Crop Production and Soil Nutrient Management

An Economic Analysis of Households in Western and Central Kenya

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Crop Production and Soil Nutrient Management

An Economic Analysis of Households in Western and Central Kenya

Beatrice D.S. Salasya

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ABSTRACT

The study examines how a combination of socio-economic and household factors influences farm household decisions on soil nutrient management and on crop production in two regions of Kenya (Kiambu and Vihiga). It further examines how these decisions impact on household objectives and on productivity. Emphasis is given to the use of inorganic fertilisers because this is one of the major sources of nutrients that hold considerable potential for increased productivity. A cross-sectional household level data set collected through a formal survey using pre-tested structured questionnaires is used for the investigations. Various methodological approaches are employed including descriptive statistics, cluster analysis, the dual and primal approach to analysing the farm production, and mathematical programming. Cluster analysis yielded three household types in each of the two regions, and these household types form the basis for further analysis.

The most important crops to the households in Kiambu are maize, potatoes and kale, as identified through farmer perception and restricted activity profit ranking. In Vihiga maize and beans remains the sole most important combination. Demand for fertiliser is price elastic with own price elasticity of -2.44 in Kiambu and -1.88 in Vihiga. Output prices of maize and of kale in Kiambu, and of maize in Vihiga also significantly influence the demand for fertiliser with elasticities of 0.90, 0.28 and 1.58 respectively. In Kiambu, fertiliser price has very low elasticities on crop outputs, particularly of kale, which would seem to imply that fertiliser does not have a big impact on crop production. However, results from the primal approach show that currently labour is the constraining factor, particularly in kale production, making the impact of fertiliser obscure. In fact, increasing the level of fertiliser use will have a substantial impact on the output of all the crops analysed, in both the regions. The results confirm previous observations that households are using much lower levels of fertiliser than is optimal.

If the market price of fertiliser and of the outputs is considered, the results show that households could profitably increase their level of fertiliser use on all the crops examined. However, the households' shadow price of fertiliser is much higher than the market price implying that households consider other costs that we do not observe e.g. credit constraints. Results from mathematical programming confirm that households are liquidity constrained. The level of the credit constraint varies across the different household types based on the level of their external remittances relative to farm size. However, households in all the farm types require credit to enable them increase their level of fertiliser use.

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With love
Beatrice

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CHAPTER 1

INTRODUCTION

1.1 Background

The majority of the households in sub-Saharan Africa (SSA) are smallholders who live in the rural areas and depend on agriculture as their major economic activity. Because of the increasing population, there is a need to increase agricultural production in these areas. In the past increased agricultural production was mainly through expansion of the area under agriculture. However, with the increasing population, the potential for expansion of cultivable area has diminished making it no longer a feasible option. Per capita arable land in SSA shrunk from 0.53 to 0.35 hectares between 1970 and 2000 (FAOSTAT, 2002). This occurred despite the fact that total arable land increased. Increasing agricultural production therefore means increasing land productivity. From the FAO statistics (FAOSTAT, 2004), yield of maize, which is a major food staple for many countries within SSA has not increased since the early nineties (see Figure 1.1).

In Kenya, most of the agricultural production is concentrated in the medium and high agricultural potential areas[1.1]. Less than 20% of the total land surface in Kenya lies within these medium to high potential areas, with the rest being classified as Arid and Semi Arid Lands (ASAL) (RoK, 1996).

As is the case in SSA, the population of Kenya is increasing, and as a result the high potential areas are becoming more and more densely populated. The population densities in some areas are in excess of 1500 persons per square kilometre (RoK, 2001). These areas are characterised by small farm sizes, averaging 0.6 ha (KARI, 1994). Meanwhile, the increasing population means that there is likely to be increased demand for food. Currently most of the food is produced within the country and mainly from the high potential areas. In view of the difficulties faced in increasing the land area under agriculture, increased agricultural output will have to be achieved through more intensified production and rising productivity (RoK, 1996).

Reflecting land scarcity, smallholder production systems in the high potential areas of Kenya are becoming more and more intensified. For example, in smallholder dairy

[1.1] The agricultural potential for cropping and dairy is as defined by Jaetzold and Schmidt (1983) which is mainly based on moisture supply differentiated by soil pattern, and gives an indication of the natural land use potential.

systems, dairy producers, who represent up to 77% of agricultural households in some high potential areas, are now going in for zero and semi-zero grazing production systems, with increased dependency of livestock on planted crop by-products and fodder (Staal et al., 1998; Bebe, 2003). Crop-livestock integration is in response to different supply and demand patterns in factor and product markets, agro-climate and population growth (Mohamed, 1998). Hassan (1996) found that greater land pressure (high population density and higher family to farm ratio) increases the odds of both intensification strategies: double cropping and inter-cropping. With this intensification and as the farms become smaller and smaller, system sustainability in terms of nutrient depletion is likely to be a serious issue resulting in higher vulnerability to degradation and lower yields in the high potential areas.

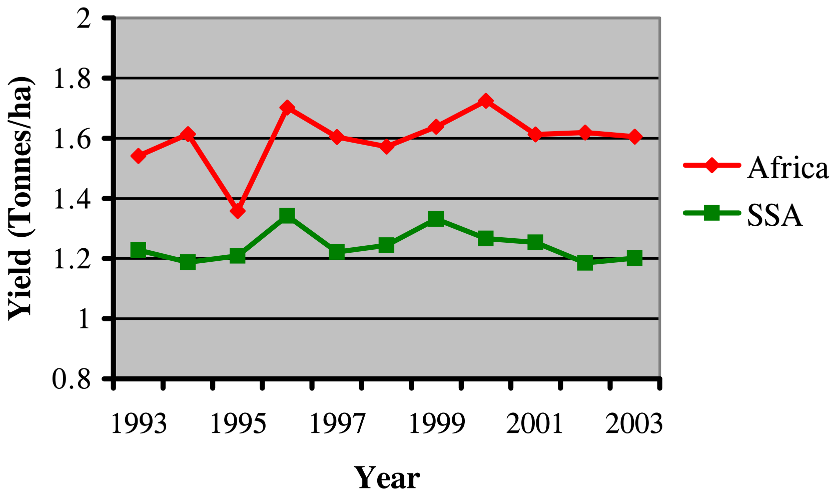

Figure 1.1: Trend in maize yield in Africa and Sub-Saharan Africa from 1993 to 2003

Source: FAOSTAT, 2004

1.2 Problem Statement

In Sub-Saharan Africa, low soil fertility has been identified as a threat to increased agricultural production (Sanders et al., 1995; De Jager et al., 1998). This is mainly because of increased population pressure, which has led to diminishing land holdings, and hence a breakdown of the fallow system, which was used to replenish soil nutrients. This breakdown in the fallow system has not been accompanied by increased input purchases to maintain soil fertility (Sanders et al., 1995). Moreover, because of the population pressure, there is also an increase in cropping frequencies, but with little or no use of soil improvement inputs, which has resulted in nutrient depleted cropping systems (Mokwunye et al., 1996; Quinones et al., 1997; Sanchez et al., 1997). However, increasing population should not necessarily lead to soil nutrient depletion. For example, the population densities in Asia are much higher than those in most African countries and yet the soils there are not becoming depleted. The key difference appears to be in the soil fertility management practices, with Asia featuring high adoption rates and increased use of inorganic fertilisers (Heisey and Mwangi, 1996).

In Kenya, like in most of sub-Saharan Africa, low soil fertility remains a major obstacle to increased agricultural production. Soil nutrient depletion is reported to be widespread (De Jager et al., 1998; KARI, 1998). Bosch et al. (1998) monitored nutrient flows and balances in three regions of Kenya and found negative balances for nitrogen and potassium - the mean balance for all farms was –71 kg N, +3 kg P, and –9 kg K ha^{-1} yr^{-1}. Disaggregating the nutrient balances by farm type, Shepherd and Soule (1998) show that the nutrient balances are negative for households with low and medium resource endowments, but positive for households with high resource endowment. However, the high resource endowed households represent only 10% of the sample. Resource endowment was defined based on many variables, but the main ones were farm size, number of cattle, number of grade cattle, and level of off-farm income.

As already observed, farming in the high potential areas of Kenya is becoming more and more intensified. The increasing intensification is likely to lead to a serious strain on the soil in terms of nutrient depletion if not accompanied by soil nutrient replenishment. In addition, yields can be substantially more improved when fertiliser and/or manure are used than when they are not used (Shepherd and Soule, 1998; Makokha et al., 2001; Salasya et al., 1998)

The above discussion suggests that households should invest in soil fertility and particularly nutrient management activities and inputs in order to maintain or increase their agricultural production. However, although some techniques and recommendations for soil fertility management exist, records and results of studies done in Kenya and elsewhere show that there is hardly any nutrient replenishment being done especially in the food crops (e.g. AFRENA, 1988; Salasya et al., 1998; Mokwunye et al., 1996; Reardon et al., 1997a). A survey carried out in 1987 noted that the use of manure and inorganic fertilisers in Kakamega and Vihiga districts (one of the study sites) was below the recommended rate resulting in serious soil fertility decline (AFRENA, 1988). Salasya et al. (1998) indicate that over 50% of the households in Kakamega and Vihiga district did not apply either organic or inorganic fertilisers during the long rains of 1996.

Inadequate understanding of farmer goals and resource limitations by agricultural researchers and extension workers has been identified as one important factor related to the food shortage problem in sub-Saharan Africa (Jahnke et al., 1986). For the farm households to be encouraged to adopt technologies that improve the soil and lead to increased productivity, it is important to understand their resource limitations, and create an enabling policy and institutional environment for them. Scoones and Toumin (1998) observed that farmers face a range of economic opportunities for investment of labour and capital, of which agriculture is only one, and within agriculture, soil fertility is only one constraint among many. They stress the importance of considering the social and economic factors that might influence farmers' investment decisions. Also, relatively little is known about how smallholders' soil fertility management decisions are linked to other features of their production systems such as other inputs and output mix, and to the external environment (Omamo et al., 2002).

Household decisions on choice of farm activities and technologies are dependent on relative prices of agricultural products, inputs and production factors and on the variation in these prices. The responsiveness of farm households to such economic incentives depend on institutions such as the existing land tenure system, the available social capital, prevalent customs and norms, and availability and inter-linkages of markets (Heerink et al., 2001: page 9). One important explanation for soil degradation in developing countries is the failure to provide sufficient access to available resources (Sanders et al., 1995). Increasing productivity through higher purchased input use depends upon the profitability of agriculture and the evolution of the input markets for seed, inorganic fertilisers and pesticides. Another hindrance to the adoption of nutrient management technologies is a liquidity or credit constraint, particularly during the cropping season.

From the above discussion it is clear that there are key questions that need to be answered concerning soil fertility management decisions by smallholders if more sustainable options are to be adopted, soil degradation capped and productivity increased. They include: to what extent is supply response and hence use of soil improving technologies constrained by poor infrastructure and lack of institutions and services (Kuyvenhoven et al., 1999)? Which social and economic factors are the households likely to consider in their investment decisions (Scoones and Toumin, 1998)? Will intensification be feasible, and will fertiliser be over-used or under-used (Kuyvenhoven et al., 1999)? What are the key constraints facing smallholders and how do their soil nutrient management decisions reflect these constraints (Omamo et al., 2002)? All the above questions point to the link between the farm household decisions on soil fertility management, other farm production decisions and the external environment.

This study examines how a combination of socio-economic and household factors influence farm household decisions on soil nutrient management and on crop production, and how these decisions impact on household objectives and on productivity. It does this by comparing household decisions of smallholders in two districts in Kenya, which are different, both in terms of the socio-economic environments surrounding them and their socio-cultural backgrounds. The results of the study will contribute towards unravelling the complexities underlying the household decisions on soil nutrient management, with a view to suggesting possible ways for policy, research, and extension, to help increase the use of soil replenishing technologies. To achieve the above objective the study is guided by four research questions:

1. What major types of farm households emerge in the study sites based on differences in household characteristics, management objectives and other socio-economic factors?
2. What are the major household and socio-economic factors influencing activity and technology choices for the different types of households within and between the two study sites?
3. What is the impact of soil nutrient improving technologies on farmers' objectives at the household level?
4. Which activity/technology combinations are economically viable (attractive) and enhance sustainability for the different household types? Under which conditions will they be adopted?

Question 1 is important because farm households are known to be heterogeneous in nature, and hence respond differently to technologies and policy instruments. Indeed it has been argued that part of the reason households do not respond to technologies is because these technologies do not target them specifically. By classifying the households into groups with similar characteristics, we are able to test whether these groups are different from each other in the way they respond to technologies and policies or not. If the groups are not different from each other, then similar technologies and policy instruments can be applied. If on the other hand the groups respond differently, then there need to be specific technologies/policy incentives for each of the groups.

Two aspects make question 2 important. First, efforts toward improving the welfare of smallholders often concentrate on traditional cash crops. But do these crops benefit the majority of the rural households or just a small section? If they do not benefit the majority, then the effort will not pay off. It is important to identify which crops benefit the majority of the rural households so that efforts towards improving their welfare can target those crops. Secondly, if the welfare of the rural households has to be improved, then it is necessary to know the factors that influence their decisions, which if dealt with will lead to increased use of soil nutrient replenishing technologies and agricultural production. For example, is the common view that peasant households are not responsive to price policy instruments true? If it is true, then what instruments/incentives do they respond to?

Once question 2 has given us the factors that drive farm households' decisions, then we need to know what the impact is of these different factors on the different farm activities. For example, are there interactions between the different inputs and outputs? Are there rigidities in the system that may lower the impact of some of the instruments? Do the different factors have the same influence on all the farm activities or do the various activities respond differently? This information is important because it enables us to understand what response to expect from the households when a particular policy instrument is applied. It also enables us to apply the policy instruments that will have the biggest impact for the intended purpose. Question 3 is therefore paramount in identifying policies that promote use of appropriate technologies and improve smallholder welfare.

Studying question 4 is intended to explore the cropping patterns that households currently maintain. For example, are the current practices the most remunerative? If not, are the households being irrational? Assuming they are not irrational, then why do they maintain the current practices? What is required for them to adopt the most remunerative practices? Answering this question is central to understanding the constraints households have and being able to recommend technologies that can be useful to them and are within their means. The answer to this question also provides information on what is required for the households to adopt the most remunerative technologies if they are not already doing so.

1.3 Methodology

The present study is a part of the "*System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high-potential areas of Eastern Africa" (PROSAM),* a research project financed by the ecoregional fund of the former International

Service for National Agricultural Research (ISNAR). The overall objective of the PROSAM project is to improve the sustainability of mixed farming systems in East Africa by providing information on the biophysical and economic impact of interventions and technology change at the household level. The current study focuses on two of the three research sites chosen by PROSAM, and contributes to achieving the PROSAM objective by generating information on the economic impacts of interventions and technology change at the household level.

1.3.1 Analytical Framework

The analytical framework of the study is as shown in Figure 1.2. The farm household is considered the appropriate unit of analysis, because decisions on allocation of land, labour and other resources to various farm activities are done at the household level. The figure shows a schematic representation of major relationships between the farm/field, the household and the external environment. The farm household plays a crucial role in linking macro-economic and agricultural policies to land use at the farm level.

The household activity and technology choices are influenced by household characteristics, the socio-economic environment surrounding them, and the agro ecological/biophysical conditions. Household characteristics include farm size, household size, education, age and ownership of other resources such as cattle, whereas the socio-economic environment includes land tenure systems, infrastructure, input/output markets and prices, credit availability, availability of labour markets and extension services. The macro policies affect the household through the socio-economic environment, which either offers incentives or disincentives for investment in sustainable alternatives.

The agro-ecological/biophysical conditions have an effect on the inherent soil fertility levels and vulnerability to land degradation, and they determine the actual range of possible agricultural activities from which households select. The land use choices households eventually make in turn influence the soil nutrient levels. Household decisions on activities and technologies thus play an important role in aggravating or reducing soil nutrient depletion processes.

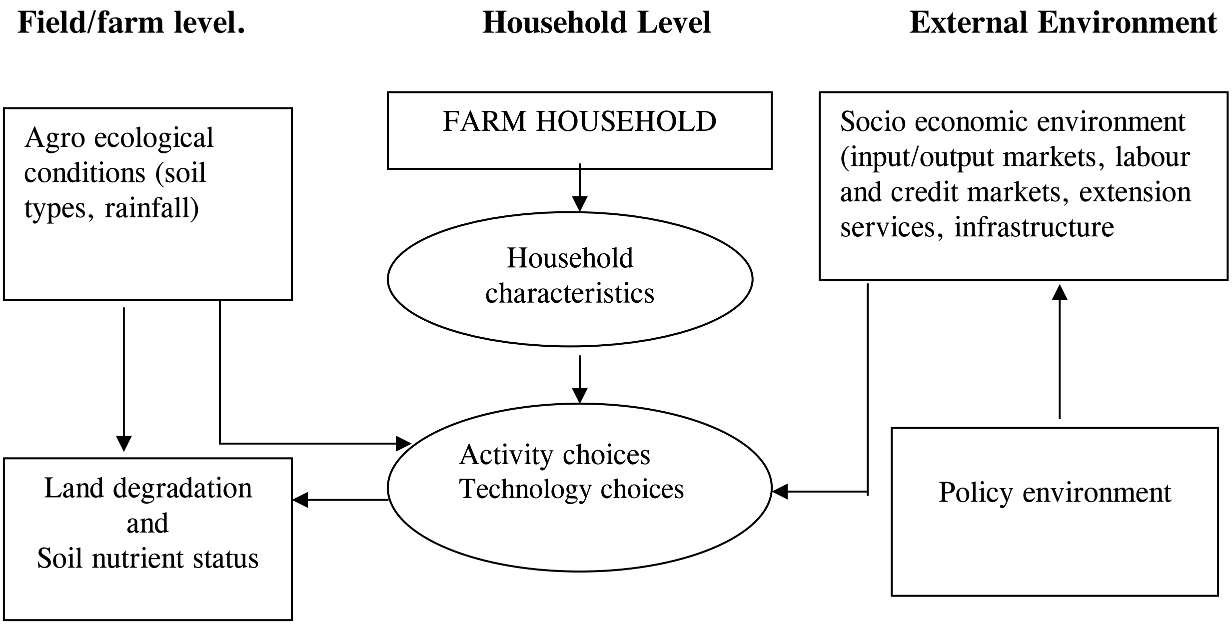

Figure 1.2: Analytical framework

1.3.2 Data and data sources

A formal household level survey was carried out on a random sample of 296 households in Kiambu and 253 households in Vihiga using a pre-tested structured questionnaire. The sites selected for the survey are within the high potential, high population density areas, where soil nutrient depletion is high due to continuous and intensive cropping. The main data sets are household data including age, gender, education level and occupation of the household head and of all the other family members, farm size, land tenure and distance to the market. Others are production data, consumption and expenditure data, credit and credit markets, extension services, off-farm employment and remittances.

1.3.3 Analytical tools

Descriptive statistics, cluster analysis, and fuzzy classification methods are first used to group together households with similar characteristics, resulting in three groups in each district. The groups form the basis for subsequent analyses.

Farm household modelling techniques are used to analyse and explore the economic attractiveness of possible farm management decisions (activity and soil nutrient management technologies) and their effects on farmers' objectives. A farm household model can either be separable – where production and consumption decisions are analysed independently, or non-separable, where production and consumption decisions are inter-dependent. A separable household model assumes perfect markets for inputs and outputs.

Non-separable household modelling is usually deemed the appropriate tool for most developing countries because, as Singh et al. (1986) and De Janvry et al. (1991) note, in economies with significant transaction costs and missing or imperfect markets, few policy implications can be drawn from conventional economic models. Some of the standard results from production and consumption theory may be reversed when production and consumption decisions are interdependent, with response to price changes being opposite to those predicted (De Janvry et al., 1991). If for example there are no labour markets, then supply of labour by the household will be influenced by how much labour is required for farm work, since extra labour cannot be hired in. In such a scenario a household may fail to respond to output price increase because of labour shortage, and may seem unresponsive to a policymaker.

Perfect markets however, are sufficient but not necessary for separability (Sadoulet and de Janvry, 1995). For example, Benjamin (1992) tested whether farm employment is correlated to household composition under imperfect labour markets. He finds that household composition has no effect on labour demand and concludes that farm labour supply and labour demand can be treated separately for Indonesian rice growers. In any case, as we will show in Chapter 3, non-separability occurs mainly through the labour decisions. We therefore in Chapter 3 adopt a separable household production model, econometrically specified to analyse the activity and technology choices. This is combined with activity ranking based on farmer perception and activity profits, so that the analysis concentrates on the most important activities to the households. The dual production model is later combined with the primal model so as to exhaustively explain the resulting effects.

We finally assume non-separability, and specify a utility maximisation model, which we use to analyse the economic attractiveness of various production technologies and identify conditions under which each of the technologies will be adopted. The utility model is specified in a mathematical programming procedure that allows for simulations and analysis of various activity/ technology combinations.

1.4 Outline of the study

There are six chapters in this study. **Chapter 1** is the general introduction and **Chapter 6** provides a general discussion of the methodologies, results and conclusions. The middle four chapters consistently follow the sequence of the research questions. **Chapter 2** gives a general introduction to farm household characterisation, and describes the study districts as well as the data collection procedures (sampling techniques and household interviews). The survey data is then used to answer the first study question of identifying the major types of households in the two districts based on household characteristics, and other socio-economic factors. The resulting groups, referred to as farm types in this study, are then described based on farm management variables, household resources, and access to key institutions such as credit markets, extension services and input/output markets. These farm types form the basis of the analysis in the following chapters.

Which farm activities are important to the households in the two regions, and what factors influence the choice of these activities and of the soil nutrient replenishing technologies? In **Chapter 3**, farmers' perception and restricted activity profit are used to rank the activities. The factors influencing the output levels of important crops identified from the ranking, and the use of inorganic fertilisers are then examined through a separable household model**.** Although there are various soil nutrient replenishing technologies, in this chapter inorganic fertilisers are singled out because they still remain the major source that holds considerable potential for provision of nutrients. Organic sources of soil fertility improvement such as manure contain low amounts of nutrients, especially phosphorus, and they are required in large amounts, which are not usually available. Moreover, the agronomic recommendation is for these organic sources to act as complements to inorganic sources rather than substitutes.

Results of the dual model used in Chapter 3 are combined with a primal model in **Chapter 4** to identify the impacts that can be expected from price instruments, soil nutrient technologies and fixed factors on output and input levels and on household profit. This is of particular interest to policymakers who want to know what instruments to apply to achieve different purposes. The chapter therefore begins with simulations based on the model of Chapter 3. We then go beyond what is usually done (giving impacts on input and output quantity), by giving the impact of price and fixed factors changes on area allocated to the crops as well. This gives interesting results as it becomes clear that households do not always respond to an increase in input prices by decreasing the rate of input application. In addition, we take a primal approach and elaborate on the results of the dual approach of Chapter 3, and present a clearer picture of the estimated effects. Furthermore, households with different characteristics and facing different resource constraints are likely to respond differently to changes in prices and other factors, hence the analysis is done not only at the whole sample level, but also disaggregated by farm types as identified in Chapter 2.

Economic attractiveness of various activity/technology options and the conditions that make each option adoptable by different household types in one of the study districts are the focus of interest in **Chapter 5**. Various soil nutrient management technologies are considered in relation to a maize/bean inter-crop for each of the farm types. How much liquidity matters to the different farm types in terms of determining their activity/technology choices is discussed. Furthermore, the liquidity level that different farm types require in order to choose the best activity/technology is also identified and discussed. We then explore the possibility of increasing farm revenues through a re-allocation of the currently available household resources. Lastly, the impact of a change in farm size on the optimal activity/technology allocation, and on household survival is considered. For these investigations a non-separable farm household model that combines production and consumption decisions is used.

Chapter 6 synthesises and discusses the most important findings of the study and their policy implications. The results provide a good opportunity to compare the two highly contrasting cases of Vihiga and Kiambu.

This study makes several contributions to the existing literature:

It demonstrates the importance of assessing the effect of prices not only on output and input quantities, but in combination with the effect on area allocated to the crops. Unlike the usual assumption that increase in fertiliser price leads to lower application rates and hence lower yields, the study shows that households respond by either reducing the crop area, or by reducing the rate of fertiliser application or both. When only impact on output is analysed and not impact on crop area, the conclusions and recommendations can actually be different.

The study also shows the importance of carefully comparing empirical results with theoretical expectations. For example, when based on observed elasticities, the price of fertiliser does not seem to have a big impact on the output quantities, particularly kale output. However, further investigation shows that, though fertiliser is important in the production of kale, labour is a constraint, making the impact of fertiliser obscure.

Additionally, by combining the dual model and the primal model the study obtains the unique result that, whereas labour is the most constraining input in one of the regions, it is in abundance in the other region, showing that different policies are required for the two regions.

Another important empirical result is the importance of kale to rural households. No study we know of has shown this importance. The study shows that kale, usually considered a minor crop, is the most important crop for income generation to farm households in Kiambu.

The study puts fertiliser in the context of prices in the right framework, and derives the optimal level of fertiliser application that is not just based on biophysical conditions, but that considers the socio-economic conditions in terms of prices and other input constraints faced by the household.

The last major contribution is the quantification of the liquidity constraint for households with specific characteristics, quantification of its impact in determining the optimal activity/technology combination and the potential impact of easing the liquidity constraint for various household types.

The study also finds that the use of fertiliser is very low, and the analysis shows that this low use can be attributed to labour scarcity in Kiambu, but even more to shadow prices of fertiliser being higher than actual observed prices. The high shadow prices are attributable to liquidity constraints particularly at planting time.

Finally, the results of this study show that currently, although there is some addition of nutrients to replace those being mined by the crops at plot level, the rate of application is far below the recommended rate to be effective. The results therefore imply that households are not currently farming sustainably in terms of nutrient management, confirming earlier observations on the soil nutrient management debate.

CHAPTER 2

CHARACTERISATION OF HOUSEHOLDS IN WESTERN AND CENTRAL KENYA

2.1 Introduction

Farm households are known to be heterogeneous in nature. The heterogeneity is in terms of their resource endowment, their objectives and their access to markets and other institutions. As a result, the degree of intensification in farming within the high potential areas also varies widely, with smallholders adopting various strategies. This makes the study of farmers' willingness to adopt technologies that are more sustainable and lead to increased productivity difficult. The targeting of agricultural production technologies and interventions in such systems is also problematic. *Ex-ante* evaluation of technology change at the household and system level is therefore critical in order to quantify potential impacts both of policy and technology changes. Farm household level models therefore have to consider this heterogeneity. One way of doing this is through classification and characterisation of the farming system. Classification is defined here as the division of households into groups according to their type while characterisation is describing the qualities and peculiarities of the households in each group. The result is groups of households with similar characteristics, referred to in this study as farm types.

There is a large amount of literature on characterising farming systems in Eastern Africa. For example Staal et al. (1998) characterised 365 dairy farmers in the central highlands of Kenya (Kiambu). Patterns among dairy households in terms of level of intensification, household resources and access to services and markets were distinguished by means of a cluster analysis. Shepherd and Soule (1998) used participatory techniques to characterise mixed farming systems in Vihiga district in Western Kenya, based on the resource endowments and constraints faced by farmers. Nicholson et al. (1998) characterised farming systems with respect to the adoption of livestock as a farm component. One aspect that is generally not considered in such studies is the fact that smallholders have multiple goals and that these drive their decision-making. Farmers' goals and attitudes influence the decisions that they make particularly in the choice of technology and enterprise mixes. There is a need, therefore, to classify and characterise farm households, not only in terms of their resource availability, but also in terms of their farm management objectives.

The objective of this chapter is to discuss the classification and characterisation of the farm households in each of the study sites into farm types (households with particular characteristics) that will then form the basis of further analysis and research. Farm household classification is a first step in developing and identifying technologies and interventions suitable for different farm households in the mixed farming systems. Household data collected from the different sites form the basis of classification.

2.2 Description of the study area

The PROSAM project focuses on high agricultural potential, high population density areas. High agricultural potential here refers to cropping and dairy, and is as defined by Jaetzold and Schmidt (1983). The pilot project is implemented in Kenya at three study sites that include the Vihiga district in Western province, the Kiambu district in Central province and the Kilifi district in Coast province. These sites, particularly Vihiga and Kiambu, were chosen because they are located in the high agricultural potential, high population density areas. In these high potential areas intensive mixed farming is prevalent and soil nutrient depletion is likely to be a major problem. In addition, the Kenya Agricultural Research Institute (KARI) and the International Livestock Research Institute (ILRI) already had ongoing activities in the two sites, so information could be shared.

This study concentrates only on Vihiga and Kiambu districts. The main objective is to examine how a combination of socio-economic and household factors influence household decisions on farm activity and soil nutrient management technology choices, and how these technology and activity choices impact on household objectives and on productivity. Given this objective, Vihiga and Kiambu districts, which both fall within the high agricultural potential, high population density areas, yet with quite different farming practices, offer a good and sufficient opportunity for achieving the objectives of the study. These two districts are different, both in terms of the socio-economic characteristics such as market access and their socio-cultural backgrounds.

Table 2.1 summarises the characteristics of the two districts and Figure 1.1 shows where the sites are located on the map of Kenya.

Table 2.1: Characteristics of Vihiga and Kiambu districts

	Western Kenya: Vihiga	Central Kenya: Kiambu
Altitude (m)	1550	1800
Average annual rainfall (mm)	1900	1000
Average temperature (°C)	20.3	18.1
Population density (km^{-2})	886	562
Landform	Rolling with small catchment areas	Rolling, occasionally steep
General land use	Maize, beans, bananas, vegetables, tea, local zebu cattle, and semi-intensive dairy	Maize, potatoes, tea, vegetables, fruits, coffee, beans and intensive dairy
Livestock trends	Low but stable	High and increasing
Soil fertility	Moderate	Moderate
Cash opportunities, access to markets	Medium to good	Good

Ref: Extracted from Jaetzold and Schmidt (1983)

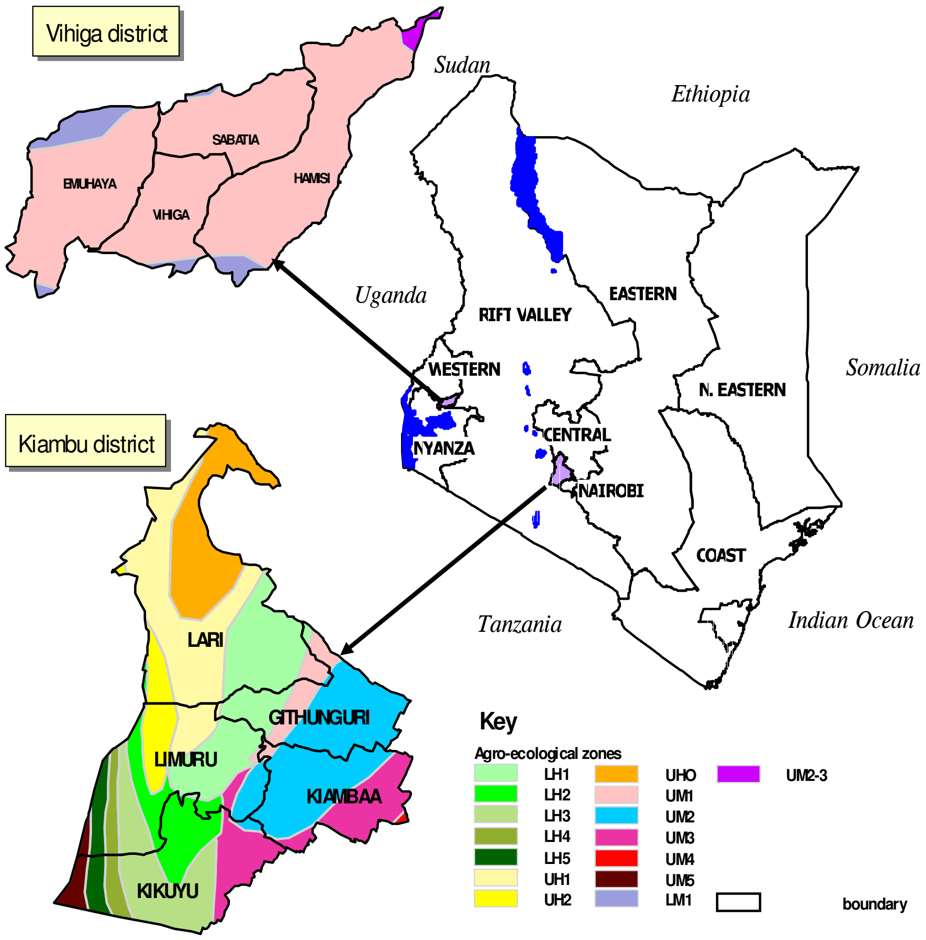

Figure 2.1: Map of Kenya showing the two study sites

Vihiga district is located in western Kenya and covers an area of 563 square kilometres. It had a total population of 498,883 in 1999, with a population density of 886 persons per square kilometre (RoK, 2001). The population density varies by sub-location (smallest administrative unit) with some sub-locations having a density as high as over 1500 persons per square kilometre. The average household has 4.7 persons living on an average of 1.3 acres (0.5 ha) of land, creating a very high dependency on agriculture (RoK, 2001). The district is a high agricultural potential area predominantly in the upper midland one (UM1) agro-ecological zone, with an average altitude of 1550 m above sea level, average temperatures of 20.3^{0}C and well-drained soils (Jaetzold and Schmidt, 1983). The area receives bimodal rainfall that ranges from 1,800 – 2,000 mm per year with long rains falling from March to June and short rains between August and November. This rainfall allows for two cropping seasons in a year. Use of nutrient replenishing inputs is low (Salasya et al., 1998) and farm households have moderate market access for both inputs and outputs, with varying transaction costs. Vihiga district has six administrative divisions: Sabatia, Vihiga, Hamisi East, Hamisi West, Emuhaya and Luanda.

