ECONOMIC OPTIMIZATION OF INTEGRATED SOIL FERTILITY MANAGEMENT STRATEGIES FOR MAIZE-BASED PRODUCTION SYSTEMS: A CASE STUDY OF SMALLHOLDER FARM TYPOLOGIES IN CENTRAL KENYA

BY

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DECLARATION

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR AWARD OF ANY DEGREE IN THIS OR ANY OTHER UNIVERSITY.

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To my beloved mother, the late Tabitha Gachoki. She was a great source of inspiration, encouragement and hope during early stages of my development. Her motherly love has stood the test of time.

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AEZ	Agro-ecological Zone
AFP	Actual farm plans
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Centre
FAO	Food and Agriculture Organisation
GoK	Government of Kenya
INM	Integrated Nutrient Management
ISFM	Integrated Soil Fertility Management
LP	Linear Programming
MoA	Ministry of Agriculture
NDP	National Development Plan
NPK	Nitrogen, Phosphorous and Potassium
NPV	Net Present Value
NRB	Natural Resource Base
NRM	Natural Resource Management
OFP	Optimal Farm Plans
PLAR	Participatory Learning and Action Research
SAPs	Structural Adjustment Programmes
SFM	Soil Fertility Management
SSA	sub-Saharan Africa
TGM	Total Gross Margin
TSBF	Tropical Soil Biology and Fertility Institute
USD	United States Dollar
KES	Kenya Shilling

ABSTRACT

In recent years, declining per capita food production in sub-Saharan Africa (SSA) has led to food insecurity, malnutrition and poverty. This has made prospects of achieving millennium development goals (MDG) of halving the world's hungry people by the year 2015 increasingly challenging. In Kenya, rapid population increase has led to land fragmentation and intensive cultivation without adequate soil fertility replenishment. At the same time structural adjustments programs (SAPs) eliminated all farm-support programs leading to depressed usage of inorganic fertilizers.

The major objective of this study was characterization of smallholder farms based on their soil fertility management (SFM) practices; and development of optimal farm plans (OFP) for profit maximization and food self-sufficiency in maize-based production systems of central Kenya. It was undertaken in Kariti and Mukanduini sites in Maragwa and Kirinyaga Districts respectively in 2003/4. Participatory learning and action research (PLAR) was used to classify farmers into different SFM-based farm typologies using local indicators of soil quality (LISQ). Population correlation coefficient, ρ (rho) was then used to determine strength of relationship between farmers' SFM status and their wealth endowment. Analysis of variance (ANOVA) was employed to test for soil fertility gradients between smallholder actual farm plans (AFP) while net present value (NPV) was used for ranking of different SFM technologies from on-farm trials. Finally, OFP for each farm typology were developed using linear programming (LP).

Population correlation coefficients, (ρ) were 0.8 and 0.5 for Kariti and Mukanduini respectively. This led to rejection of the hypothesis that "there is no correlation between farmers' SFM status and their wealth-endowment". ANOVA depicted significant differences ($P < 0.05$) in organic carbon (C), total nitrogen (N) and available phosphorous (P) between different classes. These served as technical indicators of soil quality (TISQ) and were used to verify farmers' classification previously done using LISQ. C ranged between 1.65 – 2.24 percent and between 1.39 – 1.59 percent in Kariti and Mukanduini respectively, total N ranged between 0.11 – 0.15 percent and between 0.07 – 0.10 percent in Kariti and Mukanduini respectively while available P ranged between 33 – 70 ppm and between 441 – 650 ppm in Kariti and Mukanduini respectively. Ranking of farmers using TISQ resulted in three SFM-based farm typologies: Class I (good soil fertility managers), Class II (average soil fertility managers) and Class III (poor soil fertility managers).

From 15 different SFM technologies tested in on-farm demonstrations, Manure (5 tons/ha) + Fertilizer (60 kg N/ha), Manure (5 tons/ha) + Fertilizer (40 kg N/ha) and Manure (5 tons/ha) + Fertilizer (20 kg N/ha) were ranked as the best three SFM technologies in terms NPV. Finally, OFP derived from LP enabled smallholders to maximize their respective objectives. For profit maximization objective, bananas and tomatoes dominated OFP in all typologies in Kariti and Mukanduini respectively. TGM in class I increased from Ksh. 20818 in AFP to Ksh. 133989 in OFP in Kariti and from Ksh. 324119 in AFP to Ksh. 994982 in OFP in Mukanduini. In class II, TGM increased from Ksh 5377 in AFP to Ksh 97714 in OFP in Kariti and from Ksh 93784 in AFP to Ksh 165719 in OFP in Mukanduini. In class III, TGM increased from Ksh -4372 in AFP to Ksh 63691 in OFP in Kariti and from Ksh 23845 in AFP to Ksh 200210 in OFP in Mukanduini.

In conclusion, wealthy farmers were also good soil fertility managers. Optimum application of N for maize production was Manure (5 tons/ha) + Fertilizer (20-60 kg N/ha) depending on farm typology while all smallholders' AFP were sub-optimal and therefore inefficient in farm resource allocation. About 100 % of farmers in Kariti and 98 % in Mukanduini were living below USD 1 per person per day. For profit maximization, all available land should be allocated to banana and tomato production in Kariti and Mukanduini respectively.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Intensive land use is commonly practised in many parts of sub-Saharan Africa (SSA). Due to inadequate nutrient replenishment in smallholder farms, this land-use system has led to massive soil degradation and consequent food insecurity. The major cause of African food problem has been identified as declining per capita food production leading to hunger, malnutrition and poverty (Lynam and Hassan, 1998). For instance, per capita cereal production in SSA has declined from 150 kg/person to 130 kg/person over the past 35 years (Gichuru et al., 2003). Estimates indicate that by the year 2020, the region's annual cereals' imports will be a staggering 30 million tons. According to Bationo et al (2004), over half of Africa's 340 million people live on less than USD 1 per day. This implies that many farmers do not produce adequate food to meet their daily needs (Blackie, 1994; FAO, 1996). Developing countries on the other hand are spending huge proportions of their scarce foreign exchange on food imports. At present, over USD 18 billion is spent annually on food imports (Bationo et al., 2004). Many governments also depend on food aids to feed their skyrocketing populations. According to Bationo et al. (2004), in the year 2000 alone SSA received about 2.8 million tons of food aid worth over USD 8.4 billion. In Kenya, about USD 40 – 65 million is spent annually on food aid (GOK, 2004). Consequently, the continent is now leading in food poverty, creating an urgent need for more understanding on its causes, consequences and possible solutions.

Agriculture in Kenya will continue to be the engine of economic growth, poverty reduction and rural development. It contributes about 30 percent of gross domestic product (GDP), 60 percent of foreign exchange, 75 percent of employment opportunities and over 70 percent of raw materials for agro-based industries (GoK, 1997). Despite its indispensable role, Kenyan agriculture continues to be plagued by a number of socio-economic, institutional and political setbacks that hinder its growth and sustained development (Nandwa, 2003). At the same time, the country's population is increasing at an unabated rate of 3.3 percent p.a. while its annual cereal grain increase is less than 1 percent (Smaling et al., 1997). The area under maize, the main food staple has stagnated at 1.5 million hectares while average grain yield is only 1.5 tons per hectare (CIMMYT, 2000). This implies that the current annual maize production of about 2250 thousand tons has to expand to about 3,600 thousand tons by the year 2008, to meet the projected consumption demands (GoK, 2002). This is an increase of over 35 percent and though feasible, it remains a daunting task given that the greatest proportion of this increase will have to come from resource-poor smallholders. Such farmers are greatly constrained by scarcity of productive farm resources such as land, labour and working capital. These farmers have therefore to make critical decisions about allocation of such resources amongst many competing farm enterprises.

In smallholder farming systems, land has been found to be the most limiting resource in terms of quantity and quality (Todaro, 2000). This is due to the fact that, increase in population densities has resulted in land subdivision leading to decline in farm sizes (quantity). Intensive farming activities therefore, have been carried out over the years without effective soil and environmental management (Smalling et al., 1997). This has led land degradation (quality) manifested in form of soil fertility depletion especially in smallholder farming systems of the Kenyan Highlands. According to a long-term research work done at National Agricultural Research Laboratories (NARL) Kabete, a decline in maize grain yield of more than 50 percent was recorded in a 20-year period (Swift et al., 1994). At the same time, only application of manure (10 tons per hectare) and inorganic fertilizers (120 kg N and 52 kg P per hectare) could maintain maize yield of 3.5 tons per hectare, the yield potential 20 years ago. Such a high-external input system is not affordable to most smallholders today. This scenario therefore presents grave challenges to all farmers' agro-ecosystems on how to feed the country's spiraling population from a fixed natural resource base (NRB). There is urgent need for judicious manipulation of plant nutrient stocks and flows in order to derive satisfactory and sustainable smallholder production systems. At the same time, the existing farm resources must become increasingly productive in terms of returns per unit land, labour and working capital.

~~However, there~~ are certain risks and uncertainties that impede ~~such~~ increases. In central Kenya Highlands, these challenges include erratic weather, poor and degraded soils, poor road and marketing infrastructure, limited access to credit and high costs of farm inputs. Among these bottlenecks, soil fertility depletion in smallholder farms, has been identified as the single most fundamental cause of declining per capita food production (Sanchez et al., 1996). This is because in the last two decades use of inorganic fertilizers by smallholders has declined substantially. The situation has been exacerbated by increased costs of fertilizers following removal of farm inputs subsidies in the structural adjustment programmes (SAPs) over the same period. Consequently both farm production and productivity have declined.

The major objective of Kenya's food policy is to ensure that there is adequate supply of quality food in all parts of the country at all times (GoK, 2002). This supply will largely be met from the small-scale sub-sector (Hassan, 1998). These farmers derive almost all their food and income from mining of soil nutrients (Smalling et al., 1997). Such practices are not only unsustainable over time but they also jeopardize land productivity for future generations. Small-scale farmers in central Highlands are highly heterogeneous and are from different social and gender contexts. They have different resource endowment such as land sizes, labour and working capital availability. Smallholder production systems have therefore been characterized by low output and high costs of production. Consequently, substantial numbers of these farmers have not been able to produce sufficient food to meet all their annual food requirements. However, the paradox could be solved if farm productivity could be achieved with lower unit production costs.

Despite enormous research on soil fertility problems in smallholder farming systems, workable solutions to plant nutrient depletion and declining farm productivity have been substantially elusive (Smalling et al., 1997). According to Nandwa (2003), low return to investments in soil fertility research in the past mitigates for radical change in natural resource management (NRM) research approaches. Such approaches would include integration of socio-economic and policy research with technical research. Soil infertility can no longer be regarded as a simple issue resolved by use of organic and inorganic nutrient resources only. It requires a holistic approach that will espouse interactions between nutrient deficiencies and farmers' resource endowment, farming system designs and their profitability, land degradation and poverty, and global policies and institutional failures (Bationo et al., 2004). Time has come therefore, for farmers, researchers and other collaborators to look for integrated and holistic strategies that will help poor resource-endowed farmers mitigate problems of food insecurity, malnutrition and poverty. Such an approach could lead to improvement in quantity and quality of food, income and resilience of soil productive capacity.

Integrated soil fertility management (ISFM) is the adoption of a systematic approach to research on soil fertility that embraces the full range of driving factors and consequences such as biological, physical, chemical, social, economic and political aspects of soil fertility degradation (Kimani, et al., 2003). Such an approach advocates for participatory, knowledge-intensive and development-focused soil fertility management (SFM) aspects that optimize production potential of farm resources. It entails development of SFM technologies that supply adequate organic and inorganic inputs to meet farmers' production goals and circumstances. One of this study's objectives was to evaluate economic viability of low-external input SFM technologies, which could increase SOM and plant nutrients sustainably for small-scale maize growers in the central Kenyan Highlands. Such technologies included integrated use of farmyard manure (FYM), leguminous green manure cover crops (GMCC) and biomass transfer (BT) in combination with modest levels of inorganic fertilizers. Linear programming (LP) was then employed to develop optimal and therefore the most profitable farm plans for different SFM-based classes of farmers. Such recommendations were found to be consistent with farmers' objectives under their own socio-economic circumstances.

1.2 Problem statement

The growth rate of agricultural sector in Kenya fell from impressive 6 percent per annum (p.a.) in 19970's to 1.3 percent in 1990's, the lowest in the world (GoK, 2004). This saw per capita annual income fall from USD 428 in the first two decades after independence to about USD 239 today. Consequently, percentage of Kenyans living below poverty line (1 USD per day) was 43 percent in 1992, 47 percent in 1997 and 56 percent in 2002. If current trend is unchecked poverty level will sour to about 66 percent by the year 2015. At the same time per capita annual food production declined from 150 kg per person to a bout 130 kg per person (Gichuru et al., 2003). As a result, food insecurity, malnutrition and poverty have ~~therefore,~~ escalated in rural areas in general and in subsistence agriculture in particular.

There are various factors responsible for declining per capita food production in smallholder agro-ecosystems in central Kenyan Highlands. These can be subdivided into biophysical-chemical and socio-economic factors.

Biophysical-chemical factors

Big proportions of soils in smallholder agro-ecosystems have low inherent soil fertility. This has been caused by low soil organic matter (SOM) leading to low cation exchange capacity (CEC), low water holding capacity, unfavourable PH, and nutrient toxicities (Murwira, 2003). Also, there has been profound plant nutrient depletion caused by leaching, soil erosion, nutrient mining and fixation.

Socio-economic factors

The last three decades have also witnessed significant changes in farmers' socio-economic and institutional environment (Hassan, 1998). On one hand, land under agriculture has constantly been subdivided to accommodate ever-increasing rural population. This has led to intensive cultivation and over-exploitation of plant nutrients often without adequate replenishment in most small-scale, maize-based production systems (Swift et al., 1994, Murwira, 2003). Due to increased pressure on land, some traditional SFM strategies such as bush fallowing, use of farmyard manure (FYM) and household refuse have been rendered inappropriate over the recent past (Aalangdong et al., 1999). On the other hand, inorganic fertilizers were extensively used because they were heavily subsidized. However, SAPs introduced in 1990's led to removal of fertilizer subsidies after collapse of all farm support systems (Bationo et al., 2004). Decontrol of prices led to increase in farm inputs prices and decrease in producer prices. Dilapidation of market and rural road infrastructures has worsened the already bad situation. This has led to a steady increase in the number of small-scale farmers who cannot afford high-external input SFM technologies such as inorganic fertilizers. Farm resources' productivity such as land, labour and capital has subsequently decreased over the same period.

? posed

Soil fertility decline and low farm production have paused enormous challenges to resource-poor smallholders. These farmers therefore resorted to low-external input SFM technologies in an attempt to produce sufficient food from a depleted NRB. In response, researchers have developed many similar technologies over the same time period (Kimani et al., 1998, 2000). However, most of these technologies have ignored farmers' knowledge systems, socio-economic, cultural and gender diversities. Also there has been failure during technology development processes to relate farm's nutrient depletion to economic returns from different farm enterprises (Vlaming et al., 2001). Surprisingly, there is no policy environment conducive for enhanced adoption and profitability of many low-external SFM technologies. Due to the above problems, characterization of biophysical-chemical and socio-economic circumstances of smallholder farmers has gained unprecedented importance in recent years. This would be useful in evaluation of adoption and productivity of different SFM technologies in smallholder farming systems.

1.3 Major objectives

The major objective of this study was characterization of smallholder farms based on their soil fertility management (SFM) practices and resource endowment; and development of optimal farm plans (OFP) for profit maximization and food self-sufficiency for different SFM-based farm typologies in maize-based production systems of central Kenyan Highlands.

1.4 Specific objectives

1. To determine the magnitude of relationship between smallholders' SFM practices and their resource endowment (wealth) in order to verify farmers' self-diagnosis and analysis of existing SFM strategies in smallholder farming systems.

2. To characterize small-scale, maize-based production systems in central Kenyan Highlands based on farmers' SFM practices in order to define different recommendation domains that would enhance adoption of SFM technologies.

3. To evaluate the economic viability of different low-external input SFM technologies in order to identify practical technologies appropriate to particular smallholders' biophysical and socio-economic circumstances.

4. To develop OFP for smallholders' welfare maximization in order to exploit scarce productive resources (land, labour and capital) more efficiently and profitably in different SFM-based farm typologies in central Kenyan Highlands.

1.5 Hypotheses tested

The following four hypotheses were tested:

1. That there is no relationship between smallholders' SFM status and their wealth endowment (*Wealth endowment Hypothesis*).

2. That smallholder SFM practices are common across different farm typologies (*Farm Typologies Hypothesis*).

3. That all low-external input SFM technologies are cost-ineffective in enhancement of soil fertility, crop yields and farm incomes in smallholder maize-based production systems (*Economic Viability Hypothesis*).

?? with respect to profit maximization or whichever other objective

4. That the actual farm plans (AFP) are optimal in all SFM-based farm typologies (*Optimal Farm Plans Hypothesis*).

1.6 The study area

The study was carried out in Kariti and Mukanduini sites in Maragwa and Kirinyaga Districts of central Kenya respectively (Appendix II). These districts differ in farmers' biophysical and socio-economic circumstances, which determine adoption and profitability of SFM practices in respective districts. Observation across the two districts therefore, formed a fair representation of farm characteristics in central Kenyan Highlands and indeed in most smallholder high- to medium –potential lands (HMPL) elsewhere.

Maragwa District

Maragwa District is on the eastern slopes of the Aberdare ridges, and borders Thika District to the north, Machakos District to the east, Kirinyaga and Mbeere Districts to the northeast and Nyandarua District to the west. It covers an approximate area of 1065 square kilometre (including 226 square kilometre of Gatare forest) and lies at 1100-950 m above sea level (a.s.l.) (Jaetzold and Scmidt, 1983). Maragwa District is the second most densely populated district in Central Province after Kiambu District. Its annual population growth rate is 1.8 percent p.a., and has a population of 387,969 persons with a population density of 447 persons per square kilometre (IEA, 2002). There are 95,732 farm families occupying about 48,747 farm holdings with an average farm size of 0.93 hectares (Ha). Annual average rainfall is 1300-1600 mm p.a. with mean annual temperature of 19.7-18.0 ^{0}C. Figure 1.1 shows typical rainfall patterns for the two study sites in the year 2003. The rainfall regime is bimodal with long rains falling in March to May while short rains come in October to November.

Maragwa District has the fourth lowest absolute poverty level in Central Province at 37 per cent in 1997, while its food poverty level is estimated at 33 percent (GoK, 2002). The district is sub-humid and has four main agro-ecological zones which include lower highland one (LH1), upper midland one (UM1), upper midland two (UM2), and upper midland three (UM3). The major enterprises include bananas, tea, maize-beans, potatoes, dairy, horticulture and coffee.

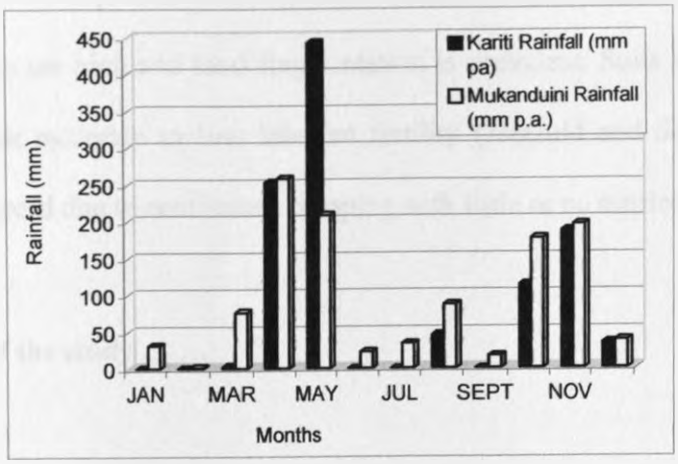

Figure 1.1. Average annual rainfall for Kariti and Mukanduini in Maragwa and Kirinyaga Districts respectively[1].

Kirinyaga District

Kirinyaga District is situated on southern slopes of Mt. Kenya and borders Nyeri and Maragwa Districts on the West, Embu District on the East and Mbeere District on the South and Southeast. Its size is about 1480 square kilometre with a population of 457,105 persons and a population density of 309 persons per square kilometre (IEA, 2002). The district has the second lowest unemployment rate in Central Province (4.93 percent). Absolute poverty level stands at 35.7 percent. Almost 80 percent of the district is arable. It has about 97,970 farm families occupying about 96,938 farm holdings with an average farm size of 1.25 hectares per family (MoA, 2003). Average annual rainfall is 1100-1250 mm p. a. with mean annual temperatures of 20.1-20.6 ^{0}C (Jaetzold and Scmidt, 1983). Major AEZ includes upper highland (UH), lower highland (LH), upper midland (UM), and lower midland (LM). The major enterprises include maize-bean, tomatoes, French beans, coffee, sweet potatoes, dairy and bananas.

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[1] *Source: District Water offices - Maragwa and Kirinyaga, 2003*

The study districts are representative of entire central Kenyan Highlands in many respects. Population densities are high and land fragmentation is prevalent. Soils are deep, well-drained, humic Nitisols with moderate to low inherent fertility (Jaetzold and Scmidt, 1983). Nutrient depletion is widespread due to continuous cropping with little or no nutrient replenishment.

1.7 Justification of the study

To Research:

The study is expected to increase understanding of concepts of socio-economic diversities of smallholders' farming systems and how such diversities may affect economic viability of various SFM technologies. Farmers have different preferences for a particular technology or same preference but face different constraints that prevent adoption at the same rate. Small-scale farmers have fewer resources and are more risk-averse than their large-scale counterparts. The study result will also form invaluable database for extension purposes and further NRM research.

To the study sites:

Small-scale farms' means of survival lies in their ability to maximise profits while minimising costs of production. This can be achieved only by adoption of sustainable and profitable SFM technologies. The study will therefore, develop OFP appropriate to specific farmers' objectives and constraints. It is expected that the results will be invaluable in guiding research, policies and extension in matters of household food security, incomes and poverty reduction in study areas. The results could also be scaled up and out to other smallholder set-ups with similar production characteristics in other regions of the country. The aim of the study is therefore in line with Kenya's development policies as outlined in poverty reduction strategy paper (GoK, 1994, 1997, 2001).

To the Economy:

Kenya's smallholders are highly heterogeneous. They have different farm sizes and capital endowment, are of different age and education levels and belong to different social and gender domains. Yet all face relatively similar production constraints, risks and uncertainties. Such include high input costs and low producer prices, poor road and market infrastructures, lack of credit and technological constraints. They occupy over 80 % of the available agricultural land and are largest employers of rural labour (GoK, 2004). It is envisaged therefore, that the research findings will be important in informing policies on NRM research, extension and financial services in the study districts. It is hoped that this will lead to better targeting of policies and programmes considering smallholders' heterogeneity. This could effectively aid farmers in combating nutrient depletion (CND) in order to improve productivity of smallholders' agro-ecosystems and rural livelihoods.

1.8 Thesis Organisation

This thesis consists of five chapters. Chapter one gives background information, problem statement and introduces the study sites. Main and specific objectives are also covered here. Chapter two is on literature review while chapter three presents the methodology used in the study. Chapter four is on results and discussion while chapter five summarises key study findings and makes logical conclusions. Possible policy recommendations are also highlighted in this chapter. Some data output discussed in the text and household questionnaire used to capture primary data are appended at the back of this thesis.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Smallholder s' SFM practices and wealth endowment

Smallholder agriculture is in dire need of transformation if it has to stem deepening rural poverty, food insecurity and environmental degradation. Decreasing per capita food production has been identified as the main cause of food insecurity in most smallholder farming systems (Lynam and Blackie, 1994; Buresh et al., 1997). This is due to large-scale nutrient mining without adequate replenishment resulting in negative nutrient balances (Smalling, 1993; Shepherd and Soule, 1998). Regrettably, this is taking place in high- and medium-potential lands (HMPL) that are best suited to intensive production systems and where highest population densities are found. Despite considerable research in SFM technologies, soil fertility degradation, rural poverty and nutrient-use inefficiency continue to be intransigent problems in most smallholder cropping systems (Pieri, 1989; Sanders et al., 1996; Barrios et al., 2000). This is because most SFM technologies have neglected farmers' socio-economic and cultural diversities, leading to low adoption and profitability. However, in this study it was recognised that the conditions under which farmers live and work are diverse in almost every respect imaginable. Farmers have different amounts and kinds of land, different levels of wealth, different attitudes toward risk, different access to labour, and different marketing and credit opportunities. Also farmers' age, gender, education level and family size are other important personal attributes that would determine profitability of actual farm plans (AFP) and also influence farmers' responses to seemingly viable SFM technologies.

