761***	***0.761***	**-**	**-**	**-**	**-**	***0.165***	***0.007***	***1.65***
36,049.2	**1,365.0**	**0.962**	**0.953**	**0.248**	**0.018**	**0.026**	**0.018**	**0.041**	**0.019**	**0.930**

Source: Survey data (2009): Optimization Results
Last and second last rows represent the existing and baseline plans respectively

(c) Risk-efficient subsistence model with unconstrained capital in seasons 1&2

This model fully eases working capital constraints. To achieve this under the current farming systems and technology requires an additional capital of Ksh 4,555 in Season 1 and Ksh 2,095 in season 2. This extra Ksh 6,650 (67 percent) per year will result in risk-efficient farm plans that earn the farmer maximum expected returns of Ksh 75,339, which exceeds that provided by the baseline plans by Ksh 31,594 (72.2 percent). The best feasible farm plan, presented in Table 4.2.3(c), features 1.018 acres of maize intercrop in season 1; 0.761 acres of maize intercrop in season 2; 0.131 acres of French beans in season 1; 0.119 acres of tomatoes in season 1; 0.164 acres of tomatoes in season 2; and 2.5 LU. In this farm plan, the levels of maize intercrop and livestock exceed subsistence requirements. The risk associated with this farm plan is Ksh 948 million (standard deviation of KSh 30,790), which is 1.3 percent lower than that of the baseline plan, and 31 percent below the existing level. This implies that by completely relaxing capital constraints, farm income risks reduce and farmers become more efficient, as shown in Figure 4.2.3.

Detailed resource requirements/allocations for each *EV* set are provided in Appendix 10. These allocations show that with relaxed capital in both seasons, farmers can utilise 83 percent of all irrigable land, compared to 24.4 percent in the current plan (239 percent increase). In addition, family labour employment increases from 148 to 272 man days, representing an increase of 84 percent. Further, returns to family labour increase from KSh 244 to 277 per man day, representing a 14 percent increase, while returns to working capital increase by 25 percent from KSh 3.6 to 4.5 per Shilling invested.

Table 4.2.3(c): Risk-efficient farm plans for a subsistence model with unconstrained capital in seasons 1&2

EV Set (Figures in Ksh)		***Optimal Enterprise Levels (Acres for crops, LU for livestock)***								
Income	**Variance(10^6)**	**Mze1**	**Mze2**	**Coff**	**Fbn1**	**Kal1**	**Kal2**	**Tom1**	**Tom2**	**Lvst**
75,500.0	*Infeasible*									
75,338.8	948.0	1.018	0.761		0.131			0.119	0.164	2.5
75,250.0	912.4	1.018	0.761		0.133			0.117	0.166	2.48
74,750.0	716.9	1.018	0.761		0.139			0.111	0.178	2.36
74,250.0	529.5	1.018	0.761		0.146			0.104	0.191	2.23
73,750.0	349.2	0.997	0.761		0.157			0.093	0.200	2.15
73,250.0	173.1	0.969	0.761		0.169			0.081	0.208	2.07
72,750.0	1.1	0.940	0.761		0.181			0.069	0.215	1.99
43,745.0	***960.4***	***0.761***	***0.761***	-	-	-	-	***0.165***	***0.007***	***1.65***
36,049.2	**1,365.0**	**0.962**	**0.953**	**0.248**	**0.018**	**0.026**	**0.018**	**0.041**	**0.019**	**0.930**

Source: Survey data (2009): Optimization Results. Last and second last rows represent the existing and baseline plans respectively

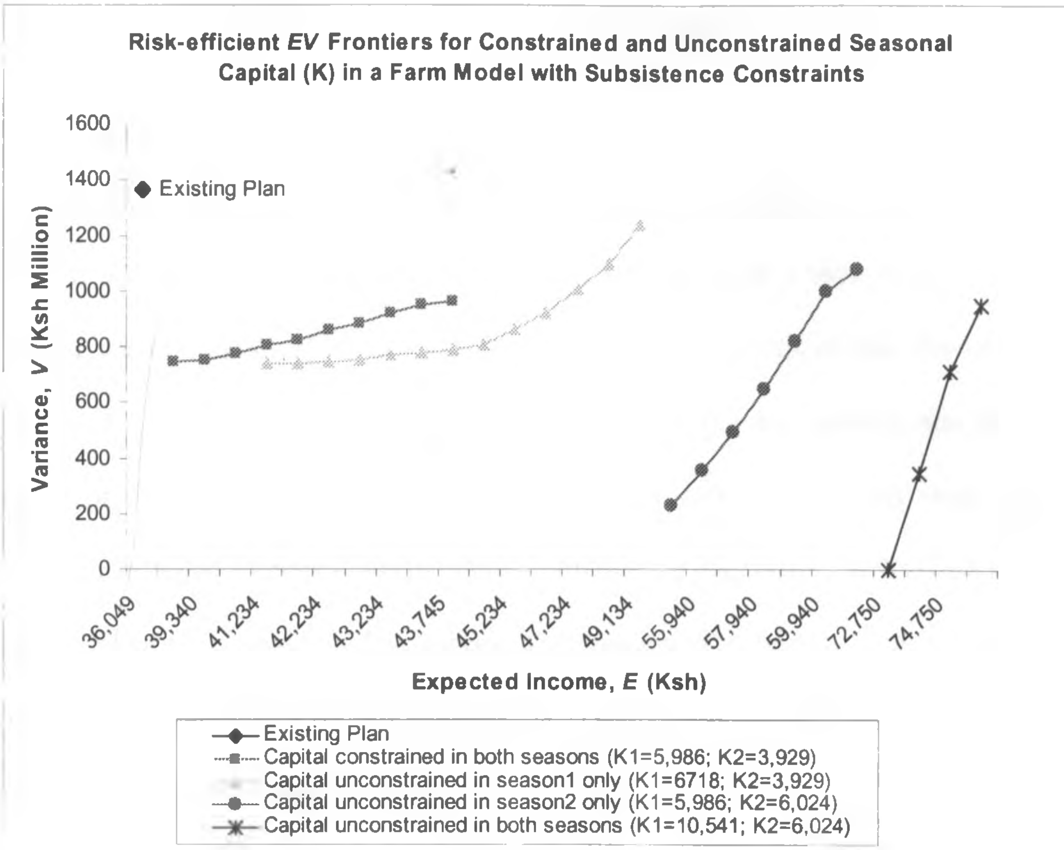

Figure 4.2.3: Risk-efficient *EV* frontier map for constrained and unconstrained seasonal capital in a farm model with subsistence constraints