Agriculture is the main economic activity in the district, with food crops being maize, beans, sorghum, finger millet, groundnuts, bananas, cassava and a variety of horticultural crops. The cash crops are tea, coffee, bananas and sugar cane, with tea being the main cash crop and maize the main food staple. Opportunities to increase tea production exist because tea-buying centres are springing up near most shopping centres and the local factory is currently operating at excess capacity. Farmers also keep livestock, including cattle, poultry, sheep and goats. Cattle are the most important livestock species, the most common being indigenous zebus, but there are also some cross breeds and a very few exotic dairy cattle. The second most important livestock are local poultry, which are kept by almost every farm household. The district is self sufficient in staple food for only six months of the year and is therefore a net buyer. The land tenure system is freehold with individual farmers having title deeds for their land parcels.

The main farming constraint is low and declining soil fertility as a result of continuous cropping without sufficient replenishment (AFRENA, 1987; Salasya et al., 1998), and leaching over the years. Other constraints are low farm income, and low yields (both crop and livestock), small and declining farm sizes and poor road infrastructure that make marketing of perishable produce such as vegetables problematic (Waithaka et al., 2000). However, an active food market exists, with private traders who undertake arbitrage between localities and periods of relative abundance and scarcity.

Kiambu, the other study district, is located in central Kenya in the vicinity of Nairobi, the capital city, and covers an area of 1,324 square kilometres. The population of the district according to the 1999 population census stood at 744,010 with an average population density of 562 persons per square kilometre (RoK, 2001). There are several large-scale tea and coffee plantations in the district that are owned by only one or a few people. When looked at on a sub-location basis, the population density in some sub-locations is over 1500 per sq km. The average household has 3.9 persons living on an average of 1.7 acres (0.7 ha) (RoK, 2001). The district is covered by varied agro-ecological (climatic) zones ranging from upper highland zero (UH0) which is mainly forest and receives the highest amount of rainfall (average of 2000 mm) to upper midland 5 (UM5), which is quite dry receiving less than 700 mm of rainfall (Jaetzold and Schmidt, 1983). The current study focuses on the upper, more humid part of the district, covering five of the zones including lower highland one and two (LH1, LH2), the upper midland one and two (UM1, UM2) and the upper highland one (UH1), all as defined by Jaetzold and Schmidt (1983). On average the district receives 1000 mm of rainfall, but average rainfall in the agro-ecological zones where the study concentrates ranges from 1100 to 2000 mm. The rainfall pattern is bimodal with the first season beginning in March and the second season beginning in October. The average altitude is 1800 m above sea level with average temperatures of 18.1^{0}C. The general fertility of the soils is moderate to high and supports the growing of several cash and food crops (Jaetzold and Schmidt, 1983).

Agricultural production is concentrated on cash crops, the major ones being tea, coffee and horticultural crops. The leading food crops grown are maize, Irish potatoes and beans. The livestock sub-sector is well developed with the leading ones in order of importance being: dairy, commercial poultry and pig farming. There is fairly good market access both for inputs and outputs and use of nutrient replenishing inputs is common. However some of the produce finds its way to distant markets such as Mombasa and western Kenya, which are well over 400 km away. The close proximity to Jomo Kenyatta International Airport has favoured floriculture and horticulture (MoA, 2001).

2.3 Data collection

A two-phase, cross-sectional characterisation survey of 549 farm households (253 in Vihiga and 296 in Kiambu districts) was conducted. The first phase was conducted in Vihiga district where data from 253 households was collected during May to July 2000 as part of a large characterisation survey covering western Kenya (Waithaka et al., 2002). The second phase took place during October to December 2001 in Kiambu district where data was collected from 296 households in a formal survey. Because the Vihiga survey was not collected with the specific objectives of this study, some important data, such as, labour for crop and for livestock production, crop outputs, household time allocation, and household consumption and expenditure were not collected. There was therefore a follow-up survey where additional data was collected from 175 of the 253 households in June 2002. Because of time limitation, and because some farms had been subdivided since the previous survey and were now different entities, only 175 households could be interviewed.[2.1]

2.4 Household classification and characterisation

As already observed, smallholders have different resources, goals and objectives, and farm-level analyses have to consider these. Individual farm households are complex decision-making units with specific economic behaviour that leads to specific strategies or farming practices. The production decisions and technical choices they make are behavioural responses to particular constraints that lead to particular factor/input use intensities and specialisation. As a consequence, in order to target the biophysical and economic interventions, it is necessary to classify the farm households in order to identify categories with similar characteristics and that exhibit similar reactions to changes in policy conditions and/or are subject to specific recommendations. The idea is to create optimal groups out of variables from particular data so that variables in the same group show close similarities and variables between groups are as unequal as possible. In this way, key variables that characterise the different groups are identified. It is important that the variables that characterise the farmers in the different farm types be relatively stable, so that the groupings do not change easily in response to policies or implementation of recommendations (i.e. households will remain in the same farm type).

2.4.1 Selection of variables used in the classification

According to Everitt (1993), the initial choice of variables for classification presumably reflects the investigator's judgement of relevance for the purpose of classification. The first step is therefore to decide what the aim of the classification is. The variables for classification should then be selected based on their relevance to the type of characterisation aimed for (Abubakr, 2000). Selection of variables used in the classification was based on the observed heterogeneity within the sample and also on issues considered to be central to

[2.1] For details on survey procedures see Appendix 2.1.

the planned focus of eventual research and potential interventions for a wider dissemination. The classification was therefore mainly based on relevant (variables that drive management decisions) structural farm household characteristics (farm size, size of the household, age of the household head, education level, gender of the household head and livestock ownership), and an institutional variable, distance to the nearest market. The structural variables are known to be relatively stable, and so, the groups that emerge should also be relatively stable groupings. Additional variables used in characterising Vihiga households were: gender of the farm manager, income share of food crops, income share of cash crops, and the breed of cattle kept. In Kiambu the number of adults over 14 years was used instead of household size. The breed of cattle kept was not included as a classification variable for the Kiambu sample because all households kept only improved breeds. Finally the emerging groups are described by variables that characterise them such as crop choice, technology choice, stocking rate, input use intensities, commercialisation rate and performance parameters such as yields and income composition.

As an alternative way to what the respondents indicated on the questionnaire as their main farming objective, the ratio of the marketed surplus to total farm production was used following Randolph (1992). In order to capture the household's revealed market behaviour, Randolph measured the degree of commercialisation by the proportion of total agricultural production marketed by the household. Three main farming objectives are anticipated: food (farming for subsistence), income (maximise profits) and a group in between the two (semi-commercial). If a farmer is marketing (selling) less than 33% of the farm produce it is assumed that that farmer's main objective in farming is food security, if they market between 33% and 66% of the farm produce they are semi-commercial and if over 66% is marketed then they are commercial.

2.4.2 Classifying Vihiga households

Cluster analysis was used to classify the households in Vihiga district. Cluster analysis, also sometimes referred to as classification analysis, refers to a group of multivariate techniques whose primary purpose is to group objects based on the characteristics they possess (Hair et al., 1998; Jain and Dubes, 1988; Hartigan, 1975; Lorr, 1983). Cluster analysis classifies objects (e.g. households, products, or other entities) so that each object is very similar to others in the cluster with respect to some predetermined selection criterion. The resulting clusters of objects should exhibit high internal (within cluster) homogeneity and high external (between clusters) heterogeneity. Its primary value lies in the classification of data, as suggested by "natural" groupings of the data themselves. A summary of the variables used for clustering the Vihiga households is shown in Table 2.3 below.

Table 2.3: Summary of variables used for classifying Vihiga households

Variable	Unit of measurement
Farm size	Acres
Size of household	Number of persons
Age of household head	Years
Education level of household head	Grade reached (1 = none, 2 = primary, 3= secondary, 4= post-secondary
Distance to the nearest market	Kilometres (km)
Objective of income	Strong, weak or none
Gender of the farmer	0 = male 1 =female
Farm manager	1=Husband, 2=wife and 3=other
Tropical livestock units (TLU) [2.1] per acre	Number
Income share of food crops	Fraction
Income share of cash crops	Fraction
Breed of cattle kept	Local, cross or grade

The results of the cluster analysis produced three farm types based mainly on farm size, age of the household head, education level of the household head, livestock ownership and household size, which seem to have been the main driving forces to the classification. The group with the smallest farm size had sixty-seven households, the medium farm size ninety-seven households and the largest farm size eighty-nine households.

2.4.3 Classifying Kiambu households

Although different cluster procedures exist, most farmer classifications use hard classification procedures that limit a household to belonging to only one group (e.g. Solano et al., 2001; Kruseman and Bade, 1998; Staal et al., 1998). However, because of the complex nature of farming systems with different combination of factors affecting households' decisions on farm practices, classification methods that limit any one case (household) to belonging to only one group may be inappropriate. Fuzzy classification was used to group the Kiambu households into farm types. Fuzzy classification is a continuous, quantitative and objective procedure in which the clusters are defined based on cluster centres in terms of membership values. The larger the membership value the stronger the linkage to a particular cluster. The methodology also accommodates qualitative and discrete attributes such as gender of the household head. In the fuzzy classification, individuals can belong totally, partially or not at all to a particular farm type. The main feature of this

[2.1]: 1 for bull; 0.7 for cow; 0.5 for heifer and young bull; 0.2 for calves (see Bebe, 2003).

method of classification is the grouping of individuals into classes where boundaries are not, should not, or cannot be exactly defined. It allows individuals to have partial class membership (i.e. an individual can belong to more than one class (Burrough et al., 1992). The resulting groups are such that each individual has a percentage of belonging to each of the farm types.

The advantage of the fuzzy system of classification over other classification methods is that it allows the researcher to check the membership allocation of individuals: the greater the membership, the stronger the linkage to a particular class (farm type in our case). This is important because it is possible to tell which households fit well in a particular farm type and which ones do not fit well and hence are likely to move in case of minor changes. It is also of particular importance for modelling a particular farming system. Households that have a high membership value for the farm type they belong to can be selected for such modelling instead of a non-existing average household within a farm type. It also makes it easy to predict which households are likely to adopt technologies designed for different farm types. It is flexible and transfers more and better information to the users. These advantages and the fact that subsequent steps of the PROSAM project involve modelling the different farm types, led to the choice of fuzzy classification procedure to classify the farm households in Kiambu district.

This continuous method has been widely used for soil classification and delineation of management units (Fridgen et al., 2000; McBratney and De Gruijter, 1992; Van Alphen and Stoorvogel, 2000; McBratney and Odeh, 1997). To the best of our knowledge, it has not been used in classifying farm households into different farm types.

The fuzzy classification approach adopted for this study is the fuzzy k-means (DeGruijter & McBratney, 1988). A fuzzy k-mean is defined by the following function:

$$J = \sum_{i=1}^{n} \sum_{k=1}^{c} m_{ik}^{\phi} d^2 (x_i c_k) \qquad [1]$$

It minimises the within-class sum of square errors functional under the following conditions:

$$\sum_{k=1}^{c} \boldsymbol{m}_{ik} = 1 \text{ for all } i = 1, 2, \ldots, n$$

$$0 \leq \boldsymbol{m}_{ik} \leq 1 \quad i = 1, 2, \ldots, n; \quad k = 1, 2, \ldots, c$$

Where m refers to the membership value of farm household i to class k, n is the number of cases (farm households), c is the number of classes and, c_k is the vector representing the centroid of class k, x_i is the vector representing variable values for farm household i and $d^2\ (x_i, c_k)$ is the squared distance between x_i and c_k according to a chosen definition of distance, which for simplicity is further denoted by d_{ik}^2. ϕ is the fuzzy exponent and ranges from (1,∞). It determines the degree of fuzziness of the final solution, that is the degree of overlap between groups. With ϕ = 1, the solution is a hard partition where an individual can belong to only one class. When ϕ exceeds one, an individual may be given partial membership in more than one class, and as ϕ approaches infinity the solution approaches its highest degree of fuzziness. The minimisation of the objective function J provides the solution for the membership function (Bezdek, 1981).

$$\boldsymbol{m}_{ik} = \frac{d_{ik}^{2(\phi-1)}}{\sum_{j=1}^{c} d_{ij}^{2(\phi-1)}}$$

$$i = 1, 2, \ldots, n;\ k = 1, 2, \ldots, c \qquad [2]$$

$$c_k = \frac{\sum_{i=1}^{n} m_{ik}^{\phi} x_i}{\sum_{i=1}^{n} m_{ik}^{\phi}}$$

$$k = 1, 2, \ldots, c \qquad [3]$$

The classification was done using the FuzME computer program. The procedure included specifying the number of classes k with $1 < k < n$, and choosing a value for the fuzziness exponent ϕ with $\phi > 1$. Five classes were specified and the fuzziness exponent used was 1.3. After observing the results, there was no added advantage to having four classes instead of three and consequently three classes were chosen. An individual farm household is assigned to the group where it has maximum membership. Appendix 2.2 shows a sample of the results of a fuzzy classification. Table 2.4 below summarises the variables used in the classification.

Table 2.4: A summary of the variables used for classification of Kiambu households

Variable description	Unit of measurement /options
Farm size	Hectares
Size of adult members over 14 years	Number of persons
Age of household head	Years
Education of household head	Years spent in school
Distance to the nearest market	Kilometres (km)
Cattle owned	Number of TLU equivalent

2.4.4 Characteristics of the resulting farm types in Vihiga

To test differences in the three farm types that emerged from the classification, the mean values of major variables in each farm type were compared with the combined means of the other two farm types using a t-statistic. The results are shown in Table 2.5a below. The right-hand column of Table 2.5a indicates the percentage variation in the variable that is explained by the cluster. Table 2.5b shows number and percentages of some variables in each farm type.

Table 2.5a: Means and standard deviations (in parentheses) of major variables for the farm types in Vihiga district

	Farm type one		Farm type two		Farm type three		Explained variation %
Number of farmers	89		97		67		
Farm size (acres)	2.82	(2.35)	2.29	(2.87)	0.93**	(0.89)	9.6
Age of household head (years)	51.5	(10.7)	59.7***	(11.2)	37.9***	(8.59)	41.0
Education level of household head (years in school)	9.07	(4.04)	7.14***	(4.02)	10.5***	(1.96)	20.2
Size of household (persons)	6.49***	(2.27)	5.90	(2.24)	5.12***	(1.58)	16.5
Distance to nearest market (km)	1.49***	(1.49)	2.42***	(1.40)	1.97	(1.36)	7.35
Tropical livestock units (TLU)	1.52***	(1.32)	1.48**	(1.22)	.55***	(0.78)	11.6
Number of grade cattle	0.56**	(1.76)	0.14	(0.66)	0.06***	(0.38)	3.57
Number of Zebu cattle	1.00	(1.41)	1.27**	(1.79)	0.46***	(0.86)	4.67
Number of cross cattle	0.94	(1.33)	1.06*	(1.70)	0.34***	(0.93)	4.35
Amount of fertiliser per acre	23.5	(23.6)	19.4	(41.8)	17.9	(23.9)	0.5
Area under food crops (acres)	1.72***	(2.32)	1.16	(1.18)	0.48***	(0.42)	8.51
Area under cash crops (acres)	0.28	(0.41)	0.32	(0.40)	0.14***	(0.20)	4.32
Area under Napier grass (acres)	0.33***	(0.44)	0.25	(0.43)	0.09***	(0.20)	
Area under pastures (acres)	0.56	(0.57)	0.58	(2.10)	0.22*	(0.38)	
Ratio of marketed farm surplus	0.28	(0.22)	0.31	(0.29)	0.25	(0.25)	
Off-farm income (ksh.'000)	78.0	(104)	45.4**	(61.1)	71.0	(74.7)	

*, **, *** Identifies the variables that are significantly different at the 10%, 5% and 1% levels respectively when the mean of one farm type is compared with the mean of the other two combined.

Table 2.5b: Frequencies for various variables by farm type in Vihiga

Variable	Farm type one		Farm type two		Farm type three	
Number of female headed households	7	(7.8%)	21	(21.6%)	10	(14.9%)
Number using fertiliser	72	(80.9%)	60	(61.9%)	46	(68.7%)
Number keeping cattle	80	(89.9%)	86	(88.7%)	26	(38.8%)
Number using manure	85	(95.5%)	95	(97.9%)	53	(79.1%)
Percentage of farm income from dairy		17%		21%		16%
Percentage of farm income from tea		10%		11%		8%
Percentage of farm income from food crops		34%		28%		34%
Income objective as second most important	58	(65.2%)	62	(63.9%)	25	(37.3%)
Total farm income (% of total hhd income)		(57%)		(64%)		(26%)

2.4.4.1 Description of the farm types in Vihiga

a) Farm type one

The first farm type includes 89 households, has the largest farm size, medium aged household heads and the largest household size. They are located nearest to the market and have the lowest percentage of households headed by females. They have the highest number of tropical livestock units, more grade cattle, and they also have a significantly larger area under Napier grass. They maintain a large area under food crops, and similarly most of their farm income is derived from food crops. Sixty-five percent of them indicated that their second main objective in farming is income generation, second to food supply (note that over 92% of households in Vihiga irrespective of farm type indicated food supply to be their main objective in farming). They are therefore classified as semi-subsistence. Semi-subsistence has been defined before as the situation where the farm households interact with the markets with the level of interaction varying widely from case to case (Guenat, 1991).

a) Farm type two

Farm type two (n = 97) has medium farm size, old household heads with low education and are located farthest from the markets. They have a higher proportion of households headed by females and more Zebus and cross cattle than farm types one and three, and they have medium Tropical Livestock Units (TLU). Notably, they have the lowest off-farm income of all the three farm types, and in addition they have the highest fraction of households using manure. They derive about 64% of their total household income from farming, which is the highest among the three farm types, and about 64% of them indicated that income generation was their second most important objective in farming. They devote about half their land (50.4%) to food crops and have the largest area under cash crops though not significantly different from the others. They can also be classified as semi-subsistence households similar to farm type one, even though there are major differences between them in other variables.

c) Farm type three

This farm type, consisting of 67 farm households, has an average farm size that is significantly smaller than the others, younger household heads, who are better educated and have a smaller household size than farm types one and two. They have fewer tropical livestock units (TLU) and fewer cattle of all three breeds. Only 37% of them mentioned income as their second most important objective, indicating that they have a much lower perception of income generation as an objective for farming. The alternative objectives mentioned by the households were maintenance of soils, livestock feed, livestock health and energy needs. This farm type may therefore be loosely described as consisting of households who mainly farm for subsistence. Subsistence production has been defined as production of adequate food to provide for the immediate family with a small surplus being sold for cash to satisfy other needs (Lulandala, 1994). Only 26% of the total household income in this farm type comes from farming and the rest from wages and other sources. Their area under cash crops and under Napier is significantly smaller compared to the other two farm types. Interestingly, the number of farm households who use manure in this farm type is more than double the number that keep cattle, implying that they get manure from relatives or neighbours. It is common in the area for sons who do not have cattle to get manure from their parents. There were no cases of manure being bought or sold.

2.4.4.2 Discussion of Vihiga farm types

Over 92% of the households in all the three farm types indicated that food supply was their main farming objective. However, the differences across farm types come in their second most important objective, where 65.2 households in farm type one, 63.9% of farm type two and 37.3% percent of farm type three indicated income generation. This result shows that in general farmers in Vihiga district consider income generation their second most important objective in farming after provision of food. However, the fact that they all endeavour to satisfy their food needs before income generation implies some kind of risk aversion where the households are unwilling to completely rely on the market for their household food requirements.

From the results it is clear that households in farm type three are different from those in farm types one and two, especially as far as income orientation is concerned. Other than having only 37% indicating income to be their second most important objective, only 26% of their income is from farming while the rest is mainly from wages, and from other sources. In addition, they only have a small area under cash crops. This group therefore fits the description of subsistence households, with food supply as their main objective.

Between farm types one and two the difference in terms of their response to the income objective is not distinct (about 65% of households for farm type one versus 64% in farm type two). In terms of market orientation, they are therefore both classified as semi-subsistence. However, there are differences between them in other variables. For example, their sources of household income are different. Farm type one get only 57% of their income from farming, whereas farm type two derive 64% of their income from farming. More notable is the level of their off-farm income, where that of farm type one is much higher than that of farm type two. Also, although farm type one has significantly more grade cattle and more cattle in total than farm type two, farm type two has a higher percentage of farm income from dairy than farm type three. Additionally, farm type two has more female-headed households than does farm type one. It appears that farm type two households are more commercially oriented than farm type one (even if the difference is not so distinct) and hence manage their farm activities better.

It is likely that the different farm types have different technology and other needs, particularly farm type three compared to one and two. Subsequent research aimed at improving the welfare of households in the different farm types should look at what technologies are appropriate for which group.

2.4.5 Characteristics of the resulting farm types in Kiambu

From the fuzzy classification procedure three farm types were obtained, with an individual farm household belonging to the farm type where it had maximum membership. There are 117 households in farm type one, 63 in farm type two and 116 in farm type three. As for Vihiga, to test differences in each variable between the groups, the mean values of major variables in each farm type were compared with the combined mean of the other two farm types using a t-statistic. Table 2.6a below summarises the means and standard deviations (in brackets) of the major variables for each of the three farm types. The right-hand column of Table 2.6a indicates the percentage variation in the variable that is explained by the cluster. Table 2.6b shows number and percentages of some binary and other variables in each farm type.

Table 2.6a: Means and standard deviations (in parentheses) of major variables for the farm types in Kiambu

Variable	Farm type one		Farm type two		Farm type three		Explained variation %
Number of farmers	117		63		116		
Number of adults (persons over 14yrs)	5.09***	(2.01)	4.12	(2.11)	2.71***	(1.07)	26.6
Distance to the market (km)	2.12	(1.68)	1.88	(1.58)	2.24	(1.61)	0.70
Farm size (hectares)	0.98	(0.83)	1.15*	(1.28)	0.63***	(0.60)	5.34
Age of household head (years)	60.1***	(9.84)	67.7***	(11.08)	39.06***	(8.17)	61.3
Education (years in school)	10.87***	(3.19)	1.07***	(2.89)	10.59***	(2.70)	64.6
Total TLU	1.39	(1.09)	1.45	(1.26)	1.10*	(1.53)	1.32
Amount of fertiliser/ha (kg)	121	(151)	103.5	(153.9)	133.	(130)	0.78
Amount of manure/ha (bags)	63.80	(62.83)	52.08***	(38.48)	95.6***	(115)	4.58
Off-farm income (ksh.'000)	88.0*** (11.5)		27.6*** (45.7)		54.9 (80.7)		6.11
Ratio of marketed farm surplus	0.66 (0.20)		0.60* (0.19)		0.63 (0.24)		1.29
Value of output per hectare (ksh.'000)	155.6 (29.8)		116.7*** (73.1)		180.7* (212.4)		2.02

*, **, *** Identifies the variables that are significantly different at the 10%, 5% and 1% levels respectively when the mean of one farm type is compared with the mean of the other two farm types combined. The value of total farm produce refers to the market value of all farm produce including what is consumed at home.

Table 2.6b: Frequencies for various variables by farm type in Kiambu

Variable	**Farm type one**		**Farm type two**		**Farm type three**	
Main occupation of hhd head						
1 = Farming	80	(68.4%)	59	(93.7%)	53	(45.7%)
2 = Non farming	37	(31.6%)	4	(6.3%)	63	(54.3%)
Number of female-headed households	15	(12.8%)	32	(50.8%)	19	(16.4%)
Number using fertiliser	101	(86.3%)	57	(90.5%)	106	(91.4%)
Number having cattle	95	(81.2%)	51	(81.0%)	84	(72.4%)
Number using manure	105	(89.7%)	57	(90.5%)	104	(89.7%)
Number having tea	22	(18.8%)	6	(9.5%)	12	(10.3%)
Number who received credit	17	(14.5%)	7	(11.1%)	21	(18.1%)
Number who had extension advice	59	(50.4%)	29	(46.0%)	46	(44.6%)
Farmer food objective	71	(60.7%)	45	(71.4%)	73	(62.9)
Farmer income objective	46	(39.3%)	18	(29.6%)	43	(37.1%)

2.4.5.1 Description of the farm types in Kiambu

Results from the comparison of means of various variables show that the key variables driving the classification of farm households in Kiambu are education level of the household head, age of the household head, number of adult members and farm size. A description of the various farm types based on the means and *t-test* follows below.

a) Farm type one

The 117 farm households in this farm type are characterised by significantly more adult members, with old household heads who are older than those of farm type three but younger than those of farm type two. They are relatively more educated and have relatively higher off-farm income.

b) Farm type two

Farm type two has the fewest members with only 63 households and is characterised by significantly larger average farm sizes of 1.15 hectares. They have the oldest household heads, who are the least educated among the three farm types, with an average of only 1.07 years in school.

c) Farm type three

This farm type has 116 households and is characterised by few adult members and significantly smaller farm size, which average 0.63 ha. They have significantly younger household heads, who are relatively well educated and have significantly fewer tropical livestock units.

2.4.5.2 Discussion of Kiambu farm types

Tables 2.6a and 2.6b present the summary descriptive statistics for all the resource and management variables, and results of the *t-test*. Households in farm type one and farm three are involved both in off-farm employment and in farming as the main occupation. Farm type one, however, has a higher percentage in farming and farm type three has a higher percentage in off-farm employment. By contrast, farm type two households are mainly (93.7%) in farming and a large percentage (50.8%) of them are female headed.

The three farm types show some differences in key management variables, particularly manure application. There are also differences in land productivity as indicated by value of total output per hectare. Smaller farms show a significantly higher productivity and this productivity decreases as the size of the farm increases. Farm type three has significantly smaller farms, has the highest productivity in terms of output per hectare and in addition uses more manure per acre. Farm type two has significantly bigger farms and has the lowest productivity in terms of output per hectare. In addition, farm type two applies manure at a significantly lower rate than the other farm types. These observations are consistent with the notion that smaller farms are managed more intensively. For example, households with smaller farm sizes in the Kenya Highlands maintained higher stocking rates and were managed more intensively in terms of using external inputs (Bebe, 2003). The farms will continue to become smaller as a result of an annual human population growth of 3% in Kenya (RoK, 2001), and technologies intended for this and similar groups of farmers will need to address these intensification issues.

Farm type one households have significantly higher off-farm income, whereas farm type two has significantly lower off-farm income. Farm type two therefore, has both the lowest off-farm income and the lowest farm productivity in terms of value of output per hectare, which may suggest a link between off-farm income and farm productivity. Related to off-farm income is the occupation of the household head, where farm type two has majority of the households involved in farming as their main occupation, with only 6.3% being in off-farm employment. Farm type one has the highest number of households indicating income generation as their main farming objective and also has the highest market surplus. By contrast, farm type two has the lowest percentage of households indicating income generation as their main farming objective and also has the lowest marketed surplus. However, although farm type two has significantly lower marketed surplus, all the three farm types in Kiambu can be described as semi-commercial, because their marketed surplus lies between 0.33 and 0.66.

What is more striking is that the percentage of variation in management variables (particularly fertiliser) that is explained by the clusters (Table 2.6a) is very low. However, assuming that markets are working, then, as stipulated in economic theory (e.g. Sadoulet and de Janvry, 1995), decisions on market purchased inputs such as fertiliser are influenced mainly by the price, as well as the price of other variable inputs, fixed factors and the output price, rather than by household variables. As we shall see in Chapter 3, the assumption of working markets is reasonable. Fixed factors in this case are farm size, number of livestock and distance to the market.

One could argue that the number of farm types is rather subjective and that an increase would improve the results. Note that the results of the analysis of variance were similar when the analysis was performed for 4 clusters. However, if the membership values to the different clusters are considered and the cluster centres for each variable are compared with the average values, it can be seen that membership values are useful indicators of how well a house fits within a cluster (farm type).

A few examples are used to illustrate whether membership values to the different farm types are actually useful indicators. Tables 2.7a and 2.7b present ten different farm households that were classified in farm type one. The main difference between the households is their membership values. To make the point clear, five of the households have high membership values that vary from 0.99 to 0.97, while five of the households have low membership values varying from 0.40 to 0.46. If membership values are useful indicators it means that household 399 (Table 2.7a) with a membership value of 0.99 resembles very much the cluster centre of farm type one whereas household 407 (Table 2.7a) with a membership value of 0.40 deviates strongly from the cluster centre (but even more from cluster centres of other farm types). Whereas we see some variation in the different variables, it is clear that households with high membership values are closer to the cluster centres. Looking at one individual variable alone may not bring out the difference clearly. However, when all six variables are examined it can be seen that households with high membership values are close to the cluster centre in most of the variables even though they may deviate from the cluster centre on one or two of the variables. It is also clear that households with low membership values deviate widely from the cluster centre in most of the variables, even though they may be close to the cluster centre in one of the variables.

The usefulness of the membership values is illustrated further in Table 2.7b, which shows the squared distance between individual observations and the cluster centre. Households with very low membership values are outliers who simply did not fit better in any of the other clusters, while those with high membership values are a true representative of the cluster. This implies that solutions developed for farm type one based on a representative farm household 407 are not prototypes that can directly be transferred to the other farm households in the cluster. On the contrary, solutions developed based on representative farm 399 can to some extent be transferred to other households in the cluster. It also implies that households with low membership values have a lower probability of adopting technologies developed for the cluster based on the cluster centres than households with high membership values. Decreasing membership values should therefore be interpreted as different farm types and may require more adaptations before management strategies developed for the cluster can be adopted.

Table 2.7a: Some households in farm type one, with high and low membership values and their individual data

		Farm size	Adults	Market distance	Age	Education	TLU
	Cluster centre	**0.93**	**4.96**	**2.13**	**59.06**	**10.86**	**1.40**
Household number	Membership value						
16	0.43	2.86	2.00	1.00	69.00	12.00	3.30
102	0.45	0.40	2.00	0.30	70.00	8.00	1.70
207	0.46	2.12	3.00	1.00	75.00	8.00	1.70
284	0.44	1.80	3.00	4.50	72.00	8.00	0.50
407	0.40	0.20	2.00	0.30	65.00	8.00	1.90
Mean	**0.44**	**1.48**	**2.40**	**1.42**	**70.20**	**8.80**	**1.82**
143	0.97	1.20	7.00	3.00	58.00	12.00	2.40
179	0.97	0.60	7.00	2.00	58.00	12.00	1.20
295	0.98	0.80	7.00	2.00	62.00	12.00	0.90
399	0.99	0.40	5.00	1.50	56.00	12.00	1.20
196	0.99	0.62	5.00	2.50	65.00	8.00	1.20
Mean	**0.98**	**0.72**	**6.20**	**2.20**	**59.80**	**11.20**	**1.38**

Table 2.7b: Some households in farm type one, with high and low membership values and their squared distance from the cluster centre

		Farm size	Adults	Market distance	Age	Education	TLU
	Cluster centre	**0.93**	**4.95**	**2.13**	**59.06**	**10.86**	**1.40**
Household number	Membership value						
16	0.43	3.72	8.72	1.27	98.79	1.30	3.62
102	0.45	0.28	8.72	3.33	119.67	8.19	0.09
207	0.46	1.41	3.81	1.27	254.06	8.19	0.09
284	0.44	0.75	3.81	5.64	167.42	8.19	0.80
407	0.40	0.54	8.72	3.33	35.27	8.19	0.25
Mean	**0.44**	**1.34**	**6.76**	**2.97**	**135.04**	**6.81**	**0.97**
143	0.97	0.07	4.19	0.76	1.13	1.30	1.01
179	0.97	0.11	4.19	0.02	1.13	1.30	0.04
295	0.98	0.02	4.19	0.02	8.64	1.30	0.25
399	0.99	0.28	0.00	0.39	9.37	1.30	0.04
196	0.99	0.10	0.00	0.14	35.27	8.19	0.04
Mean	**0.98**	**0.12**	**2.52**	**0.27**	**11.11**	**2.67**	**0.27**

The characterisation for Kiambu shows the potential for fuzzy classification in obtaining more representative farm household clusters through the membership values. At the same time however, the Kiambu data illustrate the tremendous variation in a cluster of farms and hence the limitation of working with a representative farm type especially under the hard classification.

In summary, three farm types emerged with farm type one being characterised by having significantly more adult members and old household heads who are relatively well educated. Farm type two is characterised by larger farm sizes and the oldest household heads who are the least educated. Farm type three on the other hand is characterised by few adult members, significantly smaller farms, and significantly younger household heads who are relatively well educated, and they have fewer tropical livestock units. Smaller farms (farm type three) achieve higher productivity in terms of output per unit area, and the productivity decreases with increasing farm size. In terms of their market orientation all the three farm types are classified as semi-commercial based on their marketed surplus. The potential of fuzzy clustering was explored and the results are promising. Membership values give extra insight in defining representative farm types. Nevertheless this still has to be tested in technology development and dissemination studies whether the assumptions with respect to the usage of the membership values actually will hold.

2.4.6 Comparison of households in Vihiga vs. those in Kiambu

Detailed comparison between Vihiga and Kiambu follows in subsequent chapters. However from the descriptive statistics a few observations can be made as summarised in Table 2.8 below.

Table 2.8: Comparison of households in Kiambu and in Vihiga

Variable	Kiambu	Vihiga
Farm size (hectares)	0.88	0.86
Adult household members	3.95	3.90
Distance to the nearest market (km)	2.11	2.4
Total livestock units (TLU)	1.29	1.25
Fertiliser per hectare (kg)	122	50.6
Manure in bags per hectare	73.7	26.3
Marketed surplus	0.63	0.29
Income as main objective (%of total)	36.1	7.9

The average farm sizes in the two districts are similar and so is the distance to the nearest market and total livestock units. However, the amount of fertiliser used per acre is quite different, with that in Kiambu being more than double that of Vihiga. Similarly the amount of manure applied per hectare in Kiambu is almost triple the amount applied in Vihiga. Whereas in Kiambu 36.1% of the households indicated that income generation was their main objective in farming, and the remaining 63.9% had it as their second objective, in Vihiga only 7% indicated it was their most important objective and 57.3% placed it second. Additionally, the marketed surplus is much lower for the Vihiga households compared to those in Kiambu. This points to an empirical question, why the major difference? This will be investigated in detail in the chapters that follow.