Rural landscapes are full of farms and people living and working on them. According to Ramisch (2004), farmers' decision to manage (or to ignore to manage) their soil resources is part of a trade-off analysis system that considers soil within a wider economic and livelihood framework. Farmers' socio-economic and SFM changes interact with each other in the long run determining farms[2] production and productivity (Mutiro and Murwira, 2004). Strong soil fertility managers are therefore likely to be better placed socio-economically while weak soil fertility managers are likely to be trapped in vulnerable livelihoods (Crowley (1995); Crowley and Carter, 2000). This implies that wealthier households are likely to have better access to off-farm income to support more intensive SFM strategies. Similarly, less intensive SFM strategies are associated with the middle and poor households. It is apparent therefore that SFM problems of wealthy farmers could be significantly different from those of poorer households. It was necessary therefore, to investigate how soil fertility changes (improvement or decline) are related to socio-economic dynamics of households' access to resources.

Despite an array of SFM technologies for alleviating smallholder food problem, more often than not they have turned out to be socially and financially unsound (Gichuru et al., 2003). This is because smallholders operate under diverse socio-economic circumstances (Blackie, 1994). Due to heterogeneity of farming systems and resource endowments, different farmers will undertake different SFM strategies. Most farmers are resource-poor and therefore use organic sources of plant nutrients such as animal manures, composts and a variety of other organic nutrient sources (Blackie, 1994; Kimani et al., 2000). According to Ramisch (2004), SFM is a function of knowledge and access to key productive resources (land, labour, and capital). Similarly, soil fertility is a function of inherent biophysical properties, nutrient balances and broader social context. It is prudent to appreciate that management of soil fertility always occurs in a socio-economic context and improvement in adoption of SFM strategies will be achieved only if socio-economic needs of farmers are satisfied. Most previous research has tended to neglect this aspect by treating farmers' socio-economic aspects mere "externalities" that impinge on SFM adoption processes (Ramisch et al., 2002). However, this study attempted to understand farmers' SFM practices from their socio-economic point of view and to determine what role such "externalities" play in affecting resource-poor smallholders' perception of SFM recommendations. It would be important to know to what extent would farmers' concern about the benefits and costs of particular SFM technologies affect adoption of such a technology. There was need therefore for a systematic evaluation of farmers' SFM status *vis-à-vis* their socio-economic characteristics

2.2 Characterisation of smallholder farm topologies

Soils can be classified as good or bad, productive or exhausted depending on their productive potential or quality. Soil quality is defined as "the capacity of soil to function within its ecosystem boundaries to sustain biological productivity and diversity, maintain environmental quality and promote plant and animal health" (Brady and Weil, 2002). Soil quality therefore depends on the physical, chemical and biological processes that occur in soil ecosystem. Such include leaching of nutrients, soil erosion, decomposition and mineralization of soil organic matter (SOM), and subsequent release of plant nutrients. According to Barrios et al. (2000), measurement of specific soil properties could serve as indicators of rates of these processes, the so-called indicators of soil quality (ISQ). These indicators can be classified into temporal or permanent depending on their permanence and sensitivity to management levels. Temporal ISQ are management-dependent while permanent ISQ are more dependent on inherent soil profile. In this study only temporal ISQ that significantly affected by day-to-day farmers' management practices were considered.

From decades of experimenting with soils, farmers have accumulated a wealth of knowledge and experiences regarding soil quality (Barrios et al., 2000). These skills have been used by farmers over the years to diagnose and monitor changes in soil fertility and could therefore serve as local indicators of soil quality (LISQ). LISQ involve use of local language to define soil colour, structure and texture. Also absence or presence of certain weeds, plant colour and crop yields serve the same purpose. According to Barrios et al. (2000), scientific soil parameters could also serve as technical indicators of soil quality (TISQ). These include soil PH, total nitrogen (N) and organic carbon (C), available phosphorous (P) and soil organic matter (SOM). Despite existence of numerous LISQ and TISQ, soil degradation has been going on for decades and its consequences in most cases have been irreversible (Defoer et al., 1998). The current study strived to harmonize scientific knowledge with local soil quality perceptions. Consequently researchers, extensionists and farmers could share a common understanding about soils and their management. Integration of LISQ and TISQ could therefore help in derivation of preventive rather than remedial measures for dealing with soil degradation.

The current farming systems face enormous challenges of satisfying the ever-increasing demand for food without degrading the NRB (Smalling, 1993). These challenges are not however insurmountable if there was a close correlation between LISQ and TISQ. Integration of farmers' and researchers' knowledge systems could help to build a comprehensive system for diagnosis of smallholders' soil fertility, monitor changes over time and show how such changes could collectively be addressed by all stakeholders (Defoer et al., 1998, 2000). This could provide farmers with an appropriate soil quality monitoring system (SQMS), which could aid in choice of potential SFM appropriate to a particular soil fertility- or wealth-based recommendation domain (Barrios et al., 2000; Onduru et al., 1998). This could lead to participatory technology development (PTD) for optimal resource use and prevention of further soil degradation. Such an approach could facilitate translation of local knowledge gains and research outputs into actual farm activities.

This study stratified smallholder farmers into different farm typologies, depending on existing farmers' SFM patterns. It was envisaged that this would facilitate better targeting of SFM technologies to particular groups of farmers with similar socio-economic circumstances. The study also aided in development of decision support services (DSS) as a guide for dissemination of suitable SFM recommendation. From literature search, importance of characterisation of smallholder farming system into SFM-based recommendation domains has greatly been endorsed (CIMMYT, 1988; Onduru et al., 1998; Barrios et al., 2000). However such characterization has not been very evident in past research work undertaken in central Kenya Highlands, prompting the need for this study. Generalized SFM recommendations have been developed and recommended to farmers over the years. However such recommendations ignore specific soil differences between different farms in the same locality and between different parts of the same farm. Soils are different in every physical, chemical and biological context and therefore contain different nutrient elements, SOM, and have different soil structure and texture. Therefore soils in the same locality will respond differently to same SFM treatment. Likewise farmers differ in their perception of SFM and have different financial ability to undertake different practices. There was need therefore to classify smallholder-farming systems in the study sites into specific SFM-based farm typologies. Each farm typology would form a specific recommendation domain, representing a group of farmers with similar biophysical and socio-economic circumstances and for whom the same SFM recommendation is likely to be suitable.

2.3 Integrated soil fertility management (ISFM) paradigm

Integrated soil fertility management (ISFM) paradigm is a holistic and systematic approach that takes into account all aspects of soil fertility degradation (Kimani et al., 2003). It embraces all biological, physical, chemical, socio-economical and political driving factors and consequences (Gichuru et al., 2003). ISFM aims at judicious application of all possible soil fertility management options for productive and sustainable agro-ecosystems. The main cornerstone of ISFM approach is recognition of the importance of soil organic matter (SOM) in preservation of soil fertility and soil physical properties (Kauffman, 1999). This is because plant nutrients, water availability and soil degradation are dependent on SOM content of soil (Kimani, 1999). SOM also synchronizes nutrient release from organic inputs with crop needs and improves nutrient use efficiency. This study endeavored to develop land-use and management practices, which could increase and maintain SOM content as one of the goals of ISFM strategies.

ISFM has led to renewed interests in organic resources as potential sources of major plant nutrients and SOM, the so-called 'organic input' paradigm (Vanlauwe and Sanginga, 2003). Consequently, a whole range of organic soil amendments in combination with modest levels of inorganic fertilizers has been tested in central Kenya (Kimani et al., 1998, 2000; Gitari et al., 1999; Muriethi et al., 2002). Such low-external input SFM technologies include use of crop residues, legume-cereal intercrops, animal manures, compost and leguminous green manure cover crops (GMCC). It has been established that GMCC offer great advantages in soil fertility restoration, conservation and recycling of soil mineral nutrients, weed suppression and soil erosion control (Rommelse, 2000; Mafogonya et al, 2003). However, incorporation of non-food legumes in the smallholder farming systems requires that a sacrifice of land, labour and capital normally devoted to crop production be made (Jama et al., 1997). The GMCC also have limited alternative uses apart from SFM contribution. Moreover access to seed, pests and diseases and competition with crops for soil moisture, light and nutrients may limit their adoption by smallholders. According to Breman (1997), GMCC approach also takes considerable time before returns to investments from soil improvement can be fully realised. There is need therefore for evaluation of economic trade-offs associated with adoption of various low-external input SFM technologies.

It has also been established that small-scale, resource poor farmers use animal manures extensively (Webster and Wilson, 1996). However, prospects for optimizing productivity of smallholder farming systems through use of locally available, organic resources alone are limited by insufficient quantities and poor quality of these resources (Murwira, 2003). Accordingly extensive work has been done on manure application, management and potential in central

Kenyan Highlands (Lekasi et al., 1998; Kihanda and Gichuru, 1999; Kimani et al., 2000). Little work though has been done on costs and benefits associated with adoption of such SFM technologies. On the other hand, blanket fertilizer recommendations across different farm typologies ignore specific deficient nutrients or recommend unnecessary nutrients (Qureshi, 1987; Wendt and Jones, 1993). Such recommendations have been prescriptive and input-driven leading to fertilizer-use inefficiency and have failed to acknowledge heterogeneity of small-scale farming systems and that soil fertility is also dynamic in space and time. This study however recognizes that farmers occupy different agro-ecosystems and have different land, labour and capital endowment. Such diversities are likely to affect farmers' perception of and ability to invest in high-external input SFM technologies

One of the PLAR's objectives was to assist both farmers and stakeholders in identification, experimentation and evaluation of alternative SFM practices that are both practical and appropriate to farmers' particular socio-economic circumstances (Defoer and Budelman, 2000). Such a participatory approach builds on farmers SFM practices seeking to test and develop more practical and flexible options that are best suited to varied farmers' biophysical and socio-economic conditions. Unfortunately, most studies have laid more emphasis on technologies' ability to achieve high crop yields than on their economic performance (Kipsat, et al., 2004). Economic information on how resource-poor smallholders can realize maximum returns by supplementing organic materials with mineral fertilizers seems not available. If available, such information is scanty yet this option provides substantial opportunities for optimizing productivity and profitability of smallholder farm typologies. This would explain why some of the SFM technologies that appear superior in terms of yields are not necessarily the most adopted by farmers. This study therefore aimed at evaluating economic and social trade-offs of such low-external input SFM technologies, which could be sustainable and adaptable to different smallholder agro-ecosystems. This is because even though most technologies have comparable yield responses their cost of adoption varies from technology to technology resulting in big profitability differences. Profit evaluation therefore, would provide information that would empower smallholders to chose and test economically viable, low-external input SFM technologies that could enable them exploit scarce farm resources more efficiently and profitably.

2.4 Smallholders' farm resources productivity

Since 1980's, rapid changes have taken place in structure and authority of farming systems, central governments and global economies (IFPRI, 2003). In 1990's, structural adjustment programmes (SAP's) were introduced which led to removal of farm inputs subsidies and decontrol of input and producer prices. These macro-policy changes were hastily implemented with very little regard to their consequences at micro or farm level (Bationo et al., 2004). In effect farm inputs became unaffordable to most resource-poor smallholders (Mutiro and Murwira, 2004). Consequently, resource-poor farmers' ability to invest in soil fertility restoration has been greatly undermined. According to Bationo et al. (2004), current inorganic fertilizer use in Africa is only 9 kg per hectare as compared to 87 kg per hectare in developed countries. This has caused chronic plant nutrient depletion leading to low productivity of land, labour and capital especially in smallholder maize-based cropping systems. Market liberalization and globalisation, though powerful forces for transforming global economies have therefore paused grave challenges to food security, agriculture and NRM, especially for the less developed world.

Smallholders' objectives are many and varied. Such include profit maximization, food self-sufficiency and risk aversion. To meet these objectives farmers rely on farms' scarce resources (land, labour and working capital). This implies that resource-poor farmers should adopt optimal farm plans (OFP), which ensure that scarce farm resources are allocated in the most efficient way. An OFP is one which under given physical, technical and resource conditions, shows the type and levels of different activities to be undertaken so that total gross margins (TGM) are maximized in an annual cycle (Anderson et al., 1991). OFP have been developed through linear programming (LP) technique in other similar studies but in different smallholder agro-ecosystems in Kenya. Kamunge (1989) used LP technique to develop OFPs for Tobacco + Maize/bean, Cotton + Maize/bean and Subsistence crops only farming systems in Mitunguu irrigation Project in Upper Tana catchment area. He found out that farm resources mainly land and irrigation water were under utilized. Barasa (1989) carried out a similar study to analyse economic factors causing decline of cotton production in western Kenya using LP. His study found out that cotton at the prevailing producer price (Ksh 6/kg), had the least return to factors of production (land, labour and capital) as compared to all other farm enterprises. Low cotton price, labour and technology were the most limiting factors in cotton production. In both of these studies, subsistence food requirements were imposed on the LP model as an extra constraint.

The current study is similar to the above studies in that it was conducted in smallholder farmers' set-ups, considered food self-sufficiency and aimed at maximizing farmers' welfare from scarce farm resources. However, the current study departs from the others by the fact that it examined optimization of resource use in high potential agro-ecosystems (Upper Midland Zone) under rain fed agriculture, while Kamunge and Barasa conducted their studies in marginal agro-ecosystems (Lower Midland Zone). In Barasa's study, farmers were not categorized into any classes, while in Kamunge's study farmers in the irrigation scheme were classified into three farming systems. In the current study farmers were classified into three SFM-based farm typologies. As in the other two studies, land was found to be the most limiting factor of production in all smallholder production systems. LP technique could therefore be successfully used to develop OFP, which would ensure efficient allocation of land in each SFM-based farm typology.

Concerns have been raised about labour availability in smallholder farming sector especially considering high incidences of HIV/AIDS (Mutiro and Murwira, 2004). Most NRM research, has failed to mainstream needs and constraints of men and women, aged and children in development and extension of SFM technologies (KARI, 1998). Women contribute more working hours in agricultural sector than men yet they are structurally disadvantaged in access to and control of land and working capital (Kimenye, 1998). As much as 80 percent of people infected with HIV virus are in 16-40 year age bracket, the most productive group in a society (Ndakwe, 2003). According to global statistics, 85 percent of all who died of HIV/AIDS in 2002 were from sub-Saharan Africa (SSA). More than 24 million people in SSA are infected today. In Kenya, one in every 6 people is infected with HIV and about 500 persons die of AIDS-related complications daily (Ndakwe, 2003). This demonstrates the need to study household labour availability and supply (casual and family) and how this critical resource could limit adoption of labour-intensive SFM technologies.

Many integrated SFM technological innovations have been developed as part of low-external input paradigm in the last three decades (Hassan, 1998; Vanlauwe, 2004). Such technologies include biomass transfer (BT), farmyard manures (FYM), compost and leguminous green manure cover crops (GMCC) in combination with modest levels of inorganic fertilizers. They offer great opportunities to improvement of food security, nutrition and smallholders' rural livelihoods. However, most often than not these innovations require substantial investments in terms of working capital (IFPRI, 2003). This pauses great constraint to accomplishment of smallholders' vision of achieving food and nutrition security. At the moment there is no favourable political environment in favour of low-external input SFM technologies that are affordable to resource-poor farmers (Bationo et al., 2004). This study therefore, will endeavour to promote advocacy for suitable policy framework, which could create an enabling environment for adoption of low-external input SFM technologies. Such legislations could enhance

Consider:
i) At the moment, the political environment does not favour ---

smallholders' access to micro-finance and credit; influence inputs and producer prices; and improve road and market infrastructures. This could enhance returns to farmers' capital investments and would enable the rural poor benefit from the current technological breakthroughs.

Finally, networking in a given area of speciality enables stakeholders to achieve a common objective better (Bationo et al., 2004). Such individuals and institutions, when working together reap more benefit than would have been possible if they worked individually. They build up their knowledge base, understand better the processes for promoting values, and ultimately translate their understanding into action. Collaborating institutions and individuals exchange information and experiences in the same field as professionals (Hilhorst and Toulmin, 2000). Such collaboration facilitates evaluation of socio-economic and biophysical tradeoffs of alternative SFM strategies. This study recommends closer stakeholders collaboration in investigating how best to disseminate SFM technologies with highest returns per unit of most limiting resource. Possibilities of scaling up/out of OFP from plot level to farm, landscape and national levels should be jointly explored.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Conceptual framework

There are various factors that may either enhance or restrict farmers' adoption of SFM technologies (Figure 3.1). Such includes personal, physical, institutional, socio-economic and cultural factors.

Improvement in SFM would imply increase in crop yields, farm income and enhancement of farmers' welfare. Such conceived benefits can only be fully achieved if various SFM options available to farmers are adequately explored under different social, economic and cultural contexts. Farm resources are scarce and have many alternative uses. Male and female farmers are therefore likely to choose only those technologies, which best suit their own needs under given bio-physical and socio-economic circumstances. There is thus an automatic need of choice, which can only be effectively made once underlying factors are clearly analysed and understood.

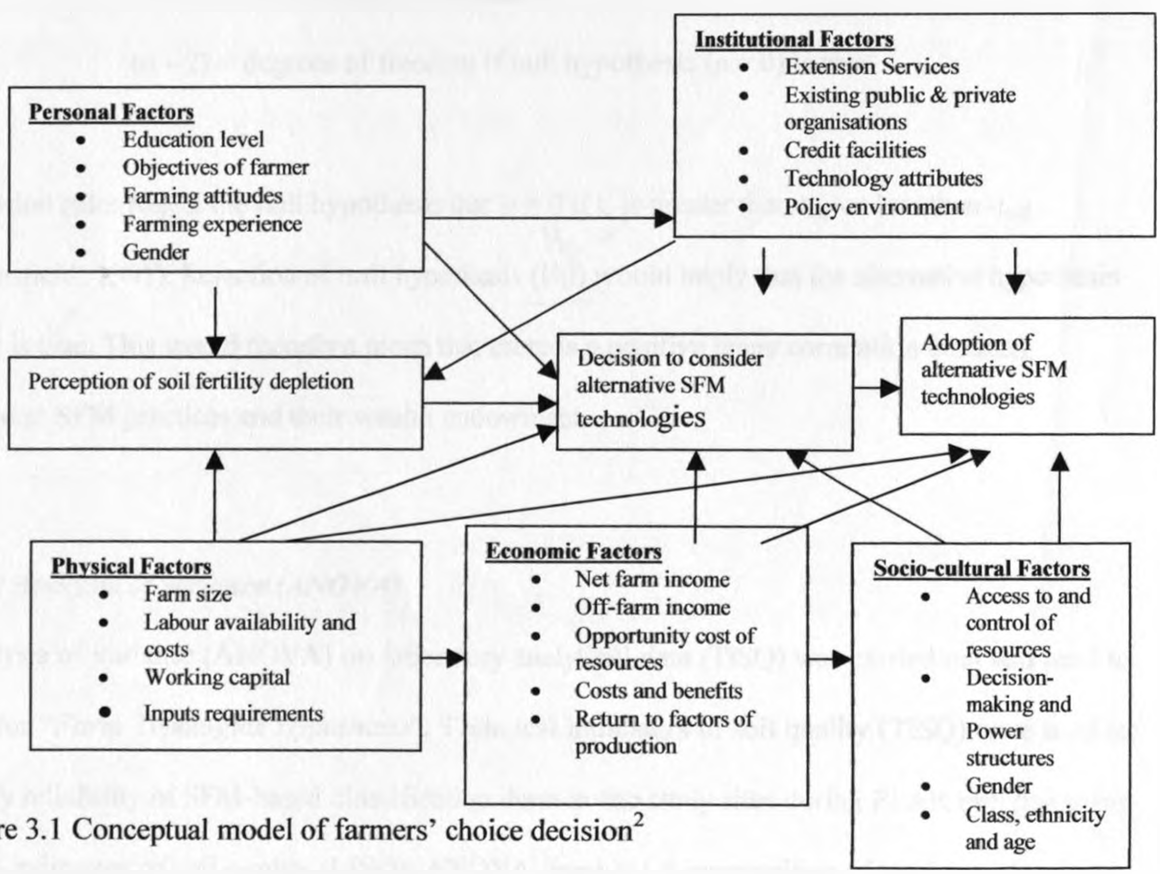

Figure 3.1 Conceptual model of farmers' choice decision[2]

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[2] *Adapted from Ervin and Ervin, 1982*

Adopted

H0: $\rho = 0$ and H1: $\rho \neq 0$

Where:

H0: = null hypothesis

H1 = alternative hypothesis

ρ = population correlation coefficient, (rho)

A two-tails t-statistic ($p < 0.05$) was then used to test this hypothesis where:

$$t_c = \frac{r}{\sqrt{\frac{(1-r^2)}{(n-2)}}} \quad (3.2)$$

Where:

t_c = calculated t value

r = sample correlation coefficient

(n – 2) = degrees of freedom if null hypothesis ($\rho = 0$) is true

Decision rule: Reject the null hypothesis that $\rho = 0$ if t_c is greater than $t_{\alpha/2}$ or less than $-t_{\alpha/2}$ (Mansfield, 1991). Rejection of null hypothesis (H0) would imply that the alternative hypothesis (H1) is true. This would therefore mean that there is a positive linear correlation between farmers' SFM practices and their wealth endowment.

3.2.2 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) on laboratory analytical data (TISQ) was carried out and used to test for "*Farm Typologies Hypothesis*". Technical indicators of soil quality (TISQ) were used to verify reliability of SFM-based classification done in the study sites during PLAR exercise using local indicators of soil quality (LISQ). ANOVA involved decomposition of total variation in the

3.2 Methods of data analysis

3.2.1 Population correlation coefficient, (ρ)

This methodology was used for analysis of PLAR data and to test for "W*ealth endowment Hypothesis*". From the sample correlation coefficient ***r***, population correlation coefficient (ρ) was inferred for various sample sizes n (Wonnacott and Wonnacott, 1979). Population correlation coefficients, ρ (rho) for the two study sites were then used to measure the degree of linear relationship between soil fertility status (Y) and wealth endowment (X) whereby:

$$\rho = \sqrt{r^2} \qquad (3.1)$$

Where:

ρ = population correlation coefficient (rho)

r^2 = coefficient of determination

Assumptions made:

(i) That both Y and X are normally distributed random variables

(ii) That standard deviation of Y is constant for all values of X

(iii) That standard deviation of Y is constant for all values of X

Hypothesis testing

Population correlation coefficient, ρ usually has a 95 % confidence interval of between –1 and 1 ($-1 \leq \rho \leq 1$). If $\rho = -1$ this represents a perfect negative linear correlation between two random variables while $\rho = +1$ indicates a perfect positive linear correlation. If $\rho = 0$, there is no linear correlation between the variables though there could be some other non-linear relations.

In this study, it was hypothesized that "there is no relationship between smallholders' SFM status and their wealth endowment":

dependent variable (Y) into constituent variations in independent variables (X) (Wonnacott and Wonnacott, 1979).

Hypothesis testing

ANOVA was to test ($p < 0.05$) for between farms soil fertility gradients using TISQ due to different SFM practices. Different TISQ used for verifying PLAR classification included organic carbon (%), total nitrogen (%) and available phosphorous (ppm).

relative organic carbon and nitrogen, and available phosphorus

It was hypothesized that "smallholder SFM practices are common across different farm typologies". Null and alternative hypotheses were therefore formulated as follows:

this cannot be since farm typologies were defined by SFM practices. Actually the candidate is comparing TISQ not SFM

$H0: \theta_1 = \theta_2 = \theta_3$ and $H1: \theta_1 \neq \theta_2 \neq \theta_3$

Where:

H0 = null hypothesis

H1 = alternative hypothesis

$\theta_{1,2,3}$ = TISQ contents from different soil samples

Decision rule: reject H0 if $\theta_1 \neq \theta_2 \neq \theta_3$. Rejection of null hypothesis (H0) would mean that there are significant differences between different TISQ in soil samples taken from different farm typologies. This would imply that there exist soil fertility gradients between different farms due to differences in farmers' SFM practices.