Source: Computed from Survey data (2009)

Chapter 5: Summary, Conclusions and Recommendations

5.1 Summary and Conclusions

This study assessed the effect of farm income risks on production decisions in Kauti Irrigation Scheme in the highlands of Machakos District, with a view to identifying farm plans that earn farmers higher incomes at existing or lower levels of risk. Two hypotheses were tested: one, that existing farm plans in the study area are optimal; and the second, that risk preference does not affect choice of optimal farm plans in the study area. The study used crop and livestock production and marketing data covering 2007/08 short rains and 2008 long rains seasons. The survey was conducted in March 2009 through a farm household survey involving 113 households. The data were analysed using linear and quadratic risk programming techniques.

The risk-neutral farm plans produced by the linear program show that with subsistence constraints, the farmer would earn an expected total farm gross margin (TFGM) of Ksh 43,746 compared to Ksh 36,049 from the existing farm plan, representing a 21.4 percent increase. On the other hand, without subsistence constraints, the farmer would earn an expected TFGM of Ksh 63,913, which is 77.3 percent above the existing level, and 46.1 percent above the income from optimal plan with subsistence restrictions. In both models, coffee, kales and French beans are excluded from the optimal plans. The resultant optimal farm plans comprise only 4 enterprises (5 if subsistence constraints are imposed) as opposed to 9 in a typical farm plan in the irrigation scheme.

The differences in TFGM between optimal and existing farm plans were statistically significant; hence the null hypothesis of equal TFGM was rejected. The implication is that the current farm plan operated in the study area is sub-optimal, and farmers can therefore improve their farm incomes under the current production technology by simply reallocating their resources to adopt optimal farm plans. In addition, as farmers produce for subsistence, they earn less income, implying that a non-subsistence farm model would utilize farm resources more efficiently than a subsistence one. However, the subsistence objective is critical for the smallholder farmers' food security; hence it would be more realistic for farmers to adopt farm plans that impose minimum subsistence requirements. Alternatively, if farmers were to increase their productivity, the subsistence needs would be easily achieved and thus be less of a challenge to commercialization or adoption of optimal plans as recommended here.

The analysis of resource allocation shows that whereas land, labour and livestock carrying capacities were underutilized in the risk-neutral farm plans, working capital was constraining. The Marginal Value Product (MVP) of capital in the optimal farm plans was at least 2.77, whereas the prevailing cost of bank credit was at most 0.19 per unit, during the period under study. This implies that it was economically feasible for farmers to use bank credit if they had access to it. Further, the results show that the optimal farm plans increase employment of farm family labour by upto 49 percent and utilization of irrigable land by up to 271 percent, over the current plan.

Results of the quadratic risk programming (QRP) under both the subsistence and non-subsistence models suggest different levels of land allocation to French beans and tomatoes in short rains season, at each level of income risk. Generally, as risk aversion decreases, farmers should allocate less land to French beans, and more land to tomatoes, in order to be risk-efficient. These results show that farm income risk affects the composition of enterprises in the optimal farm plan and hence farmers' production decisions and incomes. The results further show that the *EV* combination of existing farm plan falls below the risk-efficient frontiers for both subsistence and non-subsistence models, implying that although the existing farm plan is highly diversified, it is not risk-efficient. The risk model without subsistence constraint was also found to be more profitable and risky than the risk model with subsistence constraints. However, the subsistence plan is more likely to be adopted by farmers since it promotes household food self-sufficiency.

Sensitivity analysis indicates that relaxing capital constraints would result in risk-efficient farm plans that increase expected income by up to 109 percent compared to existing farm plan, and by up to 72 percent compared to optimal farm plans under constrained capital. Further, the farm plans reduce income risk by up to 31 percent and increase utilization of irrigable land by 240 percent; family labour employment by 84 percent; returns to family labour by 14 percent; and returns to working capital by 25 percent. The greatest impact would come from relaxing capital in both short and long rains seasons, implying that if farmers had access to adequate capital throughout the year, they would bring most of the idle irrigable land into production and adopt farm plans that reduce risks and earn them more incomes. Alternatively, if strategies were put in place to minimize fluctuations in farm incomes, then farmers would invest more capital in farming and adopt farm plans that earn them more incomes.

5.2 Recommendations for Policy and Further Research

Based on the above conclusions, four alternative farm plans that minimize farm income risks have been proposed for adoption, as shown in Table 5.2.

Table 5.2: Recommended risk-efficient farm plans

	EV, Enterprises	*Existing Plan*	*Alternative Optimal Plans* Plan I	Plan II	Plan III	Plan IV
EV Set	*Expected Total Income(Ksh)*	*36,049*	*43,745*	*49,134*	*60,347*	*75,339*
	Income Variance(Ksh Million)	*1,365.0*	*960.5*	*1,238.5*	*1,085.2*	*948.0*
Enterprises	Maize1 (acres)	*0.962*	0.761	0.761	0.761	1.018
	Maize2 (acres)	*0.953*	0.761	0.761	0.761	0.761
	Coffee (acres)	*0.248*	-	-	-	-
	French beans1 (acres)	*0.018*	-	-	-	0.131
	Kales1 (acres)	*0.026*	-	-	-	-
	Kales2 (acres)	*0.018*	-	-	-	-
	Tomatoes1 (acres)	*0.041*	0.165	0.250	0.165	0.119
	Tomatoes2 (acres)	*0.019*	0.007	-	0.250	0.164
	Livestock (Livestock Units)	*0.930*	1.650	1.720	1.650	2.500

Source: Compiled from survey data (2009).