2.4 Discussion and conclusions

Farm size, age of the household head, education level of the household head, livestock ownership and household size, were the main driving forces in the classification and characterisation of households in Vihiga district. The level of commercialisation increased with farm size such that households with the smallest farm sizes were mainly farming for subsistence with little cash earnings from the produce. Households with larger farm sizes on the other hand, had an element of income-generation in their farming, and subsequently used more external inputs and generated comparatively higher incomes from farming. The number of grade cattle kept and amount of fertiliser per hectare progressively increases from the small farm sizes to the larger ones. Similarly the number of household members increases with farm size. However, although both farm types one and two are classified as semi-subsistence, farmer type two appears to be more commercially oriented than farm type one. What is also interesting is that irrespective of their farm type, all the three groups committed more than fifty percent of their land to food crops, and about 93% of them indicated that food supply was their main objective in farming. This points to a possibility of market failures and/or risk aversion, suggesting that households are unwilling to take the risk of increasingly relying on the market for their food needs. Nonetheless, all the households interviewed indicated that foodstuffs including the food staple were always available on the market for purchase.

The key factors influencing the classification and characterisation of the farm households in Kiambu are similar to those of Vihiga and include education level of the household head, age of the household head, farm size and number of adult members. There is no farm type that is purely subsistence oriented in its farming objective as given by the ratio of the marketed farm surplus. The level of intensification increases with the size of the farm, such that small farm sizes use more manure and achieve higher output per unit area than the larger farms. Farm type three is distinct from the other two farm types in that it has the significantly smallest farm size, has significantly younger household heads and has the fewest adult members. More than 50 percent of them were in off-farm employment as the main occupation. Farm type two on the other hand is distinguished by the majority of them (about 94%) being in farming as their main occupation, having significantly larger farms and though they use a similar amount of fertiliser per unit area to the other farm types, they achieve significantly lower output per hectare. The most distinct features of farm type one are many adult members, high off-farm income and that the household heads are old and educated.

Appendix 2.1: Survey procedures and survey instruments

Survey procedures

Data collection in Vihiga district was part of a large characterisation survey for western Kenya. Previous studies show that apart from individual household characteristics, production and marketing by farm households are strongly influenced by patterns of human population densities, climate, rainfall and access to urban centres and services. To reflect these patterns in the selection of specific areas to conduct the survey within the seven districts (Bungoma, Kakamega, Vihiga, Nandi, Rachuonyo, Kisii and Nyamira), cluster analysis was used as a means of spatial stratification. The availability of digital spatial data and user-friendly Geographical Information Systems (GIS) allowed the use of cluster analysis. A diverse set of data layers on population, market access, climate and cattle distributions was used to depict differentiation throughout the districts down to the sub-location level. Therefore, instead of simply sampling from the entire subset of sub-locations in these districts, clusters of relatively homogeneous (similar) sub-locations were created to serve as a sampling base. The homogeneity of sub-locations was in terms of population densities, market access and climatic potential. The clusters of sub-locations were useful, with variation between sub-locations ranging from those with high access, good climatic potential and high household densities to the more remote and less populated sub-locations.

The agro-ecological (climatic) potential (medium and high) for cropping and dairy referred to is as defined by Jaetzold and Schmidt (1983). Market access (low, medium and high) on the other hand, was defined by the type of roads (tarmac, passable in all weather, seasonally passable) and the availability of marketing institutions. A final outcome of this clustering procedure was lists of homogenous divisions (similar in terms of population densities, climatic potential and market access) from which two contrasting divisions could be selected in each district to serve as the sampling frame for the survey. In Vihiga the two divisions selected were Hamisi and Vihiga. The interviews were carried out in six sub-locations randomly selected, three of which are in Vihiga division and three in Hamisi division. The number of households to be interviewed in each sub-location was taken as a proportion of the total number of households in the sub-location obtained from the 1989 census (CBS, 1994). In total two hundred and fifty three (253) households were interviewed from Vihiga district.

For Kiambu district, clusters of relatively homogenous agricultural potential areas were created from the ILRI geographical information system (GIS) databases to serve as a base and ensure that farm households from each of the major agricultural production zones are included. The clustering identified five production zones with zone one having the highest agricultural potential and zone five the lowest agricultural potential. A list of all the sub-locations in the district and their population densities was obtained from the 1999 population census report (RoK, 2001). Because the PROSAM project to which this research belongs focuses on high agricultural potential, high population density areas, restrictions were imposed to ensure that the areas selected for the survey fall within high agricultural potential, high population density areas.

For climate related factors annual precipitation over evapo-transpiration (PPE) proved a useful indicator. It combines elevation, rainfall and temperature data into one measure of overall humidity. Sub-locations with a PPE of less than 0.775 were left out. The PPE of 0.775 was the average of the highest and lowest PPE in Kiambu, and is also the minimum PPE under which most crops thrive. The 1999 population census results were used to eliminate less densely populated areas. To that end, a lower bound of 750 persons per square kilometre was imposed, so that a sub-location was excluded if it had a population density lower than that. This lower bound population density in addition ensured that areas selected were comparable to Vihiga district (the other study site) in terms of population density. To exclude small plots, mainly residential areas around towns commonly known as villages, an upper bound of 1500 persons per square kilometre was imposed.

The elimination process left a total of 10 sub-locations spread over four administrative divisions, namely Githunguri, Kiambaa, Limuru and Lari. The ten sub-locations are located in three of the five production zones. Production zones four and five were excluded by the PPE restriction because they are much drier. Out of the ten sub-locations, only one was in Kiambaa division. Because the production zone in which it is located was already represented by other sub-locations, it was dropped from the sample for logistical reasons. As a result nine sub-locations were selected, of which four are in Githunguri (production zone three), three in Limuru (production zone two) and two in Lari (production zone three). The target was to interview 330 farmers with a proportionally distributed number to be selected from each of the nine sub-locations based on the population density of the sub-location. A sub-location with a higher population density had more households selected for interview, than a sub-location with a lower density. The interview process proved slower than anticipated and by the end of the exercise only 297 households had been interviewed.

Selection of households to be interviewed

For both Vihiga and Kiambu, transects were used to select the specific households to be interviewed. To begin with, maps of each of the six sub-locations in Vihiga and the nine in Kiambu were created from the ILRI geographical information system (GIS) databases, and the major landmarks in each sub-location marked out on the map. Permanent features such as a school, a church, a market or a shopping centre were used as landmarks. Each landmark was given a number 1, 2, 3, up to a maximum of 9 (for each sub-location there could be a maximum of nine landmarks). To identify transects for each sub-location, two pairs of landmarks were randomly selected on the sub-location map using a table of random sets of numbers. If for example 2, 3 was selected, it meant that the transect would start at landmark 2 and end at landmark 3. Transect lines were subsequently drawn joining the pair with arrows pointing from 2 to 3. Sampling was thereafter done by a trained enumerator following as closely as possible the marked transects. Every fifth household, first on the left and then on the right, and back to the left was interviewed alternately, and in this way a random sample of households from all the sub-location was obtained. If the total number of households to be interviewed was not covered within the first transect selected, then a second transect was selected using the same procedure. The number of households to be interviewed within a sub-location, and the length of the transects selected determined the number of transects. On average three to five transects were required to complete the total number of households per sub-location. Table A2.1 shows how the households are spread in the different sub-locations.

Table: A2.1: Number of households interviewed from each sub-location in Kiambu and in Vihiga districts

Kiambu district		Vihiga district	
Sub-location	**Number of households**	**Sub-location**	**Number of households**
Githiga	39	Mbihi	51
Kiairia	30	Magui	50
Ikinu	16	Mahanga	45
Githunguri	30	Gimamoi	36
Bathi	38	Gavudunyi	43
Kambaa	48	Gimarakwa	28
Bibirioni	30		
Kamirithu	27		
Rironi	39		
Total	**297**		**253**

NB: One of the 297 farm households in Kiambu was excluded from the sample because it did not have sufficient data for the analysis.

<u>The survey instruments and data collection</u>

In both Kiambu and Vihiga pre-tested structured questionnaires were completed through interviews with respondents who were the household head, or in their absence, the most senior member available or the household member or manager responsible for the farm. The main data sets collected included household data such as farm size, and age, education level, gender and main occupation of the household head and of other family members. Also collected was production data on all the farm activities such as input use including labour and level of outputs including quantities marketed. In Kiambu the households listed and ranked their main farm activities (crop and livestock) and gave the reasons for having each activity. The other data collected were on consumption and expenditure, distance to input/output markets and prices, transport costs, time allocation, off-farm activities, credit availability, extension services, and capital items owned by the household. The geographical positions of the households interviewed and of the major shopping centres in both districts were taken using a geographical positioning system (GPS).

To identify the households' management objectives, the questionnaire included questions asking the interviewees to indicate their main objective in farming. The options were left open in Vihiga district for the respondents to mention on their own what their main objectives in farming were. However, in Kiambu district the respondents were first asked to list their main farm activities and the purpose for each activity. They were then asked to say their main objective in farming given the options of food security (subsistence), income (commercial), or both (semi-commercial). The options were given in the case of Kiambu because from the Vihiga experience, when the question was left open respondents mentioned their major objectives and the means of achieving those objectives interchangeably.

The Vihiga survey was carried out in May to July 2000, whereas the Kiambu survey was carried out October to December 2001. Because the Vihiga survey did not have the specific objectives of this research in mind, some information required such as data on labour for crop production, crop outputs and inputs, household time allocation, and household consumption and expenditure were not collected. Therefore a follow-up survey was conducted in June 2002, where additional data was collected from 175 of the 253 households. Because of time limitation, and because some farms had been subdivided since the previous survey and were now different entities, only 175 households could be interviewed. The formal surveys were carried out by six enumerators and supervised by a senior extension officer and a researcher in Vihiga and by two researchers and a senior extension officer in Kiambu. The data from the questionnaire were entered into a Microsoft access database and checked for errors.

Appendix 2.2: A sample of the results of a fuzzy classification

Questid – The questionnaire number that identifies the farm household.

MaxCls – The group (class) in which the household has maximum membership.

CI – Confusion Index - a low confusion index implies that a household has a high membership in one of the groups, whereas a high confusion index implies that a household does not have a high membership to any of the classes.

3a, 3b, and 3c – Are the different classes and the numbers are the membership values for each case (household) to that group.

QUESTID	MaxCls	CI	3a	3b	3c
1	3a	0.47038	0.75573	0.01816	0.22611
2	3a	0.35088	0.80848	0.03217	0.15935
3	3c	0.56266	0.1883	0.18606	0.62564
4	3c	0.00901	0.00401	0.001	0.995
5	3c	0.44571	0.17318	0.09935	0.72747
6	3a	0.19168	0.88524	0.03785	0.07692
7	3a	0.40868	0.76384	0.17252	0.06365
8	3a	0.58339	0.63446	0.21785	0.14769
9	3b	0.61995	0.2481	0.62815	0.12374
10	3b	0.0954	0.01845	0.94307	0.03848
11	3a	0.53323	0.71536	0.03606	0.24858
12	3c	0.00849	0.00387	0.00075	0.99538
13	3a	0.64808	0.624	0.27208	0.10392
14	3a	0.76635	0.59886	0.03593	0.36521
15	3b	0.54601	0.03422	0.70989	0.25589
16	3a	0.85113	0.43399	0.28089	0.28512
17	3a	0.76841	0.54646	0.13867	0.31487
18	3c	0.25558	0.1187	0.01819	0.86311
19	3c	0.02167	0.00917	0.00332	0.98751
20	3a	0.30725	0.81811	0.05654	0.12536
21	3c	0.57764	0.19715	0.18333	0.61951
22	3c	0.9823	0.32856	0.32517	0.34626
23	3b	0.98829	0.34046	0.35218	0.30736
24	3a	0.8204	0.55707	0.06546	0.37747
25	3b	0.09658	0.03063	0.93639	0.03297
26	3c	0.20141	0.08213	0.03715	0.88072

CHAPTER 3

CROP CHOICE, OUTPUT SUPPLY AND FERTILISER DEMAND

3.1 Introduction

Chapter 1 indicates that because of increasing population, farming in Kenya, particularly in the high potential areas, is becoming more and more intensified. This intensification is not accompanied by sufficient use of nutrient replenishing technologies, and as a result soil nutrient depletion is widespread and crop yields are low. For households to be encouraged to increase their use of soil nutrient replenishing technologies it is important to understand the factors that influence household management decisions as well as the economic performance of various activities.

Several studies have been carried out in Kenya seeking to understand households' farming decisions, especially on soil nutrient management, and more so, use of inorganic fertilisers. However, most of these studies have been adoption studies that concentrate on why farmers use or do not use fertilisers (e.g. Makokha et al., 2001; Salasya et al., 1998). Currently most households use fertiliser, but it is really important to understand what determines the level of fertiliser used, as this remains low (Owuor, 2002). De Jager et al. (1998) examined the link between nutrient balances and economic performance in Kenya. They aimed at identifying the level of ecological and economic sustainability. Their study provides useful information on farm management practices and performance in terms of nutrient mining, economic viability and cash generation.

Reardon et al. (1997a) suggest that where improved inputs are not used, it is either because farmers lack access to them, or improved input use is not justified in terms of profitability. This however, may not be exactly true, particularly in the case of Kenya. Since the liberalisation of the early nineties fertilisers are available at most local centres, and more so in the high potential areas (Omamo and Mose, 2001). Moreover, Karanja et al. (1999) have shown that fertiliser use on maize is actually profitable, especially if combined with the use of hybrid maize. Using 1997 survey data, they find the mean value to cost ratio for DAP fertiliser on maize to be 5.86, meaning that for every ksh. spent on the fertiliser, the farmer gets back ksh. 5.86 in value of maize output. Maize is one of the crops with lower returns, so by extension fertiliser will be profitable on many more highly valued crops. Omamo et al. (2002) analysed the factors influencing soil fertility management decisions of smallholder farmers. While their results provide useful information on household factors that influence soil nutrient management decisions, they do not include in their model such important economic variables as input and output prices, and farm size. They therefore miss out on the economic performance of soil nutrient technologies. Economic returns have been shown to play a critical role in households' use of soil nutrient management technologies and as a result affect their resource allocation decisions (Bamire and Manyong, 2003). Scoones and Toulmin (1998) also stress that social and economic factors are critical in understanding patterns of soil fertility management.

Household decisions on fertiliser use are closely linked to the farm activities. For example, there are different nutrient balances in the banana-based land use system compared to other land use systems in Uganda (Wortmann and Kaizzi, 1998). De Jager et al. (1998) examined the nutrient balances for cash crops and food crops in three regions of Kenya, and found that cash crops are managed more sustainably than food crops, though they do not examine the interactions between them. They also found differences in management of soil nutrients between the three regions investigated. It is important to find out what causes the differences and what the implications are.

The objective of this chapter is to identify and rank the farm activities based on their importance as perceived by the farm households, and to identify the factors influencing household decisions on the use of inorganic fertiliser and on crop output supply. The investigations are done based on household data collected from two districts in Kenya, which are different, both in terms of the socio-economic environment surrounding them and their socio-cultural backgrounds. Although there are several soil nutrient management technologies, inorganic fertiliser is chosen because it is one of the major sources of nutrients that holds considerable potential for increased productivity, but typically is applied at rates well below the recommended ones, or not at all (Tegemeo, 1998). Organic sources of soil fertility improvement such as manure contain low amounts of nutrients, especially phosphorus, which soil analysis results have shown is the most limiting nutrient. These organic sources are also required in very large amounts that are usually not available.

The sections of the chapter are organised in such a way that section 3.2 gives the ranking of main farm activities (crops and livestock) based on the number of households growing and area under the crop, farmer perceptions and activity restricted profit. The current use of fertiliser and manure and the fertiliser market are also described in 3.2. Section 3.3 gives a theoretical background to analysing input demand and output supply and 3.4 gives the empirical model used in the study. In section 3.5 the results are presented and discussed and section 3.6 gives conclusions and implications.

3.2 Activity ranking, fertiliser and manure use and the fertiliser market

3.2.1 Kiambu district

There are two main cropping seasons in Kiambu district, though a few households plant a third season commonly known in the area as Gathano. The households grow a wide variety of crops. In terms of spread (number of households growing a crop) the five most important are maize, potatoes, Napier, kale and beans in order of importance; in terms of area under the crop, the order remains the same except that tea is in the fifth position instead of beans. Coffee is number six in terms of area and number seven in terms of spread. Other important crops both in terms of area and spread are carrots, cabbages, spinach and bananas. In our surveys, households ranked the main farm activities (crops and livestock) based on how important they perceived them to be and gave the purposes for having each activity. The different activities were also ranked based on their contribution to household income using the household survey data.

3.2.1.1 Activity ranking based on farmer perception

Table 3.1 below shows how households ranked the seven most commonly mentioned activities. The table indicates for each activity the number of households who gave it a particular rank between 1 and 6 (all ranks 6 and above were lumped together as 6), where a rank of one is most important and a rank of 6 is least important. To decide which was the overall most important activity, each of the rank positions (1, 2,..., 6) were assigned a weight. The weight given to each rank declines from rank one to rank 6 such that rank one has a weight of 6 and rank 6 has a weight of one. An overall score for each activity is then calculated as shown below:

$$\mathbf{OS}_E = \sum_{i=1}^{6} Freq(E_i) * (7 - i) \, . \qquad (3.1)$$

Where

$\mathbf{OS}_E$ = The overall score for activity E

i = Rank positions (1, 2,..., 6)

$Freq(E_i)$ = Frequency activity E was mentioned in rank position i

The activity with the highest score is the overall most important while the one with the lowest score is the overall least important. This ranking therefore captures both the importance of the activity based on the rank it was given by the respondents and also based on how often an activity is mentioned (frequency). The results show that dairy is the most important activity followed by maize, potatoes, kale and Napier in order of importance. Interestingly, tea and coffee, considered the major cash crops in the area, were expected to rank high, but appear in lower positions. Apparently only a few households were growing these cash crops.

Table 3.1: Farm activity ranking (1=most important) based on the perception of 296 households interviewed in Kiambu district

Rank /Activity	1	2	3	4	5	6	Overall score	Overall Rank
Dairy	136	40	14	6	6	6	1108	**1**
Maize	20	55	73	45	30	15	897	**2**
Potatoes	27	55	47	56	32	17	874	**3**
Kale	43	34	33	25	16	11	668	**4**
Napier	11	21	15	10	15	19	310	**5**
Beans	2	5	22	30	17	27	276	**6**
Tea	16	8	8	3	0	3	180	**7**

Source: Household responses during the survey. All ranks greater than 5 are lumped together as rank 6

3.2.1.2 Activity ranking based on contribution to household income

Activities were also ranked based on their contribution to household income in terms of total revenue (including what the household consumes) less the variable costs. The results (Table 3.2) indicate that dairy (in terms of milk production) makes the highest contribution to household income, followed by kale, potatoes, tea, maize, Napier and cabbage in order of importance. The ranking is based on average contribution to all households in the sample (the last column). It is notable that where tea is grown, it is very important in terms of generating income, second only to dairy. However, only a few households benefit from this income.

Table 3.2: Seven most important activities for 296 sample households of Kiambu ranked by their contribution to household income

			Average profit per activity per household (ksh.)	
Activity	**Rank**	**Number of households**	**Only those with activity**	**All households in the sample**
Milk	1	181	36885	22548
Kale	2	180	15961	9706
Potatoes	3	264	9327	6513
Tea	4	42	36357	5158
Maize	5	268	5046	4568
Napier	6	225	4948	3761
Cabbage	7	98	11146	3690

Source: Calculations from the household level formal survey data. 1 US$ = 78 ksh. in the reference year

3.2.1.3 Purpose of having activity

The two main purposes for each of the activities are income generation and food supply. The household responses for the most important and the second most important purpose are reported in Table 3.3 below. The overall rank is taken from Table 3.1. Other purposes mentioned but not reported here are savings/security, livestock feed and manure. Savings/security and manure were mentioned by less than 1% of the respondents, whereas livestock feed was the main purpose for Napier.

Table 3.3: Main purpose of each farm activity for the 296 sample households of Kiambu

		Income		**Food**	
Activity	Overall rank	Frequency	%	Frequency	%
Dairy	1	157	72.3	57	26.3
Maize	2	30	12.0	191	76.1
Potato	3	44	18.1	199	81.8
Kale	4	118	71.5	47	28.5
Napier	5	21	23.1	0	0
Beans	6	5	4.5	106	95.5
Tea	7	42	100	0	0

Source: The household survey data

Table 3.3 shows that most of the activities have just two purposes: provision of food and generation of income, and this seems to have driven the ranking in Table 3.1. With the exception of the strict cash crops (tea and coffee) an activity whose main purpose was indicated as income generation by a certain percentage of households, usually had food provision as the second purpose indicated by almost the same percentage of households, and vice versa. For some activities, e.g. maize and Napier, the percentages do not add up to 100 because they were also used for other purposes other than income and food. Households may have diversified their activities to reduce or spread risk, but none of them mentioned risk as a reason for diversification.

From the ranking based both on farmer perception and on activity profit, we can conclude that majority of households in Kiambu consider dual-purpose activities (those which provide both food and cash) to be more important than the traditional cash crops.

3.2.1.4 Use of fertiliser

Fertiliser is the main source of soil nutrients and has a major influence on the yield of most crops in Kenya and in Kiambu. Table 3.4 below summarises the use of fertiliser on six important crops averaged over the cropping seasons. Consistent with the observations of

Owour (2002), most households use fertiliser on the different crops, but the rates of fertiliser application though considerably higher compared to application rates in Vihiga (see next section), are still much lower than the recommended fertiliser rates. It is also notable that fertiliser application rates on tea are considerably higher than those on the other crops. The tea farmers are usually contracted by KTDA[3.1], the main parastatal that deals with production of tea in Kenya. The KTDA supplies fertiliser to farmers and advises them on tea husbandry, and they also buy the tea produce from farmers. The cost of fertiliser is deducted from the tea earnings.

Table 3.4: Use of fertiliser on six important crops by the Kiambu sample households

Crop	Number growing as main crop	Average area in ha	Percentage using fertiliser	Current application rate in kg/ ha	Recommended rate in kg/ha
All crops	296		89		
Maize	248	0.35	83	63	200
Potatoes	213	0.26	83	74	200
Kale	135	0.26	87	74	200
Napier	177	0.27	26	46	65
Tea	40	0.35	88	644	750
Cabbage	65	0.15	86	99	200

[3.2] Source: The household survey data

The most commonly used fertiliser type on all crops except tea is diammonium phosphate (DAP), which is used by 87% of the households. The current application rate is therefore based on DAP except for tea. The recommended rates are also based on DAP except for maize, where the recommendation is for NPK (20:20:0). The 63 kg/ha DAP applied on maize still supplies much lower rates of nitrogen and lower rates of phosphorus than the recommended (DAP contains 18% nitrogen and 46% phosphorus). About 24% of farmers interviewed used the NPK (20:20:0) recommended for maize. On tea, NPK 25:5:5 + 5% S is used, and the recommendation is based on the same fertiliser type. Less than 14% of the households used top-dress fertiliser and mainly calcium ammonium nitrate (CAN).

[3.1] KTDA stands for Kenya Tea Development Agency

[3.2] Crop area for annual crops refers to the sum of the area under the crop for the two or three seasons when the crop was planted. The last column refers to the Ministry of Agriculture (MOA) recommendation for basal fertiliser except for tea where it is the KTDA recommendation. In addition top-dress fertiliser (CAN) is recommended at a rate of 100kg/ha for potatoes, kale and cabbage and 300kg/ha for Napier.

3.2.1.5 Use of manure

Manure is another important source of nutrients in Kiambu, and mainly cattle manure is used. However, the quality of the manure is poor, with very low nutrient levels. Makokha et al. (2001) indicate that cattle manure sampled from households in Kiambu contained only 0.4 – 1.18% N, 0.15 – 0.18% P and 1.9 – 2.6% K. The variation is due to different management systems and feed sources, and decomposition rates, which in turn depend on management and handling. Usually large quantities of manure are required, for example depending on the quality, KARI recommends up to 10 tonnes/ha for a maize/bean inter-crop. The rates applied by the households are however much lower than those recommended as can be seen from Table 3.5 below.

Table 3.5: Use of manure on the main crops by the sample households of Kiambu

Crop	Number growing crop	Number using	Application rate (tonnes/ha)	Recommended rate (tonnes/ha)
All crops		265		
Maize	248	188	3.4	**10**
Potatoes	213	173	3.2	**30**
Kale	135	104	3.8	**40**
Napier	177	137	9.2	**10**
Cabbage	65	45	3.8	**40**
Coffee	45	22	8.4	

Source: The household survey data. The recommendations are from KARI farmer information brochures (for maize and Napier) and KARI–Thika, e-mail communication (for potatoes, kale and cabbage)

The number of households using manure is similar to that using fertiliser (265 vs 264 households). About 240 households use manure on at least one of the three most important crops: maize, kale or potatoes; and of the households growing at least one of these three crops, 208 (72%) use both fertiliser and manure. Most households use their own manure, except twelve households who were either given manure by relatives or bought the manure.

3.2.2 Vihiga

There are two cropping seasons, and like Kiambu a wide variety of crops are grown, the most important five being maize and beans, Napier, eucalyptus, bananas, and tea, in order of importance based on the most commonly grown and on area under the crop. In the Vihiga survey, respondents were not asked to rank their farm activities as was done in Kiambu. However, ranking based on contribution to household income is shown in Table 3.6 below.

Table 3.6: Five most important farm activities for the 175 sample households of Vihiga ranked by their contribution to household income

			Average profit per activity per household (ksh.)	
Activity	**Rank**	**Number of households**	**Only those with activity**	**All sample households**
Maize and beans	1	172	11296	10997
Milk	2	87	12257	6093
Tea	3	48	20073	5506
Napier	4	92	6276	4125
Bananas	5	122	4330	3019

Source: Calculations from the household level formal survey data. 1 US$ = 78 ksh. in the reference year

A major difference between Kiambu and Vihiga is the relative importance of the various activities and the level of profits. In Vihiga, maize and beans is prominent, and the profit levels are much lower for most activities compared to those of Kiambu.

3.2.2.1 Use of fertiliser

About 78.3% of the interviewed households used fertiliser, and 73.7% used fertiliser on maize, showing an increase compared to 1996 (see Salasya et al., 1998). This percentage is however lower than that of Kiambu. Fertiliser was mainly used on maize and tea with a few households using it also on Napier. Table 3.7 below shows the application rates on the various crops.

Table 3.7: Use of fertiliser on four important crops by the Vihiga sample households

Crop	Number growing as main crop	Average area in ha	Percentage using fertiliser	Application rate in kg/ ha (growers)	Recommended rate in kg/ha
All crops	175		78		
Maize	172	0.59	74	29	130
Tea	48	0.23	97	697	750
Napier	92	0.14	27	23	65
Banana	59	0.07	5	10	

[3.3] Source: The household survey data

Fertiliser application rates are considerably lower in Vihiga district compared to application rates in Kiambu (Table 3.4). For example, the Kiambu application rates on maize and Napier are approximately double the application rates on the same crops in Vihiga.

[3.3] Crop area for annual crops refers to sum of the area under the crop for the two seasons it was grown. The last column refers to the MOA recommendation for basal fertiliser except for tea where it is the KTDA recommendation. In addition top-dressing fertiliser is recommended at the rate of 140 kg/ha for maize and 300 kg/ha for Napier.

The most commonly used fertilisers in Vihiga are DAP, CAN, Urea and 25:5:5:S, which is applied on tea. DAP and CAN were mainly used on maize as basal and top-dressing respectively, while urea was mainly applied on Napier. Only 23 households out of the 172 who grow maize used top-dressing fertiliser.

3.2.2.2 Use of manure

As in Kiambu, manure is yet another important source of nutrients and mainly cattle manure is used. Nutrient levels in the manure are also very low - about 1.5% to 2% nitrogen and negligible amounts of phosphorus (Waithaka et al., 2003), hence large quantities are required. However, as can be seen in Table 3.8, only small quantities are applied. The system of grazing commonly practised does not allow for the collection of good quality manure and households often leave manure to dry leading to further loss of nutrients. Urine contains slightly more nutrients than cow dung, but because of the grazing system (mainly tethering in the home compound or in maize fields after harvest) it is difficult to collect and so households rarely use it.

Table 3.8: Use of manure on three main crops by the sample households of Vihiga district

	Number growing the crop	Number using manure	Application rate in tonnes/ha	Recommended rate in tonnes/ha
All crops	175	143		
Manure on maize	172	121	1.48	10
Manure on Napier	105	69	5.95	10
Manure on banana	60	29	6.2	

Source: The household survey data

Most households use their own manure, except for a few who probably get the manure from a relative because there were no cases of selling or buying manure. Of the 172 households who grow maize, 87 (51%) used both manure and fertiliser.

3.2.3 Fertiliser Market in Kenya

Fertiliser is the major purchased input used by most farm households in Kenya and specifically in Kiambu and in Vihiga. Fundamental to wider adoption of, and more use of fertiliser is a well functioning fertiliser distribution system (Golleti and Alfano, 1995). The fertiliser markets in Kenya were totally liberalised in 1993 by abolishing import quotas and fertiliser price controls. Following liberalisation numerous private traders, ranging from specialised large-scale importers / distributors sited in major urban areas to diversified small-scale retailers operating in relatively isolated rural trading centres, have entered the fertiliser trade, and with novel marketing approaches. An example is the introduction of fertiliser packed in packets as small as 500 grams (Argwings-Kodhek, 1997). Before liberalisation fertiliser was only packaged in 50 kg bags. This change had the effect of opening up access to a significant number of smallholders who lacked the resources to purchase the standard package weighing 50 kg (Argwings-Kodhek, 1997; Omamo, 1996). This fact is evidenced by the small quantities purchased by households in the sample used in this study and the increase in the proportion of households using at least some fertiliser compared to previously. For example, only 45.6% of households who planted improved varieties of maize used fertiliser in the Vihiga and Kakamega districts in 1996 (Salasya et. al., 1998), whereas this study (Table 3.7) finds that 73.7% of the households interviewed used fertiliser on maize in Vihiga district. Farming households are now able to buy fertilisers from their local trading centres and with the numerous private traders the fertiliser prices should be competitive. Distribution of these traders and the fertiliser price however, is likely to be influenced by variations in infrastructure quality both between regions and within regions (Omamo and Mose, 2001), and by distance from the source. Consequently, fertiliser use by households close to major markets could be high and that for households far away low. Despite all these developments, the rate of fertiliser use is still low.

In Kiambu district the stockists had most of the different types of fertilisers but in Vihiga district most stockists had only DAP, CAN and Urea, which are the most commonly used in the area. However, triple super phosphate (TSP) and rock phosphate (RP), which are currently being recommended because of very low available phosphorous levels in the soils, were not available from the stockists in Vihiga district during the time of the survey.

3.3 Theoretical framework to input demand and output supply

In economic analysis research decisions on production, consumption and labour supply are usually analysed separately, through the behaviour of three classes of agents: producers, consumers and workers. The producer maximises profits with respect to levels of products and factors subject to a number of constraints determined by market prices, fixed factors and technology. A consumer maximises utility with respect to quantities of goods consumed subject to constraints determined by market prices, disposable income, household characteristics and tastes. A worker on his/her part maximises utility with respect to income and home time (leisure) subject to constraints determined by the market wage, total time available and worker characteristics (Sadoulet and de Janvry, 1995). This however is under the assumption that perfect markets exist for all products and factors so that prices are exogenous to the household and all products and factors are tradable with no transaction costs.

When not all markets work, there are direct interrelations between production and consumption decisions (Rosenzweig and Wolpin, 1993; Sadoulet and de Janvry, 1995; Ellis, 1993). Perfect markets are however a sufficient but not necessary condition for analysing production and consumption decisions separately. The two can be analysed separately whenever prices are exogenous and markets are used, even if sale and purchase prices are not identical (Sadoulet and de Janvry, 1995). Because in both Kiambu and Vihiga districts a market exists both for fertiliser and for the outputs, in modelling the fertiliser demand and output supply it is assumed that household decisions in the use of fertiliser are not influenced by household consumption factors. A profit function is therefore used from which input demand and output supply equations are derived.

3.3.1 The profit function approach

Econometric applications of production theory based on the duality relationship between production functions and variable profit functions represent a major step forward toward generating appropriate empirical estimates of agricultural supply and input demand functions (Lau and Yotopoulus, 1971; Sidhu and Baanante, 1981). Using the dual approach the producer's behaviour in the choice of inputs and outputs, given the level of market prices for a commodity and factors that can be traded, and the availability of fixed factors, can be analysed through the profit function (Sadoulet and de Janvry, 1995). The dual approach to productivity is interesting in that the first derivative of the profit function with respect to an input price gives the negative of the demand function for that input, whereas the first derivative with respect to an output price gives the supply function for that output (Coelli et al., 1998; Sadoulet and de Janvry, 1995). This relation is called the Hotelling's duality Lemma. The profit function is a function of exogenously determined output and input prices and fixed production factors, describing the farm's production technology at profit maximising points in the set of production possibilities. The derivations of output supply and input demand from the profit function using the dual approach are much simpler than the primal approach which requires an estimation of the production function.

In this study the fertiliser demand function and the output supply functions are estimated using the profit function dual approach. It is therefore assumed that households attempt to maximise farm-restricted profit defined as the return to the variable inputs.