3.2.3 Partial budget analysis (PBA) model

Again wrong sub-title

This methodology was for analysis of on-farm experimental data and for testing of *Economic Viability Hypothesis*. The first step in economic analysis of any experiment is to calculate costs and benefits that vary across different treatments (CIMMYT, 1988). This is because farmers would be interested to know what changes are involved in adopting a new technology or practice. In partial budgeting not all production costs were included in the budget except those that were significantly affected by alternative SFM treatments being considered. Such included costs of purchased inputs, labour and opportunity costs which could be incurred from adoption of different SFM treatments. Costs of land preparation, planting and weeding were assumed not to differ significantly across different treatments and were incurred regardless of the treatment undertaken. Coefficients and prices (Ksh) used in economic analysis of various treatments are given in appendix (iii).

Purchased inputs:

Field cost of an input (Ksh/ha) was determined by multiplying the quantity of input (Kg/ha) required in each technology by its field price (Ksh/kg). Field price of a farm input is the purchase price of that input plus cost of transporting one unit of that input from the local stockist to the field (CIMMYT, 1988). Purchase prices for various farm inputs were obtained from local stockist surveys while transport costs were established from interviews with farmers in the study sites. Purchased farm inputs included inorganic fertilizers, farmyard manure (FYM), green manure cover crops (GMCC) seeds, compost and Effective Micro-organisms (EM1).

Labour:

Labour implications monitored included labour spent on application of fertilizers, FYM, compost, maize stover and *Tithonia*. To obtain a common basis of comparison universal to the two study sites, there was need to standardize some of the measurements used in computation of net present value (NPV). Average wage rate, which included lunch and ten-o'clock tea, was Ksh 95 while average working time for two sites was 6.5 hours per man-day. Wage rates multiplied by number of hours spent in a given task determined the labour costs. These were compared with estimates from farmers' practice in farm surveys done in the study sites. Labour for *Tithonia* cutting, transport and application was taken as Ksh 4 per kg (Rommelse, 2000).

Crop output:

Net harvest area was demarcated by omitting one row on either side of the plots and the first and last plants of each row. At harvest maturity, maize and beans were harvested, and grain yields per plot recorded. The crop sub-samples were oven-dried to about 13 percent moisture content and dry weight taken. To reflect the differences between experimental and farmers' crop yields from same SFM treatments, experimental yields were depressed by 20 percent (CIMMYT, 1988). This was due to difference between on-farm experiment and farmers' fields with respect to crop management, plot size, time and methods of harvesting. Percentage yield increases from different SFM treatments with respect to unfertilised control were also computed whereby:

$$\text{Yield Increase}^{3} (\%) = \frac{[\text{Yield}_{treatment} - \text{Yield}_{control}]}{\text{Yield}_{control}} \times 100 \qquad (3.3)$$

Opportunity Costs (OC):

Opportunity costs (OC) of various resources were also considered where OC is defined as "the value of any resource in its best alternative use" (CIMMYT, 1988). Such included OC of family labour, maize stover, GMCC and capital. OC of capital was considered to be equivalent to its discounting rate, which is that rate at which all capital would be utilized if all possible investments were undertaken (Gittinger, 1982). Discounting rate of capital therefore reflected the choice made by farmers based on present and future returns and hence the proportions of total income farmers were willing to save or invest. Interest on borrowed capital for small-scale enterprises for most commercial banks in 2003/4 ranged between 18 – 21 percent per annum. In this study OC of capital was taken as 20 per cent per annum.

[3] Source: Gachengo et al., 1999

Gross field benefits:

Gross field benefits for each SFM treatment were given by adjusted crop yield multiplied by its field price. Field price of a crop is defined as the price that farmers receive less the costs of harvesting and marketing that are proportional to level of crop yield (CIMMYT, 1988).

Net present value (NPV):

In development of partial budget, a common measure is formulated. This enables one to make comparison between benefits and costs across different treatments with respect to unfertilised control. In this study, net present value (NPV) from different SFM treatments was used as the common measure. NPV is defined as present worth of benefits less present worth of cost of a project (Gittinger, 1982):

$$NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+I)^t} \qquad (3.4)$$

$\frac{B_t - C_t}{(1+I)^t}$

Be consistent with use of symbols

Where:

NPV = net present value

B_t = present worth of benefits

C_t = present worth of costs

$1/(1 + I)^t$ = discounting factor

t = time in years

I = interest rate on borrowed capital (%)

In this study time period of one year was used. NPV values illustrated net present return for every shilling invested in a given SFM treatment.

Hypothesis testing

Different SFM treatments were considered as an investment in natural resource capital and represented different mutually exclusive projects. NPV across different treatments were computed and compared since the treatments represent investments of same time length. It was hypothesized that "all low-external input SFM technologies are cost in-effective in enhancement of soil fertility and crop yields in smallholder maize-based production systems".

NPV was used to test *Economic Viability Hypothesis* where:

H0: NPV < 0 and H1: NPV ≥ 0

Where:

H0 = null hypothesis

H1 = alternative hypothesis

NPV = net present value

Decision rule: Reject H0, if NPV ≥ 0 (Gittinger, 1982). Rejection of null hypothesis (H0) would imply that the present worth of benefits is greater than the present worth of costs of an investment. This would then mean such an investment is economically viable and should be undertaken.

3.2.4 Linear Programming (LP) Model:

Linear Programming (LP) is an important tool in agricultural planning and decision-making processes (Anderson et al., 1991). It is a computation method for determining the most optimal farm plan (OFP) to achieve the set objectives under given resource constraints (Waugh, 1998). An OFP is one which, under given physical, technical and resource conditions, shows the type and levels of different activities to be undertaken so that total gross margins (TGM) are maximized in an annual cycle (Jain and Mehta, 2000). Different production resources considered in this study included land, labour and working capital. Since resources are always scarce and farmers' objectives many, farmers should allocate their resources in the most efficient way.

LP was employed as a prescriptive model to analyze primary data collected during farm surveys in the study sites. This helped to determine the best-bet combination of activities, which would ensure that farmers' objectives were maximized in each SFM-based farm typology. "Average farm model" for each typology was derived by aggregating and averaging resources and input-output (I-O) data from farmers who were interviewed in that particular typology. This gave a more representative farm model that captured the existing farming conditions better than a "single farm model" (Kamunge, 1989). TGM was used in the model as proxy of farmers' profits.

The general LP model used in this study is given by:

$$\text{Max } Z = C_1X_1 + C_2X_2 + C_3X_3 \ldots + C_{n-2}X_{n-2} + C_{n-1}X_{n-1} + C_nX_n \qquad (3.5)$$

Subject to:

$$a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \ldots + a_{1n}X_n \leq b_1$$

$$a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + \ldots + a_{24}X_n \leq b_2$$

.

.

.

$$a_{m1}X_1 + a_{m2}X_2 + a_{m3}X_3 + \ldots + a_{mn}X_n \leq b_m$$

And $X_1 \geq 0, X_2 \geq 0, \ldots, X_n \geq 0$

Where:

Z = total gross margin (TGM)

C_j = gross margin per hectare from jth activity

X_j = number of hectares of jth activity

a_{ij} = the amount of resources per hectare for jth activity

b_i = the level of constraint

m = the number of constraints

n = number of activities

$X_n \geq 0$ = non-negativity of activities

An LP problem has three quantitative components, the objective function, real activities for achieving the objective function and the resource constraints.

The objective function **(** C_jX_j **)*:***

The expression "C_jX_j" is the objective function, where C_j was gross margin (GM) per hectare from different enterprises while X_j were number of hectares of jth activity undertaken. In this study, it was assumed that the main objective for most small-scale farmers was to maximize their welfare from their limited resources (land, labor and working capital). This was expressed as maximization of GM per hectare, per man-day and per Kenya shilling.

The real activities **(** X_j **)*:***

Small-scale farmers in the study sites undertook different activities, in different combinations and proportions (X_j) with the objective of maximizing their welfare. The term "activity" was used to denote what is being produced; an enterprise, or a method of production requiring specific quantities of specified resources and producing specified quantities and qualities of products (Anderson et al, 1991). Real activities are those, which are produced either for sale (outputs) or are bought (inputs) in market to be used on the farms. Disposable activities were included in the LP to allow for non-use of resources. In this study different enterprises in different SFM-based classes were the real activities used to attain the objective function. These represented variables of the problem which farmers could control to achieve their objectives.

These included maize-bean intercrop, potatoes, dairy, bananas, coffee, tomatoes, French beans and sweet potatoes.

The resource constraint (b_i):

Equations "$A_{ij}X_j \leq b_i$" represented resource constraints faced by smallholders in the study sites. LP helped to identify combination of different activities that would maximize TGM under given resource constraints, b_i. Resource constraint, b_i is also called the right-hand-side (RHS) of an LP equation. Constraints must be satisfied for a solution to be feasible. In this study, b_i included amount of available land, labour and working capital. Though households' subsistence food requirement is not a resource constraint *per see*, it was nevertheless imposed as constraint in the LP model to ensure that households' food supply is sufficiently met from on-farm production.

(a) Land

Land available for planning for each SFM-based typology in each study site was obtained by subtracting land for other uses (homesteads, farm roads, etc.) from total land available. Due to high population pressure in study districts, land availability in long and short rains for annual crops was assumed to be the same.

(b) Labour

Farm labour consisted of family, casual or permanent labour or a combination thereof. Since the cost of permanent labour would be incurred irrespective of the level of different activities, it was excluded in computation of variable costs (Makeham and Malcolm, 1986). OC of labour was considered as a real cost in formulation of LP problem. Due to age differences between different members of the same family, it was necessary to standardize labour using a common weight (Table 3.3.1).

Table 3.2.1. Weights for standardization of family labour in Kariti and Mukanduini [4]

Class	Age group (Years)	Percent (%)	Man-equivalent
Child	Under 7	10	0.0
Child/Teen	8-15	22	0.5
Adult	16-64	63	1.0
Adult	65-75	2	0.5
Adult	Over 75	3	0.0

From the farm surveys, it was established that there was no difference in cost of male or female labour in both study sites and that school children were available for farm work only during school holidays (April, August and December). Farmers worked on their farms for 6 days a week, 24 days a month and 12 months a year. One man-day was found to be equivalent to eight hours in Mukandunin and only five hours in Kariti.

(c) Working capital

Working capital is defined as the total value of inputs (owned or purchased) allocated to an enterprise for future returns (CIMMYT, 1988). Working capital for 2003/4 cropping year was estimated on the basis of cash spent by farmers on seeds, fertilizers, FYM, pesticides and labour. In absence of records to help distinguish between family expenditure and farm expenditure, total cash spent on farming activities during 2003/4 was used to estimate total working capital available to farmers (Kamunge, 1989).

(d) Subsistence food constraints

Though profit maximization is the commonest overriding objective behind most smallholder farming systems, in this study household food self-sufficiency could not be overlooked.

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[4] Source: Adapted from Kamunge (1989)

Households must first satisfy their food requirements before marketing the surpluses (GoK, 1980). Maize and beans grown as an intercrop were the commonest food staples in both study sites. According to Kenya's food balance sheet (GoK, 1979) per capita annual maize and bean requirement is 118 kg and 11 kg respectively. Depending on the average number of members in a family and farms' crop yield potential, it was possible to determine the minimum land size required to meet annual household maize and bean requirements in each SFM class or farm typology (Table 3.3.2).

Table 3.2.2. Minimum land requirements for family food self-sufficiency (maize and beans) in hectares (Ha) in each SFM farm typology in Kariti and Mukanduini[5]

Site	SFM Class	Family size (Number of members)	Land requirement for subsistence maize (Ha)	Land requirement for subsistence beans (Ha)
Kariti	I	7	0.53	0.29
	II	7	0.78	0.33
	III	6	0.76	0.34
Mukanduini	I	6	0.18	0.2
	II	7	0.33	0.4
	III	7	1.00	0.4

LP problem coefficients

There are two types of coefficients in an LP problem. These include:

[5] Source: Author's Field survey (2003/4)

(a) Objective function coefficients (C_jX_j)

GM per hectare from different activities in each study site were computed. This was meant to show profitability of various activities under the actual farm plans (AFP). The gross margin of an activity is the difference between gross revenue and its total variable costs:

$$GM = GR - TVC \quad (3.6)$$

Where:

GM = gross margin

GR = gross revenue

TVC = total variable costs

GM was obtained from sale of crops, animal products and their by-products while TVC included costs of various inputs used by different activities. Several different activities were undertaken in each study site in 2003/4 and therefore TGM were the sum of the GM from individual activities. In this study it was assumed that all products from each activity were sold and that all income was received at once (Makeham and Malcolm, 1986). This overcame the problem of estimating what proportions of a product were sold, eaten or stored. From GM analysis, coefficients for objective functions (C_jX_j) were derived.

(b) Technical coefficients (a_{ij} matrix)

Resource requirements per hectare for different activities gave the technical coefficients also called input-output (I-O) coefficients, a_{ij} for various X_j activities. Since GMs were computed per hectare basis, land coefficients (a_{ij}) for different activities were entered in the LP model as 1 hectare.

Models specifications:

Smallholders' objectives are many and varied. Some farmers would be interested in purely profit maximization, while others would be concerned with ensuring food self-sufficiency from on-farm production. Family labour was found to be a critical factor of production in the study sites. It was important therefore, to determine returns per man-hour of family labour. Finally it was necessary to investigate the changes in return per shilling of working capital if farmers were to adopt new SFM technologies.

To reflect different farmers' objectives and to make the resultant OFP more realistic, four different models were therefore constructed and analysed using LP. Models are representations of real objects or situations (Anderson et al., 1991). They play a critical role as a quantitative approach to any decision making process. In an LP model, the problem's objective, activities and constraints are expressed mathematically.

The four models analysed included:

1. Model 1: Profit maximization
2. Model 2: Food self-sufficiency
3. Model 3: OC of family labour = 0
4. Model 4: Technology change

In all these profit maximization is basic. Therefore it should reflect different additional constraints or circumstances not objective. The additional circumstances therefore distinguish the model.

OFP showed the types and levels of different activities, which could be undertaken under the existing resource constraints in order to maximize the objective in each model. OFP also showed the limiting and non-limiting farm resources.

Model 1: Objective is profit maximization subject to availability of basic resources

Model 2: π-max subject to basic resources and provision for self sufficiency

Model 3: π max with zero OC

Sensitivity analysis:

In LP there is always a need to carry out sensitivity or post-optimality analysis on optimal solution from the models used. This is because real-world problems occur in a dynamic environment. If an LP model were used in such an environment, then it is expected that some of the model's coefficients would change over time. Sensitivity analysis therefore, showed how changes in coefficients of an LP problem would affect the optimal solution (Anderson, et al., 1991). These coefficients included objective function and resource constraint (RHS) coefficients. During sensitivity analysis, all other coefficients except the one being considered were held constant.

Hypothesis testing

The fourth hypothesis of this study stated that "the actual farm plans (AFP) are optimal in all SFM-based farm typologies". TGM was used as proxy for profitability of various enterprises in AFP and OFP.

To test the *Optimal Farm Plan Hypothesis,* TGM from AFP for different activities were computed and compared with TGM derived from OFP where:

$$H0: TGM_a = TGM_0 \text{ and } H1: TGM_a \neq TGM_0$$

Where:

H0 = null hypothesis

H1 = alternative hypothesis

TGM_a = total gross margins from AFP

TGM_0 = total gross margins from OFP

Decision rule: Reject H0 if $TGM_e \neq TGM_0$. This hypothesis was tested for a gap of more than 20 percent between TGM_e and TGM_0. This criterion was adopted from CIMMYT (1988), where an increase of more than 20 percent in TGM should be considered significant. Farmers would be unwilling to borrow money at 20 percent p.a. and invest it in a technology whose rate of returns is 20 percent or less. It is necessary therefore, that the minimum rate of return for a new technology be estimated at a point over and above the cost of capital in order to pay farmers for their time and efforts invested in the new technology.

Advantages of LP approach

Some of the advantages of LP approach include:

1. It can handle large number of interrelated variables at once
2. It can provide reliable guide to optimal product mixes
3. It provides shadow prices of critical resources
4. It can consider many products produced from many resources
5. It allows interrelation between wider range of alternatives than time series analyses

Limitations and assumptions of the LP approach:

However, LP has some limitations, which restrict its use. Optimal solutions from LP should therefore, be used as guidelines in decision-making processes.

This includes:

1) Linearity

LP assumes linear relations between enterprises, activities and resources. However, in real life situation there are complementary and supplementary relations between enterprises, activities and resources. LP also ignores risks and uncertainties associated with farmers' decisions. LP optimal solutions should therefore, act as guidelines for improving economic efficiency in resource allocation.

2) Uncertainty of parameters

LP optimal solution is obtained from computed input-output (I-O) data. Such are random variables and not known with 100 percent certainty. The problem is compounded by the fact that programmed solutions are not accompanied by statements of statistical significance. Similarly, the assumptions made on collected data may differ significantly from the facts. Future prices and output are also not known with perfect certainty. All these shortcomings should be put into consideration when interpreting LP solutions.

In LP approach, a number of assumptions are made in order to make the model more appropriate. Such includes:

1. Proportionality of activities and resources
2. Additivity of resources and activities
3. Divisibility of activities and resources

Proportionality means that the contribution to the objective function and the amount of resources used is proportion to the value of each decision variable. *Additivity* means that the value of objective function and the total resources used can be found by summing the objective function contribution and the resources used for all decision variables. *Divisibility* means that the decision variables are continuous while divisibility assumptions and the non-negativity constraints ensures that decision variables can take any value greater or equal to zero.

3.3 Data sources

3.3.1 Primary Data:

(i) Participatory learning and action research (PLAR) Data

The PLAR exercise generated some data on SFM- and wealth-based classification of all farmers in the study sites. During the study, this data was subjected to some statistical tests ($p < 0.05$) to determine the strength of relationship between farmers' SFM status and their wealth endowment in the study sites.

(ii) Laboratory Analytical Data

After the PLAR exercise, 30 soil samples from selected farms in different farm typologies were taken at a depth of 0-20 cm. Samples were air-dried, ground and passed through a 2 mm sieve. Organic carbon (C), total nitrogen (N), available phosphorous (P), potassium (K), calcium (Ca), sodium (Na), and magnesium (Mg) were analysed using standard TSB methods (Anderson and Ingram, 1993; Okalebo et al., 2002). Soil analysis results were used as technical indicators of soil quality (TISQ) for verifying inter-farm variability in terms of farmers' SFM as identified during the PLAR exercise using local indicators of soil quality (LISQ).

(iii) Experimental Data

After the PLAR exercise, researcher-farmer managed on-farm trials with 15 different SFM treatments (T1 – T15) were established during long and short rains in 2003 (Table 3.2.1). Plots measuring 6 x 4 m in a randomized complete blocks design (RCBD) in 3 replicates were set up. Two seeds per hole of maize (*Zea mays*) at 90 x 30 cm were planted as test crop and later thinned to 1 plant per hole. One row of beans (*Phaseolus vulgaris*) was planted between every two rows of maize in plots where green manure cover crops (GMCC) were not incorporated. T1 served as unfertilised control where no soil amendments were applied. The GMCC planted in T2 – T4 included velvet bean (*Mucuna pruriens*), and dolichos (*Lalab purpureus).* Mexican sunflower (*Tithonia diversifolia)* at 5 tons per hectare fresh weight (FW) was applied in T5 during planting time in both seasons. *Mucuna, Crotalaria* and *Lablab* planted in 1st season were harvested, weighed and ploughed back in the 2nd season. Farmyard manure (5 tons/hectare) + NPK (17:17:17) at different levels were applied in T6 – T10 at planting time to supply different N levels. Maize stover was incorporated at 5 tons per hectare dry weight (DW) during ploughing in T11 but was treated with Effective Micro-organism (EM1) in T12 to hasten microbial decomposition. Farmyard manure (1.8 % N) and compost (1.7 % N) were applied at 5 and 10 tons per hectare respectively in holes at sowing time (T13 – T15). A blanket rate of 40 kg per hectare of P in form of triple super phosphate (TSP) was applied in all treatments. Monitoring, data collection and evaluation of different treatments were jointly done by farmers, researchers and extension agents during field visits and field days.

(iv) Farm survey data

Due to difficulty in finding a "specific farm" that would be an ideal representative of other farms in each farm typology, an "average farm" was generated.

Table 3.3.1. Applied soil amendments and their rates in kilograms or tons per hectare in Kariti and Mukanduini

Treatment No.	Level of amendments (Kg, tons/ha)	Treatment No.	Level of amendments (Kg, tons/ha)
T1	Unfertilised Control	T2	Mucuna pruriens
T3	Crotalaria ochroleuca	T4	Lablab purpureus
T5	Tithonia diversifolia (5 ton/ha FW)*	T6	Manure (5 t) + Fertilizer (20 kg N[6]/ha)
T7	Manure (5 t) + Fertilizer (40 kg N/ha)	T8	Manure (5 t) + Fertilizer (60 kg N/ha)
T9	Manure (5 t) + Fertilizer (80 kg N/ha)	T10	Fertilizer (100 kg N/ha)
T11	Maize Stover (5 t/ha)	T12	Maize Stover + EM1
T13	Manure (5 tons/ha)	T14	Compost (10 tons/ha)
T15	Manure (10 tons/ha)		

[6] N = Nitrogen, EM = Micro-organisms, * 1ton dry weight (DW) of *Tithonia* contains 33kg N, 3.1 kg P & 30.8 kg K, ** 66.7 kg FW *Tithonia* is equivalent to 1 kg DW (Rommelse, 2000)

This was derived by collecting data on a number of farms sampled from each farm typology, aggregating and then averaging it to develop the "average farm". According to Kamunge (1989), an average farm is more representative than specific farm due to large number of farms involved in calculating the average farm. It captures the diverse biophysical, economic and social circumstances of many farmers better than a single farm.

During farm surveys, cross sectional data on inputs types and costs, labour availability and use, production levels and price of products from a random sample of 35 farmers in each study district was collected using a structured questionnaire (Appendix II). Enumerators were trained and the questionnaire pre-tested before conducting household interviews. Primary data for two seasons in 2003/4 was collected and used for computation of GM for various enterprises in the three farm typologies. The GM analysis provided both objective function and technical coefficients for formulation of welfare maximization problems, which were latter solved through LP.

3.3.2 Secondary Data:

Secondary data about the study area from various governmental departments and other development agencies was also used.

3.4 Sampling procedure and sample size

3.4.1 Sampling Procedure:

Prior to this study, a multidisciplinary team of researchers, extension workers and farmers conducted a 5-day PLAR exercise in Kariti and Mukanduini study sites in January and February 2003 (Kimani et al., 2003). This made integrated soil fertility management (ISFM) approach to be knowledge-intensive and enabled communities in the study sites to mobilize their human and natural resources. This helped them to evaluate and define their problems, causes, and prioritise opportunities as well plan for a systematic, site-specific plan of action (Theis and Grady, 1991; Defoer and Budelman, 2000; Ticheler et al., 2000).

Specifically, PLAR guided farmers and stakeholders in:

- Self-diagnosis and analysis of existing SFM strategies and practices in smallholder farming systems in study sites
- Identification and ranking of major causes, consequences and coping strategies and opportunities for soil fertility depletion in each study site
- Planning, experimenting and evaluating alternative SFM practices that are practical and appropriate to farmers' particular socio-economic circumstances in order to exploit available resources more efficiently and profitably

During the PLAR exercise, different LISQ were identified and ranked as indices of soil fertility. Based on such indicators, all farmers in both sites were classified into three SFM-based classes or farm typologies. These were Class I (good soil fertility managers), Class II (average soil fertility managers) and Class III (poor soil fertility managers). Wealth ranking of all farmers in study sites was also conducted using farmer-perceived local wealth indicators. Such included level of formal education, off-farm income, land size, type of farmhouse, and numbers and type of livestock. This resulted into a list of farmers based on their SFM and wealth endowment in each study site. These lists were used as sampling frames in this study. Stratified random sampling (SRS) method was then employed to determine sample sizes in each SFM-based strata while simple random sampling (RS) was used to select samples of farmers within each stratum.