The underlying assumption of these recommendations is that farmers would be willing to adopt optimal farm plans that are, at worst, as risky as the existing farm plan, provided they generate higher expected income. The farm plans also assume that farmers would use the existing farming technologies, achieve the current yields and face the current price ranges, as described in Section 4.1 above. However, these farm plans do not represent the preferences of all farmers, which is a characteristic weakness of the QRP technique (Nyikal and Kosura, 2005). This notwithstanding, the study provides other detailed plans and input-output coefficients that can be used as guidelines for developing optimal farm plans to suit each farmer's income-risk preference and resource constraints.

In this regard, the following recommendations can be made:

(a) The Ministry of Agriculture and agricultural development partners in the study area should advise farmers to adopt optimal farm plan IV. This plan suggests that farmers abandon production of coffee and kales. In the short rains, farmers should allocate

1.018 acres to maize intercrop, 0.131 acres to French beans, and 0.119 acres to tomatoes; while in the long rains, they should allocate 0.761 acres to maize intercrop and 0.164 acres for tomatoes. In addition, the farmers should keep an average of 2.5 livestock units (equivalent to 2 improved dairy cows or 1 improved dairy cow + 5 mature goats) throughout the year.

This farm plan would earn farmers a total expected income of Ksh 75,339 annually, which is more than double the current income. The income risk (variance) associated with this farm plan is Ksh 948 million (standard deviation of KSh 30,790 and is 31 percent less than that associated with the existing farm plan. Furthermore, this farm plan increases employment of family labour from the current 148 to 272 man days, representing 84 percent increase. Returns to family labour also increase from the existing Ksh 244 to Ksh 277 per man-day, an improvement of about 13 percent.

It should be noted, however, that this plan requires a working capital of Ksh 16,565, which exceeds the current capital availability by Ksh 6,650 (67 percent). This calls for increased access to working capital by farmers. Although the government (in partnership with some donors and private sector players) has set up some farm input financing programmes, most of them are sector-specific (for instance, *Kilimo Biashara* for cereals and Smallholder Horticultural Marketing Programme, SHoMaP, for horticultural crops), despite the government's call for diversification of agricultural activities by smallholder farmers. Furthermore, in the study area, most farmers have not accessed credit through such programmes[15]. There is need to assess the efficacy of these programmes, with the aim of developing a financing strategy that would allow many farmers to apply at once for a 'comprehensive' credit that would cater for working capital requirements of a diversified, risk-efficient farm plan.

[15] Information source: Ministry of Agriculture extension staff and farmers in the study area.

(b) If farmers are unable to access extra capital needed to shift them to the above plan, they can adopt alternative Farm Plans I – III. These plans generally propose that farmers abandon production of coffee, kales and French beans and only engage in maize, tomatoes and livestock production. Compared to the existing farm plan, these farm plans increase expected farm incomes by 21-67 percent, while keeping income risk at 9-30 percent below the exiting level. Further, the plans increase family labour employment by 19-32 percent, and returns to family labour by 1.5-27 percent. Based on these farm plans, farmers who cannot raise more than existing level of working capital in both seasons can be advised to adopt Plan I. However, if farmers can access an additional Ksh 731 in the short rains, they should be advised to adopt Plan II, whereas farmers who can raise Ksh 2,095 more in the long rains, but no more than Ksh 5,986 in the short rains (current level), should be advised to adopt Plan III.

(c) A number of 'new' high value enterprises that are less dependent on rainfall are also currently being promoted by the Ministry of Agriculture in the study area, the most common being mushroom and fish farming. Further research is needed to assess the possibility of integrating some of these enterprises into the risk-optimizing farm plans.

(d) Although adoption of optimal farm plans would increase farm incomes in the study area, a typical farm household has about 1.268 acres of cultivable land, which generates a maximum risk-efficient income of Ksh 75,339 (equivalent to about US$ 978.4[16]). This amount can only support 2.68 persons living on US$ 1 per day. Since the average farm household size in the study area is 6 persons, it means that more than a half of the population would live below the poverty line if they relied entirely on

[16] I US$ = Ksh 77

farming[17]. With increasing population, land subdivision is likely to further worsen the situation. Furthermore, even the most efficient farm plan would employ only 272 out of 831 man-days (33 percent) of family labour available annually. In light of this, the government, in collaboration with development partners, should develop and support more strategies that increase employment opportunities in the off-farm sector.

[17] The current poverty in the study area level is estimated at 65 percent.

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Appendices

Appendix 1: Focus Group Discussions Schedule

A: General Discussion

1. Crops Grown

Crop	Acreage Rank: Rank the first 3 food crops and 3 cash crops	Profitability Rank: Rank the 1st 3	Common Cropping Pattern
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

2. Livestock Kept

Livestock Type	Popularity Rank: (Based on Number of households involved)	Profitability Rank	Common production system (Free grazed/ Tethered, Zero-grazed...) Rank
1			
2			
3			
4			
5			

3. Activity (Farming) Calendar

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

B: Group Discussions

4. Constraints, Coping Strategies, and Proposed Measures for Alleviation

4.1 Crop Production (Group 1)

Constraint	Rank	Coping Strategy	Proposed Alleviation Measures
1.		1. 2	1. 2
2.		1. 2	1. 2
3.		1. 2	1. 2

4.2 Livestock Production (Group 2)

Constraint	Rank	Coping Strategy	Proposed Alleviation Measures
1.		1. 2	1. 2
2.		1. 2	1. 2
3.		1. 2	1. 2

5.1 Main Marketing Channels (Group 3)

Channel	Advantages	Disadvantages
1.	1. 2	1. 2
2.	1. 2	1. 2
3.	1. 2	1. 2

5.2 Crop Marketing (Group 3)

Constraint	Rank	Coping Strategy	Proposed Alleviation Measures
1.		1. 2	1. 2
2.		1. 2	1. 2
3.		1. 2	1. 2

5.3 Livestock Marketing (Group 3)

Constraint	Rank	Coping Strategy	Proposed Alleviation Measures
1.		1. 2	1. 2
2.		1. 2	1. 2
3.		1. 2	1. 2

Appendix 2: Household Survey Questionnaire

Effect of Farm Income Risk on Smallholder Production Decisions in the Highlands of Machakos District, Kenya: The Case of Kauti Irrigation Scheme.