3.3.1.1 The System of Output Supply and Input Demand

By definition restricted profit (π) is the gross revenues less the variable costs, i.e.

$$\pi = pq(p,w,z) - wx(p,w,z) = \pi(p,w,z) . \qquad (3.2)$$

Where w and p are the prices of inputs and outputs respectively, q(.) is the output supply function and x(.) is the input demand function. The producer's restricted profit (gross revenues less variable costs) is $pq - wx$. The producer is assumed to choose the combination of variable inputs that will maximise profit subject to the technology constraint. The Hotelling's duality Lemma, is that:

$$\frac{\partial \pi}{\partial p_i}(p,w,z) = q_i \text{, and } \frac{\partial \pi}{\partial w_k}(p,w,z) = -\ x_k \qquad (3.3)$$

These relations are proved by differentiating the profit function (3.2) and taking advantage of the first order conditions of the maximising problem.

These supply and demand functions satisfy the following properties:

a. *Homogeneity*. Output supply and factor demand are homogenous of degree zero in all prices and, if production exhibits constant returns to scale, homogenous of degree one in all fixed factors. In terms of elasticities this implies that the sum of elasticities of any output or input with respect to all prices is equal to zero, and, if production displays constant returns to scale (CRS), the sum of its elasticity with respect to the fixed factors is equal to one:

$$\sum_j E(q_i / p_j) = 0 \text{ and if CRS, } \sum_m E(q_i / z_m) = 1 .$$

b. *Symmetry*. Symmetry of the second-order derivatives of the profit function implies that:

$$\frac{\partial q_i}{\partial p_j} = \frac{\partial q_j}{\partial p_i} .$$

In terms of elasticities, this implies that the cross price elasticities are inversely proportional to the corresponding profit shares.

$$\frac{E(q_i / p_j)}{E(q_j / p_i)} = \frac{s_j}{s_i} \text{ with } s_i = p_i q_i / \pi$$

3.3.1.2 Choice of the functional form

Economic theory provides the basis for building production models as stated in the preceding section. However in order to use these models in analysing production decisions a functional form has to be chosen. Finding the most appropriate functional form remains a pragmatic task (Villezca-Becerra and Shumway, 1992); the researcher is never in a position to know the true functional form (Griffin et al., 1987). Determination of the true functional form of a given relationship is impossible, so the problem is to choose the best form for a given task (Griffin et al., 1987). Because of the difficulty in deciding which production function best fits the data, a number of plausible functional forms have been proposed and are now widely used. They include the Translog, (Christensen et al., 1973), the generalised Leontief (Diewert, 1971), and the normalised quadratic (Lau, 1978). Each of these is a second-order Taylor series expansion, is linear in parameters, and is appropriately labelled a "locally-flexible" functional form (Fuss et al., 1978; Griffin et al., 1987). The use of these flexible forms permits applications of the duality theory for a more disaggregated analysis of the production structure. In practice there are no strong reasons for choosing one flexible form over the other. Villezca-Becerra and Shumway (1992) used all three flexible functional forms and found that there was no functional form that gave consistently more significant estimates than any other form.

In this study the Normalised Quadratic profit function is chosen for deriving the input demand and output supply functions because of its flexibility (non-constant elasticities), as compared to the logarithmic formulations. The Normalised Quadratic profit function is widely used in the literature to obtain a coherent set of product supply and input demand relationships (e.g. Shumway, 1983; Shumway and Alexander, 1988; Hattink et al., 1998; Kheralla and Govinda, 1999). It imposes no restrictions, integrates the input demand functions with the output supply function and it uses input prices instead of input quantities, for which reliable information is obtainable both from farm households and non-farm sources. It also does not involve the problem of aggregation that is commonly associated with input quantities.

The Generalisation of the Normalised Quadratic profit function (Sadoulet and de Janvry, 1995) is:

$$\pi^* = \frac{\pi}{p_n} = \alpha_0 + \sum_i \alpha_i p_i^* + \frac{1}{2}\sum_{i,j} \beta_{ij} p_i^* p_j^* + \sum_{i,m} \beta_{im} p_i^* z_m \quad i,j = 1, .., n\text{-}1,$$

with $\beta_{ij} = \beta_{ji}$ (3.4)

The profit and prices are normalised by the price of the n th commodity or n th input:

$p_i^* = \frac{p_i}{p_n}$ is the vector of normalised output and input prices. The profit function is homogeneous in prices but not with respect to fixed factors. The derived system of output supply and input demand is:

$$q_i = \alpha_i + \sum_j \beta_{ij} \; p_j^* + \sum_m \beta_{im} z_m \qquad (3.5)$$

The elasticities can be computed at any particular value of prices and quantities as:

$$E_{ij} = \beta_{ij} \; \frac{p_j}{q_i}, \quad i,j \neq n, \quad E_{jn} = -\sum_k E_{jk}$$

$$\boldsymbol{E_{nj}} = \frac{1}{s_n}\sum_i s_i E_{ij} \text{ and } E_{nn} = -\sum_i E_{ni}$$

Where s_i are the profit shares.

3.3.2 In case of market failure/ imperfect markets

It is argued in the literature that in most developing countries such as Kenya there are significant transaction costs and missing or imperfect markets and hence few policy implications can be drawn from conventional economic models (Singh et al., 1986; De Janvry et al., 1991). This is because production and consumption decisions are interdependent, and in that context a non-separable model that combines production and consumption decisions is recommended (De Janvry et al., 1991). However, as mentioned earlier in the study areas the fertiliser market is competitive, and as shown below separability or non-separability is mainly through the labour market. If the labour market is perfect and assuming two variable inputs, labour (l_f) and fertiliser (f), we have:

$$max \; \text{u}\,(c, l_l)$$

$$\text{s.t.} \quad p_c c + w_l l_l = w_l \text{T} + \pi$$

$$\pi = p_q q - w_l l_f - w_f f$$

$$q = q(A, l_f, f)$$

$$\max_{c, l_l l_f f} \; u(c, l_l) - \lambda(p_c c + w_l l_l - w_l \mathrm{T} - p_q q(A, l_f, f) + w_l l_f + w_f f)$$

Consumer side (c) $u_1 - \lambda p_c = 0$

(l_l) $u_2 - \lambda w_l = 0$

Producer side $(l_f) - \lambda[- p_q q_l + w_l] = 0 \Rightarrow q_l = \dfrac{w_l}{p_q}$

$(f) - \lambda[- p_q q_f + w_f] = 0 \Rightarrow q_f = \dfrac{w_f}{p_q}$

If no labour markets are specified, we have:

$$max \;\; u(c, T - l_f) - (p_c c - p_q q(A, l_f, f) - w_f f) \text{ as}$$

$$p_c c = \pi^* = p_q q - w_f f = p_q q(A, l_f, f) - w_f f$$

(c) $u_1 - \lambda p_c = 0$

(l_l) $- u_2 - \lambda[- p_q q_l] = - u_2 + \lambda p_q q_l = 0 \Rightarrow q_l = \dfrac{u_2}{\lambda p_q}$

(f) $- \lambda[- p_q q_f + w_f] = 0 \Rightarrow q_f = \dfrac{w_f}{p_q}$

The effect of non-separability for fertiliser demand is only implicit in f through $q(A, l_f, f)$ in the farm labour variable. Since this chapter does not focus on labour decisions, the implicit effect of non-separability on fertiliser demand is ignored and the fertiliser demand modelled as a pure production problem. The expected non-separability in labour decisions will mainly be due to involuntary unemployment particularly in Vihiga.

On the output side, although some outputs such as maize and potatoes were mainly produced for food, an active food market exists, with private traders who undertake arbitrage between localities and periods of relative abundance and scarcity in both Kiambu and Vihiga. Additionally, Kiambu is close to Nairobi, the capital city, and hence has fairly good market access both for inputs and outputs.

3.4 Empirical estimation

Having established the theoretical framework above, empirical estimation is fairly straightforward. In this section the empirical model is specified in actual variables. The estimations are done using cross sectional data for the sample households of Kiambu and of Vihiga districts. The use of cross sectional data to estimate output supply functions has some problems. According to Sadoulet and de Janvry (1995, pp 85), "a simultaneity bias between inputs and outputs will usually occur unless experimental data are used, or it is an economy in which prices are set. Derived elasticities are long run in nature as full factor relocations and correct price expectations occur across farms. Partial adjustments and adaptive adjustments are thus not taken into account in the case of cross sectional data and this results in overestimating the short run elasticity of supply response". However, time series data that are more appropriate are usually only available at country or regional level, and rarely at household or farm level. Cross section data therefore still provide useful information for estimating supply response at the household (micro) level (e.g. Hattink et al., 1998; Jegasothy et al., 1990; Chaudhary et al., 1998; Sidhu and Baanante, 1981).

3.4.1 Kiambu district

The normalised quadratic profit function is modelled to include output prices of the three most important crops: maize, potatoes and kale (Tables 3.1 and 3.2) and two variable inputs: labour and fertiliser, which are the most important in crop production in Kiambu. Tea is not included though it is the third most important crop in terms of contribution to household income. The number of households growing tea is too small (13.5%) compared to the total sample, and also there is no variability in the output price of tea because the KTDA factories set a common price for all the households. The same applies to tea fertiliser, which is supplied by KTDA on contractual arrangements with the households. Transportation costs in tea production are also minimal because the produce is delivered at, and fertiliser collected from the numerous tea buying centres, which are close to the tea farms. Dairy is left out because the study centres mainly on fertiliser use. However, number of cattle owned in terms of tropical livestock units (TLU)[3.2] and manure are entered as explanatory variables. Ten fixed factors are included: education level of household head, age of household head, gender of household head, farm size in hectares, access to government extension advice, access to credit, quantity of manure used, total tropical livestock units owned, area under tea, and area under coffee. The fertiliser price and output prices are normalised by the wage rate. Several other studies have also used the wage rate for normalisation (e.g. Evenson, 1983; Kheralla and Govinda, 1999).

The Normalised Quadratic profit function as specified for Kiambu is:

$$\pi = \alpha_0 + \alpha_f w_f + \frac{1}{2}\beta_{ff} w_f^2 + \sum_{h=1}^{3}\delta_h p_h + \frac{1}{2}\sum_{h=1}^{3}\phi_{fh} w_f p_h + \frac{1}{2}\sum_{j=1}^{3}\sum_{h=1}^{3}\delta_{jh} p_j p_h +$$

$$\sum_{n=1}^{10}\gamma_n z_n + \sum_{h=1}^{3}\sum_{n=1}^{10}\eta_{hn} p_h z_n + \sum_{n=1}^{10}\eta_{fn} w_f z_n \qquad (3.6)$$

Where: π is the normalised restricted profit (total revenue from maize, potatoes and kale, less cost of fertiliser and cost of labour used on maize, potatoes and kale) divided by the wage rate. w_f is the relative price of fertiliser per kilo (price of fertiliser divided by the wage rate); p_{1-3} are the relative farm gate prices for maize, potatoes and kale; z_n are the ten fixed factors and $\alpha, \beta, \delta, \phi, \gamma, \eta$ are parameters to be estimated. All prices are in Kenya shillings (ksh.) and all quantities are in kilograms (kg) except for manure where the units are bags.

The fertiliser demand equation derived from the profit function using Hotelling's Lemma is:

$$x_f = \alpha_f + \beta_{ff} w_f + \sum_{h=1}^{3}\phi_{fh} p_h + \sum_{n=1}^{10}\eta_{fn} z_n \qquad (3.7)$$

And the output supply equations are:

$$q_h = \delta_h + \sum_{h=1}^{3}\delta_{jh} p_h + \phi_{fh} w_f + \sum_{n=1}^{10}\eta_{hn} z_n \qquad (3.8)$$

Where x_f is the sum of the amount of fertiliser applied on maize, potatoes and kale and q_h are the output quantities of either maize or potatoes or kale.

3.4.2 Vihiga district

In Vihiga even though the sample households grow many crops, a maize/bean inter-crop stands out as the sole most important crop, especially in terms of fertiliser use (Table 3.7). Tea is left out for same reasons given under Kiambu. The model for Vihiga is therefore similar to that of Kiambu with the exception that there is only one output, maize, instead of three outputs, and there is no coffee among the fixed factors of Vihiga.

[3.2] TLU =1 for bull; 0.7 for cow; 0.5 for heifer and young bull; 0.2 for calves (see Bebe, 2003)

3.4.3 Data and data sources

Data collection was through farm household level interviews by trained enumerators using a pre-tested structured questionnaire as detailed in Chapter 2. A total of 296 households from Kiambu and 175 households from Vihiga were interviewed. Of the total Kiambu sample there were 288 who grew either maize or potatoes or kale and combined as shown in Figure 3.1. Only 154 households grow all the three crops and 93 grow potatoes and maize but not kale. The analysis that follows concentrates on the 247 households that either grow all the three crops or at least grow both maize and potatoes. In Vihiga district, of the 175 households only three did not grow maize. The analysis is therefore done for the 172 who grow maize.

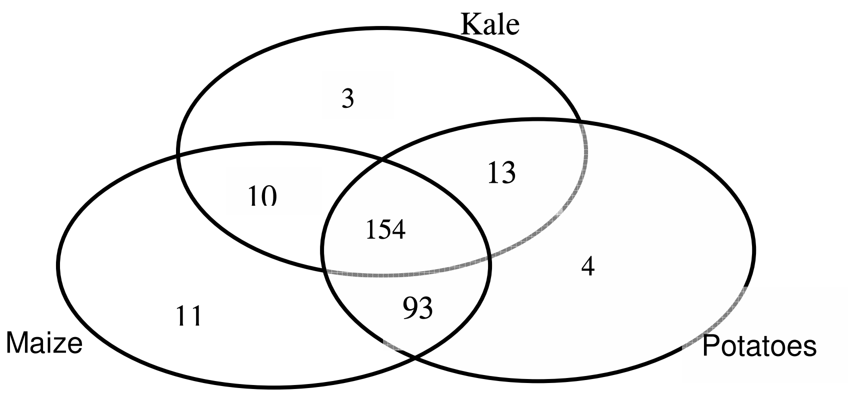

Figure 3.1: Combination of maize, potatoes and kale grown by the different households in Kiambu

Descriptive statistics of the data used in the estimations are shown in Table 3.9 below.

Table 3.9: Descriptive statistics for variables used in the fertiliser demand and output supply equations for the Vihiga and Kiambu sample households

Variable	Kiambu (n=247)		Vihiga (n=172)	
	Mean	Standard Deviation	Mean	Standard Deviation
Fertiliser use				
Number using fertiliser (households)	212		126	
Fertiliser on maize, potato, kale - all households (kg)	36.3	44.6		
Fertiliser on maize, potato, kale - only users (kg)	46.1	45.9		
Fertiliser on maize/bean inter-crop - all households (kg)			20.6	34.5
Fertiliser on maize/bean inter-crop - only users (kg)			28.6	37.8
Manure use (in bags)				
Number using manure (households)	223		121	
Amount used on maize, potato and kale (bags)	49.5	60.1		
Amount used on maize/bean inter-crop (bags)			17.2	33.4
Prices				
Average fertiliser price on maize, potato, kale (ksh./kg)	28.8	1.78		
Relative fertiliser price, maize, potatoes, kale	0.30	0.06		
Maize fertiliser price - Vihiga (ksh./kg)			30.7	2.77
Relative maize fertiliser price – Vihiga			0.61	0.07
Wage rate in ksh./man day	98.5	15.0	50.5	3.54
Kale output price (ksh./kg)	7.11	3.77		
Relative kale output price	0.07	0.04		
Maize output price (ksh./kg)	10.5	1.72	11.2	1.40
Relative maize output price	0.12	0.03	0.22	0.03
Potato output price in ksh./kg	5.54	0.71		
Relative output price of potatoes	0.06	0.01		
Production (in kg)				
Maize output	625	709	778	619
Potato output	1891	1963		
Kale output	2991	3499		
Household Resources and fixed factors				
Farm size in hectares (ha)	0.92	0.93	0.71	0.59
Education of household head (years in school)	8.40	5.08	8.59	3.88
Age of household head (years)	54.4	15.0	54.1	13.2
Total tropical livestock units (TLU)	1.30	1.37	1.00	0.78
Distance to the market (km)	2.13	1.62	2.43	4.08
Amount of manure used (bags)	49.5	59.3	17.2	33.4
Area under tea (hectares)	0.05	0.17	0.06	0.14
Area under coffee (hectares)	0.04	0.12		
Gender of the household head (number female headed)	59		31	
Access to credit (number having access)	35		25	
Access to extension (number having access)	122		103	

See Appendix 3.1 for a description of the variables.

The prices used are the retail prices plus transport costs where applicable for fertiliser and retail price less transport costs for the outputs. However, most households did not incur transport costs. Figure 3.2 below shows the differences in prices with and without transport costs and how they are distributed over the households. For fertiliser the figure shows the retail price and the retail price plus transport cost, whereas for the outputs it shows the retail price and the retail price less transport cost. From the figure transport costs are minimal both for the outputs and for fertiliser. In Vihiga only one household incurred transport costs on maize output so only the retail price is considered. There is more variation (see also Table 3.9) in the price of maize in Kiambu than in Vihiga, but more variation in the price of fertiliser in Vihiga than in Kiambu. Within Kiambu, there is more variation in the price of kale, than in the price of maize and of potatoes, which may be because there are several varieties of kale which differ in e.g. size of the leaves and the texture of leaves when cooked. Different consumers will have varying preferences for the various varieties. Secondly, kale is quite perishable so that if it is not sold the same day it is picked the price will automatically drop. It is however not clear where the rest of the variation originates from given that the data is cross sectional. There may be some other locality factors that we do not observe. For fertiliser, the variation in prices may be due to the presence of many stockists and fertiliser being packaged in many sizes ranging from 500 g to 50 kg (see Argwings-Kodhek, 1997).

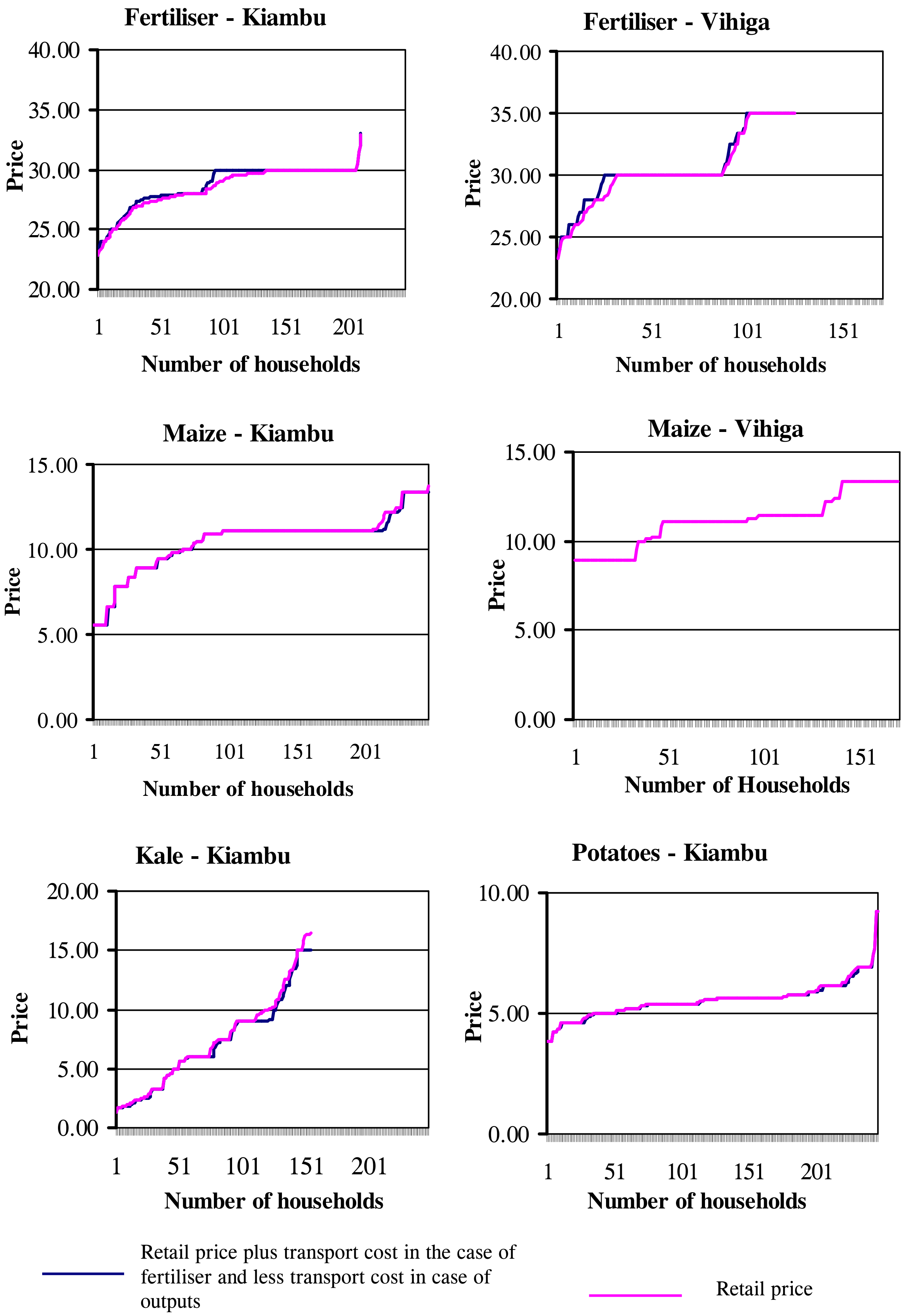

Figure 3.2: Retail prices with and without transport costs

3.4.4 Estimation Procedure

The estimation presented some problems, especially for the Kiambu sample because not all the households interviewed had all the three crops and not all the households used fertiliser. Of the 247 households analysed, only 212 use fertiliser, and only 154 grow kale. The case of fertiliser is essentially a censoring problem because fertiliser quantity used, though non-negative and continuous, takes on the value of zero for a number of cases. But in measuring the impact of kale price on fertiliser or the impact of fertiliser price on crop outputs on the other hand, we have a truncation problem because kale price is not observed for the households who do not grow the crop. Similarly fertiliser price is not observed for households who do not use fertiliser. In both cases ordinary least squares will yield inconsistent results. Tobit models are best suited to analyse the first type of problem (censoring) and the sample selection model is best suited for the second type of problem (truncation) (Verbeek, 2003). Secondly, we need to simultaneously estimate the kale and the fertiliser equations alongside those of maize and of potatoes so as to impose symmetry restrictions. Obviously the relationship is a more complex one considering the interactions between using fertiliser and growing or not growing kale, and the interactions with the other two crops, but for simplicity we have overlooked other complexities, and analysed the problem as a sample selection, one for kale and for fertiliser.

The sample selection model is the traditional model that deals with sample selection problems. Taking the example of use of fertiliser, the sample selection model (Verbeek, 2003) consists of a linear fertiliser demand equation where fertiliser is used:

$$y_i^* = x_{1i}^{'} \beta_1 + \varepsilon_{1i}, \qquad (3.9)$$

where $x_{1i}^{'}$ denotes the exogenous variables that influence the quantity of fertiliser used and y_i^* denotes household i's quantity of fertiliser used, given that they use fertiliser. A second equation, of the binary choice type, is specified to describe whether a household is using fertiliser or not. That is:

$$z_i^* = x_{2i}^{'} \beta_2 + \varepsilon_{2i}, \qquad (3.10)$$

where we have the observation rule:

$$y_i = y_i^*, \; z_i = 1 \text{ if } z_i^* > 0$$

$$y_i = 0, \; z_i = 0 \text{ if } z_i^* \leq 0$$

where y_i denotes a household's actual quantity of fertiliser used, while the binary variable z_i simply indicates using fertiliser or not using fertiliser, which is a standard probit model. The model is completed with the distributional assumption on the unobserved errors ($\varepsilon_{1i}, \varepsilon_{2i}$), usually a bivariate normal distribution with the expectations of zero, variances σ_1^2, σ_2^2, and a covariance σ_{12}. The normalisation restriction is that $\sigma_2^2 = 1$. The choice to use fertiliser is affected by the variables x_{2i} with the coefficients β_2 while the level of fertiliser used is a function of x_{1i} with the coefficients β_1. In principle the variables in x_1 and x_2 can be different (see Goetz, 1992; Verbeek, 2003)

The conditional expected fertiliser level given that a household is using fertiliser is given by

$$\begin{aligned} \mathrm{E}\{y_i \mid z_i = 1\} &= x_{1i}' \beta_1 + \mathrm{E}\{\varepsilon_{1i} \mid z_i = 1\} \\ &= x_{1i}' \beta_1 + \mathrm{E}\{\varepsilon_{1i} \mid \varepsilon_{2i} > -x_{2i}' \beta_2\} \\ &= x_{1i}' \beta_1 + \frac{\sigma_{12}}{\sigma_2^2} \mathrm{E}\{\varepsilon_{2i} \mid \varepsilon_{2i} > -x_{2i}' \beta_2\} \\ &= x_{1i}' \beta_1 + \sigma_{12} \frac{\phi(x_{2i}'\beta_2)}{\Phi(x_{2i}'\beta_2)} \qquad (3.11) \end{aligned}$$

Note that we can write $\sigma_{12} = \rho_{12}\sigma_1$, where ρ_{12} is the correlation coefficient between the two error terms. It follows from (3.11) that the conditional level of fertiliser use is equal to $x_{1i}' \beta_1$ only if $\sigma_{12} = \rho_{12} = 0$. The difference between the sample selection model and just a regression model and a probit model is the correlation coefficient between the two equations' error terms. So if the error terms from the two equations are uncorrelated, the equation can be estimated consistently by ordinary least squares, in which case the probit model could be estimated separately and OLS used separately to consistently analyse the fertiliser demand equation.

A sample selection bias arises in the OLS estimator if σ_{12} is not equal to zero. The term $\frac{\phi(x_{2i}'\beta_2)}{\Phi(x_{2i}'\beta_2)}$ is denoted $\lambda(x_{1i}' \beta_2)$ by Heckman (1979) and is therefore sometimes referred to as Heckman's lambda but also known as the Inverse Mills Ratio (IMR).

To illustrate how the sample selection bias comes in the current study, consider the case of Kiambu where the sample consists of households who grow kale (154) and households who do not grow kale (93) (see figure 1). There can therefore be two sets of equations

A) For the households that grow kale (154 observations) there are four equations:

$$\begin{pmatrix} f \\ m \\ p \\ k \end{pmatrix} = \begin{pmatrix} \alpha_{ff} & \alpha_{fm} & \alpha_{fp} & \alpha_{fk} \\ \alpha_{fm} & \alpha_{mm} & \alpha_{mp} & \alpha_{mk} \\ \alpha_{fp} & \alpha_{mp} & \alpha_{pp} & \alpha_{pk} \\ \alpha_{fk} & \alpha_{mk} & \alpha_{pk} & \alpha_{kk} \end{pmatrix} \begin{pmatrix} p_f \\ p_m \\ p_p \\ p_k \end{pmatrix} + \begin{pmatrix} c_f \\ c_m \\ c_p \\ c_k \end{pmatrix}$$

Where:

f = Fertiliser, m = maize, p = potatoes and k = kale.

B) For the sub-group of 93 households who do not grow kale there are three equations:

$$\begin{pmatrix} f \\ m \\ p \end{pmatrix} = \begin{pmatrix} \alpha_{ff} & \alpha_{fm} & \alpha_{fp} \\ \alpha_{fm} & \alpha_{mm} & \alpha_{mp} \\ \alpha_{fp} & \alpha_{mp} & \alpha_{pp} \end{pmatrix} \begin{pmatrix} p_f \\ p_m \\ p_p \end{pmatrix} + \begin{pmatrix} c_f \\ c_m \\ c_p \end{pmatrix}$$

If we take the first (fertiliser equation) as an example, we have:

$$f = c_f + \alpha_{ff} p_f + \alpha_{fm} p_m + \alpha_{fp} p_p + \alpha_{fk} p_k + \varepsilon_f \mid \text{kale} \qquad \text{(a)}$$

And for observations without kale we have:

$$f = c_f + \alpha_{ff} p_f + \alpha_{fm} p_m + \alpha_{fp} p_p + 0 + \varepsilon_f \mid \text{no kale} \qquad \text{(b)}$$

The two groups may differ in the coefficients because theoretically group (b) decided not to grow kale because of reasons related to prices and parameters, i.e.

$k = c_k + \alpha_{kf} p_f + \alpha_{mk} p_m + \alpha_{pk} p_p + \alpha_{kk} p_k + \varepsilon_k < 0$ so that optimal kale k <0, and therefore actual k $=0$. The distribution of the error term in equation (b) is conditional on kale not being grown so that expected $\varepsilon_f \neq 0$ if ε_f is correlated with ε_k. The correlation may differ between the different error terms ε_f, ε_m, ε_p.

The sample selection model was therefore applied where Heckman's two-step procedure was followed to compute the Inverse Mill's Ratio (IMR) for kale from the first step (Probit estimation) using the Limdep computer program. The IMR_{kale} results from the choice between (fertiliser, maize, potato, kale (FMPK) and fertiliser, maize, potato (FMP). Similarly the IMR for fertiliser (IMR_{fert}) was computed from the choice between FMPK (fertiliser use) and MPK (no fertiliser use). Both IMR_{kale} and IMR_{fert} were included in all the four equations in the second step, which is restricted to the households that use fertiliser, and in this group the group growing kale is distinguished from those who do not grow. The four equations were estimated simultaneously using the Seemingly Unrelated Regression (SUR) because of the cross equation restrictions imposed on the price coefficients to ensure that symmetry conditions hold. It is also possible that the error terms are correlated, making it necessary to estimate the four equations together. Linear homogeneity was achieved by dividing the fertiliser price and the output prices by the wage rate.

3.5 Results of the fertiliser demand and output supply estimations

3.5.1 Kiambu probit and SUR results

3.5.1.1 Probit results

The probit results from the first stage of the two-step Heckman's procedure are presented in Table 3.10 below.

Table 3.10: Probit results of the factors affecting the choice to grow kale and to use fertiliser in Kiambu

	Kale		Fertiliser for MPK	
Variable	Coefficient	Std. Error	Coefficient	Std. Error
Constant	1.27	1.11	1.74	1.45
Education	-0.04*	0.02	0.04	0.03
Age	-0.02*	0.01	0.01	0.01
Gender	0.23	0.24	-0.07	0.28
Farm size	-0.08	0.12	-0.13	0.12
Access to Extension	0.36**	0.19	-0.01	0.24
Access to credit	-0.11	0.28	0.45	0.36
Fertiliser price	0.01	0.01		
Kale output price			0.03	0.03
Maize output price	0.02	0.06	-0.08	0.08
Potato output price	-0.20	0.13	-0.01	0.17
Manure quantity	0.003	0.002	0.002	0.002
Tropical livestock units	0.06	0.09	-0.05	0.09
If tea is grown (1=yes)	0.52	0.33	-0.92**	0.40
If coffee is grown (1=yes)	-0.56*	0.32	-0.07	0.37
Distance to the nearest market	-0.03	0.06	0.31***	0.11
Membership of an organisation	0.47*	0.26	-0.57	0.40
Division dummy	0.94***	0.28	-0.47	0.36
McFadden R-squared	0.18		0.16	
N	247		247	

NB: MPK - Maize, Potatoes and Kale.

Apparently, household heads with more years of education are less likely to be growing kale. A high education level improves chances of getting formal and other off-farm employment. It is therefore likely that educated household heads are involved in off-farm jobs as their source of income rather than kale (kale is mainly grown as a source of income). It also appears from the results that older household heads have a lower probability of growing kale, possibly because kale is labour intensive and requires the energy of younger household heads.

Households that have access to extension advice receive the necessary information on the production of kale and hence are in a better position to grow the crop than households who do not receive any advice. Similarly, organisations such as women's groups, co-operatives or NGOs offer services to their members that include access to farm inputs such as fertiliser and marketing of the produce. Kale is a perishable product, and this is probably the reason why households who belong to such organisations are more likely to grow kale, because they may be able to market the kale via the organisation.

The coefficient on the division dummy shows that households in either Limuru or Lari divisions are more likely to grow kale than households in Githunguri division. Limuru and Lari are located along a major highway that facilitates easy transportation of kale to other regions of the country. It is therefore easier for middlemen who undertake arbitrage, to buy kale from Lari and Limuru than from Githunguri. This might imply there is a better market for kale in Lari and Limuru than in Githunguri.

For fertiliser, only two variables, the presence of tea on the farm and the distance to the nearest market, are significant. As shown in Table 3.2, tea provides substantial income to households that grow it. These households are therefore likely to concentrate on tea and pay less attention to other crops, which they can purchase from the market. The coefficient on distance to the nearest market has the wrong sign because it is usually expected that households further from the market are less likely to use fertiliser because they probably face higher transaction costs, which raises the ultimate cost of fertiliser. However in this case the nearest markets are fairly close with an average distance of only 2.13 km, which minimises the difference in transaction costs. Moreover, this result is not an isolated case, a positive correlation between distance to the market and adoption of hybrid seed and use of fertiliser on maize was also obtained for central and western Kenya in Karugia (2003). Furthermore, it has been noted that the influence of the institutional differences such as market access is sometimes ambiguous. The nearest (local markets) are in many cases narrow markets with only limited quantities traded (Sadoulet and de Janvry, 1995). It is possible that households very close to these markets are more involved in activities such as trading rather than farming.

3.5.1.2 Seemingly Unrelated Regression (SUR) results

Results from the Seemingly Unrelated Regression are presented in Table 3.11 below.