3.4.2 Sample Size:

Sample size for farm surveys was determined by use of coefficient of variation (CV) methodology, where population CV is defined as:

$$CV = \frac{\sigma}{\mu} \tag{3.7}$$

Where:

CV = coefficient of variation

σ = population standard deviation

μ = population mean

According to Nasiuma (2000), CV remains stable over time and with increase in population. CV is the relative standard error (SE) when dealing with sample values. In simple random sampling without replacement (SRSWOR), relative SE is obtained by:

$$C(\bar{y}) = \frac{\sqrt{\mathrm{var}(\bar{y})}}{E(\bar{y})} = \mathrm{C}\frac{1}{\sqrt{n}}\sqrt{\frac{N-n}{N-1}} \tag{3.8}$$

Where:

$C(\bar{y})$ = relative standard error

Var = population variance

$\bar{y}$ = population mean

$E(\bar{y})$ = expected value of population mean

C = coefficient of variation

N = population size

n = sample size

If SE is fixed at a value e, then:

$$\mathrm{e} = \mathrm{C}\frac{1}{\sqrt{n}}\sqrt{\frac{N-n}{N-1}} \tag{3.9}$$

And the sample size becomes:

$$n = \frac{NC^2}{C^2 + (N-1)e^2} \quad (3.10)$$

According to Nasiuma (2000), a CV of 30 percent and a relative SE of 5 percent are acceptable in most surveys. In this study, N = 300 and therefore n becomes:

$$n = \frac{300(0.3)^2}{(0.3)^2 + (300-1)(0.05)^2} \quad (3.11)$$

Therefore, n = 32

To cater for non-respondent errors, sample size n was rounded off to 35. For the two sites the total number of farmers sampled were therefore 70 (Table 3.4.1).

Table 3.4.1. Sampling figures in Kariti and Mukanduini in Maragwa and Kirinyaga Districts respectively[7]

Site	Values	Class I	Class II	Class III	Total
Kariti	N	16	114	163	293
	SI	6	9	9	9
	n	3	13	19	35
Mukanduini	N	5	29	240	274
	SI	2	6	9	8
	n	3	5	27	35

[7] N = population size, SI = sampling interval, n = sample size

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

In first section of this chapter, results of sample and population correlation coefficients between SFM status of different classes of farmers and their resource endowments are presented. Correlation coefficients were for determining magnitude of relationship between smallholders' SFM practices and their resource endowment. Second comes result of analysis of variance (ANOVA) between local and technical indicators of soil quality (LISQ & TISQ). This was to verify validity of PLAR classification of smallholders' recommendation domains as perceived by farmers and various stakeholders. Results on agronomic and economic evaluation to determine profitability and therefore cost-effectiveness of various low-external input SFM technologies are then presented. Finally this chapter concludes with results of LP and the resultant optimal farm plans (OFP) for different smallholder, SFM-based farm typologies in Kariti and Mukanduini.

4.1 Correlation between SFM status and wealth endowment

When interpreting soil test data in order to make their recommendations, researchers must have clear idea about the group of farmers who will use this information. They must consider not only the agronomic domain over which the results will be relevant, but also whether socio-economic factors such as different SFM practices or access to resources (land, labour and capital) would cause some farmers to interpret the results differently from others.

Ranking of farmers in the study sites using local indicators of soil quality (LISQ), resulted in three different SFM-based farm typologies (Table 4.1.1). These were: Class I (good soil fertility managers), class II (average soil fertility managers) and class III (poor soil fertility managers). Ranking of farmers based on their wealth endowment resulted also in three classes. These were: Class I (rich farmers), Class II (average farmers) and Class III (poor farmers).

Table 4.1.1. Size of SFM- and Wealth-based classes (n), and values of sample and population correlation coefficients in Kariti and Mukanduini[8]

Site	Class I		Class II		Class III		r	ρ	t_c
	SFM	Wealth	SFM	Wealth	SFM	Wealth			
Kariti	16	44	114	55	163	194	0.80	0.76	22.9
Mukanduini	5	7	29	74	239	192	0.62	0.47	12.4

The PLAR classification was paramount as it identified important farmers' socio-economic circumstances, which are critical determinants of smallholders' SFM status and wealth endowment. From the numbers of farmers in each SFM-based class (n), the strength of relation between farmers' SFM status (Y) and their wealth endowment (X) was determined. Population correlation coefficients (ρ) in all sites were greater than zero, indicating that there was a positive correlation between farmers' SFM status and wealth endowment variables. Since the calculated t values, t_c in both sites ($p < 0.05$) fell in the rejection region (outside ±1.96) then the null hypothesis "that there is no relationship between smallholders' SFM status and their wealth endowment" was rejected.

paraphrase

The hypothesis that ---- was rejected since calculated t ----

More farmers in both study sites were found in class III in terms of resource endowment than in class II and I. This trend was more so in Mukanduini (70 percent) than in Kariti (66 percent) indicating that farmers are more resource-poor in the former site than the latter. Poor resource endowment was translated into poor SFM in both sites. Again more farmers in both sites were found in class III in terms of SFM status (56 and 88 percent respectively). Only few farmers in terms of wealth endowment were found in class I in Kariti and Mukanduini (15 and 2.5 percent respectively). In terms of SFM status this was only 5 and 1.8 percent in Kariti and Mukanduini

[8] r = sample correlation coefficient, ρ = population correlation coefficient, t_c = calculated t value

respectively. These results indicated that generally wealthy farmers were also good soil fertility managers since they could afford capital investment involved in adoption of improved SFM technologies. Poor farmers are hesitant to adopt such technologies that require high capital investments, which they cannot afford. Therefore the PLAR classification done before this study using LISQ and farmers' resource endowment was confirmed.

After self-diagnosis and analysis of existing SFM strategies in smallholder farming systems, PLAR recommends that planning, on-farm experimenting and evaluation of appropriate technologies should commence (Defoer and Budelman, 2000). It was therefore imperative that such experiments be set up at locations that were representative of the relevant recommendation domains. Both agronomic and economic analyses were done on pooled data from the same domain. This provided sufficient data to be extrapolated to all farmers in a particular domain in order to exploit available farm resources more efficiently and profitably.

4.2 Characterisation of smallholder farm typologies

Development of recommendations for farmers must be as specific as possible. The socio-economic circumstances under which farmers live and work are diverse in almost every respect imaginable (CIMMYT, 1988). Farmers have different amounts and kinds of land, different levels of wealth, different attitudes towards risks, different access to labour and different marketing opportunities. Many of these differences do influence farmers' response to recommendations. While it is impossible to make separate recommendations for each farmer, researchers can identify a group of farmers with similar circumstances and for whom same recommendation may be suitable. Such a group of farmers would form a recommendation domain. Recommendation domains could be defined in terms of farmers' agronomic and/or socio-economic circumstances. One of the objectives of soil testing done during this study was to assess the overall nutrient status of a given soil from different SFM-based farm typologies. Soil test data was used to provide some information about organic and inorganic fertilizer use by small-scale farmers in the study sites. Soil tests results represented technical indicators of soil quality (TISQ) and were used to statistically validate farmers' recommendation domains delineated during the PLAR exercise using local indicators of soil quality (LISQ). TISQ indirectly reflected the levels of nutrients applied by different classes of farmers thus confirming or rejecting PLAR's definition of SFM-based recommendation domains. Results indicated significant differences ($p < 0.05$) in some TISQ between different farms but not others. TISQ with significant differences and which were used to verify PLAR classification included:

1. **Organic carbon (%)**

While soil organic carbon is not a requirement for plant growth, the levels of soil organic matter (SOM) influence a number of soil chemical and physical processes. SOM affects soil aggregation thereby improving drainage, water holding and cation exchange capacities (Okalebo et al., 2002). In low external-input cropping systems, mineralization of SOM contributes to soil fertility. SOM status therefore, is an important LISQ while SOM decline can give an effective measure of the extent of chemical and physical soil degradation. Levels of different soil nutrients in different classes in Kariti are shown in Table 4.2.1. These results showed that there were significant differences ($p < 0.05$) in carbon content in soil samples taken from different classes. This was observed between classes III and I and between classes III and II. However, no significant differences were recorded in mean organic carbon levels between classes II and I.

This trend of results is in agreement with classification done during PLAR using LISQ. From the PLAR exercise, it was established that class I farmers use more of inorganic than organic fertilizers, their soils had lower levels of organic carbon than class II.

Table 4.2.1. Soil nutrient levels and their ratings in different SFM-based farm typologies in Kariti

	Soil nutrient levels		
SFM Class	% C	% N	Ppm P
I	2.01	0.14	70.39
II	2.24	0.15	71.65
III	1.65	0.11	33.48
Mean	1.93	0.13	56.00
CV %	17.61	20.34	55.13
r^2	0.38	0.41	0.28
Rating[9]			
High	> 3.0	> 0.25	**
Moderate	1.5 – 3.0	0.12 – 0.25	
Low	0.5 – 1.5	0.05 – 0.12	
Very low	< 0.5	< 0.05	

Class III farmers use less of inorganic and organic fertilizer materials as compared to classes II and I. Class II farmers strike some balance between organic and inorganic fertilizer use. Organic fertilizer materials supply soil carbon and therefore those farmers who use more of it, their soils contain more organic carbon than others.

In Mukanduini, there were no significant differences in mean organic carbon ($p < 0.05$) between different classes (Table 4.2.2). Farmers in Mukanduini have relatively larger farm sizes and fewer animals than their counterparts in Kariti. Also animals in Mukanduini are grazed openly rather than being confined therefore losing most of animal manure. In all classes farmers end up applying less organic materials than their counterparts in Kariti. Soils in Mukanduini contain less

[9] Okalebo et al., 2002, ** Ratings not available

SOM and therefore less organic carbon (1.5 percent) as compared to soils in Kariti (2 percent). Similarly, the capacity of the soil to sequester carbon is under the control of soil texture and soil moisture regime. Mukanduini is in upper midland four (UM4) agro-ecological zone and therefore soils are relatively drier than in Kariti (UM3) and hence contain less SOM.

2. Total nitrogen (%)

Nitrogen is a major element essential for plant growth because it is an important constituent of all proteins and nucleic acids. Majority of soil nitrogen is found in SOM, which is continuously mineralised into NH_4^+ and NO_3^- ions for absorption by plants (Okalebo et al., 2002). This reflects the need to measure the forms and movement patterns of theses ions in the soil during cropping in order to make informed recommendations on types and rates of nitrogenous fertilizers and organic inputs for each SFM-based class of farmers.

Soil analysis data from soil samples from selected smallholder farms indicated that there were significant differences in mean total nitrogen between different classes or farm typologies in both study sites. In Kariti, there were significant differences ($p < 0.05$) in mean total nitrogen between classes III and I and classes III and II but not between classes II and I. This is reflective of SFM practices identified during PLAR that farmers use higher levels of inorganic fertilizers in classes I and II than in class III. Total nitrogen was lowest in Class III reflecting lowest usage of inorganic fertilizers. These results tend to confirm PLAR classification of smallholder farm typologies, which was done using LISQ. However in Mukanduini, there were no significant differences ($p< 0.05$) in mean nitrogen content between different classes.

Table 4.2.2. Soil nutrient levels and their ratings in different SFM-based farm typologies in Mukanduini

	Soil nutrient levels		
SFM Class	% C	% N	ppm P
I	1.59	0.10	441.23
II	1.52	0.07	632.67
III	1.39	0.09	649.83
Mean	1.49	0.09	582.10
CV %	16.21	35.68	24.84
r^2	0.12	0.12	0.31
Rating[10]			
High	> 3.0	> 0.25	**
Moderate	1.5 – 3.0	0.12 – 0.25	
Low	0.5 – 1.5	0.05 – 0.12	
Very low	< 0.5	< 0.05	

3. **Available phosphorous (ppm)**

Crop response to phosphorous is dependent on factors such as soil PH, soil moisture content, P-sorbing capacity of soil and clay contents (Okalebo et al., 2002). Due to diversity of such factors between the two study sites, enormous differences in mean phosphorous contents were depicted by soil analysis data. In Kariti, there were significant differences ($p < 0.05$) in phosphorous contents between classes I and III, and classes II and III but not between classes II and I (Table 4.2.1). The highest phosphorous content was recorded in class II (72 ppm) while the least was in class III (33 pmm). Mean phosphorous contents ranged between 33 - 71 ppm. In Mukanduini, significant differences in available phosphorous were observed between classes I and III, classes

[10] Okalebo et al., 2002, ** Ratings not available

I and II but not II and III (Table 4.2.2). Mean phosphorous contents ranged between 441-650 ppm.

According to Okalebo et al. (1991), nitisols of the Kenyan highlands with high clay contents and high P-sorbing capacity only respond to higher rates of phosphates. Adequate phosphorous supply enhances many aspects of plant physiology including photosynthesis, rooting, nitrogen fixation, flowering and fruiting (Brady and Weil, 2002). From farm surveys done in Mukanduini, farmers use huge amounts of inorganic fertilizers to hasten growth and ripening of commercial tomatoes, which is quite an extensive enterprise in the area leading to such astounding P figures.

From the foregoing discussion it was evident that there were significant differences between different soil parameters (TISQ) in soil samples taken from different SFM-based farm typologies. The null hypothesis that "there are no significant differences ($p < 0.05$) between carbon, nitrogen and phosphorous contents between different farms" was therefore rejected. This implies that there exist soil fertility gradients between different smallholder farm typologies due to differences in farmers' SFM practices, thereby confirming PLAR classification of farmers that was done using LISQ. Such gradients stem from the fact that smallholder farmers operate in diverse socio-economic circumstances which determines the type and levels of SFM options they undertake.

Special attention therefore should be put on the assessment of such factors that affect farmers' ability and willingness to adopt the "best-bet" SFM technologies. There is need for wholesome analysis of SFM recommendations focusing on trade-offs of alternative strategies that encompasses economic, biophysical and socio-cultural aspects to identify, define and redefine different recommendation domains throughout the process of on-farm research.

4.3 Economic optimization of low-external input SFM technologies

Different types of evaluation were carried out on pooled data from different SFM treatments in on-farm trials in each study site. They included:

Table 4.3.1 presents ---

(a) Relative agronomic analysis (RAA)

Before undertaking economic analysis of the pooled data, it was necessary to assess crop yield response data from an agronomic point of view (CIMMYT, 1988). For ease of comparison of data across different soil amendments, treatments were grouped into three categories by type:

- (i) Green manure cover crops (GMCC) + Tithonia
- (ii) Farmyard manure (FYM) + Inorganic fertilizers
- (iii) Stovers, compost and FYM alone

(i) Green manure cover crops (GMCC) + Tithonia

In Kariti, the highest mean maize yield for two seasons was from *Tithonia* (3.8 tons). This was significantly higher ($p < 0.05$) than all green manure cover crops (GMCC). This is an equivalent of 399 percent yield increase over unfertilised control (Table 4.3.1). *Dolichos* gave second highest mean maize yield (3.0 tons), which was significantly higher than *Crotalaria* and *Mucuna*. Of the GMCCs, *Mucuna* gave the lowest mean maize yield (2.4 tons), which was equivalent to 220 percent increase over unfertilised control.

In Mukanduini, the highest mean maize yield (3.58 tons) was also observed in *Tithonia* representing a yield increase of about 298 percent (Table 4.3.2). This is significantly higher ($p < 0.05$) than unfertilised control and all other GMCC. Of this category, *Dolichos* had the lowest mean yield (1.09 tons), which is equivalent to 21 percent increase over unfertilised control. *Mucuna* grew vigorously during the 1st season smothering maize and therefore depressing grain yields significantly. This effect was greater in Mukanduini than in Kariti. This is because warmer weather conditions favoured faster *Mucuna's* establishment and growth in Mukanduini than in Kariti.

Table 4.3.1. Mean crop yields (tons per hectare) and percent (%) yield increase in Kariti

Nutrient level	Yields		Yield increase	
	Maize (t ha^{-1})	Beans (t ha^{-1})	Maize (%)	Beans (%)
Control	0.75	0.16	0	0
Mucuna	2.40	0.40	220	150
Crotalaria	2.42	0.29	223	81
Dolichos	3.02	0.19	303	19
Tithonia	3.75	0.11	400	-31
M+20 kg N/ha	4.46	0.11	495	-31
M+40 kg N/ha	4.87	0.16	549	0
M+60 kg N/ha	5.28	0.24	604	50
M+80 kg N/ha	3.94	0.14	425	-13
100 kg N/ha	3.84	0.17	412	6
Stover	2.29	0.17	205	6
Stover + EM	2.25	0.25	200	56
Manure 5 t/ha	2.68	0.21	257	31
Compost10t/ha	3.37	0.20	349	25
Manure 10t/ha	4.25	0.15	467	-6
MSE[11]	0.40114	0.04833		
$LSD_{(0.05)}$	1.05930	0.11630		

In Mukanduini, soil was found to contain lower carbon and nitrogen contents than in Kariti, therefore crop yield responses followed a similar trend between the two sites. Mean bean yields displayed a different response to that of maize. Although *Tithonia* did quite well in maize yields, it did quite the opposite in bean yields in Kariti. It gave the lowest bean yields in Kairiti (0.11 tons) while it gave the highest mean bean yields (0.41 tons) in Mukanduini. The lowest bean yield in the latter site was recorded in *Dolichos* (0.07 tons) representing a yield decrease of 36 percent.

[11] MSE = Mean square error, LSD = Least significant difference

Table 4.3.2.Mean crop yields (tons per hectare) and percent (%) yield increase in Mukanduini

Nutrient level	Yields		Yield increase	
	Maize (t ha^{-1})	Beans (t ha^{-1})	Maize (%)	Beans (%)
Control	0.90	0.11	0	0
Mucuna	1.50	0.15	67	36
Crotalaria	1.94	0.14	116	27
Dolichos	1.09	0.07	21	-36
Tithonia	3.58	0.41	298	273
M+20 kg N/ha	4.98	0.26	453	136
M+40 kg N/ha	5.16	0.39	473	255
M+60 kg N/ha	5.31	0.48	490	336
M+80 kg N/ha	4.37	0.35	386	218
100 kg N/ha	3.90	0.33	333	200
Stover	1.71	0.21	90	91
Stover + EM	1.97	0.20	119	82
Manure 5 t/ha	3.04	0.32	238	191
Compost 10t/ha	2.74	0.29	204	164
Manure 10t/ha	3.81	0.45	323	309
MSE	1.15167	0.02265		
LSD $_{(0.05)}$	1.7720	0.11320		

(ii) Farm yard manure (FYM) + Inorganic fertilizers

In Kariti, the highest mean maize yield (5.28 tons) was observed from Manure + 60 kg N per hectare, equivalent to 604 percent increase over unfertilised control. Mean maize yields from Manure + 20 kg N per hectare and Manure + 40 kg N per hectare ($P < 0.05$) did not differ significantly in Kariti. Manure + 60 kg N per hectare also gave the highest mean bean yields while Manure + 20 kg N per hectare the lowest in both sites. Fertilizer alone at 100 kg N per hectare did not give the highest maize or bean yields, as one would expect in both sites. Similarly, Manure + 60 kg N, Manure + 40 kg N and Manure + 20 kg N per hectare gave the highest, second highest and third highest crop yield in Mukanduini.

(iii) Stovers, compost and FYM alone:

Mean maize yields from Manure (10 tons/ha) in both sites, were significant different ($P < 0.05$) from yields from compost and stovers. In Kariti, doubling manure rates from 5 to 10 tons per hectare almost doubled maize yields while this was not the case in Mukanduini. An extra 5 tons per hectare of manure increased maize yields by about 60 percent in Kariti but only 25 percent in Mukanduini. This implies that Kariti soil (UM3) is moister and therefore more responsive to soil organic matter (SOM) addition, and therefore doubling manure rate had a very dramatic response on maize yield. Such a phenomenon was not observed in Mukanduini (UM4). This implies that the optimal rate of manure application should be 10 and 5 tons per hectare in Kariti and Mukanduini respectively. Compost (10 tons/hectare) gave higher mean maize yield in Kariti than Mukanduini (3.4 and 2.7 tons respectively) about 350 and 200 percent over unfertilised control in Kariti and Mukanduini respectively. Bean yields from compost were significantly different ($P < 0.05$) from Maize stovers in Kariti, but were not significantly different from stovers in Mukanduini.

Of all treatments in this category, stovers gave poorest maize yield response in both sites. However, there was some significant yield increase from treating stover with effective microorganism (EM1). Bean yields seemed to increase slightly due to this treatment in Kariti but not in Mukanduini. It is important to note that farmers are more interested in variability in benefits than variability in yields. Economic analysis therefore provided a useful way of examining benefit variability associated with different SFM treatments from on-farm trials during this study.

(b) Relative economic analysis (REA)

Net present value (NPV) across different SFM treatments were computed and compared since different treatments were assumed to represent different investments of the same time length.

Amongst the GMCC, *Dolichos gave* the highest NPV (Ksh 17921) in Kariti while *Tithonia* recorded highest NPV (Ksh 20870) in Mukanduini. The NPV from different treatments in Kariti and Mukanduini sites are shown in Table 4.3.4. Of the FYM + inorganic fertilizers combinations, Manure + 60 kg N per hectare gave the highest NPV in Kariti and Makanduini. The NPV values for this treatment in both sites were Ksh 42309 and Ksh 47437 respectively. The second highest NPV was recorded in Manure + 40 kg N per hectare in both sites with NPV values of Ksh 38328 and Ksh 46342 respectively. Manure + 20 kg N per hectare had the third highest NPV values in both sites. Among the organic resources, NPV ranked Manure (10 tons) as the best in both sites. NPV values for manure (10 tons/ha) in both sites were Ksh 32669 and Ksh. 33529 respectively.

In Kariti, all SFM treatments had positive NPV leading to rejection of null hypothesis (H0) that "all low-external input SFM technologies are cost-ineffective in enhancement of soil fertility, crop yields and farm incomes in smallholder maize-based production systems". Accordingly these results suggested that all treatments in Kariti are economically viable as their NPV values are greater than zero (NPV > 0). However, in Mukanduini *Mucuna* and *Dolichos* had negative PNV values (NPV < 0) suggesting that these two treatments are economically non-viable. All other treatments had positive NPV values. The higher the NPV value the more economical a particular treatment is and therefore treatments with highest NPV ranking should be recommended to farmers. Form NPV ranking it was established that treatments from farmyard manure (FYM) + Inorganic fertilizers category had the highest NPV ranking in both sites.

Despite most treatments having positive NPV values, farmers and researchers must also take into account possible variability in experimental results. Such variability comes from various sources and therefore need to be taken into consideration during technology development processes.

Table 4.3.4. Net present values (NPV) in Ksh. per hectare of maize-bean intercrop in different SFM treatments in Kariti and Mukanduini

Nutrient level	Kariti		Mukanduini	
	NPV	NPV Rank	NPV	NPV Rank
Control	0	15	0	13
Mucuna	8706	14	-8370	14
Crotalaria	12778	13	3017	12
Dolichos	17921	8	-8574	15
Tithonia	16778	9	20870	8
M+20 kg N/ha	35003	3	43959	3
M+40 kg N/ha	38328	2	46342	2
M+60 kg N/ha	42309	1	47437	1
M+80 kg N/ha	21291	6	30528	6
100 kg N/ha	23289	5	39893	4
Stover	16133	10	9432	10
Stover + EM	15576	11	10429	9
Manure 5 t/ha	19734	7	25869	7
Compst 10 t/ha	13137	12	6969	11
Manure 10 t/ha	32669	4	33529	5

Important point to note is that experimental results vary from location to location and from year to year. In this study data was collected for two seasons only when weather conditions seemed favourable to normal crop growth and development. However such data does not give a true picture of what happens when weather conditions are not so favourable. Therefore further evaluation of agronomic and economic data over several seasons could help to determine whether given experimental locations represent a single recommendation domain or different domains. Such an assessment would help refine domain definitions and lead to more targeted recommendations.

The third specific objective of this study was "to evaluate the economic viability of different low-external input SFM technologies in order to identify practical technologies appropriate to particular smallholders' biophysical and socio-economic circumstances". FYM + modest levels of inorganic fertilizers (20, 40 and 60 kg N/ha) proved to be the most optimal SFM treatments for improving productivity and profitability of smallholder cropping systems. These technologies also tend to be compatible with farmers' practices in both study sites. From farm surveys, it was established that 99 percent of all farmers use FYM + inorganic fertilizers at various levels for maize production. This is because resource-poor framers embrace SFM technologies, which may increase stability or attempt to reduce risks. Such technologies advocate use of locally available SFM amendments, which have capacity to extend residual fertility to subsequent seasons thereby stabilizing farmers' production systems over time.