0.0 Survey Quality Control

1. Date of interview (dd/mm/yyyy)..
2. Enumerator name..
3. Checked by..
4. Checking date (dd/mm/yyyy)...
5. Data entry by..
6. Data entry date (dd/mm/yyyy)...

1.0 Farmer and Site Identification

1. Farmer (respondent) name................................... 2. Gender (1= Male 0= Female)
3. Sub-Location............................. 4. Village ....
5. Number of years in the village............. 6. Experience in farming (years)...................................
7. Were you a contract farmer in 2007-8 (1=Yes 0= No)
8. If yes, were you contracted as (1=group 0=Individual)
9. Name of contracting company...

2.0 Household Composition and Characteristics (2007-08 Cropping Seasons)

Name of household member (start with respondent)	Sex (1=Male 0=Female)	Age (years)	Years of formal Education (Codes A)	Main occupation (Codes B)	Member Availability on the farm (Codes C)											
					O	N	D	J	F	M	A	M	J	J	A	S
1.																
2.																
3.																
4.																
5.																
6.																
7.																
8.																
9.																
10.																
11.																
12.																

Codes:

Codes A

0. None
1. Adult education/1 Year
- Other years to equal actual number of completed years in school (2,3,4….)

Codes B

1. Farming
2. Salaried employment
3. Self-employed off-farm
4. Casual labourer on-farm
5. Casual labourer off-farm
6. School/college child
7. Household chores
8. Non-school child
9. None (elderly/disabled).
10. Other, specify...........

Codes C

0). Not Available
1). 1 week
2). 2 weeks
3). 3 weeks
4). Full time
5). Weekends and public holidays

3.0 Household Farm Assets

3.1 Assets owned during the Short Rains 2007-08 Cropping Seasons

Asset name	Number	Current per unit value (KSh/unit)	Total value (KSh) [Col 2*Col 3]
1	2	3	4
1. Ox-ploughs			
2. Ox-cart			
3. Water Pump			
4. Machetes/pangas			
5. Axe			
6. Spade			
7. Jembes/Hoes			
8. Sprayer			
9. Wheel barrow			
10. Bicycle			
11. Tractor			
12. Other motorized vehicles			
13. Radio			
14. Mobile phone			
15. Television (TV)			
16. Granary			
17. Livestock Housing units			
Others, specify			
18.			
19.			
20.			

3.2 Land holding (*acres*) during the 2007/2008 cropping years

	2007-8 Short Rains		2008 Long rains	
	Size (Acres)	Rent (Ksh)	Size (Acres)	Rent (Ksh)
1. Total own Land				
2. Own land used for farming				
3. Rented in land (for crops)				
4. Rented in land (for livestock)				
5. Rented out land				
6. Borrowed in land				
7. Borrowed out land				
8. Total land used for crops				

4.0 Crop Production and Utilization During the 2007-8 cropping seasons

4.1 Crops Grown and Budget during 2007-8 Short Rain season

Crop* Codes A)	Cropping System (1=Sole 2=Mixed)	Area Planted (Acres) **	Irrigated (1=Yes 0=No)	Improved seed used (kg)	Purchased Seed Sown		Non-purchased Seed*** (kg)	Own / Borrowed Manure used (Kg)****	Manure Purchased		Base Fertilizer (DAP/TSP/SSP)		Top dressing Fertilizer Used (CAN/Urea)		Pesticides Used		Labour Used – Man days **(Codes B)**								Hired Labour	
					(Qty) Kg	Cost (Ksh)			Quantity (kg)****	Value (Ksh	Quantity (kg)	Value (Ksh)	Quantity (Kg)	Value (Ksh)	Quantity (lts)	Value (Ksh)	**Land Preparation**	**Planting**	**Irrigation**	**Weeding**	**Fertilizer Application**	**Spraying**	**Harvesting & Threshing**	**Other**	Man days	Total Labour Cost (Ksh

*If an **intercrop/mixed crop**, indicate the two crop codes, separated by a + sign (e.g., Maize-Bean Intercrop = 1+2) ** For **Napier grass**, indicate no. of strips and length of strip in (eg 5x 40). ***For **fruits and coffee**, indicate number of trees. **** **Manure Estimates**: Small ox-cart = 400 kg, Big ox-cart = 500 kg, Standard wheel barrow = 50 kg, 4 Buckets = 1 wheelbarrow = 50kg.

Codes A
1. Maize
2. Beans
3. Banana
4. Mango
5. Coffee
6.. French Beans

Codes A Cont….
7. Green Maize
8. Courgette
9. Cabbage
10. Kales
11. Spinach
12. Onion

Codes A Cont….
13. Tomato
14. Pigeonpea
15. Cowpea
16. Napier Grass
17. Other (specify)…………..

4.2 Crops Grown and Budget During 2008 Long Rain season

Crop* (Codes A)	Cropping System (1=Sole 2=Mixed)	Area Planted (Acres) **	Irrigated (1=Yes 0=No)	Improved seed used (kg)	Purchased Seed Sown		Non-purchased Seed*** (kg)	Own / Borrowed Manure used (Kg)****	Manure Purchased		Base Fertilizer (DAP/TSP/SSP)		Top dressing Fertilizer Used (CAN/Urea)		Pesticides Used		Labour Used – Man days **(Codes B)**								Hired Labour	
					(Qty) Kg	Cost (Ksh)			Quantity (kg)****	Value (Ksh	Quantity (kg)	Value (Ksh)	Quantity (Kg)	Value (Ksh)	Quantity (lts)	Value (Ksh)	**Land Preparation**	**Planting**	**Irrigation**	**Weeding**	**Fertilizer Application**	**Spraying**	**Harvesting & Threshing**	**Other**	Man days	Total Labour Cost (Ksh)

*If an **intercrop/mixed crop**, indicate the two crop codes, separated by a + sign (e.g., Maize-Bean Intercrop = 1+2) ** For **Napier grass**, indicate no. of strips and length of strip in (eg 5x 40). ***For **fruits and coffee**, indicate number of trees. **** **Manure Estimates**: Small ox-cart = 400 kg, Big ox-cart = 500 kg, Standard wheel barrow = 50 kg, 4 Buckets = 1 wheelbarrow = 50kg.