Table 3.11: Factors affecting demand for fertiliser and three crop outputs in Kiambu

	Fertiliser		Maize		Potato		Kale	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	75.0***	25.1	266	316	1163	733	2308	1679
Education	-0.23	0.87	1.11	11.0	-4.81	28.6	11.2	70.1
Age	-0.25	0.27	3.95	3.53	12.9	9.28	6.57	22.2
Gender	6.20	8.67	-10.8	113	-114	298	-63	702
Farm size	19.5***	4.76	261***	62.9	1135***	166	1296***	380
Access to extension (1 = yes)	2.23	6.99	62.2	90.0	-339	237	-370	652
Access to credit (1 =yes)	-9.17	9.39	-274**	124	-332	327	-1717**	818
Price of fertiliser	-380***	97.4	-384**	188	-435.20	377	-203.7**	97.91
Output price of maize	384**	188	953	1734	-6969**	3255	4060***	1281
Output price of potatoes[3.3]	435	379	-6969**	3255			9075***	3377
Output price of kale	204**	97.9	4060***	1281	9075***	3377	16368**	7280
Manure quantity	0.003	0.08	1.99**	1.00	0.76	2.57	-3.20	8.45
Cattle numbers	8.51**	3.87	-9.93	51.1	-15.3	133	606*	338
Area under tea	-0.09	24.8	35.4	328	-2371***	866	-5434	3679
Area under coffee	-70.2**	28.8	-562	381	-2654***	993	5737	6517
IMR- kale	-4.85	6.08	-250***	79.8	-533**	210	-4090***	1430
IMR fertiliser	-7.21	26.2	444	346	62.8	903	-4279*	2446
Adjusted R-squared	0.30		0.21		0.27		0.10	
N	212		212		212		136	
Mean dependent (kg)	46.1		625		1891		2991	

Dependent variables are the fertiliser quantity and the output quantities of maize, potatoes and kale. *, **, *** Identifies the variables that are significant at the 10%, 5% and 1% level respectively. [3.4]

The SUR results are shown in Table 3.11 above. As expected, farm size has a positive impact on the supply of all the three outputs and on the demand for fertiliser. Farm size can be a proxy for wealth, implying that households with bigger farms have more resources to purchase inputs. In addition, bigger farms allow the flexibility of allocating land and other resources to farm activities more profitably and hence encourage use of more external inputs such as fertiliser, leading to increase in production. In any case land is a necessity in crop production and so the bigger the farm, the more of it is available for increased production. However, fertiliser demand elasticity with respect to farm size is 0.36, which implies that as the size of the farm increases the rate of fertiliser application in kg/ha

[3.3] The own price of potatoes though not significant had the wrong sign and was excluded from the potato equation.

[3.4] Symmetry conditions were imposed on the price of fertiliser and the output prices.

reduces. Bigger farms may allow for the possibility of other means of replenishing soil nutrients such as fallowing, and as a result need lower fertiliser application rates. An inelastic relationship between fertiliser and farm size is often obtained (e.g. Nkonya et al., 1997; Sidhu and Baanante, 1981; Chaudhary et al., 1998). The output supply response with respect to farm size is similarly inelastic, with that of maize being 0.35, that of potatoes 0.51 and that of kale 0.35. As farm size increases the yield per unit area decreases, which is logical given that the rate of fertiliser application has declined. It may also mean that as farm size increases, households diversify and allocate part of the farm to other activities not previously produced.

Availability of credit is expected to relax the financial constraints of farming households, making it possible to access production inputs on time and should therefore lead to increase in production. For example, Imai (2003) recommends that households should be availed with credit in order to raise their agricultural production. The negative influence obtained in this estimation therefore is inconsistent with expectation. The result may be due to the fact that the question on credit was not specific to agriculture, but included any form of credit. Households may have taken credit mainly for non-agricultural activities, which draw their attention away from the farm, hence lower production. This means that for credit to be useful to farming, it has to be credit that targets agricultural activities specifically.

Consistent with economic theory, the price of fertiliser has a negative influence on the demand for fertiliser and on the supply of maize and of kale. It is negative but not significant for the supply of potatoes. Interestingly, the households are price-elastic in their demand for fertiliser with an elasticity of –2.44, contrary to the commonly held notion that smallholders are not responsive to prices. Fertiliser price can therefore be an effective instrument in stimulating households to increase the use of fertiliser. Gerdin (2002), using time series data for Kenya at the national level, also obtained elastic response of agricultural production to fertiliser price. He found own-price elasticity for intermediate inputs, which were mainly fertiliser, to be -1.97. When the price of fertiliser increases and that of an alternative input is unchanged, less fertiliser is used in favour of the alternative input because the marginal benefits of fertiliser become less attractive compared to those of an alternative. Other studies that have also found elastic price response using cross sectional data are Sidhu and Baanante (1981) and Chaudhary et al. (1998). Both maize and kale are known to have a high soil nutrient requirement and reduced use of fertiliser will therefore lead to reduced yield or area under the crop and hence reduced output.

Apparently the fertiliser price elasticity for kale output is quite low (0.02), compared to that of maize (0.18), showing that in fact, changes in fertiliser price have only a small impact on kale output. This is rather strange considering that kale is the major source of cash.

The fertiliser demand elasticity with respect to the price of maize and of kale is 0.90 and 0.27 respectively, showing an inelastic response. This is not a strange result because, in a multi-crop situation as in the case of Kiambu, the impact of any one crop is reduced and an inelastic influence should be normal. Elastic relationships are more commonly obtained where households concentrate on one output (e.g. Sidhu and Baanante, 1981) or where several outputs are aggregated (e.g. Chaudhary et al., 1998). The result on maize price is consistent with the suggestion made by Omamo and Mose (2001) that "given the prominence of maize in Kenya, maize prices are a likely important influence on households' willingness to apply fertiliser".

Cross output prices are significant in all the three supply equations. The relationship is negative as expected between potatoes and maize, but it is positive between maize and kale and between potatoes and kale. Apparently kale is a complement crop to both maize and potatoes. This is inconsistent with our expectation that the three crops compete for the same resources, fertiliser, land and labour, and so a negative relationship should be expected. What immediately comes to mind is the possibility that kale was inter-cropped both with potatoes and maize. However, the data show that kale was inter-cropped with maize only in 4.5% of the cases and with potatoes 9.7% of the cases. The possible reason for the positive relationship is that many households are actually food importers so that higher prices for food crops (maize and potatoes) induce them to grow more of the cash crop (kale) in order to buy these foods. It may also be that high prices for maize and for potatoes coincide with better market conditions so that more/better opportunities exist for marketing of kale. Potatoes and maize are mainly grown for food supply, while kale is grown mainly for income generation.

The maize supply elasticity with respect to the price of potatoes is -0.64 and with respect to the price of kale it is 0.45, while the potato supply elasticity is 0.39 and 0.32 with respect to the price of maize and of kale respectively. Notably, cross price elasticities for kale are much lower: 0.16 with respect to the price of potatoes and 0.14 with respect to the price of maize. The own price was significant only for kale with a price elasticity of 0.38, which again is logical, kale being a cash crop.

Manure is one of the sources of nutrients, especially nitrogen, which are required for maize production and, in addition, it contains organic matter that helps improve the soil structure, making the soil more suitable for maize growth. The positive influence of manure on maize is therefore expected. It is however surprising that manure does not have a significant influence on the production of kale and of potatoes, or on the demand for fertiliser. This may possibly be due to the low quantities applied, and the low quality of manure. The number of cattle has a positive impact ($P<0.05$) on the demand for fertiliser and ($P<0.1$) on the production of kale. As Imai (2003) found, households who own cattle are able to ease their liquidity constraints through sale of cattle products such as milk, and hence able to purchase crop inputs such as fertiliser. In addition, like farm size, cattle ownership can be a proxy for wealth, in which case households with more livestock should be more able to buy fertiliser.

Several studies suggest that there is a positive relationship between the production of cash crops and of food crops (e.g. Jaeger, 1992; Govereh and Jayne, 2003; Karanja, 2002). They argue that income generated from cash crops is used to purchase inputs for food crops (Jaeger, 1992; Karanja, 2002), or that cash crop producers have access to key inputs such as credit and training through cash crop schemes that are not available to non participating households (Govereh and Jayne, 2003). However, this is not the result we obtain here; in fact, area under tea and coffee significantly lower the potato output, and in addition a bigger acreage under coffee lowers the quantity of fertiliser used on other crops. Our results suggest that households with large areas under tea and/or coffee pay less attention to other crops, because they can use income generated from the cash crops to purchase food and other items.

The IMR_{kale} is significant in all the supply equations, but not in the fertiliser demand equation. This implies that households who do not grow kale are distinctly different from those who grow kale, in their maize, potato and kale production decisions. However, households that do not grow kale are not different from those who grow kale in terms of fertiliser use decisions. The $IMR_{fertiliser}$ was significant only in the kale supply equation. These results show that it was important to include both the IMR_{kale} and the $IMR_{fertiliser}$ in the equations to take care of the sample selection bias.

3.5.2 The Vihiga probit and SUR results

The probit and SUR results for Vihiga are reported in Table 3.12 below

Table 3.12: Factors affecting demand for fertiliser and production of maize in Vihiga

	Fertiliser				**Maize**	
	Probit		**SUR**		**SUR**	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Constant	-1.44	1.35	2.61	42.6	-606*	334
Education	0.01	0.04	1.82*	1.08	5.06	11.9
Age	-0.02*	0.01	0.13	0.33	8.19**	3.58
Gender	-0.10	0.30	-5.12	8.65	215**	94.4
Farm size	0.84**	0.35	28.1***	7.25	327***	79.4
Access to extension (1 = yes)	-0.46*	0.25	-2.07	7.39	56.6	80.3
Access to credit (1 =yes)	0.41	0.37	-5.67	8.99	-332***	99
Price of fertiliser			-88.0*	52.7	-204*	107
Output price of maize	0.22**	0.09	204*	107	3820***	1182
Manure quantity			0.14	0.12	4.43***	1.29
Livestock numbers	-0.21	0.16	-4.24	4.81	161***	52.7
Area under tea/dummy	0.42	1.28	-9.35	26.4	-1306***	283
IMR fertiliser			-9.23	18.3	-670***	198
Distance to nearest market	0.082	0.07				
Membership of organisation	0.36	0.25				
Division dummy	0.51*	0.29				
Adjusted R-squared			0.29		0.49	
McFadden R-squared	0.14					
N	172		121		121	
Mean dependent (kg)			28.6		731	

Dependent variables for SUR are the quantities of fertiliser input and maize output. *, **, *** Identifies the variables that are significant at the 10%, 5% and 1% level respectively [3.5]

3.5.2.1 Probit results

The results imply that older household heads are less innovative and less receptive to advice compared to younger household heads, hence less likely to use fertiliser. On the other hand, younger household heads are innovative, go out to seek information and adopt recommendations. The result on farm size is not surprising, bigger farms imply more resources and hence better ability to buy fertiliser. Extension advice is the main source of information on farming, and one would expect a positive relationship between the decision to buy fertiliser and access to extension advice; the negative relationship is therefore surprising. Maize being the main food staple, and the sole most important crop in Vihiga, the sign on maize price is expected. Households will choose to use fertiliser when the maize price is high to increase their production and sell, or have enough for the family so

[3.5] Symmetry conditions were imposed on the prices.

they do not have to buy. Households in Hamisi division are more likely to use fertiliser than do households in Vihiga division. While the reasons for this finding are not clear, subsequent visits and discussions with some of the households interviewed support the result. Households in Hamisi division seem more keen on how to improve their farming and are receptive to advice than those in Vihiga division.

3.5.2.2 Seemingly Unrelated Regression results

Regression results for Vihiga presented in Table 3.12 are similar to the Kiambu results in several variables. Farm size has a positive impact on the demand for fertiliser and the supply of maize and the same explanation given under Kiambu applies. The fertiliser demand elasticity with respect to farm size is 0.74, higher than that of Kiambu, but still inelastic. As farm size increases, the amount of fertiliser used increases, but the rate of application per unit area (farm size) goes down. This does not however necessarily imply that the rate of application per crop area decreases, because not all the additional farm area may be converted to cropping. Output supply elasticity with respect to farm size is 0.32, similar to that of Kiambu. The result for credit is also similar to that of Kiambu.

Again as economic theory predicts the price of fertiliser has a negative influence ($P<0.1$) both on the demand for fertiliser, and on the output supply of maize. Like Kiambu, these households are price elastic in their fertiliser demand, with own price elasticity of −1.88. However, although both Kiambu and Vihiga households are price elastic in their fertiliser demand, Kiambu households are more responsive (own price elasticity is higher) than the Vihiga ones. The maize supply elasticity with respect to fertiliser price is 0.17, similar to the Kiambu one of 0.18.

The output price of maize positively influences both the demand for fertiliser and the supply of maize, with the fertiliser demand elasticity being 1.58, while the maize supply elasticity is 1.16. Apparently these households obey the law of supply and demand - an increase in output price will lead to increased production of that output, and hence increased demand for the input. Both the fertiliser demand and the maize output supply elasticities with respect to maize price are much higher for Vihiga, than for Kiambu, with the response being elastic in Vihiga, but inelastic in Kiambu. Maize is most important to the Vihiga households because it is their staple food, and also the only main crop, hence the larger impact its price has on fertiliser demand and output supply. Though Vihiga is a maize deficit district, some households still sell maize at harvest because of immediate cash needs, only to buy later. It is important to note that, according to the Vihiga households, and for most of western Kenya, if they have no maize, they have no food, even if they have other food staples such as bananas and sweet potatoes.

Both the quantity of manure used and the number of tropical livestock units have a positive impact ($P<0.001$) on the maize output in Vihiga. These variables are however not significant in the fertiliser demand equation, showing that the quantity of manure used has no influence on the level of fertiliser used. Area under tea has a negative impact on the quantity of maize produced, indicating that tea competes with maize for the limited resources and does not promote its production as usually presumed (see discussion on the same under Kiambu).

3.5.3 Comparison of Kiambu and Vihiga

Some differences between Kiambu and Vihiga are observed. The average fertiliser price in Vihiga is 6.6% higher than that of Kiambu (Table 3.9). The fertiliser used in Kenya is usually imported and so the source within Kenya is the port at Mombasa. From Mombasa it is transported to Nairobi and then to other major towns and regions. As the fertiliser moves from Mombasa to Nairobi and to other regions, there are mark-up margins on the price by the various players (wholesalers and retailers) due to distribution costs such as transportation and other losses. These margins will increase as distance from the source increases and also based on the quality of the infrastructure. Wanzala et al. (2001) found that mark-ups on the price of fertiliser by wholesalers ranged from 0 – 6% and those of retailers from 2 – 9%. According to Wanzala, the mark up margins by traders are generally low, indicating that the relatively high prices of fertiliser in regions far from the source are due to high costs incurred in domestic distribution and not excessive profits of fertiliser traders. The low mark up margins at every stage also indicates that there is strong competition in fertiliser trade, at least in wholesaling and retailing. The fertiliser price difference between Kiambu and Vihiga is therefore due to mark-ups caused by their relative distance from the source. Vihiga is located about 400 kms from Nairobi whereas Kiambu is located less than 50 km from Nairobi.

The 6.6% percent difference in fertiliser price means that a household in Vihiga pays about ksh. 100 more for a 50 kg bag of fertiliser than a household in Kiambu, implying that returns to a bag of fertiliser used are ksh.100 lower in Vihiga than in Kiambu. This may be partly the reason why use of fertiliser is higher in Kiambu both in terms of proportion of households using and the rate of application. For example, while Kiambu households applied an average rate of 63 kg/ha on maize, Vihiga households applied only 28.6 kg/ha, and while 89% of sample households in Kiambu used fertiliser, 78.3% used fertiliser in Vihiga (Tables 3.4 and 3.7).

Whereas many studies usually consider distance to the nearest market an important variable to explain differences in input use, in our case it is distance to the major markets/source that influences the price and actions of households. Government efforts that reduce distribution costs of fertiliser will reduce fertiliser price and increase its use especially in regions situated far away from the source. For example, Wanzala et al. (2001) indicate that the cost, insurance and freight (C.I.F.) price of DAP in Mombasa during the survey period (1999) was roughly 45 – 55% of the farm gate price in western Kenya. This shows that there is a big potential to reduce farm gate prices in Vihiga and western Kenya as a whole.

The other major difference between Kiambu and Vihiga is the wage rate: that of Kiambu is almost double that of Vihiga. Presumably Kiambu, being in the vicinity of Nairobi, faces stiffer competition for farm labour with off-farm activities in the city, which can be accessed at relatively lower transaction costs, and this drives up the wage rate. In Vihiga, on the other hand, there is little opportunity for off-farm employment to absorb the available labour force and so the wage rate remains low. This observation implies that even though Kiambu households pay less for fertiliser, hence increasing their farm profits compared to Vihiga, their profit is lowered by the higher wage rate. It also implies that Vihiga is likely to use more labour than required in farm production activities.

The incomes from the different farm activities are much higher for Kiambu compared to Vihiga. The biggest difference is with earnings from tea and from milk. For example, earnings from milk in Vihiga are less than a third of the earnings in Kiambu. From Table 3.9 it can easily be seen that there is neither much difference in the average number of cattle in the two districts, nor is there a big difference in the area under tea. Kiambu has an average of 1.30 TLUs and 0.05 ha of tea, whereas Vihiga has an average of 1.00 TLUs and 0.06 ha of tea. The big difference in the dairy earnings therefore, must have to do with the breed kept and the management. In Kiambu only improved breeds are kept, whereas in Vihiga the local Zebu, which produces very little milk, dominates.

For tea, the result is even more surprising because households in Vihiga actually apply a higher fertiliser rate than those in Kiambu (see Tables 3.4 and 3.7). Again the difference must have to do with management, and most likely tea picking. Output prices are similar in the two regions. There is a great potential to increase production of tea in Vihiga, just by improving on the management.

Notably, the number of cattle owned affects production decisions differently in Kiambu and in Vihiga. In Kiambu the number of cattle has a positive influence on the quantity of fertiliser used, which implies that sales from cattle products such as milk provide cash to purchase fertiliser. In Vihiga however, the number of cattle owned has no impact on the quantity of fertiliser used, but has a positive impact on the quantity of maize produced. This can be translated to mean that cattle ownership affects maize production through production of manure.

3.5.4 Differences by farm types

We indicated in Chapter 2 that classification of households into farm types is meant to deal with their heterogeneity. However, the results reported in this chapter are not disaggregated by farm type mainly because the use of fertiliser did not vary significantly across farm types both in Vihiga and in Kiambu. In a separate regression (not reported) we included farm type dummies, but the results did not change much. The same variables are significant at the same levels with only minor differences in the size of the coefficients. In the Kiambu case, the farm type dummies are significant only in the kale output equation, showing that farm type three produce significantly more kale than farm types one and two. In Vihiga, the farm type dummies are significant only in the maize output equation and show that farm type one produces more maize than the others.

3.6 Conclusions and implications

Farmer perception and restricted activity profit were used to rank farm activities, and the Normalised Quadratic profit function used to analyse household decisions on fertiliser demand and crop supply.

The results are interesting in that the most important crops in the Kiambu sample are kale, potatoes and maize, and not tea and coffee, usually considered the most important cash crops in the area. The latter rank lower because only a small proportion of households grow them. Kale is the most important crop in terms of cash generation to the households, and is a complementary crop both to maize and to potatoes, which is an added advantage. Government efforts aimed at improving the welfare of smallholders in Kiambu need to focus more on maize, potatoes and kale – and especially on kale, which is often overlooked as a minor crop, and yet our results show that it makes the highest contribution to household income among the crops. Policy interventions that focus on the marketing and pricing of kale will improve rural incomes in Kiambu. In Vihiga there were no surprises, maize remains the sole most important crop followed by tea, bananas and Napier.

The variables that had a positive impact on the demand for fertiliser by the Kiambu sample were size of the farm, output price of maize and of kale, and the number of tropical livestock units. The price of fertiliser had a negative impact as expected, but unexpectedly, area under coffee too had a negative impact. Apparently households who have a large area under coffee use less fertiliser on other crops. The important variables for the Vihiga sample are education of the household head, farm size and output price of maize, all having a positive impact, and the price of fertiliser, which had a negative impact.

The households in both districts are price elastic in their fertiliser demand with the own price elasticity being –2.44 for Kiambu and –1.88 for Vihiga. Kiambu households are more price elastic than Vihiga households, but for both districts the results show that price of fertiliser can be an effective instrument for stimulating households to increase the level of fertiliser use, reduce the decline in soil fertility, increase farm productivity and reduce poverty. Similarly, output prices, and particularly the output price of maize, are an important determinant of household decisions on the use of fertiliser. Maize price has the highest impact; it is elastic in the Vihiga sample and has near unitary elasticity in the Kiambu sample. Output pricing policy is therefore another important instrument that can be used to increase the level of fertiliser used and hence agricultural production. This is an important result, in that it is a challenge to the widely held view that smallholder households are not responsive to prices in their input demand and output supply.

The significance of the level of education on fertiliser use emphasises the importance of adult education and informal training for the farming households. It also emphasises the importance of educating children, who form the future farming community. It is notable that this variable is only significant in the Vihiga sample, which as we have noted achieves much lower farm incomes compared to Kiambu even when similar cattle numbers or area under tea are maintained. This implies that the Vihiga households require more extension advice and education on farming.

It is surprising that manure did not have a significant influence on fertiliser demand or on any of the outputs except maize. It is usually expected that in low-income countries like Kenya, manure will play a supplementary role to fertiliser. Indeed, Omamo et al. (2002) found a supplementary relationship between inorganic fertiliser and organic manures. However, their result is contradicted by that found by Waithaka et al. (2003) and Salasya et al. (1998), who both report a complementary relationship between the two. That manure has no significant influence particularly on potato and kale output may be due to the low quantities of manure applied and due to the low quality of manure.

The major policy implications that come out of this chapter can be formulated as follows:

It is important to reduce distribution and other transit costs of fertiliser from the port to the final destination. This will reduce the fertiliser price at the farm level and hence make fertiliser use more profitable, and increase its use especially in regions situated far away from the source. Details on how this can be done are contained in Wanzala et. al. (2001).

There is a need to train and encourage households to improve the quality of manure, through participatory methods. This will increase maize production, particularly in Vihiga where manure and livestock ownership play an important role in maize production. Currently efforts are being carried out by the PROSAM project to encourage households to improve the quality of manure by incorporating crop residues and leguminous plants. The government could intensify these efforts and expand to other places.

Improving production and marketing of kale can increase rural incomes in Kiambu and other similar places. Kale is usually considered a minor crop that is never referred to specifically but generalised under horticultural crops, yet it has turned out to make substantial contribution to household income. Of particular importance is that this crop, unlike maize, is perishable, hence improved infrastructure and transportation are necessary if its marketing is to be facilitated. Improving the production and marketing of kale will have a greater impact on improving the welfare of the rural community, than focusing on crops such as tea and coffee, which are only grown by a few households.

Access to major markets plays an important role in determining farming choices. Kiambu households are able to grow crops like kale possibly because of their closeness to Nairobi. While it is not possible to transfer each region to be close to the city, the city can go to them if there is good infrastructure and efficient transport system. An efficient transport system should therefore be a priority goal.

In Kiambu district the dairy industry is well established and has a positive influence on the use of fertiliser on crops, as it relaxes the liquidity constraint. In Vihiga where it is not well established, its influence on crop production only comes in through provision of manure. Improvement of the dairy sector in Vihiga may, if profitable, lead to increase in fertiliser use as well.

Appendix 3.1: Description of variables used in the analysis

Level of education of the household head: This is the number of years spent in school. Exposure to education should increase the ability to obtain, process and use information relevant to agricultural production. It is therefore expected that education will have a positive impact on the demand for fertiliser and on the supply of the different outputs.

Age of the household head: Older household heads possibly have more experience in farming and so make better decisions, which implies that a positive coefficient should be expected. However younger household heads may be more innovative and less risk averse. The coefficient on age (years) may therefore be negative or positive.

Gender of the household head: This is a dummy where 1 = female. Female-headed households are hypothesised to have fewer resources than male-headed households and hence a negative sign is expected.

Farm size is the total land that a household had access to during the reference year. It included land that the household owned plus land rented in and less the land rented out. Farm size is a proxy for wealth, and perhaps a proxy for social status within a community. It is expected that households with larger pieces of land will both choose to use fertiliser and use more of it. A positive sign is therefore expected on the farm size coefficient both for fertiliser demand and output supply.

Access to credit: This is a dummy (1= yes) to indicate a household that had access to credit. Households who have access to credit can relax their financial constraints and allocate their resources more profitably. A positive coefficient is therefore expected both for the fertiliser demand and the output supply equations.

Access to extension advice: This is a dummy (1= yes) indicating access to government extension services, which is the main source of farming information in the two study regions. Access to extension advice should result in households making better farming decisions, including on use of fertiliser. A positive coefficient is therefore expected both for the fertiliser demand and for the output supply.

Price of fertiliser: This is the average price of fertiliser in ksh./kg used on the three crops in Kiambu and on maize in Vihiga, plus transport cost where applicable, averaged over the seasons. Based on economic theory a negative coefficient is expected on the fertiliser price, both for the fertiliser demand equation and the output supply equations.

Wage rate: The average daily wage rate in ksh. as reported by the different households is used. Labour is very important in these areas because the farms are too small for machinery such as tractors to be cost effective, and so households rely on labour for all the farm operations. A negative coefficient is expected both for input demand and output supply equations. The wage rate was however used for normalisation.

Fertiliser: This is the fertiliser quantity in kg calculated by adding the amount of fertiliser used on maize, potatoes and kale, over the different growing seasons in the reference year in Kiambu. In Vihiga it is the fertiliser used on maize summed for the two growing seasons.

Output prices: Farm gate prices in ksh. of the three outputs (maize, potatoes and kale) are used in Kiambu. Similarly in Vihiga the farm gate price of maize output is used. The outputs are the total quantities in kg of each crop summed over the growing seasons.

Manure: This is the total amount of manure that was used during the reference year measured in bags. A positive coefficient is expected on all the output equations.

Livestock: The number of total tropical livestock units owned by the household during the reference year. Sale of livestock products can provide cash that can be used for purchase of inputs like fertiliser. A positive coefficient is therefore expected.

Area under permanent crop: This is area under tea and area under coffee in hectares. One hypothesis is that cash crops like tea generate income and enable households to purchase inputs for other farm activities. In that respect a positive sign should be expected. However cash crops also compete for the available inputs, especially land and labour, and so a negative sign on the output supply equations is possible.

CHAPTER 4

IMPACT OF SOIL NUTRIENT MANAGEMENT AND INPUT/OUTPUT PRICES ON CROP PRODUCTION

4.1 Introduction

Product and input prices are powerful factors in household decisions on the use of soil nutrient management technologies. Governments and policymakers therefore often use price incentives to encourage households to adopt these technologies. In order to formulate price incentives that stimulate farm households to adopt soil nutrient management technologies like fertiliser, it is important to understand how the households are likely to respond to these incentives. For example, when the price of fertiliser changes it is important to know on which crops it will have the greatest impact, and what will be the effect on other crops in the farming system. The results of Chapter 3 show that the prices of fertiliser and of outputs significantly influence the demand for fertiliser and the various output levels. Most studies that have analysed farm production systems usually do not go beyond identifying the factors that influence output supply and input demand and the magnitude and direction of the influence in terms of elasticities (e.g. Hattink et al., 1998; Gerdin, 2002; Sidhu and Baanante, 1981). Some of these studies e.g. Hattink et al. (1998) find very low supply response elasticities. The usual approach is to assume that the results are reasonable and explain the low elasticities as being due to the unresponsive nature of farm households. However, is this always the case or could there be other rigidities faced by the households that may not be easily seen from the elasticities?

De Janvry et al. (1991), while trying to unravel why smallholders do not always seem to respond to policy incentives in the way that governments expect, investigated the influence of market failures on the observed behaviour. They found that low response to change in price of the cash crop was a structural feature, associated with market failures in the food and labour markets, rather than a behavioural trait of peasants. In their analysis they found that both the price elasticity of cash crop supply and the cross price elasticity of the food crop declined substantially when both food and labour markets failed. Their results show the importance of paying close attention to the results we obtain before we draw conclusions based on them.

Singh et al. (1986) note that pricing policies are often oriented toward specific commodities, mainly traditional cash crops, but in a household setting other crops will be affected as well, and those may be more important. In Chapter 3, we found that although fertiliser price significantly influenced maize and kale output, the impact on production in terms of elasticities was much lower for kale compared to maize. This is rather surprising given that kale is grown mainly for cash and maize mainly for food, and furthermore kale makes the highest contribution to household farm profit. The reverse would have been more acceptable because economic returns have been shown to play a critical role in the households' use of soil nutrient management technologies, and as a result affect their resource allocation decisions (Bamire and Manyong, 2003). This drives us to think that there is more to the results than the obtained elasticities.

In this chapter, we therefore go beyond what is usually done and elaborate on the results of Chapter 3, in an attempt to present a clearer picture of the estimated effects. We do this in the following ways: first we examine the impact of a change in prices and in fixed factors (manure and farm size) on the physical quantities of the fertiliser used and on the level of crop outputs. To do this, simulations are carried out on the system of equations estimated in Chapter 3. The simulations allow us to predict the households' response to changes in prices and fixed factors in terms of crop production decisions. Moreover, we go further and investigate how changes in prices and fixed factors influence land area allocated to the different crops. This is done by re-estimating the system of supply equations analysed in Chapter 3 with area under each crop replacing output quantities as the dependent variable. Simulations are then done on the re-estimated equations. Lastly, to explain differences in the various crop responses to change in fertiliser price, a quadratic production function is estimated to examine how the three crops respond to fertiliser application and other inputs in terms of output quantities. The investigations are done both at the whole sample level and disaggregated by different household types as identified in Chapter 2.

The structure of the sections that follow is such that: first the impact of a change in prices and in fixed factors on fertiliser demand, and on output levels is presented in section 4.2. The impact of input and output price changes on restricted household profit is then presented in section 4.3. Section 4.4 discusses the impact of change in prices and fixed factors on input and output levels disaggregated by farm types, and finally discussion and conclusions are in section 4.5.

4.2 Impact of a change in prices and fixed factors on input and output levels

Economic theory suggests that when the price of an input such as fertiliser increases, other factors remaining the same, demand for that input will decrease. This change will have an impact not only on the level of the input demanded, but also on the level of production of outputs where that input is employed. If there is an increase in price of the output, then it should cause an increase in the level of production of that output, and also in the level of inputs employed in its production. In this study there are three outputs and two inputs considered for Kiambu, and one output and two inputs for Vihiga. The outputs are maize, potatoes and kale for Kiambu, and only maize for Vihiga, whereas the inputs in both regions are labour and fertiliser. The wage rate was used for normalisation so in the first part of this section only the price of fertiliser is simulated. In a later sub-section a simultaneous decrease in all prices is made to represent an increase in the wage rate. We use the model obtained from the system of input and output equations of Chapter 3 to carry out simulations by increasing one price or fixed factor at a time by 10%, while holding the other prices and fixed factors constant. The simulations are done for each individual household (observation) before taking the mean of the simulated values. Table 4.1 presents a summary of the impact of this change in prices and fixed factors on the input and output levels, calculated at their mean values. Part of Table 4.1 may seem to be a repetition of the elasticities calculated in Chapter 3, but it is necessary to have them here for the investigations that follow.

Table 4.1: Percent change in input and output quantities as a result of a 10% change in prices and fixed factors for the Vihiga and Kiambu sample households

	Fertiliser price	Maize price	Potato price	Kale price	Farm size	Manure
Kiambu						
Fertiliser quantity	-24.4	8.95	5.39	2.76	3.58	-0.03
Maize output	-1.82	1.64	-6.37	4.54	3.53	1.44
Potatoes output	-0.68	-3.96		3.22	5.07	0.18
Kale Output	-0.19	1.37	1.64	3.84	3.54	-0.41
Vihiga						
Fertiliser quantity	-18.8	15.8			7.35	0.78
Maize output	-1.71	11.6			3.35	0.96

NB: Price of potatoes was excluded from the potato equation because, though not significant, it had the wrong sign

4.2.1 Impact of 10% change in prices on fertiliser demand and on output supply

Results presented in Table 4.1 show that a 10% increase in the price of fertiliser will lead to a 24.4 % reduction in the mean fertiliser level, in the Kiambu sample. The common view is that the reduction in fertiliser will lead to a reduction in the rate of fertiliser application, leading to a reduction in yield and consequently lower output. But this does not have to be the case. The reduction in the amount of fertiliser can, in fact, impact on the level of crop output through two avenues. The first is the common view mentioned above. But, households may also respond to the reduction in fertiliser quantity by reducing the area allocated to a crop, in particular a crop that uses fertiliser more intensively, but maintain the rate of application. In the latter case, the yield of the crop does not reduce, but total output is lowered because of a lower acreage. Unfortunately, it is not known a priori whether households will respond by reducing crop area or by reducing the rate of fertiliser application. It is important to differentiate the two lines of action because they have different environmental consequences in terms of soil nutrient management. For example, if the action is reduced crop area, then it might mean that some land is left fallow for nutrient replenishment, whereas reduced fertiliser application means increased nutrient depletion. Reduced crop area may also mean that the households revert to crops that perform relatively better under low fertiliser application. In section 4.2.1.1 we therefore investigate this point further and identify which of the two lines of action the households will take.

Surprisingly, the simulation results in Table 4.1 show that the 10% increase in the price of fertiliser does not have the same effect on the three outputs in the Kiambu sample. It causes the output of maize, potatoes and kale to go down by 1.82%, 0.68% and 0.19% respectively, showing that of the three crops, maize is the most responsive and kale is the least responsive. But why should this be? While the impact in terms of elasticities should not be necessarily similar across the crops, where there are differences it is logical to expect that the effect will be greater on kale, which is grown mainly for cash, than on maize and potatoes that are grown mainly for food, but this is not the case here. Several hypotheses can be put forth to explain these results:

One hypothesis is that currently the rate of fertiliser use in maize is lower compared to that of potatoes and kale, so that maize is, for example, in the area of increasing returns on the production function and kale in the area of diminishing marginal returns. If that were the case, then one could justify the results based on the neoclassical theory of farm production, specifically the principle of diminishing marginal returns. However, fertiliser use statistics reported in Table 3.4 of Chapter 3 do not show a big difference in the rates of fertiliser use for the three crops – 63 kg/ha for maize and 74 kg/ha both for kale and for potatoes. Moreover, the rates of application for all three crops are far below the recommended rates. This hypothesis is therefore not plausible.