In conclusion, farmers' socio-economic environment is not perfectly stable. Crop prices, input costs, land and labour availability change from year to year and from season to season. Although such changes may be difficult to predict with precision, LP technique was used to review such recommendations in view of diverse farmers' socio-economic circumstances in both study sites.

4.4 Optimal farm plans (OFP) for objective function maximization

As stated in the fourth objective of this study, farmers in different socio-economic circumstances must use scarce farm resources in the most optimal way. From farm surveys undertaken in Kariti and Mukanduini in the course of this study, farmers' land, labour and working capital availability and use in three SFM-based typologies were determined. Analysis of the questionnaire also enabled current farmers' plant nutrient application levels for every farm typology to be computed (Table 4.4.1).

All smallholder farmers should invest their resources in activities or enterprises, which gives the highest return per unit of the most limiting resource. It is incumbent on this section therefore, to prove whether or not the actual farm plans (AFP) under the existing socio-economic circumstances are optimal or not.

Table 4.4.1. Nutrient levels, land, labour and working capital availability in different farm typologies in Kariti and Mukanduini[12]

Study site	SFM Class	Farmyard manure (tons/ha)	Fertilizer level (Kg N/ha)	Total available planning land (ha)	Total available labour (MD)	Total working capital (Ksh)
Kariti	I	5000	35	1.77	1105	314312
	II	2500	28	1.34	992	27478
	III	3500	23	0.99	861	245174
Mukanduini	I	5700	28	3.93	2057	586746
	II	3000	23	1.91	1699	449056
	III	2800	18	1.77	1311	333451

The TGM gap between AFP and OFP was used to test hypothesis number four, the *Optimal Farm Plans Hypothesis*.

4.4.1Gross margin (GM) analysis

Gross margins (GM) per hectare, man-hour of labour and shilling of working capital were computed for the actual plans (AFP) as the first step towards development of optimal farm plans (OFP) for different farm typologies in each study site. Division of enterprises' GM by their labour requirements and total variable costs per hectare derived GM per man-hour and GM per shilling of working capital respectively.

[12] Source: Author's Field survey (2003/4)

The GM were computed from primary data captured in a structured questionnaire (Appendix II) in the two study sites. Annual TGM for a given SFM-based farm typology were computed by summing up the products of GM from individual enterprises multiplied by area under each enterprise. Total land for which GM were computed in each SFM-based class was much larger than the actual land available due to existence of two cropping seasons in the study sites. Owing to population pressure, land available in long rains was exactly the same land available for second rains and therefore land under annual crops was doubled. Detailed GM analysis outputs are appended at the back of this thesis (Appendices V-XVII).

Kariti, Maragwa District:

GM were computed by subtracting total variable costs (TVC) from the gross revenue (GR) in each farm typology. Data was synthesized from 3 farms out of 16 (19 percent) in class I, from 13 farms out of 114 (11 percent) in class II and from 19 farms out of 163 (12 percent) in class III. Major enterprises included maize-bean intercrop, potatoes, dairy, bananas and coffee. TGM for the three SFM-based farm typologies are illustrated in the following sub-sections.

Class I farm typology

Table 4.4.2 shows the gross margins (GM) per hectare of land, man-hour of labour and Kenya shilling of working capital for class I SFM-based farm typology in Kariti. From the table, it was established that the most common enterprises were maize-bean intercrop, potatoes, dairy, bananas and coffee. In AFP, out of 1.77 hectares (ha) of land available for planning in class I, maize-bean intercrop took most land, followed by coffee and dairy while the least land went to potatoes and bananas in that order. The TGM for the "average farm model" in this class was Ksh. 20818. To demonstrate profitability of an enterprise in terms of returns to land, labour and working capital, it was necessary also to compute GM per unit resource invested. GM per unit labour and per unit working capital were derived by dividing enterprise GM by their respective labour requirements in hours and respective variable costs per hectare in shillings. In this typology the highest GM per hectare, man-hour of labour and shilling of working capital were Ksh. 75700, Ksh. 104 and Ksh. 0.68 respectively recorded from bananas.

Table 4.4.2. Farm organization and gross margins (GM) per hectare, enterprise, unit man-hour and working capital for profit maximization in class I in Kariti[13]

Enterprise	Land (Ha)	GM/hectare (Ksh)	GM/enterprise (Ksh)	GM/man hour (Ksh)	GM/working capital (Ksh)
Maize/Beans	1.08	15670	16924	10.0	0.27
Potatoes	0.16	5896	943	4.3	0.08
Dairy	0.10	3480	346	3.0	0.08
Bananas	0.05	75700	3785	104.0	0.68
Coffee	0.38	-3105	-1180	-5.2	-0.12
TOTAL/AVERAGE	**1.77**	**97621**	**20818**	**23.3**	**0.20**

Land, labour and working capital had highest returns if invested in production of bananas than in other enterprises. Although maize-bean intercrop took most land in this class (1.08 ha), it did not record the highest returns per unit of resources invested, as one would expect. Instead, it gave the second highest GM per hectare of land, man-hour of labour and shilling of working capital invested. Potatoes gave the third highest GM while the lowest GM were recorded from dairy and coffee in that order. Coffee ranked last with negative GM per unit of all production resources invested implying that the value of output was not even enough to offset variable costs. This

[13] Source: Author's Field survey (2003/4)

implies that at present output and price, it is uneconomical for smallholders to continue to invest their scarce farm resources in production of coffee.

Class II farm typology

Total land available for planning in class II was 1.34 ha. Again land allocation amongst different enterprises followed the same order as in class I above (Table 4.4.3). The TGM for "average farm model" in this class was Ksh 5377.

Table 4.4.3. Farm organization and gross margins (GM) per hectare, enterprise, unit man-hour and working capital for profit maximization in class II in Kariti[14]

Enterprise	Land (Ha)	GM/hectare (Ksh)	GM/enterprise (Ksh)	GM/man hour (Ksh)	GM/working capital (Ksh)
Maize/Beans	0.82	5095	4177	3.6	0.13
Potatoes	0.14	-10181	-1425	-8.4	-0.15
Dairy	0.07	1489	108	1.5	0.04
Bananas	0.04	72920	2917	115.7	0.68
Coffee	0.27	-1481	-400	-3.0	-0.07
TOTAL/AVERAGE	**1.34**	**67842**	**5377**	**21.9**	**0.13**

Although maize-bean intercrop took most of the land in this class, it did not give the highest GM per unit resources invested. It gave the second highest GM per hectare (Ksh. 5095) as compared to bananas (Ksh. 72921). In terms of returns per unit labour and capital, maize-bean intercrop gave Ksh 3.64 and Ksh. 0.13 respectively as compared to bananas with Ksh. 115.8 and Ksh.

[14] Source: Author's Field survey (2003/4)

0.68. In terms of returns per unit resource invested dairy was number three followed by coffee. Coffee gave negative GM per unit land, labour and capital. Potatoes gave the least returns (Ksh –10182). This implied that gross revenues (GR) from coffee and potatoes were not enough to cover respective total variable costs (TVC). It would therefore, be uneconomical to invest available land, labour and working capital in these enterprises.

Class III farm typology

The total amount of land available in this class was 0.99 hectares while TGM was Ksh –4372 from all enterprises. As in the other two farm typologies above, bananas gave the highest GM per hectare, man-hour of labour and shilling of working capital followed by Dairy (Table 4.4.4). All the other enterprises had negative GM. Again maize-bean intercrop dominated the AFP in terms of land allocation yet it did not give the highest returns per unit resource invested. The GM per hectare, man-hour and shilling from this enterprise were all negative (Ksh. –3283, -2.6 and –0.08), showing that GR from this enterprise was inadequate to offset TVC. Potatoes and coffee gave the least returns per hectare of land (Ksh –19269 and –12777).

From the foregoing discussion, one would automatically expect farmers in all classes in Kariti to allocate their entire farm resources (land, labour and capital) to bananas enterprise as it had the highest GM per hectare. Yet in reality farmers continued to undertake production of maize-bean intercrop, potatoes and coffee despite negative GM. This could be due to a number of reasons:

1. Most smallholders are risk-averse and would hesitate to invest all their scarce farm resources in bananas, which although it had the highest returns it required high initial capital investments.

Table 4.4.4. Farm organization and gross margins (GM) per hectare, enterprise, unit man-hour and working capital for profit maximization in class III in Kariti[15]

Enterprise	Land (Ha)	GM/hectare (Ksh)	GM/enterprise (Ksh)	GM/man hour (Ksh)	GM/working capital (Ksh)
Maize/Beans	0.68	-3283	-2232	-2.6	-0.08
Potatoes	0.04	-19269	-771	-19.1	-0.36
Dairy	0.04	703.38	28	0.7	0.02
Bananas	0.02	64334	1287	117.0	0.64
Coffee	0.21	-12777	-2683	-31.6	-0.68
TOTAL/AVERAGE	**0.99**	**29708**	**-4371**	**12.9**	**-0.09**

These farmers lack such capital and would feel secure to continue to undertake low or negative-return enterprises such as maize-bean and potatoes, which could guarantee some subsistence food. Resource-poor farmers prefer to diversify and tend to invest in familiar enterprises rather than undertake a new, high-return enterprise whose returns they are sceptical of.

2. During the seventies, production of coffee was so lucrative that every farmer rushed to its production in all coffee zones of the study sites. By then coffee prices were very attractive, weather conditions were favourable and input subsidies were prevalent and almost every farmer undertook production of coffee even in marginal coffee zones. By then the crop had became so esteemed that it served as sign of self-worth in smallholders' societies. Unfortunately the scenario has greatly changed particularly due to collapse of

[15] Source: Author's Field survey (2003/4)

coffee world market and introduction of SAPs in the last three decades. Yet in hope that the situation would improve, farmers continue to cling to coffee in all SFM farm typologies even though the enterprise has evidently become unproductive.

3. Some coffee legislation (Coffee Act, Cap 333) prohibits uprooting of coffee trees in all circumstances. Such should now be revised to provide for uprooting of trees in land parcels where it has become economical to continue with its production. Subdivision of land brought about by increasing population has rendered such legislations ineffective over the last three decades.

Mukanduini, Kirinyaga District

In gross margin (GM) analysis in Mukanduini, data was synthesized from 3 farms out of 5 (equivalent to 60 percent) in class I, from 5 farms out of 29 (equivalent to 11 percent) in class II and from 27 farms out of 239 (equivalent to 10 percent) in class III. Actual land sizes in different farm typologies in Mukanduini were relatively larger than in Kariti. These were 2.41, 1.18 and 1.10 hectares in classes I, II and III respectively. Eight main enterprises were undertaken both for subsistence and commercial purposes. These included maize-bean intercrop, potatoes, French beans, bananas, sweet potatoes, coffee, tomatoes and Dairy.

Class I farm typology

From Table 4.4.5, total land available for undertaking of different enterprises was 3.93 hectares while TGM for class I farm typology was Ksh. 324119. This was almost sixteen times more than TGM (Ksh 20818) obtained in Kariti from the same farm typology. This is due to larger farm sizes allowing undertaking of a variety of commercial enterprises (tomatoes, French beans, bananas) in Mukanduini than in Kariti. Apart from dairy and coffee, other enterprises in Kariti were more of subsistence than commercial nature therefore registering little or negative returns to resources invested. Tomatoes recorded the highest GM per unit land (Ksh. 173495) followed by French beans (Ksh. 102475) and bananas (Ksh. 43100). Maize-bean intercrop was fourth in terms of GM per hectare while coffee recorded the least GM per ha (Ksh.-9217).

Table 4.4.5. Farm organization and gross margins (Ksh) per hectare, enterprise, unit man-hour and working capital for profit maximization in class I in Mukanduini[16]

Enterprise	Land (Ha)	GM/hectare (Ksh)	GM/enterprise (Ksh)	GM/man hour (Ksh)	GM/working capital (Ksh)
Maize/Beans	2.00	40909	81817	17.8	0.67
Potatoes	0.20	9700	1940	4.0	0.17
F/Beans	0.04	173495	6939	52.9	1.61
Bananas	0.30	102475	30742	96.3	0.82
S/Potatoes	0.05	20083	1004	17.2	0.92
Coffee	0.34	-9217	-3134	-7.5	-0.35
Tomatoes	0.80	253176	202541	65.7	1.80
Dairy	0.20	11340	2268	10.0	0.25
TOTAL/AVERAGE	**3.93**	**601961**	**324119**	**32.0**	**0.74**

Class II farm typology

Total land available in this class was 1.91 ha while TGM was Ksh. 93784. This was seventeen times over and above TGM recorded in class I in Kariti. Tomatoes, bananas and French beans continued to lead in terms GM per unit land, labour and capital (Table 4.4.6). Maize-bean intercrop was fifth in this class while dairy and coffee had negative GMs per unit land, labour and capital.

[16] Source: Author's Field survey (2003/4)

Table 4.4.6. Farm organization and gross margins (GM) per hectare, enterprise, unit man-hour and working capital for profit maximization in class II in Mukanduini[17]

Enterprise	Land (Ha)	GM/hectare (Ksh)	GM/enterprise (Ksh)	GM/man hour (Ksh)	GM/working capital (Ksh)
Maize/Beans	1.00	25767	25767	13.1	0.54
Potatoes	0.08	5614	449	3.1	0.12
F/Beans	0.04	70300	2812	28.7	0.98
Bananas	0.10	94643	9464	108.5	0.81
S/Potatoes	0.05	14400	720	14.0	0.77
Coffee	0.20	-8441	1688	-8.0	-0.35
Tomatoes	0.34	165719	56344	51.5	1.89
Dairy	0.10	-838	-84	-0.8	-0.02
TOTAL/AVERAGE	**1.91**	**367164**	**93784**	**26.3**	**0.59**

Class III farm typology

Total amount of land available in this class was 1.77 and TGM was Ksh. 23845. This was about six times more than TGM from the same class in Kariti. Farmers in this class did not grow any French beans (Table 4.4.7). This perhaps was due to high labour and working capital requirements of the enterprise. Also its market is not as readily available as that of tomatoes and bananas. In this class, tomatoes gave the highest GM per ha (Ksh 113113) followed by bananas (Ksh. 90897) and sweet potatoes (Ksh. 12208). All other enterprises including maize-bean intercrop had negative GMs per unit land, labour and capital.

Theoretically, the foregoing discourse suggests that all farms' scarce resources in all classes should be allocated to bananas and tomatoes in Kariti and Mukanduini respectively. This is because these enterprises gave the highest returns per unit land, labour and working capital.

[17] Source: Author's Field survey (2003/4)

Although maize-bean intercrop took most land in every class and site, it did not give the highest GM per hectare. Returns per unit resource invested from some of the enterprises were also negative.

Table 4.4.7. Farm organization and gross margins (GM) per hectare, enterprise, unit man-hour and working capital for profit maximization in class III in Mukanduini[18]

Enterprise	Land (Ha)	GM/hectare (Ksh)	GM/enterprise (Ksh)	GM/man hour (Ksh)	GM/working capital (Ksh)
Maize/Beans	1.08	-7112	-7681	-4.0	-0.19
Potatoes	0.06	6389	383	3.7	0.15
F/Beans	0.00	0.00	0.00	0.0	0.00
Bananas	0.10	90897	9090	117.1	0.80
S/Potatoes	0.15	12208	1831	12.7	0.73
Coffee	0.10	-19589	-1959	-19.6	-0.80
Tomatoes	0.20	113113	22623	47.4	1.70
Dairy	0.08	-5526	-442	-4.6	-0.17
TOTAL/AVERAGE	**1.77**	**190381**	**23845**	**19.1**	**0.28**

Most of farmers in Kariti and Mukanduini are food-insecure, generate very little farm incomes and consequently live in poverty. From AFP, about 100 percent of all farmers in Kariti and about 98 percent in Mukanduini live below the poverty line of USD 1 per person per day (Table 4.4.8). Per capita daily income (USD) was computed by dividing the TGM for a given farm topology by the product of average family size in that class and the number of days in one year, the answer was then converted to USD. These results imply that all AFP were insufficient to ensure food

[18] Source: Author's Field survey (2003/4)

self-sufficiency, enhanced farm incomes and reduce poverty. Farm resource allocation was inefficient in all SFM-based farm typologies and therefore the AFP were sub-optimal.

Table 4.4.8. Annual total gross margins (TGM), farm incomes (Ksh/month) and equivalent per capita daily income (USD/day) for all SFM-based farm typologies in Kariti and Mukanduini[19]

Site	Class	Number of farmers	Percent (%)	Annual TGM	Farm income (Ksh/month)	Per capita income
KARITI	I	16	5	20818	1735	0.10
	II	114	39	5377	449	0.03
	III	163	56	-4371	-364	-0.03
TOTAL/AV.		**293**	**100**	**7275**	**606**	**0.03**
MUKANDUINI	I	5	2	324119	27009	1.9
	II	29	11	93784	7815	0.5
	III	239	87	23845	1987	0.1
TOTAL		**273**	**100**	**147249**	**12271**	**0.8**

However, it would be premature at this juncture to make a final conclusion until TGM from OFP were also computed and other viable smallholders' objectives adequately explored. This was done in the proceeding sub-section.

4.4.2 Optimal farm plans (OFP)

Optimal farm plans (OFP) for various SFM-based farm typologies in each study site were developed using linear programming (LP). TGM per year was used as a proxy for profits

[19] AV. = Average (TGM, Net income per month and Per capita daily income in USD). 1 USD = 77 KES (Kenya shillings)

comparison between AFP and OFP. GM per unit land, labour and working capital served as indicators of productivity of an individual resource. AFP showed the type and levels of activities undertaken to meet different farmers' objectives, under their own socio-economic circumstances. The gap in TGM between the two farm plans was used to test for optimality of AFP and therefore accept or reject *Optimal Farm Plans Hypothesis.*

It must be remembered that the basic LP solution discussed here emphasizes one objective at a time, while in actual life situation a farmer may want to maximize several objectives. The solutions so presented therefore should be used as guidelines on possible courses of action that a farmer may take in improving their allocative efficiency in carrying out farming operations.

Optimal Farm Plans in Kiriti, Maragwa District

Kariti, Maragwa District:

Optimal farm plans (OFP) and output interpretation for various models, in Kariti study site is presented in the following sub-sections.

Model 1: Profit maximization

In this model, it was assumed that small-scale farmers are purely profit maximizers. They will invest all scarce farm resources in enterprises that guarantee the highest return per unit of the most liming resource. GM analysis suggested that farmers in all farm typologies should allocate all farm resources to production of bananas in Kariti. This enterprise gave the highest returns per unit land, labour and capital invested. However, due to diversity in socio-economic circumstances of smallholder farmers, it was necessary to develop OFP for profit maximization for specific SFM-based farm typologies.

Class I farm typology

Table 4.4.9 shows levels of different activities or enterprises, individual enterprise contribution to TGM, optimal farm plans' TGM and shadow price or marginal value product (MVP) of the most limiting resource.

Table 4.4.9. Optimal Farm Plan (OFP) for class I farm typology under profit maximization model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.00	0.00	0.00	1.77	0.00	1.77
Enterprise GM (Ksh/ha)	15670	5896	3460	75700	-3105	97621
Entze. Contribution to TGM (Ksh)	0.00	0.00	0.00	133989	0.00	133989

TGM=Ksh 133989

Most limiting resource	Units	Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares	1.77	1.77	0.00	75700

MVP is defined as "the change in the value of objective function per unit change in right hand side (RHS) of a constraint" (Anderson et al., 1991). Land had a MVP of Ksh 75700 while MVP of labour and working capital was zero. Therefore, land was the most limiting resource.

Bananas dominated the OFP in this class while all other enterprises did not appear. TGM increased from Ksh. 20818 in AFP to Ksh. 133989 in OFP. This is equivalent an increase in TGM of over 500 percent. For resource-use optimisation, all available land should be allocated to production of bananas as it had the highest GM per hectare of land (Ksh 75700).

? testing hypothesis ✓

Class II farm typology

From Table 4.4.10, bananas again dominated the optimal farm plan while all other enterprises did not appear in the plan.

Table 4.4.10. Optimal Farm Plan (OFP) for class II farm typology under profit maximization model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.00	0.00	0.00	1.34	0.00	1.34
Enterprise GM (Ksh/ha)	5095	-10182	1489	72921	-1481	67842
Entze. Contribution to TGM (Ksh)	0.00	0.00	0.00	97714	0.00	97714

TGM = Ksh 97714

Most limiting resource	Units	Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares	1.34	1.34	0.00	72921

Land was the most limiting resource in this class, suggesting that it would be more economical to allocate all available land to bananas. TGM from AFP was Ksh 5377 as compared to Ksh. 97714 from OFP in this farm typology. This was equivalent to an increase in TGM of more than 1700 percent as one moved from AFP to OFP.

? testing hypothesis ✓

Class III farm typology

In class III farm typology, bananas had the highest TGM and also GM per unit land, labour and capital (Table 4.4.11). It dominated the OFP while all other enterprises were excluded. TGM in this typology was Ksh. –4372 from the AFP as opposed to Ksh. 63691 in OFP. This is equivalent to an increase in TGM of over 1500 percent. This implies that for profit maximization, all available land should be allocated to bananas.

Table 4.4.11. Optimal Farm Plan (OFP) for class III farm typology under profit maximization model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.00	0.00	0.00	0.99	0.00	0.99
Enterprise GM (Ksh/ha)	-3283	-19269	703	64334	-12777	29708
Entze. Contribution to TGM (Ksh)	0.00	0.00	0.00	63691	0.00	63691
TGM = Ksh 63691						
Most limiting resource	Units		Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares		0.99	0.99	0.00	64334

Total gross margins (TGM_o) from OFP, were found to be many hundred-folds over and above total gross margins (TGM_a) from AFP. This led to rejection of null hypothesis (H0) advanced in this study that "the actual farm plans are optimal in all SFM-based farm typologies". This implies that the existing resource allocation by smallholders is inefficient and that the AFP are sub-optimal. Therefore, there is substantial capacity to generate higher farm incomes by optimizing the use of available resources. The OFP from profit maximization model favored specialization. The OFP has only one activity (bananas) while the AFP had 5 five activities (Maize-bean, potatoes, Dairy, bananas and coffee). If farmers were to maximize their profits, they need to allocate all farm resources (land, labour and capital) to production of bananas only.

this number is not consistent with numbering on page 74 (of Model 1)

1. **Model 2: Food self-sufficiency model**

Though TGM (proxy for profits) were high and seemed attractive in model 1, farmers were also interested in meeting their families' food requirements from domestic production. It was therefore necessary to carry out quantitative analysis of another farm model, which ensured that all household food requirements are met from on-farm production. Minimum land required for food production in each farm typology was imposed on the model as an extra constraint, to investigate how the optimal solution would behave. During the farm surveys, maize and beans were established as the most important foodstuffs in both study sites while the average number of members per family in each farm typology was determined. Maize-bean intercrop was the most predominant cropping system.

Class I farm typology

In model 2, maize-bean and bananas enterprises dominated the optimal farm plan. Minimum land required for subsistence food production in this class was 0.53 hectares (Table 4.4.12).

Table 4.4.12. Optimal Farm Plan (OFP) for class I farm typology for food self-sufficiency model *in Kariti*

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.53	0.00	0.00	1.24	0.00	1.77
Enterprise GM (Ksh/ha)	15670	5896	3460	75700	-3105	97621
Entze. Contribution to TGM (Ksh)	8305	0.00	0.00	93868	0.00	102173

TGM=Ksh 102173

Most limiting resource	Units	Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares	1.77	1.77	0.00	75700

TGM declined from Ksh 133989 in pure profit maximization model to Ksh 102173 in this model, a decrease of only 16 per cent. TGM from AFP was Ksh 20818 as compared to Ksh 102173 in OFP, representing an increase of more than 500 percent.

Class II farm typology

From Table 4.4.13, maize-bean intercrop took 07.8 hectares while the remainder of land over and above subsistence food requirements was allocated to bananas (0.56 hectares). This is because bananas had the highest GM per unit land, labour and working capital as compared to all other enterprises. TGM from AFP was Ksh 5377 as compared to Ksh 44810 from OFP, representing an increase of over 700 percent. Even though TGM from model 2 was slightly lower than TGM from model 1, all household food requirements were assured from a sustainable and cheaper on-farm supply.