Codes A
1. Maize
2. Beans
3. Banana
4. Mango
5. Coffee
6.. French Beans

Codes A Cont….
7. Green Maize
8. Courgette
9. Cabbage
10. Kales
11. Spinach
12. Onion

Codes A Cont….
13. Tomato
14. Pigeonpea
15. Cowpea
16. Napier Grass
17. Other (specify)………….

4.3 Utilization and Marketing of Crops Produced

Crop (From Tables 4.1 and 4.2; column 1)	Season (1=2007/8 2=2008) [Begin with 2007/8]	Yield (kg)	Non-marketed Output (kg)		Sales in local markets (open markets, shops, schools, other farmers)			Sales to Middlemen/ Non-contracting company			Sales to Contracting Company			Crop Residue sales		
			Consumed at home	Gifts/ Donation	Quantity (kg)	Price/ kg (Ksh)	Transport Cost (Ksh)	Quantity (kg)	Price (Ksh)	Transport Cost (Ksh)	Quantity (kg)	Price/ kg (Ksh)	Transport Cost (Ksh)	Quantity	Units	Sales (Ksh)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	17	18	19

5.0 Livestock Production and Utilization During the 2007-8 Production Year

5.1 Livestock Kept During 2007-8 Production Year

Livestock (Codes A)	Main Production System (Codes B)	Opening stock (Oct 2007)		Born (No.)	Purchased		Gifts in		Consumed at Home		Gifts out		Sold		Deaths		Closing Stock (Oct 2008)	
		No.	Value (Ksh)		No.	Value (Ksh)	No.	Value (Ksh)	No.	Value (Ksh)	No.	Value (Ksh)	No.	Value (Ksh)	No.	Value (Ksh)	No.	Value (Ksh)

Codes A

1. Indigenous Dairy cows
2. Exotic Dairy cows
3. Crossbreed cow
4. Indigenous Bulls
5. Crossbreed Bulls
6. Calves
7. Indigenous Female goats
8. Exotic Female goats
9. Crossbreed female goat
10. Indigenous Male goats
11. Crossbreed male goat
12. Young goats
13. Indigenous Female sheep
14. Indigenous Male sheep
15. Young sheep
16. Female Donkeys
17. Male Donkeys
18. Young donkey (untrained)
19. Poultry-Indigenous
20. Poultry-Broilers
21. Poultry-Layers
22. Mature Pigs
23. Young Pigs
24. Other (specify)……..

Codes B

1. Grazing
2. Semi-grazing
3. Tethering
4. Zero-grazing
5. Caged
6. Free range
7. Other (specify)………

5.2 Livestock Production Expenses during 2007-8 Production Year

	Pastures and Feeds Used										**Total Labour Used (Man days)**							**Hired Labour**		
Livestock Group **(Codes A)**	Grazing Land (Acres)	Own Pastures (Indicate Units)	Purchased Pastures (Indicate Units)	Value of Purchased Pastures (ksh)	Own crop residues (Indicate Units)	Purchased crop residues (Indicate Units)	Value of Purchased crop residues (Ksh)	Concentrates (kg)	Value of concentrates (ksh)	Cost of vet Drugs & Services (Ksh)	**Feeding**	**Vaccination/Treatment**	**Dipping/ Spraying**	**Milking**	**Egg collection**	**Slaughtering/ Dressing**	**Other**	Man days	Cost per man day (Ksh)	Total labour Cost (Ksh)

Codes A:
1. Cattle
2. Goats
3. Sheep
4. Donkeys
5. Poultry
6. Pigs

Codes B
1. Feeding
2. Vaccination/Treatment
3. Dipping/Spraying
4. Milking
5. Egg collection
6. Slaughtering/dressing
7. Other (specify)……….

5.3 Utilization and Marketing of Livestock Products

Product (Codes A)	Livestock (Codes B)	Quantity Produced	Units of production (Codes C)	Frequency (Codes D)	No of Production Months	Non-marketed Output			Marketed Output				
						Consumed at home							
						Quantity	Units (Codes C)	Frequency Codes D)	Quantity	Units	Frequency (Codes D)	Average Price per unit (Ksh)	Value of Sales (Ksh)

Codes A:
1. Milk
2. Eggs
3. Dressed Animal
4. Meat
5. Draught power
6. Manure
7. Other (specify)

Codes B
1. Cattle
2. Goats
3. Sheep
4. Donkeys
5. Poultry
6. Pigs

Codes C
1. Litres
2. Kilograms
3. Pieces
4. Trays

4. Animal hours
5. Other

Codes D

1=Daily
2=Weekly
3=Monthly

Appendix 3: Gross Margin Calculations for Livestock Enterprise.

Gross margin = Value of Enterprise Output - Variable Costs *(A3.1)*

Where: Value of output = Net trading + Inventory Change *(A3.2)*

Net Trading = Sales – Purchases *(A3.3)*

Inventory change = (Closing number – Opening number) * per head market value *(A3.4)*

It was necessary to modify the above guidelines due to a number of reasons. First, not all livestock were acquired through purchasing or disposed of through selling: some animals joined the herd as gifts received from friends/relatives, while some exited from the herd as gifts to friends/relatives or through home consumption or death. Second, the above guidelines do not include physical outputs. After incorporating these considerations, equations *A3.2* was modified as follows:

Value of output = Value of physical output + Change in herd value *(A3.5)*

Where: Value of physical output = Value of milk + Value of manure *(A3.6)*

Change in herd value = $(V_1+V_{GO}+V_{CH}+V_{SO}) - (V_0+V_{GR}+V_{PU}+V_{DTH})$ *(A3.7)*

Where: $\mathbf{V_1}$ = Value of herd at the end of the year (September 2008),

$\mathbf{V_{GO}}$ = Value of livestock given out as gifts,

$\mathbf{V_{CH}}$ = Value of livestock consumed at home,

$\mathbf{V_{SO}}$ = Value of livestock sold,

$\mathbf{V_0}$ = Value of herd at the beginning of the year (October 2007),

$\mathbf{V_{GR}}$ = Value of livestock received as gifts,

$\mathbf{V_{PU}}$ = Value of livestock purchased,

$\mathbf{V_{DTH}}$ = Value of livestock which died.