A second hypothesis has to do with the efficiency of fertiliser use by the different crops. We hypothesise that kale has a higher response to fertiliser application in terms of output (has a higher use intensity) than maize and potatoes. If that is the case, then it implies that if the amount of fertiliser used decreases, a rational farmer will rather use it on kale than on maize or on potatoes. To investigate this point, input use intensities of the three crops are calculated and shown in Table 4.2. The table shows for each crop how many units of the input are needed to produce ksh.1000 worth of output. It shows that kale, in fact, has higher use intensity (requires less input to produce one Kenya shilling) for all the three inputs. The result confirms our hypothesis that kale uses fertiliser more efficiently compared to maize or potatoes, and partly explains the low response of kale to fertiliser price. The results mean that when the price of fertiliser increases, less fertiliser is purchased, but the purchased fertiliser is diverted from maize to kale so that it appears as though kale is not sensitive to changes in the fertiliser price.

Table 4.2: Input use intensities of maize, potatoes and kale for the Kiambu sample households

Input	**Input units/ksh. 1000 earned**		
	Maize	Potatoes	Kale
Fertiliser (kg)	5.02	2.72	2.00
Labour (md)	6.37	4.04	3.76
Land (ha)	0.09	0.04	0.03

Source: Calculation from the household survey data

The third and last hypothesis for the higher response of maize than kale to a change in fertiliser price is that another input is constraining the production of kale more than fertiliser, so that the effect of fertiliser is obscured. To investigate this further, a primal approach is taken and response of the three crops to fertiliser application and other inputs is investigated in section 4.2.1.2. In addition, the effect of labour (simulation of all price decreases) on the different outputs is compared with that of fertiliser to explain the differences. From Table 4.2, of the two inputs of labour and fertiliser, kale uses labour more intensively (higher rates of labour to fertiliser) than maize. For example, per 10 kg of fertiliser 12.7, 14.9 and 18.8 man-days are used in maize, potatoes and kale respectively.

In the case of Vihiga, the increase in the price of fertiliser causes fertiliser quantity to go down by 18.8% but the output of maize goes down by only 1.71%, a value similar to that observed for maize in Kiambu. This is expected because fertiliser is only one of the inputs influencing the level of maize production. However, we still need to identify the avenues through which reduced fertiliser affects maize output (crop area or rate of application), and also investigate hypothesis three above.

The effect of the output prices on fertiliser demand is consistent with the previous observation in that a change in the price of maize has the highest impact on fertiliser demand, and a change in the price of kale has the lowest impact. As already mentioned, the response of the different crops to fertiliser application is investigated further in a later section to unravel these observed effects. In Vihiga, the price of maize has a much bigger impact on the demand for fertiliser than do any of the output prices in Kiambu, which again is expected because maize is the only main output in Vihiga.

Of the outputs' own price, that of kale has the highest impact. Kale is the major source of cash for the sample households, whereas maize and potatoes are mainly grown for food production, with income generation as a second objective. It is therefore possible that some households do not sell or buy maize and potatoes and this lowered their elasticities. Key et al. (2000) have shown that output price response can be lowered if some households in the sample are autarkic – they do not sell or buy. Cross-output prices have a bigger impact than own price in maize and potato production. As expected, maize output in Vihiga is much more responsive to maize output price than in Kiambu because, maize in addition to being the only major output, it is the food staple in Vihiga. Moreover, Vihiga is a maize deficit district, and chances that most households are involved in the market either as buyers or sellers are high.

4.2.1.1 Crop area response to changes in prices and fixed factors

It was mentioned that there are two avenues through which households can respond to a fertiliser price increase: either by reducing area under the crop, or by lowering the rate of fertiliser application but maintaining the same acreage, or both. Similarly a change in output prices may impact either on the area allocated to a crop or on the rate of input application. In this section the impact of a change in prices and fixed factors on area allocated to each of the three crops in Kiambu and to maize in Vihiga is investigated. To do this, the system of output supply equations used in Chapter 3 is repeated with area under each of the crops replacing the output levels as the dependent variables. The new supply equations for Kiambu become:

$$A_h = \delta_h + \sum_{h=1}^{3} \delta_{jh} p_h + \phi_{fh} w_f + \sum_{n=1}^{10} \eta_{hn} z_n$$

where p_h are output prices of maize, potatoes and kale, w_f is the price of fertiliser, z is a vector of 10 fixed factors, and A is the area allocated to each of the three crops: maize, potatoes or kale, in the case of Kiambu, and maize in the case of Vihiga, and δ, ϕ, η are parameters to be estimated. The three supply equations for the Kiambu sample are again estimated as a system using the SUR, but the Vihiga maize area equation is estimated by Ordinary Least Squares (OLS). In the land area equations for Kiambu only the households who planted maize, potatoes or kale as a main crop are included. The sample is therefore smaller than that used in Chapter 3, which included cases where the three crops were second crops especially within tree crops like avocado and pears. In order to effectively compare the impact of price changes on the households' allocation of land to the various crops, with the impact on input and output quantities, it is important to have exactly the same sample. The profit function of Chapter 3 is therefore repeated with the exact sample used in the crop area regressions. In Vihiga the same sample as the one used in Chapter 3 is also used on the crop area estimation because maize was always a first (main) crop. From the SUR/OLS results of both regressions, simulations are carried out on prices, on farm size, and on manure. The results and discussion of the land area regressions are reported in Appendix 4.1. Results of the re-estimated profit function on output supply and fertiliser demand are not reported here because they are similar to those of Chapter 3. However, simulation results are presented and discussed in comparison with the simulations from the crop area equations. These results are reported in Table 4.3 below.

Table 4.3: Impact of 10% increase in prices and fixed factors on crop area and on input/output quantities in Kiambu and Vihiga districts (in %)

	Fertiliser price	Maize price	Potato price	Kale price	Wage rate[4.1]	Farm size	Manure
Kiambu							
Fertiliser quantity	-17.6	7.86	3.73	2.88	3.36	3.68	-0.32
Maize output	-1.66	2.09	-4.25	5.23	-0.38	2.44	1.25
Maize area	-5.05	0.14	-1.29	2.09	4.88	3.67	0.16
Potatoes output	-0.46	-2.46		2.64	1.12	4.86	0.38
Potato area	-4.58	-2.61	0.15	1.25	6.24	4.69	-0.25
Kale Output	-0.17	1.32	1.16	5.24	-7.55	2.92	0.53
Kale area	-8.99	2.86	0.81	6.06	-0.74	1.55	-0.72
Vihiga							
Fertiliser quantity	-18.8	15.8			3.01	7.35	0.78
Maize output	-1.71	11.6			-9.91	3.35	0.96
Maize area	-0.96	5.93			-4.97	4.17	0.64

a) Impact of fertiliser price

The impact of fertiliser price on fertiliser demand of -17.6% (Table 4.3) is less than the -24.4% of Table 4.1 because Table 4.1 is based on all households who grow the three crops, whereas Table 4.3 is based on only those who grow the three crops as the main crop. Those who grow these crops as a second crop are likely to be those with opportunistic behaviour, and are therefore more responsive to prices. On the contrary, those who grow the three crops as a main crop are more decided on growing the crop and hence less responsive to price.

The households respond to an increase in the price of fertiliser not only by reducing the rate of fertiliser application, but also by reducing the area allocated to each of the crops. The reduction in the rate of application is shown by the fact that, for all the three crops, the percent reduction in area is less than the percent reduction in fertiliser. Logically, reduced rate of fertiliser application should cause the yield of these crops to decline. Strikingly, this does not happen, their yield actually increases as shown by the lower reduction in output compared to the reduction in crop area. One possible explanation is that when the price of fertiliser increases, less fertiliser is used, but labour is used more intensively. Intensive use

[4.1] There are two ways of deriving the elasticities for the wage rate, which was used as the numeraire, with respect to output and input equations. One is to use the formula given in Chapter 3 ($E_{jn} = -\sum_k E_{jk}$) where n is the numeraire. The other is the approach we used, which is to do the simulation by changing all relative prices simultaneously, and that represents a wage rate change in the opposite direction. Essentially the two approaches should give the same result. In Table 4.3 there is a slight difference in the coefficients for the Kiambu fertiliser, maize and potato equations, which is caused by the fact that all prices include kale price which is estimated for only part of the sample (not all the households estimated grow kale). The coefficients are exactly the same for the kale equation and for all the Vihiga equations.

of labour may take the form of better crop husbandry practices such as timely operations that lead to increased yields despite the reduced fertiliser application rate. The reduction in output is therefore more a result of reduction in crop area rather than a reduction in crop yield.

Another interesting result is that the change in fertiliser price causes area under kale to reduce by almost double the percentage by which potatoes and maize area reduces, but the output of kale reduces least of all – by 0.17% versus 0.46 for potatoes and 1.66 for maize. A reduction in the demand for fertiliser leads to a larger increase in the yield of kale than in maize or potato yield (notwithstanding the fact that total output actually declines). This is consistent with the previous results where kale is the least responsive to changes in fertiliser price, and also implies that the alternative input whose use increases as a result of fertiliser price increase is more productive in kale, than in potatoes or maize. Moreover, we observed in Table 4.2 that kale utilises fertiliser more efficiently and hence if the quantity of fertiliser should decline, a rational farmer will use it more on kale. These results therefore confirm that the households in Kiambu are rational. Besides, kale is a cash crop, and households tend to apply more fertiliser on the cash crop than on the food crop. The other implication of this result is that it is more beneficial for households to maintain a smaller area of kale and manage it intensively rather than to maintain a larger area.

For Vihiga, the increase in the price of fertiliser results in maize output decreasing by a higher percentage than does the area under maize, which implies that the yield of maize declines. The reduced output is therefore the result of both a reduction in crop area, and a reduction in yield, possibly due to the reduced use of fertiliser. This result also means that the productivity of the alternative input, whose use should increase when fertiliser use decreases, is not high enough to offset the effect of fertiliser reduction, as is the case in Kiambu. Fertiliser therefore has a bigger impact on maize production in Vihiga than does the alternative input.

b) Impact of output prices

An increase in the price of maize impacts on the production of potatoes such that both potato output and area decline by an almost similar percentage, showing that the yield of potatoes does not change. In the case of kale, however, although both area and output increase, yield actually declines, because area increases by a larger percentage than output. The increase in area does not seem to be accompanied by a sufficient increase in other inputs, hence the yield decline. Interestingly, the change in maize price does not have a big impact on maize area, but impacts positively on the demand for fertiliser. Most likely, the increased fertiliser is injected into maize production leading to the higher maize yields. In Vihiga, the increase in maize output is a result of both higher yields due to increased fertiliser application, and increased area under the crop.

The increase in the price of potatoes has only minor effects on kale and potato outputs and area, but has a bigger impact on maize. Both maize area and maize output decrease, but the output decreases more than the area meaning that the yield of maize reduces. An increase in the price of kale on the other hand, has substantial impact both on the output quantities and on crop area. The area and the output of maize and of potatoes increase, and in both crops the results imply that yield increases. This increase in yield implies there is increased use of inputs. However, the quantity of fertiliser increases by only a small percentage, showing that there is another input whose rate of use increases both in maize and in potato production.

c) Impact of the wage rate

A simultaneous decrease in all prices by 10% (equivalent to a 10% increase in the wage rate) has a big impact on both crop area and crop output. Surprisingly, it leads to an increase in maize and potato area, which seems inconsistent given that the amount of labour has declined. However, though the area under the two crops increases by almost 5 % for maize and over 6% for potatoes, the impact on their outputs is small. That of maize reduces by only 0.38% and that of potatoes increases by 1.12%. This means that their yields decrease substantially, implying that even though area increases, labour is used less intensively. The increase in the wage rate has only a marginal impact on kale area, but there is a substantial decline in kale output, implying a substantial decline in kale yield. This decrease in yield must be from less labour input because the quantity of fertiliser used increases. This result begins to unravel our earlier hypothesis that possibly another input is constraining kale production more than fertiliser is. The change in wage rate has a bigger impact on kale output than does the change in fertiliser price.

In Vihiga a simultaneous 10% decrease in all the prices causes the quantity of fertiliser applied to increase by 3.01%, the maize output to decline by 9.91% and the area under maize to decrease by 4.97 %. The decrease in output is greater than the decrease in crop area (almost double), which implies that the yield of maize declines. Since the fertiliser has increased, the decrease in output must be due to the decreased labour input.

d) Impact of fixed factors

When farm size increases, area allocated to each of the three crops in Kiambu increases. However, what is interesting to note is that the output of maize and potatoes increases by a smaller percentage than the increase in area. This implies that yield of these two crops actually declines, which by extension means that the rate of usage of other inputs decreases. For example the 10% increase in farm size resulted in only 3.68% increase in fertiliser, implying a decrease in the rate of fertiliser application. However, unlike maize and potatoes, the yield of kale increases as shown by the higher increase in output compared to area. Apparently when farm size increases, more area is allocated to maize and to potatoes but more fertiliser is allocated to kale leading to higher yields for kale, but lower yields for potatoes and maize. This is reasonable considering the results of Table 4.2, which show that kale has the highest fertiliser use intensity. A change in the quantity of manure leads to only marginal effects both on the area allocated to the three crops and on input and output quantities.

In summary, the results of this section clearly demonstrate the importance of considering not just the impact of changes on output, but also on crop area. For example, the results reveal that when farm size increases, households tend to allocate more land to crops that do not use fertiliser intensively, but instead allocate more fertiliser to those crops that use fertiliser more intensively. Without this disaggregation it will simply be assumed that increase in farm size leads to lower fertiliser application to all the crops.

Another important result that this section brings out is the impact of the price of fertiliser. Without analysis of its impact on crop area it could have been assumed that increase in fertiliser price leads to lower rates of fertiliser application, lower yields and lower output. However, it is clearly shown that, in fact, yield increases for all the three crops in Kiambu, but crop area and rate of fertiliser application decline. It further reveals that another input has greater impact on the output levels, particularly kale output, than fertiliser does, which also points to the fact that currently fertiliser is not the most limiting factor on crop outputs in Kiambu. Most likely this is labour because operations such as timely planting and weeding and other husbandry practices, all of which depend on availability of labour, play a major role on output levels. Indeed if these operations are not properly and timely carried out, crop yields will be less even if fertiliser was applied.

4.2.1.2 Crop output response to input application

Table 4.1 showed that of the three crops analysed in Kiambu, maize is most responsive to changes in the price of fertiliser and kale is the least responsive. It also showed that a 10% increase in the price of maize leads to 8.9% more maize produced, and only 1.6% more fertiliser used. On the other hand a 10% increase in the price of fertiliser leads to a 24% reduction in the quantity of fertiliser, and only 1.8% reduction in maize output. This clearly shows that another input in addition to fertiliser must be influencing the maize output as the price of fertiliser changes. The same can be said of the results for kale vis-à-vis maize, (remember our third hypothesis). To gain more insight into what is happening to input and output quantities when prices change, response of the three crops to fertiliser application and to other inputs is investigated in this section. A quadratic production function as specified in Fuss et al. (1978) is estimated for each of the three crops.

$$\boldsymbol{q_h} = \alpha_0 + \sum_{i=1}^{n} \alpha_i \boldsymbol{x}_i + \sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{ij} \boldsymbol{x}_i \boldsymbol{x}_j + d_1 + d_2$$

where, $\boldsymbol{q_h}$ is the output level of either maize or potatoes or kale in the case of Kiambu, $\boldsymbol{x}_i$ is a vector of the main inputs used in the production of these crops, which in this case include area under the crop, manure, fertiliser and labour. Because not all the households used fertiliser on the different crops a fertiliser use dummy (d_1), where one indicates fertiliser is used and zero otherwise, is included as an explanatory variable. It is intended to test whether the output was significantly different for households who used fertiliser and those who did not. Also some households inter-cropped maize, potatoes, or kale with other crops, which benefit from the inputs particularly fertiliser and manure, so an inter-crop dummy (d_2) is included where one indicates the crop is planted in a mixture with one or more other crops, and zero indicates it is a pure stand. The marginal effects of the inputs are calculated from the production function by taking the first derivative of $\boldsymbol{q_h}$ with respect to each of the inputs:

$$\frac{\partial q_h}{\partial x_i} = \alpha_i + \sum_{i=1}^{n} \alpha_{ij} x_j$$

The estimations are done using OLS, and normality requirements are adhered to.

a) Kiambu

Results of the quadratic production functions for Kiambu are shown in Table 4.4 below:

Table 4.4: Response of maize, potatoes and kale outputs to four inputs for Kiambu Sample households

	Maize		Potatoes		Kale	
Variable	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	153	155	592*	304	286	561
Area (ha)	901**	369	2753*	1616	-5408*	3082
Manure (manure)	5.46	10.6	2.60	27.6	51.6	41.3
Fertiliser (kg)	20.5***	6.66	34.9**	15.1	-5.47	34.5
Labour (md)	11.3	8.49	24.8*	12.9	105***	29.0
Area squared	-59.6	105	-808	2499	15449***	4243
Manure squared	-0.07	0.22	-1.84**	0.89	0.03	0.70
Fertiliser squared	-0.17**	0.06	0.09	0.16	1.82***	0.65
Labour squared	0.08	0.16	-0.41**	0.17	-0.86*	0.44
Area*manure	-5.25	13.1	-48.9	85.2	301**	133
Area*fertiliser	5.74	6.54	-48.8	40.1	-189**	95
Area*labour	0.59	12.5	35.6	34.8	32.9	79.3
Manure*fertiliser	0.22	0.18	0.36	0.51	-2.94**	1.11
Manure*labour	-0.07	0.24	1.57**	0.68	-1.61	1.13
Labour *fertiliser	-0.22	0.16	0.13	0.20	1.06	0.79
Fertiliser dummy (1=fertiliser is used)	-182	127	-390	259	-80.2	544
Inter-crop dummy (1 = inter-cropped)	-273***	80.4	-157	159	141	303
Adjusted R-squared	0.43		0.67		0.77	
n	222		188		99	

NB: * ** *** indicate the statistically significant levels of 10%, 5% and 1% respectively

The difference between the sample size in the production functions (Table 4.4) and the crop area equations (Table 4A.1) occurs because in the crop area regression the equations are run as a system, and a condition is imposed that a household should at least be growing both maize and potatoes. The parameter estimates for maize, potatoes and kale reported in Table 4.4 show that all the first terms except crop area and fertiliser in the kale equation are positive as expected. Furthermore, monotonicity conditions (positive marginal products) are satisfied at the means of all input allocations. The coefficient on the fertiliser quadratic term in kale and potato equations is positive implying that the marginal returns to fertiliser on these outputs are non-decreasing with increase in fertiliser.

The inter-crop dummy is not significant in the kale and in the potato equations, but it is significant in the maize equation. Maize yield is therefore significantly reduced because of being inter-cropped with other crops, but that of potatoes or kale is not significantly affected. Maize is more prone to inter-cropping than either potatoes or kale. From the data used in the production functions, kale was inter-cropped in 46% of the cases, potatoes in 52% of the cases and maize in 83% of the cases. In all cases these three crops were the main crop. Fertiliser use dummy is not significant in any of the equations. Only less than 9% of the households did not use fertiliser on kale and 16% did not use fertiliser on potatoes or on maize.

To further illustrate our findings in the previous sections on the relative scarcities of the different inputs, marginal physical products (MPP) for the four inputs are derived from the production functions, and the corresponding marginal value products (MVP) for fertiliser and for labour calculated and presented in Table 4.5 below. The marginal value products are calculated by multiplying the MPPs with the respective output prices in Kenya Shillings (ksh.).

Table 4.5: Marginal Physical and Value Products (MPP&MVP) for the inputs used in the production of maize, potatoes and kale in Kiambu, evaluated at the mean

Crop	Crop area (ha)	Manure (bags)	Fertiliser (kg)		Labour (md)	
	MPP (kg)	MPP (kg)	MPP (kg)	MVP (ksh.)	MPP (kg)	MVP (ksh.)
Maize	919	4.24	13.5	142	10.6	111
Potatoes	2017	6.68	32.3	179	27.9	155
Kale	970	24.7	22.2	158	53.6	381

NB: In 2001 the exchange rate was 1USD =78 ksh.

The marginal value products (MVP) for both fertiliser and labour in the different crops show a relationship to the input use intensities reported in Table 4.2. The MVP of labour is highest in kale, which also had the highest labour use intensity and both MVPs for fertiliser and labour are lowest in maize, which also had the lowest use intensities. However, the marginal value products for fertiliser in all three crops are far above the average fertiliser price of ksh. 28.8, showing that fertiliser is being used much below the profit maximising level. This could mean that the households' shadow price for fertiliser is higher than the market price, as the households may be considering aspects like waiting and credit constraints, which are not captured in the price. If the standard deviation in price of the outputs is considered, then the marginal value product for fertiliser in kale will range between ksh. 73.9 and 242, that of maize between ksh. 118 and 165, and that of potatoes between ksh. 156 and 202.

Whereas the MVPs for fertiliser show only small differences across the three crops, the same cannot be said in the case of labour. The MVP of labour in kale production is over three times that of maize and over two times that of potatoes. Again, considering the standard deviation in output prices, the marginal value product for labour in kale ranges from ksh. 178 to 584, in maize from ksh. 92.8 to 129, and in potatoes from ksh. 135 to 174. Given the current wage rate of ksh. 98.5, it is easy to see that labour is being utilised at an almost optimal level in maize, a little less than optimal in potatoes but at a far less than optimal level in kale. It may be recalled that the reason we estimated the production functions was in an attempt to unravel the result that though fertiliser price significantly influences kale output, it has a much smaller impact on the kale output than on the maize output. We hypothesised that another input, possibly labour, is limiting the production of kale more that fertiliser is. From Table 4.4, kale output is very sensitive to labour (the labour coefficient is significant at $P<0.001$). We further see that there is a positive interaction between fertiliser and labour, so that the marginal productivity of fertiliser is higher when more labour is used. In principle $\frac{p_k}{w_l}\frac{\partial q_k}{\partial l}$ should be 1 (the MVP of labour should equal the wage rate). If the use of fertiliser were to increase, the marginal productivity of labour $\left(\frac{\partial q_k}{\partial l}\right)$ would increase. In order to bring $\frac{\partial q_k}{\partial l}$ down and make the first order conditions hold, the labour input then needs to increase. But apparently there are imperfections in the labour market making labour a constraint as shown by a very high MVP. The smaller response of kale to the price of fertiliser compared to maize and potatoes (see Table 4.1) may therefore be due to the fact that labour is a constraint. Increased productivity of fertiliser requires that more labour is used, but the labour is not available.

Another interesting result is that the MVP for fertiliser in kale production is over five times the price of fertiliser, yet the price of fertiliser has very little impact on kale output. Because labour is a constraint, the impact of fertiliser on kale output cannot be seen through the elasticities, and without further analysis, it would seem that the households are just unresponsive.

Now that fertiliser is apparently used at a far less than optimal level, what then is the optimal fertiliser rate for these households, given their other resource levels? To answer this question, a range of marginal products is derived from the maize marginal product function for fertiliser by changing fertiliser levels while holding the other inputs constant. This range of marginal products and their corresponding marginal value products are presented in Table 4.6 below. Unfortunately, the same range is not derived for kale or potatoes because their production functions are not well behaved. As already mentioned the coefficient on the fertiliser quadratic term is positive, implying that the marginal effect of fertiliser on output will continue to increase with an increase in fertiliser.

Table 4.6: Range of MPP and MVP for fertiliser on maize production in Kiambu

Rate (kg/plot)	Rate (kg/ha)	MPP (plot)	MVP (plot)
10.0	32.258	15.850	171.184
12.93*	**41.710***	**14.875**	**160.649**
17.1**	**55.161****	**13.487**	**145.655**
20.0	64.516	12.521	135.229
30.0	96.774	9.192	99.273
40.0	129.032	5.863	63.317
49.6***	**160.000*****	**2.667**	**28.799**
50.0	161.290	2.533	27.361
57.6	185.806	0.003	0.034
60.0	193.548	-0.796	-8.595

NB: * the fertiliser level if price of fertiliser increases by 10%, ** the current fertiliser use level, and *** the optimal fertiliser level given the average fertiliser price and average maize output price. [4.2]

The relationship between the rate of fertiliser application per hectare and the marginal physical products and marginal value products is linear as depicted in Figure 4.1 below:

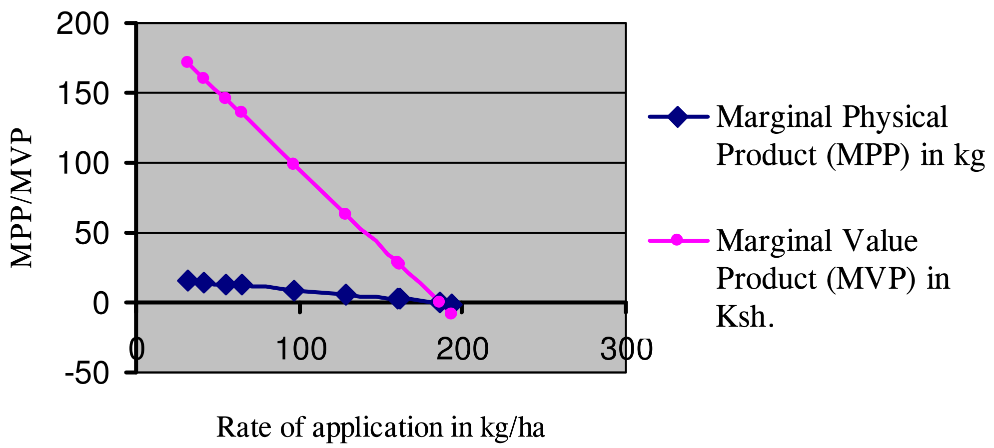

Figure 4.1: Rate of fertiliser application vs MPP/MVP in maize production for the Kiambu sample households

The current rate of fertiliser application from the data used in the production function is 17.1 kg/plot and the average plot size is 0.31 ha giving an application rate of about 55 kg/ha. At this rate of fertiliser application, the households are not operating at the profit

[4.2] The current (in reference year) price of maize is ksh. 10.8/kg and that of fertiliser is 28.8/kg maximising level, if the market price is assumed to be the true price[4.3]. At the current average fertiliser price of ksh. 28.8, the range of MVPs shows that the economic optimal rate of fertiliser application is 49.6 kg (approximately 50 kg per plot), because this is the rate where the MVP fertiliser is equal to the price of fertiliser. This translates to an application rate of 160 kg/hectare, which is comparable to the Ministry of Agriculture recommendation for fertiliser on maize in the area of 200 kg/ha. If the lowest maize output price (ksh. 5.56/kg) observed in the sample were to be used, then the optimal fertiliser level would be 135 kg/ha. The households' rate of fertiliser use ranged from zero to 275 kg per hectare, with less than 6% applying 160 kg/ha or more.

There are two possible reasons why households applied these low levels of fertiliser. First, the households' price of fertiliser is higher than the market price because of payment in advance, which adds credit costs and/or risk, and also households consider the cost of waiting and time spent going to buy fertiliser, which are not captured in the price. The second is that the households' price of maize is lower than the market price because much of the maize is not sold.

Summarising, the results for Kiambu shed some light on the possible reasons why kale is less responsive to fertiliser price compared to maize. First, there is a positive interaction between fertiliser and labour, so that the marginal productivity of fertiliser is higher when more labour is used. But we also found that labour is a constraining factor, particularly in the production of kale, as shown by the very high MVP. The smaller response of kale to the price of fertiliser may therefore be due to the labour constraint which makes the impact of fertiliser obscure. The second is that, kale uses fertiliser more efficiently than maize, and so when fertiliser price increases, fertiliser is diverted from maize to kale. By combining the results of the dual model and the primal model we are thus able to better explain the differences in responsiveness to changes in fertiliser price by the different crops. These results emphasise the importance of keenly comparing empirical results with theoretical expectations, and doing further analysis in cases where the observed results are not consistent with theoretical expectations, before drawing conclusions.

[4.3] The market price in this case is the farm gate price, which includes transport costs, but does not include other costs such as waiting or time spent on purchasing the fertiliser.

b) Vihiga

Results of the maize production function for Vihiga are shown in Table 4.7 below.

Table 4.7: Response of maize output to four inputs for the Vihiga sample households

	Coefficient	Standard error
C	128	78.7
Maize area (ha)	364*	207
Manure (bag)	9.69*	5.07
Fertiliser (kg)	6.63***	2.22
Labour (md)	1.23	1.99
Area squared	-29.2	141
Manure squared	-0.13***	0.04
Fertiliser squared	-0.03***	0.01
Labour squared	-0.0003	0.01
Manure*area	15.9**	6.33
Fertiliser*area	1.33	2.12
Labour*area	0.43	2.30
Fertiliser*manure	-0.03	0.03
Labour*manure	-0.08	0.08
Fertiliser*labour	0.03	0.03
Fertiliser use dummy (1=fertiliser is used)	16.5	62.2
Adjusted R-squared	0.72	
N	168	

Results of the Vihiga maize production function are similar to the Kiambu maize production function in that both the first term and the squared term of fertiliser are highly significant, and the squared term is negative implying the presence of diminishing marginal returns. The coefficients on all the first terms are positive as expected, and similarly the coefficients on all the squared terms are negative as expected. The coefficients on the interaction terms also have the expected signs. Unlike Kiambu, the coefficient on labour is not significant, implying that maize production in Vihiga is less sensitive to the labour input than maize production in Kiambu.

The marginal products for the four inputs are again calculated at their mean values by taking the first derivatives with respect to each of the inputs. The outcomes are presented in Table 4.8 below alongside their corresponding marginal value products.

Table 4.8: Marginal Physical Products (MPP) for the inputs

Crop	**Crop area (ha)**	**Manure (bags)**	**Fertiliser (kg)**		**Labour (md)**	
	MPP	MPP	MPP	MVP	MPP	MVP
Maize	521	12.1	7.05	78.9	1.44	16.1

As in Kiambu, the marginal value product for fertiliser is much higher than the price of fertiliser showing that fertiliser is being applied far below the profit maximising level, or that the households' shadow price for fertiliser is much higher than the market price. More interestingly, for Vihiga the MVP for labour is much lower than the current wage rate of ksh. 50.5, showing that the labour input is being applied much above the economic optimum level. Apparently the households' shadow price for labour is far below the market wage. Using the market wage rate, this result implies that some labour should be withdrawn from maize production, and the level of fertiliser increased. Moreover, this finding is not unique to this study, Waithaka et al. (2003) made the same observation on the need to withdraw excess labour from farming, by creating off-farm opportunities. This also confirms our earlier result that for Vihiga, fertiliser is the most limiting input, not labour as is the case in Kiambu.

A range of marginal products and the corresponding marginal value products for fertiliser derived from the maize marginal product function are presented in Table 4.9 below.

Table 4.9: Range of fertiliser levels and the corresponding Marginal Physical and Value Products for maize production in Vihiga

Rate (kg/plot)	Rate (kg/ha)	MPP (plot)	MVP (plot)
10	17.544	7.896	88.436
19.3*	**33.860***	**7.325**	**82.040**
20	35.088	7.282	81.559
23.8**	**41.754****	**7.049**	**78.946**
40	70.175	6.054	67.805
60	105.263	4.826	54.050
80	140.351	3.598	40.296
90	157.895	2.984	33.418
94***	**164.912*****	**2.738**	**30.667**
100	175.439	2.370	26.541
110	192.982	1.756	19.664
120	210.526	1.142	12.787
138.5	242.982	0.006	0.064

NB: * the fertiliser level if price of fertiliser increases by 10%, ** the current fertiliser use level, and *** the optimal fertiliser level given the average fertiliser price and average maize output price. [4.4]

As for Kiambu the relationship between rate of fertiliser application per hectare and the marginal physical products and marginal value products is linear as shown in Table 4.9 and Figure 4.2.

[4.4] The current (in reference year) price of maize is ksh. 11.2/kg and that of fertiliser is ksh. 30.7/kg.

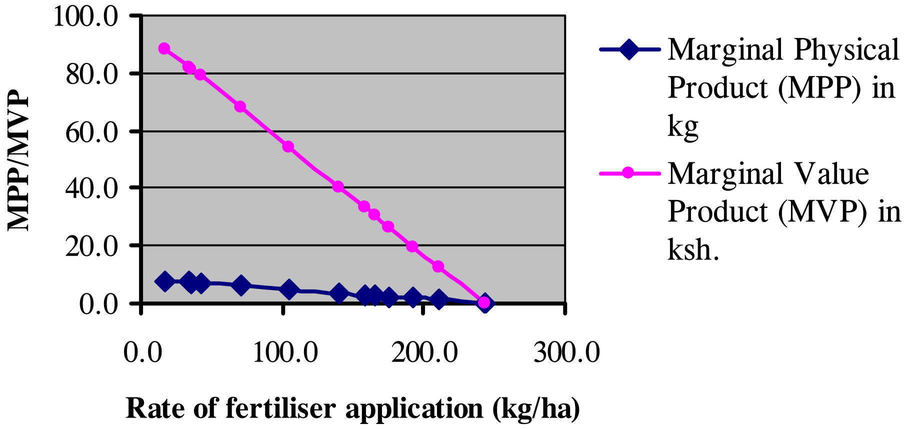

Figure 4.2: Rate of fertiliser application vs MPP/MVP for maize production in Vihiga district

The current fertiliser application rate is 23.8 kg/plot, which given the average plot size of 0.57 ha gives a per hectare application rate of 41.8 kg. Given the current average fertiliser price of ksh. 30.7, the range of MVPs shows that the economic optimal rate of fertiliser application is 94 kg per 0.57 ha. This amounts to an application rate of 165 kg/ha. The research recommendation for fertiliser on maize in Vihiga is 130 kg/ha of Diammonium Phosphate (DAP) fertiliser plus 140 kg/ha CAN fertiliser. The rate of 165 kg/ha is thus higher than the DAP recommendation for provision of phosphorus in terms of P_2O_5, but is below the recommendation in terms of provision of nitrogen. If the lowest maize output price (ksh. 8.89/kg) observed in the sample were to be used, then the optimal fertiliser level would be 144 kg/ha. The households' rate of fertiliser use ranged from zero to 200 kg per hectare, with less than 6% applying 130 kg/ha or more and only one household applying more than 165 kg/ha. The maize output price that justifies the current fertiliser use level to be optimal (possibly the households' shadow price for maize) is ksh. 3.90 per kg (ksh. 350 per 90 kg bag), much higher than that of Kiambu.