Table 4.4.13. Optimal Farm Plan (OFP) for class II farm typology for food self-sufficiency model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.78	0.00	0.00	0.56	0.00	1.34
Enterprise GM (Ksh/ha)	5095	-10182	1489	72921	-1481	67842
Entze. Contribution to TGM (Ksh)	3974	0.00	0.00	40836	0.00	44810

TGM = Ksh 44810

Most limiting resource	Units	Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares	1.34	1.34	0.00	72921

Class III farm typology

This model suggested that 0.76 hectares of land should be allocated to maize-beans enterprise in order to meet household food self-sufficiency (Table 4.4.14). The remaining land (0.23 ha) was allocated to bananas. TGM from AFP in this model was Ksh –4372 as compared to Ksh 12302 from OFP, representing an increase of over 380 percent. Again, even though TGM in this model (Ksh 12302) was lower than TGM from model 1 (Ksh 63691), it met all family food requirements.

Table 4.4.14. Optimal Farm Plan (OFP) for class III farm typology for food self-sufficiency model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.76	0.00	0.00	0.23	0.00	0.99
Enterprise GM (Ksh/ha)	-3283	-19269	703	64334	-12777	29708
Entze. Contribution to TGM (Ksh)	-2495	0.00	0.00	14797	0.00	12302
TGM = Ksh 12302						
Most limiting resource	Units		Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares		0.99	0.99	0.00	64334

In a purely competitive market environment, it would be advisable to allocate all land to bananas and in turn purchase all household food requirements. Given that the market price for a produce *p*, would be fixed all what a farmer has to do is to determine how much of the produce *x*, he requires for his household food needs. This scenario assumes that there are many farms producing an identical product *q*, and that each farm is only a small part of the market (Varian, 2000). However, markets are not 100 percent perfect and therefore, food procurement is likely to suffer from price distortions (Nyikal, 2000). Over time, it is likely that supply of food from markets would be more expensive than own production. OFP from this model implied that, if all other factors were held constant, it is more economical to meet household food requirements from on-farm production. Nevertheless, smallholders prefer allocating their scarce farm resources to food production than just for purely profit maximization. hypothesis ?

strange numbering

2. Model 3: Opportunity cost of family labour is equal to zero

This section is devoted to exploring what would be the effects on optimal solution from changes in magnitude of right-hand side (RHS) of a constraint. In an LP model change in RHS, implies that there is a change in the level of that particular constraint. Such a model would help to investigate the effects on optimal solution from changes in farmers' resource levels.

From slack values, family labour was the second most limiting resource after land in smallholder farming systems. In the foregoing two models, cost of family labour was considered as a "real" cost and its opportunity cost (OC) included in development of optimal farm plans. However in this model, cost of family labour was assumed to be a "sunk" cost, and its OC taken as zero. A "sunk" cost is one that is not affected by decision made and will be incurred regardless of the values of decision variables (Anderson et al., 1991). OC of family labour was therefore not reflected in the objective function. This model helped to investigate returns per man-hour of labour when cost of family labour was disregarded. The opportunity cost of family labour is also called the shadow price of labour. When cost of a resource is a "sunk" cost, the shadow price of resource can be defined as "the value of an additional unit of that resource".

Class I farm typology

In this class, TGM increased considerably and each enterprise recorded positive returns per unit labour. Banana production was the most dominant enterprise in the OFP (Table 4.4.15). TGM in this model rose from Ksh 20818 in AFP to Ksh 152700 in the OFP, an increase of over 600 percent. Return to labour in this model was higher than in model 1. Average return to labour in GM per man-hour rose from Ksh 23 in model 1 to Ksh 202 in model 3. This GM gap between the two models (Ksh 206) represented the shadow price of family labour. As defined above, this represented the value of an additional man-hour of family labour. Smallholder farmers rely more on family labour than hired labour, therefore family labour had greater opportunity cost.

hypothesis ?

Table 4.4.15. Optimal Farm Plan (OFP) for class I farm typology when opportunity cost of *family labour = 0 in* Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.00	0.00	0.00	1.77	0.00	1.77
Enterprise GM (Ksh/ha)	38492	26079	20225	86271	11850	182917
Entze. Contribution to TGM (Ksh)	0.00	0.00	0.00	152700	0.00	152700
TGM= Ksh 152700						
Most limiting resource	Units	Amnt. Avail	Amnt. Used		Surplus	MVP (Ksh)
Land	Hectares	1.77	1.77		0.00	86271

Class II farm typology

All other enterprises apart from bananas did not appear in OFP (Table 4.4.16). OFP favoured specialization, which seemed to agree with the concept of profit maximization of undertaking those activities that guaranteed the highest returns per unit of most limiting resource. In model 3, all returns to resources were positive while in model 1 where OC of family labour was considered as a "real" cost; potatoes and coffee recorded negative GMs. TGM increased from Ksh 5377 in AFP to Ksh 111073 in OFP in model 3, representing an increase of about 2000 percent. GM per man-hour of labour in models 1 and 3 were Ksh. 22 and 317 respectively.

Again, the difference between the two GM (Ksh 295) represented the shadow price of family labour. Shadow price of labour in class II farm typology is more than that in class I. This is because farmers in class II rely more on family labour than those in class I due to their relatively lower wealth status.

Table 4.4.16. Optimal Farm Plan (OFP) for class II farm typology when opportunity cost of family labour = 0 in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.00	0.00	0.00	1.34	0.00	1.34
Enterprise GM (Ksh/ha)	27221	9168	17423	82890	13524	150226
Entze. Contribution to TGM (Ksh)	0.00	0.00	0.00	111073	0.00	111073
TGM=Ksh 111073						
Most limiting resource	Units		Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares		1.34	1.34	0.00	82890

Class III farm typology

Table 4.4.17 shows OFP for class III farm typology in Kariti study site. All other enterprises apart from bananas were excluded from the OFP. TGM for AFP was Ksh –4371 as compared to Ksh 72918 in OFP in model 3. The increase in TGM was more than 1700 percent. From gross GM analysis, relative productivity of family labour increased from Ksh 13 in model 1 to Ksh 552 per man-hour in model 3. The difference in GM per man-hour (Ksh 539) showed that family labour in this farm typology had a greater OC than in all other classes. According to PLAR wealth-based classification, class III farmers were the poorest and therefore heavily reliant on family labour for almost all farm operations. Use of casual labour in class III was limited to only 6 percent as compared to 12 and 16 percent in classes II and I respectively.

These results indicated that, family labour was the second most limiting resource after land in all smallholder farm topologies in Kariti. In fact it becomes even more limiting as one moves from class I to class III. This was illustrated by OC of family labour, which increases as one goes down the SFM-based farm typologies.

Table 4.4.17. Optimal Farm Plan (OFP) for class III farm typology when opportunity cost of family labour = 0 in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.00	0.00	0.00	0.99	0.00	0.99
Enterprise GM (Ksh/ha)	18258	-2144	16820	73655	1760	108349
Entze. Contribution to TGM (Ksh)	0.00	0.00	0.00	72918	0.00	72918
TGM = Ksh 72918						
Most limiting resource	Units		Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares		0.99	0.99	0.00	73655

This is contrary to a popular belief that there exists excess labour in smallholder farming systems. This section helped to conclude that, OC of family labour in all farm typologies is a "real" cost and cannot be considered as a "sunk" cost (OC = 0). Farmers therefore, need to invest family labour in the most profitable way to ensure that they get the highest returns per man-hour of labour. The gap in TGM between the two farm plans in all farm typologies was much more than the 20 percent rule, advanced for test of *optimal farm plans* hypothesis in this study.

3. Model 4: Technology change

Maize is the most important food staple in Kenya today (GoK, 1979, GoK, 1980, Hassan, 1998). A lot of research has been done on varieties development, agronomy, physiology and marketing

(KARI, 2002). This is meant to boost productivity of the smallholders farming systems, both for subsistence and commercial purposes. From the AFP, it was established that 99 percent of all farmers in both study sites use FYM with modest levels of inorganic fertilizers as an integrated SFM approach to combating nutrient depletion. It was necessary therefore, to investigate the economic competitiveness of maize-bean enterprise in AFP as compared to some of SFM technologies demonstrated in on-farm trials in the course of this study. Crop yield increase alone is a necessary but not sufficient criterion to justify adoption of a new SFM technology by smallholder farmers. There is need to provide an economic justification for any new technology in order to ensure high returns to scarce farm resources. A new technology would imply a change in total variable costs (TVC) that farmers would incur if they were to adopt such a technology. Its adoption may lead to changes in land, labour and/or working capital levels requirements.

This model was used to investigate changes in returns per shilling of working capital that would be brought about by adoption of a new SFM technology. Agronomic and economic data from some selected technologies in on-farm mother trials were used to formulate this model. From NPV values of various integrated SFM technologies presented in the previous sections, Manure (5 ton/ha) + Fertilizer (60 kgN/ha), Manure (5 tons/ha) + Fertilizer (40 kg N/ha) and Manure (5 tons/ha) + Fertilizer (20 kg N/ha) were ranked as the best three technologies in that order. These SFM technologies could help resource-poor smallholders build up their soil nutrient stocks. Shadow prices for resources in technology change model were used to determine return to working capital from Manure + Fertilizer technologies under actual farmers' resource constraints.

Class I farm typology

From farm surveys carried out in Kariti, it was established that plant nutrient levels applied by farmers in class 1 were Manure (5 tons/ha) + Fertilizer (35 kg N/ha). If farmers in this class were to adopt Manure (5 ton/ha) + Fertilizer (60 kgN/ha), it would be important to compare the model's TGM and returns per working capital to that of AFP (Table 4.4.18). Land allocated to maize-bean enterprise declined from 0.53 hectares in model 1 to 0.16 hectares in model 2. This implied that more land was relocated from maize-bean enterprise to bananas. TGM from AFP was Ksh 20818 as compared to Ksh 132627 from OFP. This is an increase of over 500 percent. Also return per unit working capital increased from Ksh 0.2 to Ksh 0.3 in model 4. Therefore the new technology increased productivity of working capital by 50 percent. This implies that every shilling of working capital invested in this technology, was 1.5 times more productive when invested in the new technology than in the actual farmers' technology.

Table 4.4.18. Optimal Farm Plan (OFP) for class I farm typology under improved technology model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.16	0.00	0.00	1.61	0.00	1.77
Enterprise GM (Ksh/ha)	67188	5896	3460	75700	-3105	149139
Entze. Contribution To TGM (Ksh)	10750	0.00	0.00	121877	0.00	132627
TGM=Ksh 132627						
Most limiting resource	Units		Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares		1.77	1.77	0.00	75700

Class II farm typology

Farmers in this class, use Manure (2.5 tons/ha) + Fertilizer (28 kg N/ha) for replenishment of soil fertility while Manure (5 ton/ha) + Fertilizer (40 kgN/ha) was number two in terms NPV ranking. Land required for household food production declined from 0.8 ha in model 2 to only 0.16 ha in this model (Table 4.4.19). Food requirements could be met from less land under the new technology than under actual farmers' technology. The extra land was relocated to bananas resulting in more TGM. TGM from AFP was Ksh 5377 as compared to Ksh 96292 from OFP in this model. This increase is equivalent to over 1500 percent. Average returns to working capital also increased as one moved from model 1 to model 4. It rose from Ksh 0.13 in model 1 to Ksh 0.28 in model 4, representing an increase of 115 percent. This implied that every shilling invested in the new technology is about 2 times more productive than in actual farmers' technology.

Table 4.4.19. Optimal Farm Plan (OFP) for class II farm typology under improved technology model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.16	0.00	0.00	1.18	0.00	1.34
Enterprise GM (Ksh/ha)	64030	-10182	1489	72921	-1481	1267770
Entze. Contribution to TGM (Ksh)	102445	0.00	0.00	86047	0.00	96292

TGM = Ksh 96292

Most limiting resource	*Units*	*Amnt. Avail*	*Amnt. Used*	*Surplus*	*MVP (Ksh)*
Land	Hectares	1.34	1.34	0.00	72921

Class III farm typology

Plant nutrient levels used in class III by farmers were Manure (3.5 tons/ha) + Fertilizer (28 kg N/ha) while Manure (5 ton/ha) + Fertilizer (40 kgN/ha) were ranked as number three in terms of NPV per hectare. TGM was Ksh -4372 in AFP as compared to Ksh 63233 from OFP in this model (Table 4.4.20). This increase was more than 1500 per cent. Returns per shilling of working capital also increased from Ksh – 0.09 in model 1 to 0.13 in model 4, equivalent to more than 240 percent increase. This implied that every shilling invested in the new technology was about 2.4 times more productive than in actual farmers' technology.

Table 4.4.20. Optimal Farm Plan (OFP) for class III farm typology under improved technology model in Kariti

Activity	Maize and beans	Potatoes	Dairy	Bananas	Coffee	Total
Activity Level (Ha)	0.15	0.00	0.00	0.84	0.00	0.99
Enterprise GM (Ksh/ha)	61286	-19269	703	64334	-12777	94277
Entze. Contribution to TGM (Ksh)	9193	0.00	0.00	54041	0.00	63233
TGM = Ksh 63233						
Most limiting resource	Units		Amnt. Avail	Amnt. Used	Surplus	MVP (Ksh)
Land	Hectares		0.99	0.99	0.00	64334

Technology change model led to a big increase in productivity and profitability of smallholders' production systems. It was established from farm surveys that most farmers do not produce enough food to meet their annual subsistence needs. It was established from model 4 however, that maize and bean outputs could be more than enough to meet all household food requirements. Extra land that would have otherwise been allocated to food was reallocated to the most profitable enterprise. TGM and GM/Ksh of working capital under new technologies increased many times over and above TGM and GM/Ksh under actual farmers' technologies. In fact productivity of working capital increased even more as one moved down the SFM-based farm typologies. This is because technology change increased output and therefore profitability of maize-bean enterprise substantially. Farmers should therefore be encouraged to take up these technologies.

* What value does this sensitivity analysis add to your discussion? Any effect on hypothesis?

Sensitivity analysis

The primary reason why sensitivity or post-optimality analysis is important is that real world problems exist in a dynamic environment. Prices of inputs and outputs change, demand and supply of labour fluctuate while land availability is not fixed over time. In such an environment, some of the LP model coefficients are expected to change. It is important therefore for a decision maker to determine how such changes could affect the optimal solution to an LP problem. Such information would enable one to respond to such changes without requiring that the solution be completely revised. However, sensitivity analysis from computer software packages considers only one change at a time while all other coefficients of an LP problem are held constant.

Is this statement correct?

In addition to the output already mentioned in the preceding sections, information on sensitivity analysis was also obtained from the computer printouts. These included:

1. Objective coefficients range

Objective coefficients range is also called optimality range. This shows the range of values over which an objective coefficient may vary without causing any change in values of decision variables in the optimal solution. To obtain the upper limit of optimality ranges, allowable increases were added to the current values of the coefficients. To get the lower limit of optimality range, allowable decreases were subtracted from the current values of the coefficients. Bananas were the most profitable enterprise and its ranges over which the solution remain feasible are showed in Table 4.4.21.

The objective coefficients range for class I in model 1 for example, implies that profit from bananas could decrease to about Ksh 60,030 per hectare or increase to infinity and still banana would remain to be the most profitable enterprise. A drop in banana prices, output or increase in input prices could bring a decline in profits while an increase in banana prices, output or decrease in input prices would lead to increase in profits.

Table 4.4.21. Sensitivity analysis ranges for objective coefficients (Ksh) over which the basis remained unchanged in all the four models in Kariti[20]

Model	SFM Class	Current coefficient	Allowable increase	Allowable decrease
1	I	75700	INFINITY	60030
	II	72921	INFINITY	67826
	III	64334	INFINITY	63631
2	I	75700	INFINITY	60030
	II	72921	INFINITY	67826
	III	64334	INFINITY	63631
3	I	86271	INFINITY	47779
	II	82890	INFINITY	55669
	III	73655	INFINITY	55397
4	I	75700	INFINITY	8512
	II	72921	INFINITY	8891
	III	64334	INFINITY	3048

Objective coefficients range could give the decision maker some room over which he can allow these factors to fluctuate without adversely affecting the optimal solution.

Other ranges in different classes and model from the table could similarly be interpreted. Of all the objective function coefficients ranges, class III in model 4 had the widest range, indicating that bananas had a very wide profit margin as compared to other enterprises.

[20] Source: Computer LINDO printout

2. RHS coefficients range

Sensitivity analysis also provided information showing RHS coefficients' ranges over which the basis is unchanged (Table 4.4.22). This is also called feasibility range and shows range over, which the RHS coefficients may vary without changing the value of dual or shadow price. In this case land was found to be the most limiting resource and its ranges over, which the solutions remained feasible, are also shown. In all classes and models, land was the most limiting resource and therefore had very narrow ranges over which optimal solution could remain valid. The optimal solution used up all land in every class. Such scenario does not leave a decision maker with much room for maneuver when it comes to land allocation. Managerial attention should be focused on those coefficients that have narrowest ranges and near the end points of such ranges. In such cases, a small change in RHS coefficients could necessitate modifying the entire optimal solution.

Optimal Farm Plans in Muk..., Kirinyaga

Mukanduini, Kirinyaga District:

Again four different models were analysed through LP. These included:

1. Model 1: Profit maximization
2. Model 2: Food self-sufficiency
3. Model 3: OC of family labour = 0
4. Model 4: Technology change

Optimal farm plans derived from these models are illustrated in the following sub-sections. Discussion of the results followed the same analogy as in Kariti and may not be presented in much detail here.

Table 4.4.22. Sensitivity analysis ranges for land coefficients (Hectares) over which the basis remained unchanged in all the four models in Kariti[21]

Model	SFM Class	Current RHS	Allowable increase	Allowable decrease
1	I	1.77	1.04	1.77
	II	1.34	1.21	1.34
	III	0.99	1.44	0.99
2	I	1.77	1.30	1.24
	II	1.34	1.70	0.56
	III	0.99	1.90	0.23
3	I	1.77	0.47	1.77
	II	1.34	0.63	1.34
	III	0.99	0.83	0.99
4	I	1.77	1.30	1.61
	II	1.34	1.54	1.18
	III	0.99	1.70	0.84

1. Model 1: Profit maximization

Actual farm plans (AFP) showed the type and levels of enterprises undertaken to meet different farmers' objectives, under their own socio-economic circumstances. TGMs from AFP were compared with TGM from optimal farm plans (OFP) to test for optimality in resource use in different farm typologies.

[21] Source: Computer LINDO printout

Class I farm typology

In Mukanduini, land was the most limiting resource and had a MVP of Ksh 253176 (Table 4.4.23). Tomatoes dominated the OFP in this class while the rest of enterprises did not appear. TGM increased from Ksh. 324119 in AFP as compared to Ksh. 994982 in OFP.

Table 4.4.23. Optimal farm plan (OFP) for class I typology for under profit maximization model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.00	0.00	0.00	0.00	0.00	0.00	3.93	0.00	3.93
GM (Ksh/Ha)	40909	9700	173495	102475	20083	-9217	253176	11340	601961
TGM (Ksh)	0.00	0.00	0.00	0.00	0.00	0.00	994982	0.00	994982
TGMo	**= Ksh**	**994982**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	3.93	3.93	0.00	253176			

This is an increase of over 200 percent. For resource use optimization, all available land should be allocated to tomatoes as it had the highest GM per hectare of land (Ksh 253176).

Class II farm typology

From Table 4.4.24, tomatoes were the only enterprise in the OFP. It would be more economical then to allocate all available land to tomatoes. TGM from AFP was Ksh 93784 as compared to Ksh. 316524 from OFP in this farm typology. This represented an increase of over 70 percent in TGM as one moved from AFP to OFP.

Table 4.4.24. Optimal farm plan (OFP) for class II farm typology under profit maximization model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.00	0.00	0.00	0.00	0.00	0.00	1.91	0.00	1.91
GM (Ksh/Ha)	25767	5614	70300	94643	14400	-8441	165719	-838	367164
TGM (Ksh)	0.00	0.00	0.00	0.00	0.00	0.00	316524	0.00	316524
TGMo	**= Ksh**	**316524**							
	Ltng Resource	Units	Available Amnt	Used Amnt	Surplus	MVP (Ksh)			
	Land	Hectares	1.91	1.91	0.00	165719			

Class III farm typology

In class III farm typology, tomatoes had the highest TGM and also GM per unit land, labour and working capital (Table 4.4.25). TGM from AFP was Ksh 23845 as opposed to Ksh 200210 in OFP. This TGM gap between AFP and OFP was over 700 percent. This implies that for profit maximization, all available land should be allocated to tomatoes.

In profit maximization model, TGM in both AFP and OFP fell considerably as one moved from class I to class II farm typologies. This is because farmers allocated less land to tomatoes as total available land decreases down SFM classes. Also due to decline in labour and capital availability and productivity, returns to these resources equally fell across SFM farm typologies. Tomatoes are grown extensively in Mukanduini and have big market in the district and beyond. This is activity is undertaken purely for commercial purposes and fetches very high prices especially off-season crop.

Table 4.4.25. Optimal farm plan (OFP) for class III under profit maximization model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.00	0.00	0.00	0.00	0.00	0.00	1.77	0.00	1.77
GM (Ksh/Ha)	-7112	6389	0.00	90897	12208	-19589	113113	-5526	190380
TGM (Ksh)	0.00	0.00	0.00	0.00	0.00	0.00	200210	0.00	200210
TGMo	**= Ksh**	**200210**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	1.77	1.77	0.00	113113			

2. **Model 2: Food self-sufficiency model**

Again minimum land requirement for food security was imposed on this model as an extra constraint, to investigate how the optimal solution would behave.

Class I farm typology

In model 2, maize-bean and tomatoes enterprises dominated the OFP. Land required for subsistence in this class was 0.18 hectares. TGM declined slightly from Ksh 994982 in pure profit maximization model to Ksh 956774 in this model, a decrease of only 4 percent (Table 4.4.26). However, all food supply to the household was assured. TGM from AFP was Ksh 324119 as compared to Ksh 956774 in OFP in this model. This represents an increase of about 195 percent.

Table 4.4.26. Optimal Farm Plan (OFP) for class I under food self-sufficiency model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.18	0.00	0.00	0.00	0.00	0.00	3.75	0.00	3.93
GM (Ksh/Ha)	40909	9700	173495	102475	20083	-9217	253176	11340	601961
TGM (Ksh)	7364	0.00	0.00	0.00	0.00	0.00	94941	0.00	956774
TGMo	**= Ksh**	**956774**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	3.93	3.93	0.00	253176			

Class II farm typology

From Table 4.4.27, maize-bean intercrop took 0.33 hectares while the remainder of land over and above subsistence food requirements was allocated to tomatoes (1.58 hectares). TGM from AFP was Ksh 93784 as compared to Ksh 270339 in OFP, representing an increase of over 188 percent. Again even though TMG from model 2 was slightly lower than TGM from model 1, all household food requirements were assured from a sustainable and cheaper on-farm supply.

Table 4.4.27. Optimal Farm Plan (OFP) for class II farm typology under food self-sufficiency model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	
Act level (Ha)	0.33	0.00	0.00	0.00	0.00	0.00	1.58	0.00	1.91
GM (Ksh/Ha)	25767	5614	70300	94643	14400	-8441	165719	-838	164
TGM (Ksh)	8503	0.00	0.00	0.00	0.00	0.00	261836	0.00	
TGMo	**= Ksh**	**270339**							
	Ltng Resource	Units	Available Amnt	Used Amnt	Surplus	MVP (Ksh)			
	Land	Hectares	1.91	1.91	0.00	165719			

Class III farm typology

This model suggested that 1.0 hectares of land should be allocated to maize-beans enterprise in order to meet household food self-sufficiency (Table 4.4.28). The remaining land (0.77 ha) should be allocated to tomatoes. TGM from AFP was Ksh 23845 as compared to Ksh 79985 in OFP, representing an increase of 235 percent. Again, even though TGM in this model (Ksh 79985) was lower than TGM from model 1 (Ksh 200210), all family food requirements were met from on-farm production.

Table 4.4.28 Optimal Farm Plan (OFP) for class III under food self-sufficiency model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	1.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	1.77
GM (Ksh/Ha)	-7112	6389	0.00	90897	12208	-19589	113113	-5526	190380
TGM (Ksh)	-7112	0.00	0.00	0.00	0.00	0.00	87097	0.00	79985
TGMo	**= Ksh**	**79985**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	1.77	1.77	0.00	113113			

3. Model 3: Opportunity cost (OC) of family labour = 0

As mentioned in previous sections, family labour was the second most limiting resource after land in smallholder farming systems. In this model, OC of family labour was assumed to be zero and was therefore not reflected in the objective function.