The values for non-marketed livestock were calculated using the minimum price the farmer would have paid (accepted) in order to acquire (dispose) the animal.

Appendix 4: Risk-neutral (Linear Programming) model input data.

```
GAMS Rev 145  x86/MS Windows
MSc.Project
C o m p i l a t i o n


    Muange, E.N. MSc. Agricultural and Applied Economics, University of Nairobi.
    Project Data, Kauti Irrigation Scheme, Machakos
    Risk-neutral model with subsistence restrictions


    SET   j enterprises           /mze1,mze2, coff, fbn1, kal1,
                                   kal2, tom1, tom2, lvst /

          i resource constraints  /nonirrland1, nonirrland2,
                                   irrigland1, irrigland2, labour1, labour2,
                                   capital1, capital2, totalcc/

          k subsistence constraints /subsland1, subsland2, subscc/;

    PARAMETER

     g(j) gross margins per unit /mze1 11943, mze2 6027, coff 11339,
                                  fbn1 77770, kal1 17340, kal2 23110,
                                  tom1 58419, tom2 68337,lvst 12097/

     r(i) resource constraints   /nonirrland1 1.018, nonirrland2 1.018,
                                  irrigland1  0.250, irrigland2 0.250,
                                  labour1  397, labour2  434,  capital1 5986,
                                  capital2 3929, totalcc 2.5/

     s(k) subsistence constraints /subsland1 0.761, subsland2 0.761, subscc 1.
    65 /;

    TABLE a(i,j)       resource coefficients
                       mze1  mze2 coff   fbn1   kal1 kal2   tom1 tom2   lvst
     nonirrland1       1     0    1      0      0    0      0    0      0
     nonirrland2       0     1    1      0      0    0      0    0      0
     irrigland1        0     0    0      1      1    0      1    0      0
     irrigland2        0     0    0      0      0    1      0    1      0
     labour1           34.6  0    6.1    164.3  128  0      80.8 0      33.7
     labour2           0     32.2 23.7   0      0    137    0    75.8   33.7
     capital1          4313  0    2454   23274  7256 0      7666 0      873
     capital2          0     3190 623    0      0    7824   0    8623   873
     totalcc           0     0    0      0      0    0      0    0      1 ;

    TABLE b(k,j)       subsistence coefficients
                       mze1  mze2 coff   fbn1   kal1 kal2   tom1 tom2   lvst
     subsland1         1     0    0      0      0    0      0    0      0
     subsland2         0     1    0      0      0    0      0    0      0
     subscc            0     0    0      0      0    0      0    0      1

    POSITIVE VARIABLES    x(j) level of enterprise (acres or LU);

    VARIABLES             NETRETURNS ;

    EQUATIONS             Objective, constraint(i), subsistence(k);

    Objective..        NETRETURNS =e= SUM(j,(g(j))*x(j)) ;
    constraint(i)..                   SUM(j,a(i,j)*x(j))  =l= r(i);
    subsistence(k)..                  SUM(j,b(k,j)*x(j))  =g= s(k);

    MODEL    LPSUBSISTENCE /ALL/;
    SOLVE    LPSUBSISTENCE USING LP MAXIMIZING NETRETURNS;
```

Appendix 5: Risk (Quadratic programming) model input data.

```
GAMS Rev 145  x86/MS Windows
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
C o m p i l a t i o n

     Muange, E.N. MSc. Agricultural and Applied Economics, University of Nairobi.
     Project Data, Kauti Irrigation Scheme, Kathiani
     Risk model without subsistence restrictions


 Set j  enterprises  /mze1,mze2, coff, fbn1, kal1,
                       kal2, tom1, tom2, lvst /; alias (i,j);

 set r  resource constraints  /nonirrland1, nonirrland2,
                               irrigland1, irrigland2, labour1, labour2,
                               capital1, capital2, totalcc/;

PARAMETER
 g(j) gross margins per unit /mze1 11943, mze2 6027, coff 11339,
                              fbn1 77770, kal1 17340, kal2 23110,
                              tom1 58419, tom2 68337,lvst 12097/

 c(r) resource constraints   /nonirrland1 1.018, nonirrland2 1.018,
                              irrigland1  0.250, irrigland2 0.250,
                              labour1  397, labour2  434,  capital1 5986,
                              capital2 3929, totalcc 2.5/;

 TABLE a(r,j)     resource coefficients
                  mze1  mze2 coff   fbn1   kal1 kal2   tom1 tom2  lvst
 nonirrland1      1      0    1     0      0     0     0     0     0
 nonirrland2      0      1    1     0      0     0     0     0     0
 irrigland1       0      0    0     1      1     0     1     0     0
 irrigland2       0      0    0     0      0     1     0     1     0
 labour1          34.6   0    6.1   164.3  128   0     80.8  0     33.7
 labour2          0      32.2 23.7  0      0     137   0     75.8  33.7
 capital1         4313   0    2454  23274  7256  0     7666  0     873
 capital2         0      3190 623   0      0     7824  0     8623  873
 totalcc          0      0    0     0      0     0     0     0     1 ;

 Table v(i,j)  variance-covariance matrix (millions)

         mze1   mze2     coff     fbn1      kal1    kal2     tom1      tom2      lvst
 Mze1    94.0   55.3     35.0    -36.6      9.6      36.4     87.0     305.6     18.1
 Mze2    55.3   61.7    -6.1      49.1      37.0     127.0  -143.7   -77.7      -5.0
 Coff    35.0  -6.1      158.5    577.5    -60.0    -24.4     395.7    118.0     -30.9
 Fbn1   -36.6   49.1     577.5    7145.3    2013.0   3608.5 -1199.7 -13180.7  -291.0
 Kal1    9.6    37.0    -60.0     2013.0    354.3    677.2    476.7    92.2      17.2
 Kal2    36.4   127.0   -24.4     3608.5    677.2    723.6    455.1   -273.9     -76.8
 Tom1    87.0  -143.7    395.7   -1199.7    476.7    455.1    6275.1   3684.2    17.3
 Tom2    305.6 -77.7     118.0   -13180.7   92.2    -273.9    3684.2   3545.4   -593.7
 Lvst    18.1  -5.0     -30.9    -291.01    17.2    -76.8     17.3    -593.7     224.2;

 POSITIVE VARIABLES   x(j) Enterprise level (Acres or LU);

 Variables  x(j) Size of enterprise units to be produced (Acres or LU)
            variance  variance of income from farm plan;

 EQUATIONS  income, risk, constraint(r);

 income..          sum(j,(g(j))*x(j))               =e=  62730;
 risk..            sum(i, sum(j,v(i,j)*x(i)*x(j))) =e=  variance;
 constraint(r)..   sum(j,a(r,j)*x(j))               =l= c(r);

 Model NsubsEVfarmplans  / all/;
 Solve NsubsEVfarmplans using QCP minimizing variance;
```