Comparing Vihiga and Kiambu, labour is a constraint to the production of all crops in Kiambu, especially kale, while labour is in abundance in Vihiga. Farm profits in Vihiga will increase if paid labour input is reduced, but in Kiambu farm profits will increase if labour input is increased. Vihiga needs some off-farm opportunities to absorb excess labour force. In both districts increased use of fertiliser will raise farm profits.

4.2.2 Impact of a change in manure on fertiliser demand and output supply

The results on the impact of manure and of farm size are shown in Table 4.1. Manure is one of the sources of soil nutrients and it can be expected that in low-income countries like Kenya it may play a substitution role to fertiliser. However, the simulation results show that the quantity of manure applied has little impact on the quantity of fertiliser demanded both in Kiambu and in Vihiga. It has a higher but still low impact on the outputs, particularly maize output. This may be because the amount of manure being currently applied is too low to have an impact. For example, in order to improve yield of a maize bean inter-crop, it is recommended that manure be applied at a rate of 10 tonnes/ha (KARI). The sample households, however, applied only 49 bags/ha (3.6 tonnes/ha) in maize, 48 bags/ha (3.5 tonnes/ha) in potatoes and 54 bags/ha (3.9 tonnes/ha) per hectare in kale. In Vihiga manure is applied at a rate of 1.48 tonnes/ha. Secondly, as presented in Chapter 3, the quality of manure used in both districts is low. Efforts that encourage households to improve the quality of manure may lead to manure having a greater impact. Also the general recommendation is to apply both inorganic fertiliser and manure and not either one or the other (KARI) and our results support that.

4.3 Impact of input and output price changes on restricted household profit

To investigate the impact of price changes on farm profit, results from the dual estimation of output supply and input demand equations in Chapter 3 are fitted in the primal model and used to calculate restricted profit from the three crops included in the model. This is done by multiplying the estimated output level of each crop by its price and subtracting the product of the estimated input quantities (fertiliser) and its price. Simulations of price and fixed factors done on the input demand and output supply are used to examine the impact of changes in these prices and fixed factors on profit, calculated at their mean values.

From Chapter 3 the definition of restricted profit (π) is the gross revenues less the variable costs, i.e.

$$\pi = \sum_{h=1}^{n} \boldsymbol{p}_h \boldsymbol{q}_h - \sum_{i=1}^{k} \boldsymbol{w}_i \boldsymbol{x}_i \text{ which in our case is } = \sum_{h=1}^{3} \boldsymbol{p}_h \boldsymbol{q}_h - \sum_{i=1}^{2} \boldsymbol{w}_i \boldsymbol{x}_i ,$$

where $\boldsymbol{p}$ is a vector of n output prices and $\boldsymbol{q}$ a vector of n output quantities, $\boldsymbol{w}$ a vector of k input prices and $\boldsymbol{x}$ a vector of $\boldsymbol{k}$ input quantities. The estimations in Chapter 3 were done using a normalised profit function, where the profit and the prices were divided by the wage rate:

$$n\pi = \frac{\pi}{w_l} = \sum_{h=1}^{n} \frac{p_h}{w_l} q_h - \sum_{i=1}^{k} \frac{w_i}{w_l} x_i$$ which in the case of the Kiambu sample is:

$$= \sum_{h=1}^{3} \frac{p_h}{w_l} q_h - \frac{w_f}{w_l} x_f - x_l$$

where $n\pi$ is normalised profit, w_l is the wage rate and x_l is the amount of labour. x_l is left out in the simulations, which are done on the relative input and relative output prices, but the profit calculation is done on the actual estimations of input demand and output supply quantities. From economic theory, if all the prices change by a certain factor λ, then profit should necessarily change by the same factor λ (see Varian, 1992). However, in our case a change in all included relative prices is equivalent to a change in the wage rate in the opposite direction. It should therefore be interpreted as the impact of a change in wage rate on profit. The results of the simulations are reported in Table 4.10 below. As before they show the impact of an increase in a particular price or fixed factor when all others are held constant. For the wage rate all prices are simultaneously decreased by 10%.

Table 4.10: Percentage change in restricted farm profit as a result of 10% increase in prices and in fixed factors

Item	Kiambu	Vihiga
Fertiliser price	-0.03	-0.63
Maize price	1.49	23.6
Potato price	2.45	
Kale price	9.70	
Wage rate	-11.1	-20.3
Farm size	3.97	2.87
Manure	0.09	0.98

In Kiambu, a change in the price of kale has the greatest impact on the farm profit among the outputs, with a 10% increase in kale price causing an almost equal percentage increase in profit. In contrast, a change in maize price has the least impact on profit among the outputs, which is no longer surprising because, from Chapter 3, kale makes the highest contribution to household income, and maize makes the least contribution among the three crops analysed. The least impact on profit, however, is caused by change in the price of fertiliser. Given our discussion in the preceding sections, this is again not surprising. It has been shown that labour is more constraining, particularly in the case of kale production, than fertiliser and kale makes the highest contribution to profit, hence the lower impact of fertiliser price on profit. Also, labour takes a much larger share of the cost compared to fertiliser. To confirm this, the results show that the wage rate actually has the highest overall impact on profit, stressing the importance of labour in the Kiambu cropping practices.

In Vihiga the highest impact on profit is when maize price increases and the price of fertiliser remains constant, which is expected. It causes an impact much larger than that observed for maize price in Kiambu because maize is the only main crop in Vihiga. The second highest impact is when the wage rate changes. Increase in fertiliser price alone still has a minimal impact on profit in Vihiga, though higher than that of Kiambu, again because fertiliser has a much smaller share of the cost compared to labour.

A change in farm size has a larger impact on profit in Kiambu than in Vihiga, implying that the change leads to a relatively higher productivity of land in Kiambu than in Vihiga. This is mainly because the output of kale and of potatoes, which make a higher contribution to profit than maize, increase more than that of maize, as a result (see Table 4.3). This increase in farm size is apparently at the cost of off-farm work because it means that extra labour is required. Manure has a bigger impact in Vihiga than in Kiambu, possibly because of the lower fertiliser rates in Vihiga.

4.4 Impacts disaggregated by farm types

In Chapter 2 the sample households both in Vihiga and in Kiambu were classified into three farm types each. In this section we use results of the simulations on prices and fixed factors to compare response to these changes by households in the different farm types. In order to know if there are any significant differences in response across the farm types, the elasticities are calculated at individual household level, not at the mean values as in the previous sections. Differences in response between the three farm types are then compared using a *t-statistic*, where the mean of the elasticities in one farm type are compared with the combined mean of the other two farm types. The results are discussed below.

4.4.1 Kiambu

Table 4.11 presents results of the price and fixed factor simulations and *t-statistic* test for the Kiambu sample disaggregated by farm type.

Table 4.11: Percentage change in input and output quantities due to a 10% change in prices and fixed factors for the Kiambu sample households disaggregated by farm type

	Fertiliser price	Maize price	Potato price	Kale price	Manure	Farm size	Wage rate
Fertiliser							
Whole sample (individual prediction)	**-31.7**	**11.4**	**6.89**	**3.05**	**-0.04**	**3.60**	**11.5**
Farm type one	-27.1	9.83	5.83	2.78	-0.03*	3.73	9.65
Farm type two	-29.8	11.4	6.72	2.68	-0.04	4.13	10.4
Farm type three	-37.5*	13.0	8.05*	3.53**	-0.03*	3.12*	14.1
Maize output							
Whole sample (individual prediction)	**-2.98**	**2.30**	**-10.6**	**5.81**	**1.25**	**3.75**	**5.89**
Farm type one	-1.83	1.43	-5.60	4.75*	0.33*	3.28	2.80
Farm type two	-1.69	1.58	-6.07	3.99***	1.23	3.23	3.95
Farm type three	-4.92*	3.63*	-18.5**	7.90***	2.18**	4.54	10.8*
Potato output							
Whole sample (individual prediction)	**-0.81**	**-4.68**		**3.60**	**0.18**	**4.75**	**3.18**
Farm type one	-0.46	-2.23		3.14**	0.06	4.63	0.56
Farm type two	-0.63	-3.92		2.81***	0.16	4.31	2.96
Farm type three	-1.27**	-7.57*		4.50***	0.30	5.14	5.90
Kale output							
Whole sample (individual prediction)	**-0.28**	**1.82**	**2.45**	**4.42**	**-0.82**	**3.73**	**-8.41**
Farm type one	-0.16	1.10	1.30	2.71*	-0.48	1.38	-4.95
Farm type two	-0.18	1.30	1.44	3.53	-0.42	3.18	-6.10
Farm type three	-0.44**	2.82*	4.15**	6.61**	-1.48*	6.39	-13.1**

*, **, *** identifies the variables that are significantly different at the 10%, 5% and 1% levels respectively when the mean of one farm type is compared with the mean of the other two combined.

From Chapter 2, the three farm types in Kiambu can briefly be described as follows. Farm type one consists of 117 households that are characterised by significantly more adult members, with household heads who are much older than those of farm type three but younger than those of farm type two. They are relatively well educated and have relatively higher off-farm income.

Farm type two has 63 households and is characterised by significantly larger average farm sizes of 1.15 hectares. They have the oldest household heads, who are the least educated among the three farm types, with an average of only 1.07 years in school. Over 50% of them are female headed.

Farm type three has 116 households and is characterised by having the fewest adult members and significantly smaller farms, the average being 0.63 ha. They have significantly younger household heads, who are relatively well educated, and have significantly fewer cattle.

Not all households respond by the same magnitude to changes in prices and in fixed factors. In most cases response by farm type one and farm type two is not significantly different, but response by farm type three is significantly different from the others. For example, response to changes in fertiliser price is significantly higher by farm type three households both in input demand and output supply. Similarly, farm type three has significantly higher response to changes in the price of maize, the price of potatoes and the price of kale in all quantities (outputs and input). Farm type three is composed of young and educated household heads who tend to be more innovative and responsive to prices. The opposite is true for farm type two; they are old, not educated and less responsive to prices. More educated household heads probably have more exposure to and a better understanding of the economics of inputs and outputs.

Additionally, farm type three has significantly smaller farms, which implies that households with smaller farms are more sensitive to prices. Furthermore, from Chapter 3, farm type three produces significantly more kale than farm types one and two. Because kale is mainly grown as a cash crop these households must be commercially oriented in their farming and a higher response to prices should be expected. Farm type three also has significantly higher maize output response to changes in manure quantity.

Farm type one and farm type two respond differently only in the case of the impact of kale price on the three outputs, and the impact of changes in manure quantity on maize output. In those cases, farm type two has significantly lower response to kale price in all three outputs, whereas farm type one has a lower response to manure. Response to changes in farm size is similar across all the three farm types.

Apparently there are two distinct groups of households in the Kiambu sample in relation to responsiveness to input and output price changes. One group consists of the old and uneducated who have relatively bigger farms and who are less responsive to price changes. This group combines farm type one and farm type two. The other group consists of the young and educated household heads who own relatively smaller farms and are quite responsive to input and output prices in their input demand and output supply.

4.4.2 Vihiga

Results of the price and fixed factor simulations and *t-statistic* test for the Vihiga sample disaggregated by farm type are presented in Table 4.12 below.

Table 4.12: Percentage change in fertiliser and maize quantities due to a 10% change in price and fixed factors for the Vihiga sample households disaggregated by farm type

	Fertiliser price	Maize price	Manure	Farm size	Wage rate
Fertiliser demand					
Whole sample – individual prediction	**-21.0**	**18.0**	**0.67**	**7.21**	**3.01**
Farm type one	-20.0	17.8	0.74	7.72	2.26
Farm type two	-24.7	20.1	0.83	6.29	4.57
Farm type three	-17.0	15.1	0.31	8.23**	1.90
Maize output					
Whole sample – individual prediction	**-3.01**	**18.8**	**0.99**	**3.92**	**-15.8**
Farm type one	-2.67	17.1	0.90	4.36	-14.5
Farm type two	-2.11*	14.3*	0.81	3.56	-12.2*
Farm type three	-5.01***	28.8***	1.44**	3.75	-23.8***

*, **, ***, identifies the elasticities that are significantly different at the 10%, 5% and 1% levels respectively when the mean of one farm type is compared with the mean of the other two combined.

In Vihiga, farm type one households have medium education, have relatively large household size and are located closest to the nearest market. Farm type two households have relatively old household heads, are poorly educated and are located farthest from the market. Farm type three households have relatively small farm sizes, relatively young household heads who are better educated and have the smallest household size.

Results of the simulation on price and fixed factors for Vihiga by farm type (Table 4.12) are similar to the Kiambu results in many ways. As in Kiambu, response by households in farm types one and two is similar both in terms of fertiliser demand and maize output supply. Households in farm type three however, respond significantly differently from the other two. They have significantly higher fertiliser price, maize price, and wage rate (all at $p<0.01$) elasticities in relation to maize output, similar to farm type three in Kiambu.

Incidentally, farm type three in Vihiga has more or less the same characteristics as farm type three in Kiambu - both have younger household heads, are better educated and have smaller farm sizes. The fact that both are significantly more responsive to price changes is an indication that age, education level and farm size play a role in households' responsiveness to prices. Farm type three also has significantly higher maize output response to changes in manure quantity and significantly higher fertiliser demand response to changes in farm size. These results imply that in terms of response to prices and fixed factors, the Vihiga sample, like the Kiambu one, can be effectively grouped into two farm types instead of three. Farm types one and two are more or less the same in their response, whereas farm type three behaves differently.

The results both for Kiambu and for Vihiga mean that in terms of encouraging households to increase their level of fertiliser use, there is a need to target two groups of households. The two target groups may require different approaches. For the households represented by farm type three in Vihiga and in Kiambu, price modifications will be effective in stimulating them to increase their use of fertiliser and consequently their output levels. The households represented by a combination of the other two farm types both in Vihiga and in Kiambu may require more extension advice and adult education in addition to price incentives. It is notable for example from Chapter 2 that, farm type two households in Kiambu achieved significantly lower productivity and farm type three significantly higher productivity even though fertiliser rates per hectare were not significantly different across the farm types.

4.5 Discussion, conclusions and implications

A key concern of farm households and policymakers in Kenya is to increase yields of agricultural produce. Increasing crop yield requires increased input use, particularly of soil nutrient technologies. Prices and availability of agricultural input and output markets are key elements that households consider regarding which crops to grow and the quantity of the different inputs to apply. Consequently output and input prices are powerful instruments recommended as incentives for stimulating households to increase use of purchased inputs (e.g. Reardon et al., 1997a; Kuyvenhoven et al., 1998).

In this chapter, the impact of soil nutrient technologies and input/output prices on fertiliser demand, crop output supply and profit were examined for the two districts, Kiambu and Vihiga. The price of fertiliser has a big impact on the quantity of fertiliser used both in Kiambu and in Vihiga. Output prices also have an impact on the quantity of fertiliser used, with maize price having the biggest impact.

When considering only elasticities, the price of fertiliser does not seem to have a big impact on the output quantities, particularly of kale. However, further investigations show that the marginal productivity of fertiliser is higher when more labour is used. But labour is constraining, particularly in the production of kale, as shown by the very high MVP. The smaller response of kale to the price of fertiliser may therefore be due to the shortage of labour which makes the impact of fertiliser obscure. Secondly, kale uses fertiliser more efficiently than maize, and so when fertiliser price increases, though less fertiliser is purchased, households being rational divert it from maize to kale. Fertiliser is otherwise important in kale production as shown by its marginal value product. It has been noted that output price modifications can be effective provided labour availability is not a bottleneck (Kuyvenhoven et al., 1999). This means that applying output price policy when labour is a bottleneck will render that policy ineffective. At the current resource use levels, increasing the level of labour input will create a big impact on kale output.

By combining the results of the dual model and the primal model we are thus able to better explain the differences in responsiveness to changes in fertiliser price by the different crops and give more concrete results. Clearly, complexities within the households, such as the different input scarcities that affect each other, were not being captured in the elasticity from the profit function. The results therefore stress the importance of keenly comparing empirical results with theoretical expectations and, in the case of inconsistencies, carrying out further investigations to ensure that the correct conclusions are drawn.

On the whole, our results show that households can still raise their farm profits by increasing the level of fertiliser at the present fertiliser and output prices. The plausibility of this result is supported by the fact that it is not just unique to the current study. Karanja et al. (1999) found that the mean value to cost ratio for DAP fertiliser on maize was 5.86, i.e. for every ksh. spent on the fertiliser, the farmer gets back ksh. 5.86, in the value of maize output. However, the household shadow price for fertiliser is higher than the market price because of other considerations such as liquidity constraints and risk. What may be needed more therefore is to deal with initial liquidity constraints for purchase of inputs.

It is important to examine the impact of price changes, not only on output quantities, but in combination with the impact on area allocated to the crops. Results of this chapter show that households did not just respond to an increase in fertiliser price by reducing the rate of fertiliser application and hence obtaining lower crop yields, as is often assumed. They responded by either reducing the area under each of the crops, or by reducing the rate of fertiliser application per unit area or both. In some cases the crop yield actually increased as area under the crop declined. Further investigations are required to find out what happens to the crop area that is put out of production, when the response is reduction in crop area. One possibility is that it is left fallow, which has important implications in terms of nutrient management.

At the current input level (fertiliser and labour) households in Kiambu will raise their farm profits by investing more labour in the production of kale and less in the production of maize and of potatoes. Kale has both the highest labour use intensity and the highest response to labour. For fertiliser, kale has the highest use intensity but potatoes have the highest response (marginal productivity). Fertiliser should thus be invested both in kale and potato production more than in maize. It is not by chance that the price of kale has the highest impact on the profit level. However, marketing of kale needs to be looked into especially in terms of infrastructure and transport facilities, to ensure that the increased production finds a ready market.

Unlike Kiambu, the Vihiga households need fertiliser to increase farm profits and not additional labour. The marginal value product of labour in maize production shows that withdrawing paid labour will actually raise profits. Vihiga district thus needs off-farm opportunities to absorb the excess labour force.

In terms of encouraging households to increase their level of fertiliser use and crop outputs, it is necessary to target two distinct groups of farm households in both regions. One group consists of the elderly and uneducated household heads, who have relatively large farms and are less responsive to price changes. This group may require more extension advice and adult education in addition to price incentives. The other group consists of the young and educated household heads, who own relatively small farms and are quite responsive to input and output prices. For this group price incentives will be effective in stimulating them to increase their use of fertiliser and consequently their output levels.

Further research is required to find out whether the labour constraint in crop production in Kiambu is due to lack of liquidity to hire in labour, or whether no labour is available for hiring. The latter may mean that farm work is not competitive enough compared to other available options.

Appendix 4.1: Factors influencing area allocation to the different crops

Table 4A.1: Regression results on factors influencing crop area under maize, potatoes and kale in Kiambu

	Maize (n=166)		**Potatoes** (n=166)		**Kale** (n=91)	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Constant	0.2033*	0.1121	0.2809***	0.1025	0.3419**	0.1354
Level of education	0.0039	0.0041	0.0045	0.0037	-0.0057	0.0049
Age of household head	0.0011	0.0012	0.0003	0.0011	-0.0021	0.0015
Gender of household head (1= female)	0.1069**	0.0424	0.1016***	0.0377	0.0551	0.0507
Farm size	0.1232***	0.0219	0.1464***	0.0195	0.0516**	0.0237
Access to extension (1=yes)	-0.0113	0.0330	-0.0912***	0.0295	-0.0251	0.0414
Access to credit (1=yes)	-0.0093	0.0421	-0.0171	0.0376	-0.0656	0.0507
Fertiliser price	-0.5188	0.4554	-0.4063	0.4329	-0.8983**	0.4325
Maize price	0.1179	0.9184	-0.6257	0.7853	0.3419*	0.1354
Kale price	0.3419*	0.1354	0.4240	0.3892	2.2015***	0.4758
Potato price	-0.6257	0.7853	0.0441	1.7883	0.4240	0.3892
Manure quantity	0.0001	0.0003	-0.0002	0.0003	-0.0005	0.0006
Total TLU (cattle)	-0.0069	0.0184	-0.0009	0.0164	0.0243	0.0229
Area under tea	0.0829	0.1069	-0.1529	0.0956	-0.3453	0.5415
Area under coffee	-0.2225	0.2767	-0.0450	0.2475	-0.0997	0.5023
IMR-kale	-0.0348	0.0272	-0.0428*	0.0247	0.0974	0.0863
Adjusted R-squared	0.19		0.25		0.13	

From Table 4A.1 area allocated to each of the three crops is influenced positively by size of the farm. This is logical; if more land is available, more can be allocated to the various crops. Female household heads tend to allocate more area to maize and to potatoes than do their male counterparts possibly because maize and potatoes are a food staple in the area and females are usually concerned with household food supply more than the males. It is not clear why access to extension service has a negative influence on the area allocated to potatoes, but a possible explanation is that households that have access to extension services achieve higher productivity, so that more potatoes are produced on a smaller area. The coefficient on the extension services in the potato output equation of Chapter 3 was also negative but not significant. The price of fertiliser has a negative influence on area under all the crops, but is significant only in the kale equation. The households possibly will rather reduce area under kale than reduce the rate of fertiliser application. Maize price positively influences the area allocated to kale and consequently kale price positively influences the area allocated to maize. The two are complements, a confirmation of the observation made in the quantity equations. The IMR kale is significant ($P<0.1$) only in the potato area equations.

Table 4A.2: Regression results on factors influencing crop area allocated to maize in Vihiga

Variable	Coefficient	Standard error
Constant	-0.348	0.492
Education of household head	0.017	0.012
Age of household head	0.005	0.004
Gender of household head	0.057	0.096
Farm size	0.352***	0.081
Access to extension advice	0.097	0.083
Access to credit	-0.205**	0.100
Fertiliser price	-0.096	0.607
Maize output price	1.667	1.203
Manure quantity	0.003**	0.001
Total TLU (cattle)	0.061	0.054
Area under tea	-0.794***	0.295
IMR fertiliser	-0.293	0.204
Adjusted R-squared	0.37	
N	121	

*, **, *** indicate 10%, 5% and 1% significant levels.

Results of the crop area regression for the Vihiga sample shown in Table 4A.2 indicate that farm size and the quantity of manure used have a positive impact on the area under maize, which is expected. Meanwhile a large area under tea means that there is less land available for maize. As observed in Chapter 3 the result on credit may be due to the fact that the question on credit was not specific to agriculture, but included any form of credit. It is possible that households took credit for non-agricultural activities. Simulation results from both the land area equation and the equivalent output quantity equation are shown in Table 4.3.

CHAPTER 5.

ACTIVITY/TECHNOLOGY COMBINATIONS FOR LIQUIDITY CONSTRAINED HOUSEHOLDS

5.1 Introduction and objectives

In Vihiga district, which is located within the high potential areas of Kenya, maize is the sole most important crop. The households rely on maize as the food staple, and even though Vihiga is a maize deficit district, sometimes they still sell some maize at harvest time to meet immediate cash needs, and buy later (mostly at higher prices). Surveys carried out in the district (KARI, 1994) constantly report that maize yields are much lower than the expected yields based on research recommendations. For example, the data used in this study reveal that the current annual maize yield is less than 27% of the potential yield. This is because households do not follow the recommended agronomic practices, particularly the use of soil nutrient replenishing technologies and improved seed. One major reason given for not using these recommendations is lack of cash for purchasing the inputs (Salasya et al., 1998). RoK (1996) mentions inadequate input application and inaccessibility of credit for smallholder farmers as major constraints to increased agricultural production. Liquidity constraints have also been found to hinder or lower agricultural production in many other developing countries (e.g. Freeman et al., 1998; Imai, 2003; Dercon, 1998). However, none of these studies has quantified the magnitude of the liquidity problem and its impact on activity/technology combinations and on farm household objectives. The objective of this chapter is therefore to investigate how much a liquidity constraint matters to households in Vihiga in terms of determining their optimal activity/technology choices and its impact on household objectives. A non-separable household model linking demand for and supply of labour by the households is used for the analysis.

The rest of the chapter is structured as follows: section 5.2 describes the modelling framework including the empirical model, the production technologies, and resources available to the different household types. In section 5.3 the calibration and parameterisation of the utility model is described and section 5.4 discusses the results. Discussion and conclusions are given in section 5.5.

5.2 The modelling framework

For the investigations we specify a mathematical programming model that allows for simulations and analysis of various activity/technology combinations. Programming models are suitable for this because they allow for discrete choices among technologies and land use as opposed to econometric models, which are more suited for continuous choices (Antle and Cabalbo, 2001; Mills, 1984). There are five activity/technologies specified from which a household can choose. Considering that low soil nutrient levels are a major cause of low yields and that maize is the sole most important crop in Vihiga, four of the activities define different soil nutrient management practices in a maize/bean inter-crop. They include the recommended practice, the current farmer practice of low-level external input use, the improved fallow technology, and the use of manure under the current farmer practice. The fifth activity/technology is production of a cash crop, tea, under the current farmer practice.

The different practices require different levels of cash and of labour for a given land size. For example, the recommended practice requires relatively more cash and labour than the current practices and the improved fallow, but normally achieves higher yields. The improved fallow requires the least amount of cash and the least amount of labour for a given size of land, but has the lowest yields. The current farmer practice requires more cash and labour compared to the improved fallow, but also achieves higher yields than the improved fallow. The manure technology is similar to the current farmer practice, except that no fertiliser is used and yields are lower. Production of tea, a cash crop, is based on farmers' practice, but is similar to the KTDA recommended practice. From the survey data, households mainly financed the purchase of production inputs from exogenous remittances and/or by hiring their labour out. Whether from remittances or from labour revenue, the cash has the dual purpose of meeting consumption needs and/or purchase of inputs.

Production decisions and technical choices households make are behavioural responses to particular constraints that lead to given factor/input use intensities and specialisations. To take care of the heterogeneity among households in their resource constraints, we model three types of households as defined in Chapter 2. There may still be differences in resource constraints even within a particular farm type. Consequently, rather than providing one optimal activity/technology combination for each farm type, as is usually done, we provide a basket of alternatives for households facing specific resource constraints. The model assumes a time horizon of a single calendar year, which consists of two cropping seasons. Limited access to long-term credit markets has been shown to result in myopic behaviour of asset-poor households (Deaton, 1989). When a household chooses a particular activity/technology, it has implications for sustainability in terms of soil nutrients. This chapter builds on earlier studies (e.g. De Janvry et al., 1991; De Janvry et al., 1992; Omamo, 1998) by using farm household modelling techniques to analyse the impact of liquidity and other constraints on the household activity/technology choices. A statistically representative sample is used to parameterise and calibrate the model.

Whereas many experiments can be run with the model, four capture the impact of liquidity and other resource constraints on activity/technology choices and on household incomes. We start by identifying the liquidity level required for the households to choose the best activity/technology given farm size and labour levels. We do this by varying the liquidity level while holding land and labour at their current levels until the most profitable activity/technology is the only one in the optimal solution. This is important in terms of informing policymakers and development agencies (if credit facilities were to be available about the level of credit required by different households and what impacts should be expected. We then identify the optimal activity/technology choice for these households given the current liquidity level, and compare the results with the current (actual) resource allocation. This is important for extension agencies who advise farmers and for the farm households.

The next experiment investigates the impact of a change in farm size on the activity/technology choice and on farm revenues. With continuous land sub-divisions due to the prevailing inheritance customs, farm size is becoming smaller and smaller. It is important to identify the effect this will have on the activity/technology choices and on households' survival, especially if they rely solely on the farm. We finally identify optimal activity/technology choice and the impact on farm revenues in a situation where labour is not available for hiring in. Other runs are similar to the second run, but with area under tea fixed for households who already have it, and with tea excluded for households who do not already have it. The investigations are done under three assumptions concerning opportunities for hiring out excess labour (no opportunities; can be hired out given a probability of getting hired; and can always be hired out).

Deficiencies of the model

This is not a dynamic model and so it is not able to capture what impact continuous cropping of a high yielding crop such as maize and beans with recommended practice will have on the soil and other factors in the long run. For example, very high maize yields with only addition of phosphorus and nitrogen may lead to potassium deficiencies in the long run. The continuous cropping may also lead to a build-up of pests and diseases associated with maize and beans. Another important factor not considered and yet a possible reason to cause households to refrain from the recommended practice is the presence of a weed known as striga that adversely reduces maize yields, sometimes even under heavy fertilisation. The crop loss if there is striga is higher with the recommended practice because of higher investment costs and expected yields.

5.2.1 The empirical model

We consider a farm household that is maximising a utility function with respect to production and consumption decisions. Farm output includes the food staple and/or a cash crop. The food crop is also a potential cash crop. The factors used in production include land, labour and purchased inputs – fertiliser and seed. Products and factors are related through the production technology. The household consumption bundle includes the staple food, breakfast items, other foods, non-food items and leisure, which is a complement in total time of the household's labour supply on and off farm. A household may be a net seller or a net buyer of any product and factor, and is assumed to take all market prices of products and factors as exogenously given. The inseparability of the model comes in mainly because of the expected link between labour demand and labour supply. If labour is not actively traded in the market, households with a higher labour/land ratio will use more labour intensive technologies than other households (Benjamin, 1992). Whereas labour markets with a known wage rate exist in the study area, opportunities for off-farm employment for excess household labour are rare. A household member can therefore not be sure of being hired when she/he goes out in search of employment, in other words there is involuntary unemployment. This in turn influences the demand for and supply of labour by the households. In addition, there is a liquidity constraint, implying a trade-off between using cash for purchase of inputs or for immediate consumption.

Production decisions involve resource allocation among the five pre-specified activities/technologies. Each activity has different input requirements. The model can allocate all the available resources to one activity/technology or to several activities/technologies, so as to maximise the objective function (utility in this case). The activities/technologies chosen determine the level of farm revenue earned. The household jointly makes its production and consumption decisions subject to various constraints as specified below.

The empirical model uses a Stone-Geary utility function, mathematically formulated as:

Maximise $\boldsymbol{Z} = \prod_{j=1}^{4}\left(c_j - \gamma_j\right)^{\beta_j} \prod_{s=1}^{12}\left(c_l^s - \gamma_l^s\right)^{\beta_{ls}}$ Utility function = objective function (5.1)

where c_j are the four consumption items without leisure, and γ_j are the autonomous consumption levels for those four items. c_l^s is monthly leisure consumption, $\gamma_l^s = \gamma_l/12$ is the monthly autonomous consumption of leisure and $\beta_{ls} = \beta_l/12$ is the marginal budget share of leisure divided by 12. Labour demand for farm work varies on a monthly basis, and so we also specify consumption of leisure on a monthly basis because of the expected link between labour demand and labour supply.

Subject to constraints:

$\sum_{j=1}^{4} p_j c_j + \sum_j m_j \left(b_j + d_j\right) \leq \sum_{h=1}^{3} p_h q_h + E^{ho} - l^c - x^c + R$ Cash constraint (5.2)

$\boldsymbol{c_j} = q_h + b_j - d_h$ Quantity balance in case consumer good *j* is the same good as producer good *h* (5.3)

$\sum_i a_i \leq A$ Land constraint (5.4)

$l_s^f = E_s - l_s^l - l_s^{ho}$ Family labour constraint in season *s* (5.5)

$\sum_i l_{is} a_i \leq l_s^{hi} + l_s^f$ Labour constraint in season *s* (5.6)

$x^c + l^c \leq E^{ho} + r * 0.5 * 4$ Cropping season liquidity constraint (5.7)

$q_h = \sum_i^5 y_{hi} a_i$ Quantity of crop *h* produced . (5.8)

$l^c = \sum_{s=1}^{12} l_s^{hi} w_{hi}$ Expenditure on hired labour (5.9)

$x^c = \sum_k \sum_i x_{ki} p_k a_i$ Expenditure on inputs (5.10)

$E^{ho} = \sum_s v_s l_s^{ho} w_{ho}$ Expected off-farm earnings (5.11)

$R = 12 * r$ Total annual remittances

Where:

x^c - Cost of inputs

l^c - Cost of hired labour

q_h - Quantity of good h produced (h_{1-3} = maize, beans, tea)

b_j - Quantity of good *j* bought

d_j - Quantity of good *j* sold

m_j - Marketing costs

p - Input and output market prices

E^{ho} - Expected off-farm earnings

R - Exogenous annual remittances

r - Monthly exogenous remittances

E_s - Total monthly household time available

l_s^f , l_s^{ho} , l_s^l - Monthly family labour used on the farm, hired out, and committed to leisure

l_s^{hi} - Monthly hired in labour

l_{is} - Labour requirement per acre of technology *i* in season *s*

y_{hi} - Yield of crop *h* per acre of activity *i*

x_{ki} - Quantity of input k used per acre of activity i

a_i - Area allocated to activity *i*

v_s - Probability of a household member getting hired in season *s*

s - Season (months of the year)

Labour constraint: Labour requirements are based on the cropping seasons (months) of the year when the different operations (land preparation, planting, weeding, top-dressing, harvesting, drying and threshing) are carried out. Each household has an initial endowment E_s of monthly time in man-days. Household labour used on the farm cannot exceed total monthly household time, less hired out labour and less time consumed as leisure for each month. Households can hire in labour for production activities, but they pay a higher wage rate than what they receive when they get hired. The probability of a household member getting hired out varies with the cropping season such that during the peak cropping seasons of planting, weeding and harvesting, the probability is higher and during off peak periods it is lower. Labour for hiring in is assumed to be always available, as indicated by respondents during the survey and in informal interviews.[5.1]

Land constraint: The household has a fixed area of land, which it can allocate to the different activities/technologies. Possibilities of hiring in land are very rare in this area, so it is assumed that land is not hired.