Class I farm typology

All enterprises recorded positive GM per unit land except coffee. Tomatoes were the most dominant enterprise in the optimal farm plan (Table 4.4.29). TGM in this model rose from Ksh 324119 in AFP to Ksh 1078156 in OFP, an increase of over 233 percent. Average return to labour rose from Ksh 32 in model 1 to Ksh 67 per man-hour in model 3. This GM gap between the two models (Ksh 35) represented the shadow price of family labour in class I. This is the value of an additional man-hour of family labour.

Table 4.4.29. Optimal Farm Plan (OFP) for class I under opportunity cost of family labour = 0 model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.00	0.00	0.00	0.00	0.00	0.00	3.93	0.00	3.93
GM (Ksh/Ha)	53552	22944	188895	108316	26485	-2452	274340	17594	689674
TGM (Ksh)	0.00	0.00	0.00	0.00	0.00	0.00	1078156	0.00	1078156
TGMo	**= Ksh**	**1078156**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	3.93	3.93	0.00	274340			

Class II farm typology

All other enterprises apart from tomatoes did not appear in the optimal farm plan (Table 4.4.30).

Table 4.4.30. Optimal Farm Plan (OFP) for class II farm typology under family labour = 0 model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.00	0.00	0.00	0.00	0.00	0.00	1.91	0.00	1.91
GM (Ksh/Ha)	38789	17645	84345	100397	21211	-1461	165255	5906	432087
TGM (Ksh)	0.00	0.00	0.00	0.00	0.00	0.00	315637	0.00	315637
TGMo	**= Ksh**	**315637**							
	Ltng Resource	Units	Available Amnt	Used Amnt	Surplus	MVP (Ksh)			
	Land	Hectares	1.91	1.91	0.00	165255			

TGM increased from Ksh 93784 in AFP to Ksh 315637 in OFP in model 3, representing an increase of about 237 percent. Returns per man-hour of labour in models 1 and 3 were Ksh. 26 and 68 respectively. Again, the difference between the two GM (Ksh 42) represented the shadow price of family labour in class II.

Class III farm typology

All other enterprises apart from tomatoes were excluded from the OFP (Table 4.4.31). TGM from AFP in model 3 was Ksh 23845 while that from OFP was Ksh 202169. This is equivalent to an increase of more than 740 percent. From gross GM analysis, relative productivity of family labour increased from Ksh 19 in model 1 to Ksh 68 per man-hour in model 3. The difference in GM per man-hour (Ksh 49) showed that family labour in class III had a greater OC than in other classes.

Table 4.4.31. Optimal Farm Plan (OFP) for class III under family labour = 0 model in *Mukanduini*

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.00	0.00	0.00	0.00	0.00	0.00	1.77	0.00	1.77
GM (Ksh/Ha)	7047	19855	0.00	97026	19798	-11687	114220	3874	250133
TGM (Ksh)	0.00	0.00	0.00	0.00	0.00	0.00	202169	0.00	202169
TGMo	**= Ksh**	**202169**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	1.77	1.77	0.00	114220			

Class III farmers therefore relied more heavily on family labour for almost all farm operations. Use of casual labour in class III was limited to 18 percent as compared to 30 and 42 percent in classes II and I respectively. Farmers in all classes in Mukanduini used more casual labour than in Kariti. This could be due to relative large farm parcels and labour-intensive enterprises such as tomatoes and French beans.

Shadow price of family labour was Ksh 35, 42 and 49 in classes I, II and III respectively. This indicated the importance of family labour as one moves down the SFM-based farm typologies. OC of family labour cannot be assumed and therefore should be treated as a "real" cost. Farmers need to invest family labour in the most profitable way to ensure highest returns per man-hour of labour.

Model 4: Technology change

This model was used to investigate changes in returns per shilling of working capital brought about by adoption of a new technology. TGM from Manure (5 ton/ha) + Fertilizer (60 kg N/ha), Manure (5 tons/ha) + Fertilizer (40 kg N/ha) and Manure (5 tons/ha) + Fertilizer (20 kg N/ha) were compared with TGM from actual farm plans (AFP) using the current levels of manure + fertilizers.

Class I farm typology

The plant nutrient levels applied by farmers in class 1 in Mukanduini were Manure (5.5 tons/ha) + Fertilizer (30 kg N/ha). If farmers in this class adopted Manure (5 ton/ha) + Fertilizer (60 kg N/ha), it would be important to compare its TGM and returns per shilling of working capital to that of AFP (Table 4.4.32). From AFP, TGM was Ksh 324119 as compared to Ksh 976032 in the OFP, an increase equivalent to 200 percent. Return per shilling working capital increased from Ksh 0.7 in model 1 to Ksh 0.8 in model 4. Every shilling of working capital invested in this technology, was 14 percent more productive than in actual farmers' technologies. In this model land allocated to maize-bean enterprise decreased from 0.18 to 0.11 hectares in model 2. This implies that more land would be allocated to tomatoes than in model 1.

Table 4.4.32. Optimal Farm Plan (OFP) for class I under technology change model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.11	0.00	0.00	0.00	0.00	0.00	3.82	0.00	3.93
GM (Ksh/Ha)	80905	9700	173495	102475	20083	-9217	253176	11340	641957
TGM (Ksh)	8896	0.00	0.00	0.00	0.00	0.00	967132	0.00	976032
TGMo	**= Ksh**	**976032**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	3.93	3.93	0.00	253176			

Class II farm typology

Farmers in this class used Manure (3 tons/ha) + Fertilizer (26 kg N/ha) for replenishment of soil fertility while Manure (5 ton/ha) + Fertilizer (40 kg N/ha) was number two in terms NPV ranking. TGM from AFP was only Ksh 93784 as compared to Ksh 305127 from OFP in this model (Table 4.4.33). This increase is equivalent to 225 percent. Average returns to working capital also increased from Ksh 0.6 in model 1 to Ksh 0.7 in model 4, representing an increase of about 17 percent. Again, working capital invested in the new technology for maize production was 17 percent more productive than in actual farmers' technology. Land for household food production declined from 0.33 ha in model 2 to only 0.14 ha in this model. Food requirements therefore, were met from less land under new technology than under farmers' technology. The extra land was relocated to tomatoes resulting in more TGM.

Table 4.4.33. Optimal Farm Plan (OFP) for class II farm typology under technology change model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.14	0.00	0.00	0.00	0.00	0.00	1.77	0.00	1.91
GM (Ksh/Ha)	84320	5614	70300	94643	14400	-8441	165719	-838	425717
TGM (Ksh)	11805	0.00	0.00	0.00	0.00	0.00	293323	0.00	305127
TGMo	**= Ksh**	**305127**							
	Ltng Resource	Units	Available Amnt	Used Amnt	Surplus	MVP (Ksh)			
	Land	Hectares	1.91	1.91	0.00	165719			

Class III farm typology

Plant nutrient levels used in class III by farmers were Manure (2.5 tons/ha) + Fertilizer (18 kg N/ha) while Manure (5 ton/ha) + Fertilizer (20 kg N/ha) were ranked as number three in terms of NPV per hectare. TGM from AFP was Ksh 23845 in model 1 as compared to Ksh 183352 from OFP in this model was (Table 4.4.34). This increase was about 669 percent. Returns per unit shilling of working capital also increased from Ksh 0.3 in model 1 to 0.4 in model 4, which is equivalent to more than 33 percent increase. This implies that every shilling of working capital invested in this model were 33 percent more productive than in actual farmers' technology.

Table 4.4.34. Optimal Farm Plan (OFP) for class III from technology change model in Mukanduini

Activity	Maize & beans	Potatoes	French beans	Bananas	Sweet potatoes	Coffee	Tomatoes	Dairy	Total
Act level (Ha)	0.22	0.00	0.00	0.00	0.00	0.00	1.55	0.00	1.77
GM (Ksh/Ha)	36487	6389	0.00	90897	12208	-19589	113113	-5526	233979
TGM (Ksh)	8027	0.00	0.00	0.00	0.00	0.00	175325	0.00	183352
TGMo	**= Ksh**	**183352**							
	Ltng Resource	Units	Available	Used	Surplus	MVP (Ksh)			
	Land	Hectares	1.77	1.77	0.00	113113			

From farm surveys carried out in Mukanduini, 99 percent of farmers were found to use a combination of FYM + inorganic fertilizers in varying levels for SFM. However, farmers apply less of Manure + inorganic fertilizer per hectare than Manure (5 ton/ha) + inorganic fertilizers (20 –60 kg N/ha) which were ranked in terms of NPV as the best three SFM technologies in this study. Technology change model therefore, could lead to a big increase in productivity and profitability of smallholders' production systems. Model 4 had more TGM and returns per shilling working capital than model 1. Productivity of working capital increased more substantially as one moved down the SFM-based farm typologies. This is because technology change increased output and therefore profitability of enterprises even more.

Sensitivity analysis

This section dealt with evaluation of how the optimal solution could behave within given LP problem coefficients ranges. Such coefficients ranges included:

1. Objective coefficients range

The range implies that a given solution will remain optimal provided that the objective coefficients remained within the given ranges of optimality. Tomatoes were the most profitable enterprise and its ranges over, which, the solutions remained feasible, are showed in Table 4.4.35.

Table 4.4.35. Sensitivity analysis ranges for objective coefficients (Ksh) over which the basis *remained unchanged in all the four models in* Mukanduini[22]

Model	SFM Class	Current coefficient	Allowable increase	Allowable decrease
1	I	253176	INFINITY	79681
	II	165719	INFINITY	71076
	III	113113	INFINITY	22216
2	I	253176	INFINITY	79681
	II	165719	INFINITY	71076
	III	113113	INFINITY	22216
3	I	274340	INFINITY	85445
	II	165255	INFINITY	64858
	III	114220	INFINITY	17194
4	I	253176	INFINITY	79681
	II	165719	INFINITY	71076
	III	113113	INFINITY	22216

Tomatoes were the most profitable enterprise in Mukanduini. The objective coefficients range for all classes and models implied that profit from tomatoes could decrease to amount shown or

[22] Source: Computer LINDO printout

increase to infinity and still it would remain the most profitable enterprise. Changes in tomatoes prices, output levels or input prices could bring about corresponding changes in profits. Due to wide objective coefficient ranges for tomatoes, this could give decision makers ample room over which to vary these factors without adversely affecting the optimal solution.

2. RHS coefficients range

This is also called feasibility range and showed range over, which the RHS coefficients may vary without changing the value of dual or shadow price (Table 4.4.36). Again, land was the most limiting resource and therefore had very narrow range over which optimal solution could remain valid. However, due to high profitability of tomatoes compared to other enterprises, the RHS range gave a decision maker much more room for land allocation than for bananas in the previous sections. In this case, a small change in amount of land allocated to tomatoes could not necessitate modifying the entire optimal solution.

Testing of Hypothesis

After sensitivity analysis, hypothesis testing was conducted. In all the four models, total gross margins (TGM_0) from optimal farm plans (OFP), were found to be many hundred-folds over and above total gross margins (TGM_a) from actual farm plans (AFP) in both Kariti and Mukanduini. This led to rejection of null hypothesis that "The actual farm plans are optimal in all SFM-based farm typologies".

The gap between TGM from the AFP and OFP, were used to test for *Optimal Farm Plans Hypothesis* where:

$$H0: TGM_a = TGM_0 \text{ and } H1: TGM_a \neq TGM_0$$

Table 4.4.36. Sensitivity analysis ranges for land coefficients (Hectares) over which the basis remained unchanged in all the four models in Mukanduini[23]

Model	SFM Class	Current RHS	Allowable increase	Allowable decrease
1	I	3.93	0.24	3.93
	II	1.91	2.32	1.91
	III	1.77	2.63	1.77
2	I	3.93	0.35	3.75
	II	1.91	2.44	1.58
	III	1.77	2.88	0.77
3	I	3.93	0.25	3.93
	II	1.91	2.29	1.91
	III	1.77	2.41	1.77
4	I	3.93	0.38	3.82
	II	1.91	2.37	1.77
	III	1.77	2.68	1.55

Where:

H0 = null hypothesis

H1 = alternative hypothesis

TGM_c = total gross margins from AFP

TGM_0 = total gross margins from OFP

Decision rule: Reject H0 if $TGM_a \neq TGM_0$. This hypothesis was tested for > 20 % gap between TGM_a and TGM_0 (Kamunge, 1998, CIMMYT, 1988).

[23] Source: Computer LINDO printout

This implies that the existing resource allocations by smallholders in both sites were inefficient and that AFP were sub-optimal (Table 4.4.37).

Table 4.4.37. Annual total gross margins (TGM) from OFP and their equivalent per capita daily income (USD) in all SFM-based farm typologies from the four models in Kariti and Mikanduini[24]

		KARITI		MUKANDUINI	
Model	Class	TGM from OFP (Ksh)	Per capita daily income	TGM from OFP (Ksh)	Per capita daily income
I	I	133989	0.7	994982	5.9
	II	97714	0.5	316524	1.6
	II	63691	0.4	200210	1.0
II	I	102173	0.5	956774	5.7
	II	44810	0.2	270339	1.4
	III	12302	0.07	79985	0.4
III	I	152700	0.8	1078156	6.4
	II	111073	0.6	315637	1.6
	III	72918	0.4	202169	1.0
IV	I	132627	0.7	976032	5.8
	II	96292	0.5	305127	1.6
	III	63233	0.4	183352	0.9

[24] 1 USD = 77 KES

Therefore, there is substantial potential for higher TGM generation through optimization of resource use. All OFP in Mukanduini except class III in models III and IV had TGM over and above the poverty level (USD 1/day). OFP in all classes in Kariti were slightly below USD 1 mark. It is important to note that TGM were computed for existing input rates (seeds, fertilizers and chemicals) as used by farmers while banana were local varieties. Such varieties were late maturing, susceptible to pests and diseases, and had low-yielding potential. However, productivity and profitability of OFP could be further improved through application of biotechnology and policy reforms such as:

1. Use of clean, high yielding tissue culture (TC) bananas
2. Development of typology-specific banana recommendations
3. Use of certified maize, bean and tomato seeds
4. Macro-policies reforms to reduce farm input prices

OFP from profit maximization model favored specialization while farmers objective are many. Food self-sufficiency is a paramount objective of many smallholders. Farmers would tend to prefer OFP that incorporate household food production as one of their components. Such OFP would be less risky and therefore compatible with smallholders' farming systems. In this case adequate household food would better be produced from least land possible in order to release the rest of land (the most limiting resource) to enterprises with highest returns in each site. This would call for use of improved SFM technologies so that the same amount of food is produced from less land. If farmers were to optimize profits and reduce poverty, they need to allocate all farm resources (land, labour and capital) to production of TC bananas or improved tomato varieties in Maize-bean intercrop under Manure (5 ton/ha) + Inorganic fertilizers (20 – 60 kg N/ha) in Kariti and Mukanduini respectively.

In conclusion, the OFP so developed in this study are purely prescriptive and present "what ought to be" situation. This is because:

1. Smallholder farmers and their environment are infinitely variable in every aspect imaginable. Only after quantitative and qualitative decision-making processes have fully been exhausted, should a decision to implement the 'best-bet' OFP be made. Farmers need to combine their site-specific indigenous knowledge and experiences with quantitative recommendations derived from this study. OFP could then facilitate efficient allocation of scarce farm resources.

2. Smallholders in both Kariti and Mukanduini grew potatoes in very small portions in all AFP despite negative GM in some farm typologies. This is because potatoes are an important ingredient in local diet. However, its productivity and profitability could be increased through use of clean seed, improved crop husbandry and typology-based SFM. Then it would feature in the OFP as an economically viable enterprise.

3. Dairy was undertaken in AFP for farmyard manure (FYM) and milk production for food and sale. It was also used as an indicator of wealth in the study sites. Nevertheless, it gave negative GM in some SFM-based farm typologies and did not feature in OFP. However, Napier productivity could be improved to make Dairy competitive enough so as to appear in OFP. Clean, high yielding planting materials (Kakamega I) could be sourced from Kenya agricultural research institute (KARI) and bulked collaboratively for local distribution.

Why sneak in dairy goats while it is nowhere in earlier pages?

4. Improved breeds of Dairy goats for milk, meat and manure production could be promoted due to ever-diminishing land parcels. Such an enterprise could enhance food availability, food access and food utilization in smallholders' farming systems.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The importance of maize as the main food staple in Kenya cannot be over emphasized (GoK, 2002). Over 80 percent of all maize growers are the smallholder farmers who are constrained by scarcity of production resources (GoK, 2004). This research aimed therefore at understanding how declining land, labour and working capital availability and productivity have affected smallholder food output, incomes and livelihoods over the last three decades in the central Kenyan Highlands. The broad objective of this study was characterization of smallholder farms based on their soil fertility management (SFM) practices and resource endowment; and development of optimal farm plans (OFP) for profit maximization and food self-sufficiency for different SFM-based farm typologies in maize-based production systems of central Kenyan Highlands.

The major problem in the smallholder farming systems has been escalating food insecurity, malnutrition and poverty. About 56 percent of the Kenyan population live below the poverty line (< USD 1), 80 percent of who live in rural areas. Some of the causes of this problem include increase in population that has outstripped available land. This has led to land subdivision and intensive cultivation without adequate soil fertility management (SFM). Escalating prices of inorganic fertilizers on the other hand, have exacerbated the situation after the collapse of farm support programs in the 1990's. Resource-poor smallholders have therefore resorted to low-external input SFM technologies, the so-called 'organic input' paradigm. However, adoption and profitability of such technologies have been constrained by ignorance of farmers' socio-economic diversities and their knowledge systems during many technology development processes. The consequences have been further plant nutrient depletion, land degradation and decline in per capita food production in smallholder agro-ecosystems.

Characterisation of smallholder farming systems based on farmers' biophysical and socio-economic circumstances was one of the specific objectives of this study. Ranking of farmers in Kariti and Mukanduini study sites in Maragwa and Kirinyaga Districts respectively using local indicators of soil quality (LISQ) resulted in three different SFM-based farm typologies. These were Class I (good soil fertility managers), Class II (average soil fertility managers) and Class III (poor soil fertility managers). LISQ involved use of local language to define soil colour, structure and texture. Correlation of smallholder SFM status and farmers' resource endowment was determined from population correlation coefficients (ρ) for different SFM-based classes. ρ (rho) values were 0.8 and 0.5 for Kariti and Mukanduini respectively. Since ρ values were greater than zero in both sites, the hypothesis that "there is no relationship between smallholders' SFM status and their wealth endowment" was rejected.

There was need however to verify SFM-based recommendation domains for smallholders in the study sites using soil test data. This provided technical indicators of soil quality (TISQ), which gave information on organic and inorganic fertilizer use in different farm typologies. TISQ with significant differences ($p < 0.05$) included organic carbon (%), total nitrogen (%) and available phosphorous (ppm). Carbon ranged between 1.65 – 2.24 percent and between 1.39 – 1.59 percent in Kariti and Mukanduini respectively, total nitrogen ranged between 0.11 – 0.15 percent and between 0.07 – 0.10 percent in Kariti and Mukanduini respectively while available phosphorous ranged between 33 – 70 ppm and between 441 – 650 ppm in Kariti and Mukanduini respectively. In both study sites soil analysis results depicted the highest TISQ contents (carbon, nitrogen and phosphorous) in class I farm typology while the lowest contents were confined to class III farm typology. These differences in soil parameters could be explained by differences in soil textures and structure, clay and moisture contents, levels of farmyard manure (FYM) and inorganic fertilizer use in different SFM-based farm typologies.

Farmers' ability and willingness to adopt the "best-bet" SFM technologies differed substantially in different recommendation domains. To illustrate this, 15 different SFM technologies were tested for two seasons (2003/4) in on-farm demonstration sites in Kariti and Mukanduini. Such included green manure cover crops (GMCC), biomass transfer (*Tithonia*), FYM + inorganic fertilizers and composts. Partial budgeting for analysis of costs and benefits of different SFM technologies was undertaken. Out of FYM + inorganic fertilizers category, FYM (5 tons/ha) + Fertilizer (60 kg N/ha), FYM (5 tons/ha) + Fertilizer (40 kg N/ha) and FYM (5 tons/ha) + Fertilizer (20 kg N/ha) were ranked as the best three SFM technologies in terms of net present value (NPV). This is in agreement to other studies conducted elsewhere (Mutiro and Murwira, 2004), which derived the most optimal level of supplementing 5 tons of manure as 43 kg N/ha. However, farmers' socio-economic and agro-ecological environment is not perfectly stable and is subject to changes. In this study, linear programming (LP) technique was then employed to review such recommendations in view of diverse farmers' socio-economic circumstances.

This study hypothesized that "the actual farm plans (AFP) are optimal in all SFM-based farm typologies". Primary data was collected by use of a structured questionnaire from 35 randomly selected farmers in each study site. Gross margins (GM) per hectare, man-hour of labour and shilling of working capital were computed from AFP as the first step towards testing of this hypothesis and for development of optimal farm plans (OFP) for different farm typologies.

LP empirically identified types and levels of activities to be carried out, under actual smallholders' resource constraints so that farmers' objectives could be maximized. To derive realistic OFP, a variety of smallholder objectives were embraced during model formulation process. These included profit maximization, food self-sufficiency and increased returns to family labour and working capital. It was established that banana and tomatoes were the most profitable enterprises in Kariti and Mukanduini respectively. For profit maximization, all available land in every farm typology should be allocated to their production. In class I, TGM increased from Ksh. 20818 in AFP to Ksh. 133989 in OFP in Kariti and from Ksh. 324119 in AFP to Ksh. 994982 in OFP in Mukanduini. In class II, TGM increased from Ksh 5377 in AFP to Ksh 97714 in OFP in Kariti and from Ksh 93784 in AFP to Ksh 165719 in OFP in Mukanduini. In class III, TGM increased from Ksh -4372 in AFP to Ksh 63691 in OFP in Kariti and from Ksh 23845 in AFP to Ksh 200210 in OFP in Mukanduini. From TGM for "average farm" in each farm typology, it was established that most of the AFP are sub-optimal and do not meet all the annual household food requirements. In Kariti, farmers live on less than USD 1 per day in all farm typologies while in Mukanduini only farmers in class I lived above the international poverty line (USD 1.8).

Similarly Food self-sufficiency, Opportunity cost of family labour = 0 and Technology change models were solved through LP and the resultant OFP analysed. It was established in both sites that it is more economical and sustainable to meet household food requirements from on-farm production. Smallholders are risk averse and tend to prefer SFM technologies that would safeguard domestic food self-sufficiency before embarking on production for marketing purposes. Technology change model helped to evaluate the impact of adoption of superior SFM technologies on household food production and farm incomes. Adoption of OFP from new SFM technologies meant food production was met from lesser land than in AFP. This implied then that the extra land freed from subsistence could be reallocated to commercial enterprises, namely bananas and tomatoes in Kariti and Mukanduini respectively.

5.2 Conclusion

Characterisation of smallholder farm typologies

From the key study findings, the following conclusions were drawn:

1. Participatory learning and action research (PLAR) produced objective database, which could be used by other researchers and collaborators in future. This is because it was conducted in a multidisciplinary, knowledge-intensive way generating valuable background information on integrated SFM in each study site. Some of the data collected included socio-economics, soils and agro-forestry, crop and livestock production, and general land use.

2. PLAR analysis model could therefore be successfully applied to delineate smallholders' farm typologies along inter-class soil fertility gradients and resource endowment status in similar studies. In this study, all farmers in Kariti and Mukanduini were classified into three SFM-based classes (Class I, II and III). Such characterisation enabled farmers and stakeholders to participate equally in derivation of class-specific SFM problems, coping strategies and opportunities depending on farmers' socio-economic circumstances. This approach could enhance adoption of appropriate SFM technologies leading to increased productivity and profitability of smallholders' agro-ecosystems.

3. In this study, population correlation coefficient, ρ (rho) was used to measure strength of relationship between farmers' SFM status and their wealth endowment. In every study site, ρ was found to be greater than zero. Therefore, it can be concluded that wealthy farmers are also generally good soil fertility managers. This is because adoption of improved SFM would entail increase in working capital, which smallholders would hesitate to incur unless they were in good financial standing.