Appendix 6: Alternative farm plans for subsistence model under constrained capital

	EV, Enterprises, Resources	Existing Levels	Optimal Levels of Alternative Farm Plans						
			I	II	III	IV	V	VI	VII
EV Set	*Income(Ksh)*	***36,049***	***38,340***	***39,340***	***40,340***	***41,340***	***42,340***	***43,340***	***43,745***
	Variance(Ksh Million)	*1,365.0*	*746.1*	*753.7*	*775.7*	*812.5*	*863.8*	*929.6*	*960.5*
Enterprises	Maize1	*0.962*	0.761	0.761	0.761	0.761	0.761	0.761	0.761
	Maize2	*0.953*	0.761	0.761	0.761	0.761	0.761	0.761	0.761
	Coffee	*0.248*	-	-	-	-	-	-	-
	French beans1	*0.018*	0.054	0.044	0.034	0.024	0.014	0.004	-
	Kales1	*0.026*	-	-	-	-	-	-	-
	Kales2	*0.018*	-	-	-	-	-	-	-
	Tomatoes1	*0.041*	-	0.030	0.061	0.091	0.122	0.152	0.165
	Tomatoes2	*0.019*	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	Livestock	*0.930*	1.650	1.650	1.650	1.650	1.650	1.650	1.650
Resource Requirements	Irrigable land1	*0.085*	0.054	0.075	0.095	0.116	0.136	0.157	0.165
	Irrigable land2	*0.037*	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	Subsistence land1	*0.962*	0.761	0.761	0.761	0.761	0.761	0.761	0.761
	Subsistence land2	*0.953*	0.761	0.761	0.761	0.761	0.761	0.761	0.761
	Non-irrigable land1	*1.018*	0.761	0.761	0.761	0.761	0.761	0.761	0.761
	Non-irrigable land2	*1.018*	0.761	0.761	0.761	0.761	0.761	0.761	0.761
	Family Labour1	*75.7*	90.9	91.7	92.5	93.3	94.1	94.9	95.2
	Family Labour2	*71.8*	80.6	80.6	80.6	80.6	80.6	80.6	80.6
	Working Capital1	*5,986*	5,986	5,986	5,986	5,986	5,986	5,986	5,986
	Working Capital2	*3,929*	3,929	3,929	3,929	3,929	3,929	3,929	3,929
	Subsistence LU	*0.930*	1.650	1.650	1.650	1.650	1.650	1.650	1.650
	Total LU	*0.930*	1.650	1.650	1.650	1.650	1.650	1.650	1.650

Appendix 7: Alternative farm plans for non-subsistence model under constrained capital

	EV, Enterprises, Resources	Existing Levels	Optimal Levels of Alternative Farm Plans					
			I	II	III	IV	V	VI
EV Set	*Income(Ksh)*	***36,049***	**59,730**	**60,730**	**61,730**	**62,730**	**63,730**	**63,913**
	Variance(Ksh Million)	*1,365.0*	1.2	379.8	783	1,240.4	1,760.8	1,863.1
Enterprises	Maize1	*0.962*	-	0.014	0.106	0.258	0.410	0.438
	Maize2	*0.953*	-	-	-	-	-	-
	Coffee	*0.248*	-	-	-	-	-	-
	French beans1	*0.018*	0.139	0.122	0.091	0.050	0.008	-
	Kales1	*0.026*	-	-	-	-	-	-
	Kales2	*0.018*	-	-	-	-	-	-
	Tomatoes1	*0.041*	0.111	0.128	0.159	0.200	0.242	0.250
	Tomatoes2	*0.019*	0.235	0.212	0.203	0.203	0.203	0.203
	Livestock	*0.930*	2.200	2.400	2.500	2.500	2.500	2.500
Resource Requirements	Irrigable land1	*0.085*	0.250	0.250	0.250	0.250	0.250	0.250
	Irrigable land2	*0.037*	0.235	0.212	0.203	0.203	0.203	0.203
	Subsistence land1	*0.962*	-	-	-	-	-	-
	Subsistence land2	*0.953*	-	-	-	-	-	-
	Non-irrigable land1	*1.018*	-	0.014	0.106	0.258	0.41	0.438
	Non-irrigable land2	*1.018*	-	-	-	-	-	-
	Family Labour1	*75.7*	105.3	111.9	115.8	117.5	119.2	119.3
	Family Labour2	*71.8*	91.4	97.1	99.6	99.6	99.6	99.6
	Working Capital1	*5,986*	5,986	5,986	5,986	5,986	5,986	5,986
	Working Capital2	*3,929*	3,929	3,929	3,929	3,929	3,929	3,929
	Subsistence LU	*0.930*	-	-	-	-	-	-
	Total LU	*0.930*	2.200	2.400	2.500	2.500	2.500	2.500

Appendix 8: Alternative farm plans for subsistence model under relaxed capital in season1