4. Soil analysis data provided technical indicators of soil quality (TISQ), which were used to verify classification of farmers' SFM status using local indicators of soil quality (LISQ). In this study, TISQ which exhibited significant differences ($p < 0.05$) included organic carbon (%), total nitrogen (%) and available phosphorous (ppm). TISQ reflected soil's ability to supply required nutrients and hence its quality. Integration of LISQ and TISQ could provide farmers and other stakeholders with an appropriate soil quality monitoring system (SQMS). SQMS could help in diagnosis and monitoring of soil degradation processes at plot, farm and landscape levels and therefore aid in choice of SFM technologies suitable to specific recommendation domains. Once understood by all stakeholders, SQMS could then become part of decision support system (DSS) for natural resource management (NRM).

5. Once characterisation of farmers based on their soil fertility status at farm level was accomplished, on-farm experimentation and evaluation of 15 SFM technologies commenced. This paved the way for participatory technology development (PTD) in demonstrating and packaging of SFM strategies that are appropriate to specific farmers' biophysical and socio-economic circumstances in each study site. Adoption of such technologies could lead to efficient use of scarce farm resources leading to enhanced food security, income and smallholders' welfare.

Optimization of low-external input SFM technologies

1. Before economic analysis of viable SFM technologies could be done, it was necessary that relative agronomic evaluation (RAE) of biophysical data from different treatments be undertaken. This way, the optimum Manure + inorganic fertilizer (Kg N/ha) levels that gave the highest yields per hectare was determined. From RAE, it was clear that on

application of increasing levels of any input, there was a corresponding incremental rise in crop yields.

2. The optimum application of nitrogen (N) was found in Manure (5 tons/ha) + Fertilizer (60 kg N/ha). As the level of inorganic nitrogen increased from 20 to 60 Kg N/ha, yields increased dramatically. Beyond 60 Kg N/ha, yields started increasing at a decreasing rate indicating an excess application of N. This then implies that if all other factors of production were held constant, additional increases in maize output resulting from each additional application of N beyond 60 kg/ha will begin to decrease. Based on their SFM and socio-economic (wealth) domains, farmers in Classes I, II and III should be advised to use FYM (5 ton/ha) + 20, 40 and 60 kg N/ha respectively as the optimal recommendations for maize production in both sites. It would be uneconomical to apply N above or below this range in each farm typology.

3. Based on agronomic responses, doubling manure rate from 5 to 10 tons/ha almost doubled maize yields in Kariti while it had no such effect in Mukanduini. Likewise NPV ranking improved from 7 to 4 in Kariti and from 7 to 5 in Mukanduini as one moved from 5 to 10 tons/ha. This results suggested that appropriate rate of manure application in Kariti should be 10 tons per hectare while that of Mukanduini should be 5 tons per hectare. However, use manure (5 tons/ha) + inorganic fertilizers (20 – 60 kg N/ha) had higher NPV and were more economical and sustainable opportunities than manure alone. Combinations of FYM + Inorganic fertilizers were widely practiced by farmers in both study sites. Therefore, such SFM technologies could be more acceptable than FYM alone leading to enhanced smallholders' soil fertility, farm incomes and food self-sufficiency.

4. Decision based on biophysical data alone cannot be conclusive enough until costs of these added elements are considered and the accruing benefits analysed, the so-called economic analysis. From partial budgets, it was observed that treatments with the highest yields were not necessarily the most economical. Farmers were also interested to know the extra costs and benefits involved in adopting a new technology. Since different SFM technologies were treated as mutually exclusive projects, net present value (NPV) was used for ranking of different treatments. FYM + Fertilizers ranked between 1 – 5, Manure alone between 6 – 10 while GMCCs ranked between 11 – 15 in terms of NPV ranking. Treatments with NPV value of more than zero were considered to be economically viable and should be adopted. The higher the NPV value, the more viable the treatment.

5. Adoption of SFM technologies depends on farmers conceived benefits over the extra costs accrued from such technologies. From farm survey conducted in Kariti and Mukanduini it was established that over 99 per cent of all smallholder uses organic and inorganic nutrient sources at one level or another. From literature search, evidence showed overwhelming potential of low-external input SFM technologies in reduction of smallholders' food poverty, improvement of farm incomes and livelihoods. Yet no evidence of appropriate legislation promoting use of organic resources was found. There is need therefore, for some policy support towards use of organic materials by low-income smallholders who form over 80 per cent of Kenya's farming community.

Optimal farm plans (OFP)

Solution from OFP indicated that:

1. Land was the most limiting farm resource in smallholder maize-based production systems. In class I, land had a MVP value of Ksh 75700 and Ksh 253176 per hectare Kariti and Mukanduini respectively while labour and working capital had MVP value of

zero. From a profit maximization model, OFP indicated that all land should be allocated to the enterprises that give the highest return per hectare. From AFP, about 99 per cent of all farmers in the three farm typologies in Kariti and Mukanduini, was living below the international poverty line (USD 1 per day).

2. Smallholder farmers' objectives are many and varied. Therefore, there was need to consider household food self-sufficiency objective in this study. TGM from OFP in profit maximization model in all classes were high and attractive (Ksh 133989, 97714 and 63691 in Kariti and Ksh 994982, 316524 and 200210 in Mukanduini). However, food self-sufficiency model ensured that even if profits were compromised slightly, all household food requirements were met cheaply and sustainably from on-farm production. This could save the households' scarce off-farm incomes used for food purchases from markets besieged with imperfections.

3. Family labour was the second most limiting resource after land. In the third model, opportunity cost (OC) of family labour in smallholder farming systems was treated as a "sunk" cost. Returns to family labour increased as one moved down the SFM-based farm typologies. OFP indicated that OC of family labour should taken as "real" cost and always be included in economic analysis of any smallholder production system.

4. It would be more profitable for farmers in all farm typologies to adopt improved Manure + Fertilizer technologies in varying levels. This would provide an integrated SFM approach to combating nutrient depletion depending on farmers' biophysical and socio-economic circumstances. Technology change model exhibited an increase in TGM and GM per shilling of working capital in all smallholder farm typologies. The resultant OFP

also ensured that household food requirements were met more adequately and sustainably from on-farm production

5. TGM from OFP in all models and sites, were many hundred-folds over and above TGM from AFP. This led to the conclusion that all smallholders AFP were sub-optimal. Farmers should be advised to adopt OFP developed from LP, which are more efficient in resource allocation and which meet specific farmers' objectives. Such farm plans are likely to lead to optimisation of resource use for enhancement of soil fertility and farm incomes in smallholder farming systems. ~~What happens to markets~~? Would one trust markets to supply all food required? ✓

5.3 Recommendations

Based on the study results, the following recommendation were formulated:

1. The actual farm plans (AFP) in both study sites were sub-optimal and inefficient in scarce resource allocation. About 99 percent of all farmers in both study sites live on less than USD 1 per person per day. For farmers to maximize profits and reduce poverty, all farm resources should be allocated to commercial production of bananas and tomatoes in Kariti and Mukanduini respectively. From the OFP these enterprises depicted higher TGM and GM/ha than any other enterprise. Farmers may do very little about land, labour and working capital availability but can do a lot about their productivity. Farm typology-specific technological packages for bananas and tomatoes should therefore, be developed by researchers in conjunction with relevant stakeholders and disseminated to farmers in Kariti and Mukanduini respectively.

2. It was established in this study that SFM status of smallholders depend on their wealth endowment. 70 and 66 percent of all farmers in Kariti and Mukanduini respectively were classified as class III (poor) in terms of resource endowment. Theses farmers cannot afford high external-input SFM technologies as advocated in blanket fertilizer recommendations. OFP that favour adoption of low-input, high-output SFM technologies by resource-poor smallholders in central Kenyan Highlands should therefore be actively promoted. However, the battle against nutrient depletion and food insecurity will not be won in a day, but in small incremental steps. Such can be achieved by farmers in different SFM-based recommendation domains adopting Manure + inorganic fertilizers at increasing levels depending on their socio-economic circumstances.

3. In this study, Manure (5 ton/ha) + Fertilizer (20 – 60 kg N/ha) proved successful in enhancing production and profitability in the three SFM-based farm typologies. All

relevant stakeholders should therefore network together in order to scale up and out these technologies in the study sites and beyond. Research-extension linkages should be strengthened further in order to play their technology development and transfer roles more effectively. The indisposed smallholder agro-ecosystems in study sites could be revitalized from low-input low-output systems, better known for hunger, malnutrition and poverty, to low-input high-output systems. This could enable farmers meet their household food needs more profitably and efficiently. Smallholders' sector transformation would facilitate achievement key national policy goals of reduction of food insecurity, poverty and unemployment.

4. More than 99 percent of all smallholders in Kariti and Mukanduini were found to use organic + inorganic resources at different levels for SFM. However, at present there are no legislations favouring mainstreaming organic resources in Kenya's agricultural sector. Such legislations would make organic resources more widely acceptable both at farm and all decision-making levels. There is also need for macro-policies that would also lower input prices and increase producer prices to encourage resource-poor farmers invest in soil as a capital resource.

5. Lack of affordable credit was identified as a major impediment to intensified use of inorganic fertilizers in the central Kenyan Highlands. Farmers are unable undertake high-external input SFM technologies, as they may not afford the initial investments. Consequently, the government should undertake policy and institutional reforms aimed at improving capacity of financial institutions to direct more resources to farming communities. Affordable, formal and non-formal credit facilities should be encouraged and supported. Farmers' organisations (co-operatives), common interests groups (CIG), community based organisations (CBO) and non-governmental organisations (NGO),

which could undertake participatory technology development (PTD), support rural savings and credit schemes and marketing should be facilitated and promoted.

6. Poor rural road infrastructures were sited as the major constraint in transport of farm produce and inputs especially during the rainy seasons. Gravelling and regular grading of rural access roads would facilitate cheap movement of products and inputs between production and consumption points. Lowering of transport costs could reduce the variable costs accruing from adoption of improved technologies. More benefits will be received, as farmers will be able to transport bananas and tomatoes cheaply and in time to capture good prices offered in the local markets and beyond.

7. Markets are very crucial outlets of farm produce, source of inputs and provide an avenue of exchange for goods, services and information in both study sites. Produce prices fluctuate very widely between season and off-season crops. The local authorities (LAs) and other relevant stakeholders should streamline market imperfections that promote price distortions and hinder free flow of market information. This could make marketing systems more efficient and responsive to farmers' needs and objectives. Such systems could promote investment in bananas and tomatoes production in Kariti and Mukanduini respectively.

8. During farm surveys, it was established that the number of risk-averse, small-scale farmers especially women who cannot afford costly inorganic fertilizers has increased tremendously. This has caused profound decline in soil fertility and shortfall in household food production. There is need therefore to review gender policies so as to integrate gender analysis in NRM research for enhanced adoption of SFM technologies in small-scale, maize-based production systems in central Kenya. Risk programming (RP) could

also be undertaken to confirm OFP and demonstrate their potential in maximizing farmers' welfare despite prevalence of risks and uncertainties.

9. Gender issues need to be incorporated in all agricultural interventions at community level through participatory approaches. Adoption of Manure (5 tons/ha) + Inorganic fertilizers (20 – 60 kg N/ha) will entail investment of more resources by farmers in both study sites. Such resources include land, labour, capital and market information. Different gender has different access to and control over such resources. However, adoption of such technologies and the resultant OFP will increase profits for both men and women in smallholder farming systems without undue physical exhaustion, justifying such investments.

10. The price most people are paying for irresponsible use of sex in the study districts is appalling. So is the cost of care for those affected and infected by HIV/AIDS especially in the most active age group (16 – 64 years), which formed over 63 % in each study site. This has been translated into loss of labour, a very valuable resource in smallholder set-ups. Relevant stakeholders in the study sites should actively be supported in provision of more reliable information about HIV/AIDS pandemic, which should be accompanied by guidance on how to use sex more responsibly. Constituent's HIV/AIDS committees should be more innovative and play instrumental role in promoting education and information campaigns aimed at changing peoples' attitudes and behaviours. This is because healthy attitudes toward sex have been more difficult to acquire, yet substantial information about sex has been available.

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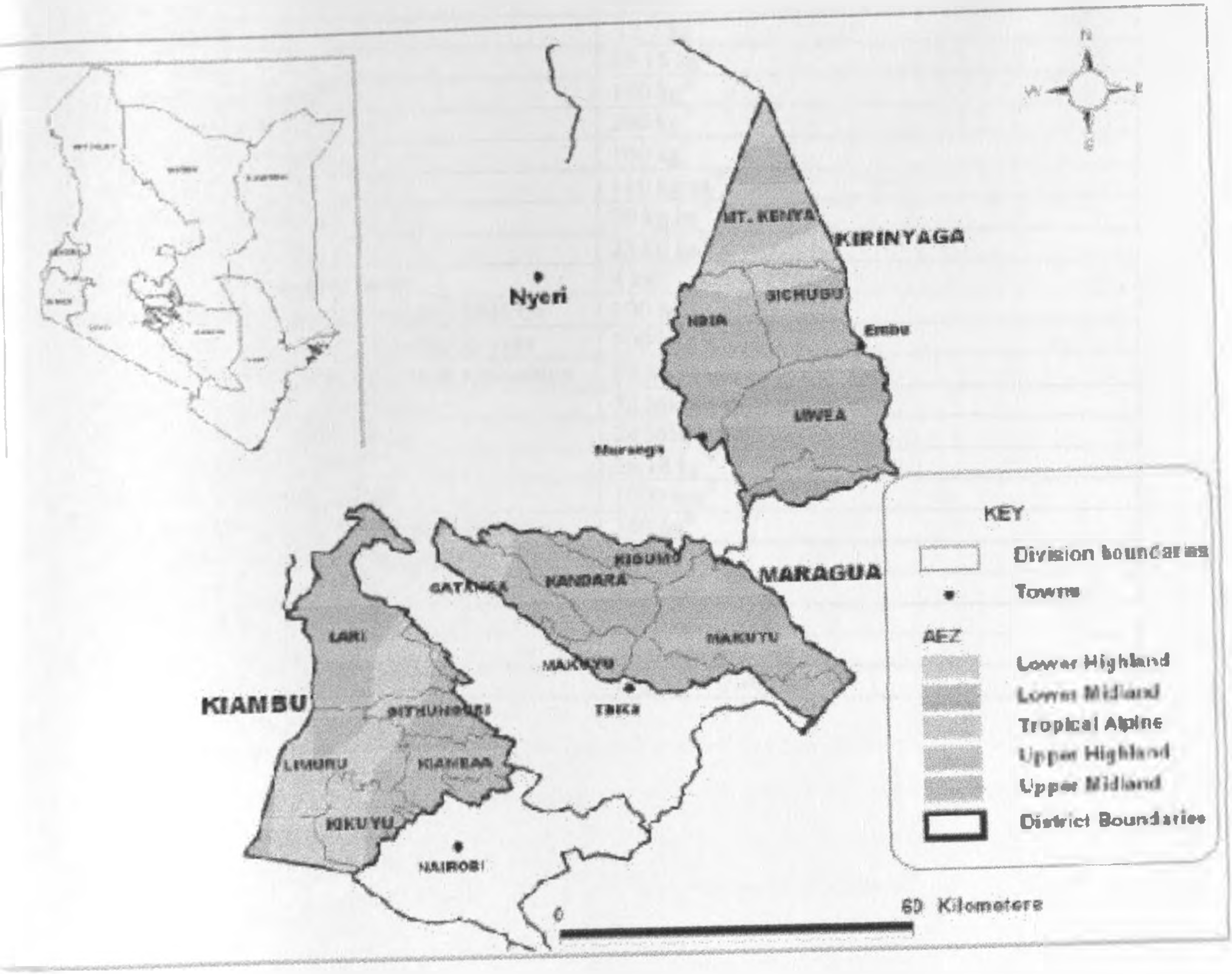
APPENDICES

APENDIX I: Map of the study sites



APPENDIX III: Coefficients and prices (Ksh) used in economic analysis of various SFM treatments[25]

Data	Value (Ksh)
Labour cost	14.6 hr^{-1}
Price of maize	13.3 kg^{-1}
Price of beans	25.15 kg^{-1}
Cost of *Mucuna* seeds[@]	100 kg^{-1}
Cost of *Clotalaria* seeds	200 kg^{-1}
Cost of *Dolichos* seeds	100 kg^{-1}
Seed rate for *Mucuna*[@]	110 kg ha^{-1}
Seed rate for *Clotalaria*	20 kg ha^{-1}
Seed rate for *Dolichos*	23 kg ha^{-1}
Labour for *Tithonia* application	4 kg^{-1}
Labor for chopping & incorporating GMCCs	100 MHRS ha^{-1}
Labor for chopping & incorporating stovers	100 MHRS ha^{-1}
Labour for Manure transportation & application	64 MHRs ha^{-1}
Labour for Compost application	32 MHRs ha^{-1}
Labour for Fertlizer application	24 MHRs ha^{-1}
Price and transport of 17:17:17	26.18 kg^{-1}
Price of Manure and compost	1000 ton^{-1}
Baseline labour cost for Fertilizer application	300 ha^{-1}
Price of Effective Microorganism (EM)	200 lr^{-1}
Amount of EM required	5 lts. ha^{-1}
Opportunity cost of maize stover	1500 ha^{-1}
Opportunity cost of capital[**]	10% $season^{-1}$
6.67 kg FW[+] *Tithonia*	1 kg DW[#] *Tithonia*

[25] [+] FW is fresh weight, [#] DW is dry weight, [*]Prices valid in 2003/04, [***] Discounting rate therefore becomes 0.9, [@] Prices and seed rates for GMCCs are from Legume Research Network Projects (LRNP), NARL (KARI), Kabete.

APPENDIX IV: Gross margin (GM) analysis for Maize-bean enterprise in Kariti[26]

Maize-beans	Class I	Class II	Class III
Maize yields (kgs)	3133	2004	1786
Price per Kg (Ksh.)	12.50	12.50	12.50
Value of stover	3000	3000	3000
Beans (kg)	1072	612	372
Price per Kg (Ksh)	29.08	29.08	29.08
Gross output (Ksh)	73340	45845	36143
Total variable costs (Ksh)	57670	40750	39426
GM/hectare (Ksh)	**15670**	**5095**	**-3283**

APPENDIX V: Gross margin (GM) analysis for Potatoes enterprise in Kariti

Potatoes	Class I	Class II	Class III
Yields (kgs)	10934	7516	4566
Price per Kg (Ksh.)	7.50	7.50	7.50
Gross output (Ksh)	82005	56370	34245
Total variable costs (Ksh)	76109	66551	53514
GM/hectare (Ksh)	**5896**	**-10182**	**-19269**

APPENDIX VI: Gross margin (GM) analysis for Dairy enterprise in Kariti[27]

Dairy	Class I	Class II	Class III
Milk Sale (Ksh)	34160	29463	25620
Manure Sale (Ksh)	4568	2582	2853
Calf Sale (Ksh)	7000	6000	5000
Total Gross output (Ksh)	45727	38045	33473
Total variable costs (Ksh)	42268	36556	39143
GM per head (Ksh)	**5460**	**1489**	**703**

[26] Maize-bean intercrop was the predominant cropping system and therefore GM were computed together

[27] Milk production at time of interview was 7.3, 6.9 and 6.0 litres/animal/day in classes I, II and III, price was Ksh. 14/litre and lactation period was taken as 305 days. It was assumed that a cow would give 1 *calf/year. Sale of manure from animals was also included.*

APPENDIX VII: Gross margin (GM) analysis for Bananas enterprise in Kariti[28]

Bananas	Class I	Class II	Class III
Yields (Bunches/ha)	1250	1200	1100
Price per Bunch (Ksh)	150	150	150
Gross output (Ksh)	187500	180000	165000
Total variable costs (Ksh)	111800	107079	100666
GM/hectare (Ksh)	**75700**	**72921**	**64334**

APPENDIX VIII: Gross margin (GM) analysis for Coffee enterprise in Kariti

Coffee	Class I	Class II	Class III
Yields (kgs)	4005	4063	2190
Price per Kg (Ksh)	5.8	5.2	2.8
Gross output (Ksh)	23361	21059	6021
Total variable costs (Ksh)	26465	22540	18799
GM/hectare (Ksh)	**-3105**	**-1481**	**-12777**

APPENDIX IX: Gross margin (GM) analysis for Maize-bean enterprise in Mukanduini

Maize-beans	Class I	Class II	Class III
Maize Yield (kgs)	6732	4380	1290
Price per Kg (Ksh)	12.6	12.6	12.6
Value of stover	3000	3000	3000
Beans Yield (kg)	630	660	512
Price per Kg (Ksh)	22.6	22.6	22.6
Gross output (Ksh)	102061	73104	30825
Total variable costs (Ksh)	61152	47337	37937
GM/hectare (Ksh)	**40909**	**25767**	**-7112**

[28] Source: Author's Field Survey (2003/4)

APPENDIX X: Gross margin (GM) analysis for Potatoes enterprise in Mukanduini

Potatoes	Class I	Class II	Class III
Yields (kgs)	9000	6800	6500
Price per Kg (Ksh)	7.5	7.5	7.5
Gross output (Ksh)	67500	51000	48750
Total variable costs (Ksh)	57800	45386	42360
GM/hectare a (Ksh)	**9700**	**5614**	**6390**

APPENDIX XI: Gross margin (GM) analysis for French beans enterprise in Mukanduini[29]

French beans	Class I	Class II	Class III
Yields (kgs)	11250	7120	0
Price per Kg (Ksh.)	25	20	0
Gross output (Ksh)	281250	142400	0
Total variable costs (Ksh)	107754	72100	0
GM/hectare (Ksh)	**173496**	**70300**	**0**

APPENDIX XII: Gross margin (GM) analysis for Bananas enterprise in Mukanduini[30]

Bananas	Class I	Class II	Class III
Yields (Bunches/ha)	1300	1210	1170
Price per bunch (Ksh.)	175	175	175
Gross output (Ksh)	227500	211750	204750
Total variable costs (Ksh)	125025	117107	113853
GM/hectare (Ksh)	**102475**	**94643**	**90897**

[29] Farmers in class III did not grow any French beans

[30] Bananas were planted as scattered stools in farms, except some few farmers who had bananas as pure stands. Most were established from local planting materials that were late maturing, low yielding and susceptible to pests and diseases.

APPENDIX XIII: Gross margin (GM) analysis for Sweet potatoes enterprise in Mukanduini

Sweet potatoes	Class I	Class II	Class III
Yields (kgs)	7000	5500	4826
Price per Kg (Ksh.)	6.0	6.0	6.0
Gross output (Ksh)	42000	33000	28956
Total variable costs (Ksh)	21917	18600	16748
GM/hectare (Ksh)	**20083**	**14400**	**12208**

APPENDIX XIV: Gross margin (GM) analysis for Coffee enterprise in Mukanduini

Coffee	Class I	Class II	Class III
Yields (kgs)	2870	2666	1994
Price per Kg (Ksh.)	6.0	5.8	2.4
Gross output (Ksh)	17220	15463	4786
Total variable costs (Ksh)	26437	23904	24374
GM/hectare (Ksh)	**-9217**	**-8441**	**-19589**

APPENDIX XV: Gross margin (GM) analysis for Tomatoes enterprise in Mukanduini[31]

Tomatoes	Class I	Class II	Class III
Yields (kgs)	52500	36200	29454
Price per Kg (Ksh.)	7.5	7.0	6.1
Gross output (Ksh)	393750	253400	179669
Total variable costs (Ksh)	140574	87680	66556
GM/hectare (Ksh)	**253176**	**165720**	**113113**

[31] Disparity in tomatoes prices was due to the fact that some farmers in classes I and II could afford to irrigate tomatoes during the dry season, therefore getting higher prices than those who relied on rainfall.

APPENDIX XVI: Gross margin (GM) analysis for Dairy enterprise in Mukanduini[32]

Dairy	Class I	Class II	Class III
Milk Sale (Ksh.)	48098	28975	20862
Manure Sale (Ksh.)	4327	3125	1542
Calf Sale (Ksh.)	5000	4000	3700
Total Gross output (Ksh)	57425	36100	26104
Total variable costs (Ksh)	46085	36937	31629
GM per head (Ksh.)	**11340**	**-838**	**-5526**

[32] Milk production at time of interview was 8.3, 5.0 and 3.6 litres/animal/day in classes I, II and III, price was Ksh. 19/litre and lactation period was taken as 305 days. It was assumed that a cow could give 1 calf/year. Sale of manure from animals was also included.