	EV, Enterprises, Resources	Existing Levels	Optimal Levels of Alternative Farm Plans				
			I	II	III	IV	V
EV Set	*Income(Ksh)*	***36,049***	***41,235***	***43,235***	***45,235***	***47,235***	***49,133.6***
	Variance(Ksh Million)	*1,365.0*	*740.7*	*769.8*	*857.2*	*1003*	*1238.5*
Enterprises	Maize1	*0.962*	0.761	0.761	0.761	0.761	0.761
	Maize2	*0.953*	0.761	0.761	0.761	0.761	0.761
	Coffee	*0.248*	-	-	-	-	-
	French beans1	*0.018*	0.081	0.061	0.041	0.021	-
	Kales1	*0.026*	-	-	-	-	-
	Kales2	*0.018*	-	-	-	-	-
	Tomatoes1	*0.041*	0.014	0.075	0.136	0.197	0.250
	Tomatoes2	*0.019*	0.007	0.007	0.007	0.007	-
	Livestock	*0.930*	1.650	1.650	1.650	1.650	1.720
Resource Requirements	Irrigable land1	*0.085*	0.095	0.136	0.177	0.218	0.250
	Irrigable land2	*0.037*	0.007	0.007	0.007	0.007	0.007
	Subsistence land1	*0.962*	0.761	0.761	0.761	0.761	0.761
	Subsistence land2	*0.953*	0.761	0.761	0.761	0.761	0.761
	Non-irrigable land1	*1.018*	0.761	0.761	0.761	0.761	0.761
	Non-irrigable land2	*1.018*	0.761	0.761	0.761	0.761	0.761
	Family Labour1	*75.7*	96.4	98.0	99.6	101.2	104.6
	Family Labour2	*71.8*	80.6	80.6	80.6	80.6	82.5
	Working Capital1	*5,986*	6,717	6,717	6,717	6,717	6,717
	Working Capital2	*3,929*	3,929	3,929	3,929	3,929	3,929
	Subsistence LU	*0.930*	1.650	1.650	1.650	1.650	1.650
	Total LU	*0.930*	1.650	1.650	1.650	1.650	1.650

Appendix 9: Alternative farm plans for subsistence model under relaxed capital in season2

	EV, Enterprises, Resources	Existing Levels	Optimal Levels of Alternative Farm Plans			
			I	II	III	IV
EV Set	*Income(Ksh)*	***36,049***	***54,940***	***56,940***	***58,940***	***60,346.9***
	Variance(Ksh Million)	*1,365.0*	*228.2*	*495.5*	*821.2*	*1,085.2*
Enterprises	Maize1	*0.962*	0.761	0.761	0.761	0.761
	Maize2	*0.953*	0.761	0.761	0.761	0.761
	Coffee	*0.248*	-	-	-	-
	French beans1	*0.018*	0.054	0.034	0.014	-
	Kales1	*0.026*	-	-	-	-
	Kales2	*0.018*	-	-	-	-
	Tomatoes1	*0.041*	-	0.061	0.122	0.165
	Tomatoes2	*0.019*	0.250	0.250	0.250	0.250
	Livestock	*0.930*	1.650	1.650	1.650	1.650
Resource Requirements	Irrigable land1	*0.085*	0.054	0.095	0.136	0.165
	Irrigable land2	*0.037*	0.250	0.250	0.250	0.250
	Subsistence land1	*0.962*	0.761	0.761	0.761	0.761
	Subsistence land2	*0.953*	0.761	0.761	0.761	0.761
	Non-irrigable land1	*1.018*	0.761	0.761	0.761	0.761
	Non-irrigable land2	*1.018*	0.761	0.761	0.761	0.761
	Family Labour1	*75.7*	90.9	92.5	94.1	95.2
	Family Labour2	*71.8*	99.1	99.1	99.1	99.1
	Working Capital1	*5,986*	5,986	5,986	5,986	5,986
	Working Capital2	*3,929*	6,024	6,024	6,024	6,024
	Subsistence LU	*0.930*	1.650	1.650	1.650	1.650
	Total LU	*0.930*	1.650	1.650	1.650	1.650

Appendix 10: Alternative farm plans for subsistence model under relaxed capital in seasons 1&2

	EV, Enterprises, Resources	Existing Levels	Optimal Levels of Alternative Farm Plans			
			I	II	III	IV
EV Set	*Income(Ksh)*	***36,049***	***72,750***	***73,750***	***74,750***	***75,338.8***
	Variance(Ksh Million)	*1,365.0*	*1.1*	*349.2*	*716.9*	*948*
Enterprises	Maize1	*0.962*	0.941	0.997	1.018	1.018
	Maize2	*0.953*	0.761	0.761	0.761	0.761
	Coffee	*0.248*	-	-	-	-
	French beans1	*0.018*	0.181	0.157	0.139	0.131
	Kales1	*0.026*	-	-	-	-
	Kales2	*0.018*	-	-	-	-
	Tomatoes1	*0.041*	0.069	0.093	0.111	0.119
	Tomatoes2	*0.019*	0.215	0.2	0.178	0.164
	Livestock	*0.930*	1.990	2.150	2.360	2.500
Resource Requirements	Irrigable land1	*0.085*	0.250	0.250	0.250	0.250
	Irrigable land2	*0.037*	0.215	0.200	0.179	0.164
	Subsistence land1	*0.962*	0.940	0.997	1.018	1.018
	Subsistence land2	*0.953*	0.761	0.761	0.761	0.761
	Non-irrigable land1	*1.018*	0.940	0.997	1.018	1.018
	Non-irrigable land2	*1.018*	0.761	0.761	0.761	0.761
	Family Labour1	*75.7*	135.0	140.1	146.5	150.6
	Family Labour2	*71.8*	108.0	112.0	117.4	121.2
	Working Capital1	*5,986*	10,541	10,541	10,541	10,541
	Working Capital2	*3,929*	6,024	6,024	6,024	6,024
	Subsistence LU	*0.930*	1.650	1.650	1.650	1.650
	Total LU	*0.930*	1.650	2.150	2.360	2.500

Notes for Alternative Farm Plans:

1. In the '**EV, Enterprises, Resources**' column, 1 represent season1 (short rains) and 2 represents season2 (long rains).
2. The figures given are in acres for land as a resource and for the crop enterprises, LU for livestock enterprise, Ksh for capital, and Man-days for labour.
3. All farm plans are computed from survey data (2009).