Liquidity constraint on input purchase: Expenditures on fertilisers, seed and hired labour have to be incurred ahead of harvest and this requires financial liquidity at that time of the year. For this the household uses a fraction of its exogenous remittances, r_s, received ahead of harvest time and/or labour revenue where labour is hired out.

5.2.2 Description of the production technologies

The crucial part for this study is the production activity/technology that a household will pick given specific resource constraints. A detailed description of the five activity/technologies considered follows below:

a) The recommended practice (MB-rec)

This is the maize and bean inter-crop as recommended by the Kenya Agricultural Research Institute (KARI) at Kakamega for the study area and is both cash and labour intensive. Its elements are application of fertiliser at a rate of 60 kg/ha P_2O_5 and 60 kg/ha N, which translates into 130 kg/ha, DAP and 141 kg/ha CAN per season. Other types of fertiliser can also be used but the above are chosen because they were the most commonly used. Improved maize and bean seeds are planted at the rate of 25 kg/ha and 50 kg/ha respectively. If the households were not resource constrained, they would all choose this practice because it has the highest return to all inputs.

b) The current farmer practice (MB-cur)

This is as extracted from the survey data and includes fertiliser application at a rate of 45.0 kg/ha (18.2 kg/acre) of DAP per year with no top-dressing. In addition manure is applied at the rate of 1.5 tonnes/ha. A mixture of improved (4 kg/ha) and local (26.9 kg/ha) maize seed and local bean seed (37.8 kg/ha) is used.

[5.1] See Appendix 5.3 for details on monthly labour requirements and the probability of getting hired.

c) Improved fallow (MB-fal)

Improved fallow technology is selected from the ICRAF farmer-managed trials carried out in part of the study district and reported in Place et al. (2003a) and Rommelse (2000). Natural fallows are defined as withdrawal of land from cultivation for a period of time to permit natural vegetation to grow on the plot. The breaking of the crop cycle leads to regeneration and the fallows can also recycle nutrients. An improved fallow is then the enrichment of a natural fallow by purposeful planting of trees, shrubs, or herbaceous legumes at high density to improve soil fertility (Rommelse, 2000; Place et al., 2003b). The two most promising species in the study area are *Tephrosia vogelli* and *Crotalaria grahamiana*. In this study we use the results of *Tephrosia vogelli* with zero fertiliser, which from the two trials presented in Place et al. (2003a) and Rommelse (2000) had the highest returns both to land and to labour. This practice demands the lowest amounts of cash and of labour. A household that is both cash and labour constrained, may therefore prefer it. [5.2]

d) Manure (MB-man)

This is a maize/bean inter-crop with only application of manure without any inorganic fertiliser, and is also extracted from the survey data. About 20% of the households interviewed used this practice and applied manure at an average rate of 1.9 tonnes/ha. Maize and bean seeds are used at the same rate as in the current farmer practice except that less of the improved maize seed (2 kg/ha) is used. The practice is less cash intensive compared to the recommended practice and the current farmer practice. A household that is cash constrained but has more labour is therefore likely to go for it.

e) Tea

Tea is the main cash crop in Vihiga and is grown by about 27 % of the sample. A tea factory was recently built in the area, and tea-buying centres are being constructed in several places close to the farm households. There are therefore possibilities of more households getting into tea production, but of course there is the liquidity requirement for initial establishment. The households who grow tea apply fertiliser at a rate of 697 kg/ha split in two applications a year – in April and in September. The model assumes that tea is already planted so the cost of establishment is not included.

[5.2] For additional details on the improved fallow see Appendixes 5.4 and 5.5.

A maize/bean technology where neither fertiliser nor manure is applied is not included because it was not common; less than 7% of the sample households practised it. A technology of horticultural production is not included because of lack of sufficient data. Even though households earned some income from horticulture, they had tiny plots of different types of vegetables/fruits, without consistent data on input and output levels.

A summary of key elements of the different activities/technologies is presented in Table 5.1 below. Two seasons are planted in a year so the data are a combined sum of the two seasons. [5.3] For the recommended practice a range of yields was given, but the lower limit is used here.

Table 5.1: Inputs, yields and gross margins per ha for the different production technologies included in the model

	Labour (MD)	Labour costs (ksh.)	Fertiliser and seed cost (ksh.)	Maize/tea yield (kg/ha)	Bean yield (kg/ha)	Gross margin
MB-rec	603	42,210	37,274	10,225	1440	66,716
MB-cur	273	19,110	5793	2754	797	23,476
MB-fal	228	15,960	3648	2561	481	19,657
MB-man	257	17,990	3870	2223	789	19,943
Tea	434	28,980	18,261	4386		52,237

Source: Calculation from the household survey data

Cattle are an important activity in the farming systems of Vihiga. The main breed kept is the zebu, together with a few crosses and very few pure breeds. The tethering system where cattle are tethered in the homestead and along roads and boundaries is mainly used. Some households, especially those having crosses and pure breeds, feed Napier (either planted or bought) to the cattle. Because the main interest of this study is soil nutrient management, and given that currently over 66% of the cropped land is under maize and less than 15% under Napier, dairy is not included in the model. Manure is treated as a fixed factor in the current practice and in the manure technology. It is however assumed that households will keep the current stock of cattle. Waithaka et al. (2002) indicate that the cattle numbers in Vihiga are stable. The labour input into livestock is therefore deducted from the total household labour available for farming. Also area currently under Napier and labour used on Napier are excluded from the area and labour available for cropping. The other common link between cropping and cattle observed in many places, provision of draft power (e.g. Omamo, 1995), is not a case in the study area. None of the households interviewed used draft power or owned cattle for draft power purposes.

[5.3] For more details on cropping seasons, see Appendix 5.2.

5.2.3 Household data used for calibrating the model

Most household models developed before have taken the total number of adult equivalents or total household members of working age to represent the total labour force available to the household for production (e.g. Omamo; 1998, De Janvry et al., 1992). This study recognises that in a household not every person is available to perform farm work. The study therefore uses data collected on household time to separate time already committed to off-farm, non-agricultural activities and time available for farm work. Time available for farm work is further separated from time spent on housekeeping chores so that what is entered in the model is time actually available. Off-farm activities include formal employment e.g. teaching for members living on the farm and informal employment such as carpentry and masonry, again for members living on the farm. The importance of separating this labour from labour available for the farm is that the different jobs do not have uniform wage rates. Cash earned from off-farm activities is treated as remittances, which can be used for purchase of inputs and for consumption. It is assumed that school-going children spend all their time in school. The data used in this model should therefore fit well the system analysed and the results can be directly applied.

Household resources available to each of the three farm types are summarised in Table 5.2. The major difference between farm type two and farm type three is the level of remittances. Households are assumed to use half of their monthly remittances on purchase of inputs and half on consumption during the months of February, March, June and July. During the months of December, January, April, May, August and September, all remittances go to consumption either because children are on holidays, hence increased expenditure on food items, or they are going back to school and have to pay school fees, increasing expenditure on non-food items. Also in April and May there is a food shortage as the previous harvest is depleted and they have yet to harvest, hence there is increased food purchase. Remittances possibly saved in October and November are depleted in December and January through increased consumption and school fees.

Table 5.2: Resources available to households in the three farm types of Vihiga

Household type	Amt of land (acres)	Amt of labour (md)	Remittances (ksh)	Land: labour ratio	Land: cash ratio
Farm type one	1.80 (0.73ha)	80	12,680	1:44	1:7044
Farm type two	1.60 (0.65ha)	80	6950	1:50	1:4344
Farm type three	0.91 (0.37ha)	43	10,940	1:47	1:12,022

Source: Household survey data

5.3 Calibration and parameterisation of the model

The household models are numerically calibrated, coded and solved using the General Algebraic Modelling System (GAMS). The simulation model combines a Leontief representation of the farming system from field survey data and a Stone-Geary utility function. The Stone-Geary utility function is chosen because the linear expenditure system which derives from it can be calibrated using income elasticities. The more flexible forms such as the Translog utility function and the Almost Ideal Demand System (AIDS) require price elasticities for calibration and these cannot be estimated from the cross sectional data available. Primary data from the survey are used to construct household budgets and demographic data. Table 5.3 below gives the factor and product market parameters used.

Table 5.3: Input and output prices

Item	Unit	Value
Maize output price	ksh./kg	11.2
Beans output price	ksh./kg	22.0
Tea output price	ksh./kg	23.0
Basal fertiliser (DAP) price	ksh./kg	30.5
Top-dress fertiliser (CAN) price	ksh./kg	29.4
Tea fertiliser price	ksh./kg	26.2
Improved maize seed price	ksh./kg	140
Local maize seed price	ksh./kg	20.2
Improved bean seed price	ksh./kg	140
Local bean seed price	ksh./kg	29.2
Tree seed for improved fallow	ksh./acre	260
Hire in wage	ksh /md	70.0
Hire out wage	ksh /md	50.0

5.3.1 The Stone-Geary utility model

The Stone-Geary utility model as given by (Deaton and Muellbauer 1980) is:

$$\mathrm{U} = \prod_{j=1}^{n} \left(c_j - \gamma_j\right)^{\beta_j} \tag{5.12}$$

where U is utility, c_j is a vector of total quantities of consumption items j and γ_j is a vector of the autonomous (subsistence) consumption. Consumption cannot fall below the subsistence level. The corresponding linear expenditure system (LES) is:

$$p_j c_j = p_j \gamma_j + \beta_j \left(x - \sum_k p_k \gamma_k \right) \tag{5.13}$$

The LES can also be expressed as a system of demand functions:

$$c_j = \gamma_j + \frac{\beta_j}{p_j} \left(x - \sum_k p_k \gamma_k \right) \tag{5.14}$$

where p_j is the price of consumption item j so that $p_j c_j$ is the total expenditure on consumption item j and $p_j \gamma_j$ is the autonomous (subsistence) expenditure of consumption item j; and x is household full income. The interpretation of equation 5.13 is therefore that the autonomous expenditures are bought, leaving a residual "supernumerary expenditure" (the term in brackets), which is allocated between goods in fixed proportions β_j. β_j s are the marginal budget shares $\partial\, pc/\partial x$, which indicate how expenditure on each commodity changes as income changes. $\beta_j > 0$ and so the system does not allow for inferior goods. For adding up to be satisfied $\sum \beta_j = 1$, which is not a very restrictive constraint because all it implies is that extra expenditure equals extra income.

To be able to calibrate the Stone-Geary utility model the total quantities consumed of each budget item, the subsistence quantities and the marginal budget shares need to be known. The total quantities of item j consumed are calculated directly by the model, but the subsistence quantities (γ_j) and the β_j have to be derived from the LES. To calculate β_j we take advantage of the specification of income elasticities in the LES, given by

$$\eta_j = \beta_j / w_j \qquad (5.15)$$

Where w_j is the budget share of commodity j. In this study the income elasticities are estimated directly from the household survey data unlike in most applied research where income and other elasticities are taken from the literature and are usually representative of the macro level consumption behaviour, but not necessarily specific to given micro level behaviour. To obtain income elasticities for the different budget items, Engel curves were estimated. Various forms of Engel curves are commonly used. We use the semi-logarithmic, which from the empirical standpoint tends to perform best (Sadoulet and de Janvry, 1995). It also has variable income elasticities that are empirically a desirable property. It is specified as:

$$c_j = \alpha_j + \beta_j \ln y \qquad (5.16)$$

and the income elasticity is $\eta_j = \dfrac{\beta_j}{c_j}$

The Engel curves for each of the budget items were estimated using OLS, without imposing any constraint, but the resulting β_j s were checked for adherence to the constraints imposed by the LES. The income elasticities (η_j s) are used to calculate the β_j s because w_j in equation (5.15) is known from the data. Although no constraint was imposed in estimating the Engel curves, the derived β_i s satisfy $\sum \beta_i = 1$. To compute the subsistence quantities the procedure suggested by Keller (1979) and also used by Kuiper (2005) was used:

$$\gamma_j = (1 - \eta_j)\, c_j \qquad (5.17)$$

where as before γ_j is the autonomous consumption level for consumption item i, η_j is the income elasticity and c_j is the consumption level of item j. The Keller procedure has a disadvantage in that consumption items with income elasticities greater than one will have negative subsistence quantities. To overcome this, the elasticities are normalised by the maximum elasticity (see also Dellink, 2003; Kuiper, 2005) so that equation (5.17) becomes

$$\gamma_i = \left(1 - \frac{\eta_i}{\max(\eta_i)}\right) c_i \qquad (5.18)$$

This calibration will reproduce the initial elasticities if they satisfy the restriction ($\sum \beta_i = 1$). The estimated income elasticities are reasonable and comparable to those obtained by Omamo (1995), the small difference may be due to the fact that those computed by Omamo are based on more general data whereas those derived in this study are based on data specific to the study area. The elasticities together with the budget shares and the marginal budget shares are reported in Table 5.4, and Table 5.5 gives other household expenditure data.

Table 5.4: Elasticities, marginal budget shares and budget shares of households in Vihiga

Budget item	Price	Income elasticity	Budget share (w_i)	Marginal share of income (β_i)
Food staple (Maize)	11.2	0.34	0.13	0.04
Teas	36.8	0.53	0.23	0.12
Other foods	58.1	0.53	0.26	0.14
Non- food items	8.60	2.00	0.30	0.60
Leisure	70	1.53	0.06	0.09

Source: Computed from formal survey data of a random sample of 175 households as at 2001.

The food staple is maize; the breakfast items include milk, tea, bread and sugar; and other foods are beans, vegetables, rice, wheat flour, meat, chicken, cooking fat, fish, eggs, tomatoes and onions. Non-food items include school fees, wood fuel, kerosene, clothing, bar soap, toilet soap, medical care, and social functions; and leisure is a complement in household time's labour supply on and off farm.

Table 5.5: Household expenditure data disaggregated by farm type

	Adult equivalents	Annual expenditure per adult equivalent	Monthly expenditure per adult equivalent
Farm type one (medium remittances, large farms)	5.2	20,755	1730
Farm type two (low remittances, medium farms)	4.7	16,499	1375
Farm type three (high remittances, small farms)	4.1	20,649	1721
Whole Sample	4.7	18,930	1578

Source: Calculation from survey data on a random sample of 175 households in 2001. In this year the average exchange rate was 1US$ = Ksh. 78.

All factor and output prices are the actual 2001 prices as indicated by the households. According to the agricultural extension office and farmers, 2001 was a normal year.

5.4 Results and discussion

The constrained maximisation of the Stone-Geary utility function for different household types is simulated under different levels of resource constraints. They include the required liquidity level that allows the best activity/technology to be chosen; the optimal cropping patterns given the current resource availability; the impact of a change in available land on activity technology choice and on survival; and the optimal cropping patterns in the event that labour cannot be hired in. As already mentioned, the simulations are done under three assumptions concerning opportunities of hiring out excess household labour (no opportunities; can be hired out given a probability of getting hired; and can always be hired out). The activities/technologies and scenarios for labour are initialised in the results as:

Scenarios for labour

None = No opportunities at all for hiring out excess labour

Medium = Excess labour can be hired out given a probability of being hired

High = All excess labour can be hired out

Activities

MB-rec: Maize and beans recommended practice

MB-cur: Maize and beans current farmer practice of low external input level

MB-fal: Maize and beans improved fallow practice

MB-man: Maize and beans manure only current farmer practice

Tea: Tea under the current farmer practice

5.4.1 Required liquidity level for the best activity/technology choice.

Land is fixed and it is assumed that labour for hiring in is always available, so the constraining resource is cash. The simulations are therefore done varying the liquidity level until the highest returns are achieved. This is important for informing policymakers and development agencies about the level of credit required by different household types and what impacts should be expected. The results are summarised in Table 5.6.

Table 5.6: Required liquidity level for the best activity/technology choice by three household types in Vihiga district

	Farm type one *(land – 1.80 acres and labour- 80 md)*			**Farm type two** *(land – 1.60 acres and labour- 80 md)*			**Farm type three** *(land – 0.91 acres and labour- 43 md)*		
Off-farm opportunities	None	Medium	High	None	Medium	High	None	Medium	High
Activity picked									
- MB-rec	1.80	1.80	1.80	1.60	1.60	1.60	0.91	0.91	0.91
Farm revenue	78,698	86,349 (78,698)	97,049 (78,698)	70,750	82,710 (70,750)	94,010 (70,750)	40,144	43,967 (40,144)	49,867 (40,144)
Required liquidity level	27,900	20,200	9500	24,000	12,000	700	13,800	9900	4000
Shadow values									
- Land	53.0	29.3	21.7	66.6	26.9	18.7	52.5	29.7	21.7
- Labour	0.57	0.98	1.36	0.27	1.00	1.42	0.60	0.99	1.37
- Cash	0.00	0.009	0.009	0.00	0.012	0.012	0.00	0.009	0.009

Farm revenue = Net farm earnings including revenue from hired out labour. In brackets are net earnings from cropping only (less labour revenue).

Adopting the best activity/technology means committing all the resources to maize and beans under the recommended practice. The liquidity levels required to adopt this recommended technology on the whole farm are shown in Table 5.6 above. When there are no off-farm labour opportunities, farm type one requires its current liquidity level to be more than doubled and that of farm type two to be more than tripled to have only the recommended practice in the optimum solution. Interestingly, with medium and high employment opportunities, farm types one and three hire out relatively less labour than farm type two, and consequently generate less revenue compared to farm type two. Farm types one and three therefore require relatively higher external liquidity levels to achieve the best activity/technology than farm type two. If, for example, farm type two's land is increased to 1.80 acres, giving the same land size and labour force as farm type one, then, with high employment opportunities, they will require only ksh. 7300 to achieve the best activity/technology, compared to ksh. 9500 required by farm type one.

According to the theory of the "drudgery averse" peasant (Ellis, 1993), the households face two opposing objectives of either working on- or off-farm to generate extra income, or consuming leisure. The influencing factor is the need for consumption of other items apart from leisure. Because farm type two has much lower external remittances compared to both farm types one and three (see Table 5.2), they have a higher utility of income and are thus compelled to hire out more labour to increase their income level. This means they consume relatively less leisure compared to farm types one and three. Interestingly, from the results we see that the level of external remittances to a household has an influence on their farming practices. It implies that more remittances lower the incentive of household members to work, both on farm and off farm, to generate additional income; especially if the off-farm remuneration is not high, they will rather consume leisure. The result on farm type two also implies that households with lower external remittances are more ready to adopt more profitable technologies if the conditions make it conducive to do so.

5.4.2 Identification of the best practice given current resources

Households who lack sufficient liquidity will tend to adopt low external input technologies and achieve lower revenues (Dercon, 1998; Imai, 2003). However, it is possible that they can increase their farm revenues by allocating the current resources better. This section identifies the optimal practice(s) given the current resources (land, cash, and labour). As before, it is assumed that labour for hiring in is always available when required. The results of these simulations are presented in Table 5.7 below.

Table 5.7: Optimal activity/technology combination at current resource levels of three farm types in Vihiga district

	Farm type one			Farm type two			Farm type three		
Off-farm opportunities	None	Medium	High	None	Medium	High	None	Medium	High
Activity									
- MB-rec		1.20	1.80		1.13	1.60	0.53	0.91	0.91
- MB-man	0.26			0.90					
- Tea	1.54	0.60		0.70	0.47		0.38		
Farm revenue	54,664	82,920 (72,823)	93,869 (78,698)	36,892	79,115 (65,404)	90,250 (70,750)	35,885	43,655 (40,144)	47,365 (40,144)
Shadow values									
- Land	16.9	26.2	39.4	18.8	26.3	46.5	30.4	47.9	43.8
- Labour	0.29	1.00	1.02	0.13	1.00	0.88	0.40	0.77	0.94
- Cash	0.050	0.013	0.002	0.057	0.013	0.00	0.025	0.00	0.00
Leisure			251			198			161

Household current resources are farm type one (Land = 1.80, labour = 80, liquidity = 12,680), farm type two (Land = 1.60, labour = 80, liquidity = 6950) and farm type three (Land = 0.91, labour = 43, liquidity = 10,940). Farm revenue = Net farm earnings including revenue from hired out labour. In brackets are net earnings from cropping only (less labour revenue).

From Table 5.7 households in all the three farm types are unable at the current resource levels to allocate all the land to the recommended practice when they cannot hire out their excess labour. Farm types one and two, which have lower cash relative to land, completely pull out of the recommended practice and go for tea and the manure practice. Comparing this result with the currently observed household practices, farm type two is allocating their resources almost optimally given their current resource constraints. Farm type one slightly deviates from its optimal allocation whereas farm type three deviates most from its optimal resource allocation. Farm type one can slightly improve on their resource allocation by increasing area under tea, and farm type three can substantially increase their farm revenues by adopting the majority of the recommended practices, even with their current resources. The same result lingers when area under tea is fixed at its current level (see Table A5.1) and when tea is not grown (see Table A5.2) - farm types one and three can improve on their resource allocation. Apparently for farm type two, their current practices are the most rational given their liquidity constraint.

When both farm types one and two can hire out labour, the major difference between them is again the level of income generated from hired out labour, or in other words the consumption of leisure. For example, under high employment opportunities farm type two hires out 390 man-days, but farm type one only hires out 303 man-days, mainly because farm type two is more in need of extra revenue than farm type one. Farm type one values the wage from the extra man-day hired out less than it values the consumption of leisure. Figure 5.1 below further illustrates how the level of remittances influences the time spent working on and off farm and time spent on leisure. The figure shows the level of leisure consumed by the different farm types at current remittance levels and when there are no remittances under high off-farm opportunities. With remittances farm types one and three consume considerably more leisure than farm type two, but without remittances their consumption of leisure is much reduced as they all have to work very hard to survive.

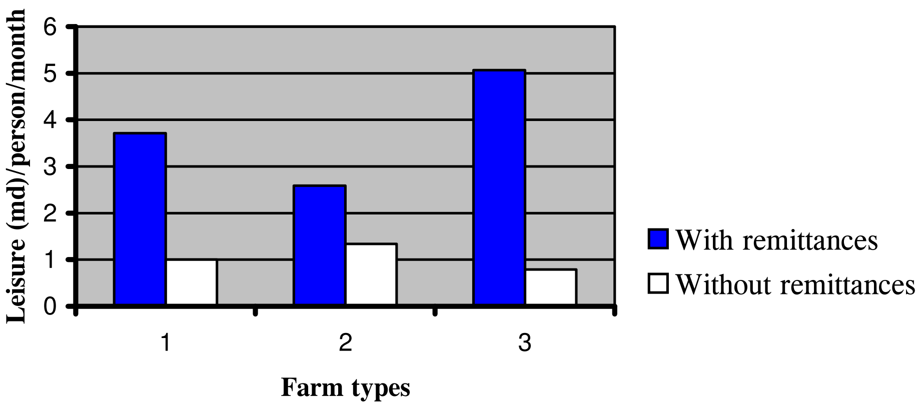

Figure 5.1: Consumption of leisure by farm type

The magnitude of the liquidity constraint for the different farm types can be measured by comparing the maximum farm revenue these households can earn when not constrained (Table 5.6) with the farm revenues given optimal allocation with current resources (Table 5.7). Assuming no off-farm opportunities, households in farm types one, two and three achieve respectively 30%, 48% and 11% less farm revenues than they will achieve when they are not liquidity constrained. It is not surprising that farm type two is the most liquidity constrained given our previous discussion; they have the lowest current liquidity level. The cash constraint is greatly reduced when households can hire out their excess labour as shown by the difference in the shadow values for cash between none, medium and high off-farm opportunities (Table 5.7). Farm type two is able to increase its farm income by 144% when it can hire out all its excess labour compared to when it cannot hire out any labour. That of farm type one increases by 71% and that of farm type three by 31%. The magnitude of the liquidity constraint varies across the farm types based on their current level of remittances relative to farm size.

Figure 5.2 below gives a graphical presentation of the seasonal shadow values for labour under medium off-farm opportunities for the three farm types. As mentioned earlier, the highest amount of labour is required in August and September when harvesting and drying the first season crop, and land preparation and planting the second season crop are going on concurrently. The graphs are similar for farm types one and two because they have similar amounts of labour and only a small difference in available land.

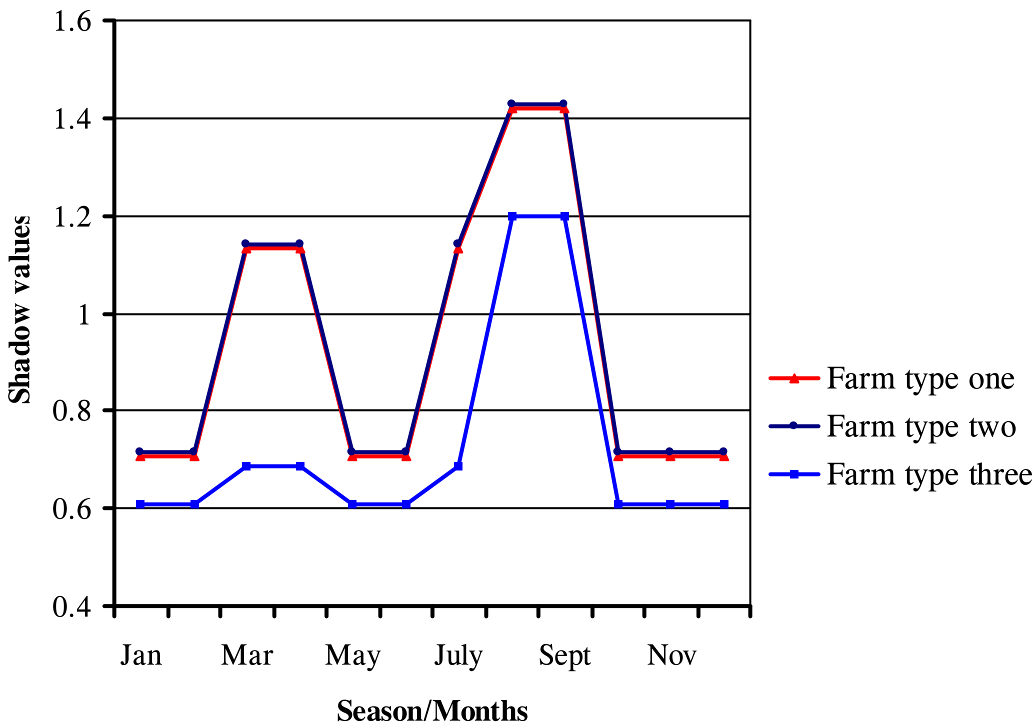

Figure 5.2: Seasonal shadow values for labour under medium off farm opportunities

5.4.3 Impact of farm size on the activity/technology choice and on farm revenues

Area under Napier and labour used for Napier production were excluded from land and labour available for cropping. Simulations on the impact of farm size therefore start by including both area under Napier and labour used on Napier, to find out if it is economical for these households to have Napier in their cropping patterns. The next simulation examines the impact of a 50% decrease in land under the current liquidity and labour levels, to see the effect this will have on the activity/technology choices and on households' survival, especially if they rely solely on the farm. It is unlikely that the farms in Vihiga will increase, so we do not look at the impact of a 50% increase. All simulations here are done under medium off-farm opportunities for hiring out labour. The results are shown in Table 5.8 below.

Table 5.8: Impact of a change in farm size on activity/technology choice and farm revenues for three household types in Vihiga

	Farm type one		Farm type two		Farm type three	
	Napier area included	50% less land (current other resources)	Napier area included	50% less land (current other resources)	Napier area included	50% less Land (current other resources)
Activity						
- MB-rec	1.02	0.90	0.99	0.80	1.01	0.46
- MB-man						
- Tea	1.03		0.83			
Farm revenue	89,808 (78,986)	53,711 (39,797)	85,563 (71,067)	53,616 (35,375)	49,203 (44,661)	27,205 (20,341)
Change in revenue	6888 (6163)		6448 (5663)		5548 (4517	
Shadow values						
- Land	26.2	53.8	26.3	54.0	52.0	54.0
- Labour	1.00	0.62	1.00	0.62	0.67	0.62
- Cash-	0.013	0.000	0.013	0.00	0.00	0.00

Household current resources are farm type one (Land = 1.80, labour = 80, liquidity = 12,680), farm type two (Land = 1.60, labour = 80, liquidity = 6950) and farm type three (Land = 0.91, labour = 43, liquidity = 10,940). Farm revenue = Net farm earnings including revenue from hired out labour. In brackets are net earnings from cropping only (less labour revenue). Napier labour is 8 md for farm type one and 5 md for farm types two and three.

A concept closely related to the economics of choice of activity/technology is that of opportunity cost. Given the households' resource level, and assuming that at least one of these resources is binding, the output of one activity/technology can only be increased or produced by withdrawing resources from the production of other activity/technologies. The consequent reduction in output in other activities represents a cost measured by the income forgone. Including both area under Napier and labour used on Napier in the available resources makes it possible to identify the income foregone by not including these resources. This income forgone represents the opportunity cost of growing Napier and is measured by the maximum income that these resources will have earned in alternative uses.

The opportunity cost of growing Napier turns out to be ksh. 6163 for farm type one, ksh. 5663 for farm type two, and ksh. 4517 for farm type three. For the presence of Napier to be justified among the cropping patterns, it should bring in a minimum net income equal to its opportunity cost. The survey data showed that households who grow Napier for sale (those who do not have cattle) earn from it a net income of ksh. 4663 in farm type one, ksh. 6271 in farm type two and ksh. 3829 in farm type three. The implication of this result is that households in farm types one and three who grow Napier purely for sale will be better off by withdrawing resources from production of Napier and transferring them to alternative activities/technologies. Apparently for farm type two growing Napier is more profitable than the alternative activities. When Napier is grown for sale, there are two possibilities; households can either sell the Napier before it is harvested and the buyers harvest themselves, in which case it fetches lower returns. Alternatively, the household can choose to harvest the Napier and sell it at the market place, and then the returns are higher. It is possible that households in farm type two harvest the Napier themselves and sell it at the market, whereas those in farm types one and three sell it *in situ*.

The result of a 50% decrease in land is very interesting because, for all the farm types the shadow value of cash is zero, showing that increasing the liquidity level cannot increase farm revenues any further. All the farm types are able to put all the land under the recommended practice using current resources without any problem. Shadow values for land and labour change, reflecting the change in relative scarcities, with the shadow value of land more than doubling for farm types one and two (compare with results of Table 5.7 under medium hiring out opportunities). More interesting, however, is the fact that if the 50% decrease in farm size is accompanied by a scenario where there are no remittances, even for consumption, then farm type three (smallest farm size) cannot survive – they cannot meet their minimum requirements for subsistence. Farm type one and two will manage to consume just the basic minimum required for subsistence for all the consumption groups. The minimum farm size that just enables farm type three to consume the basic requirements is 0.6 acres. Moreover, this is with the assumption that they are able to hire out their excess labour under medium opportunities and that they will adopt the maize and beans recommended practice.

5.4.4 Optimum activity/technology choice if labour cannot be hired in

If labour cannot be hired in, then households are constrained to rely on household labour and this will affect the farming practices they adopt and the farm revenues they achieve. This simulation investigates this and the results are reported in Table 5.9 below.

Table 5.9: Optimum activity/technology choice if labour cannot be hired in

	Farm type one			Farm type two			Farm type three		
Off-farm opportunities	None	Medium	High	None	Medium	High	None	Medium	High
Activity									
MB-rec		1.20	1.58		1.13	1.60	0.53	0.88	0.88
MB-man	0.26			0.90					
Tea	1.54	0.60	0.22	0.70	0.47		0.38	0.03	0.03
Farm revenue	54,663	82,919 (72,823)	91,383 (77,035)	36,892	79,115 (65,404)	90,250 (70,750)	35,885	43,414 (39,864)	47,172 (39,864)
Shadow values									
Land	16.9	26.2	30.2	18.8	26.3	46.5	30.4	34.1	30.4
Labour	0.29	1.00	1.21	0.13	1.00	0.88	0.40	1.05	1.22
Cash	0.050	0.013	0.00	0.057	0.013	0.00	0.025	0.00	0.00

Household current resources are farm type one (Land = 1.80, labour = 80, liquidity = 12,680), farm type two (Land = 1.60, labour = 80, liquidity = 6950) and farm type three (Land = 0.91, labour = 43, liquidity = 10,940). Farm revenue = Net farm earnings including revenue from hired out labour. In brackets are net earnings from cropping only (less labour revenue).

It is striking that the results when labour cannot be hired in (Table 5.9) are almost a replica of the results when labour is available for hiring in (Table 5.7). What these results mean is that households in all the three farm types given their current resources do not need any external (hired) labour for farm work. A minor difference is found in the solution of farm types one and three with high employment opportunities. This result concurs with the results of Chapter 4, which show that currently the labour input in maize production is above the optimum level. Because there are no off-farm job opportunities outside the farm, more labour is used in own farm work, even though they could do with less. The other implication of this result is that, agricultural off-farm work is hardly available in the area because the average household does not need any extra labour. What these households require most is an off-farm opportunity to absorb their excess labour and raise the level of remittances, particularly for farm type two, which will in turn raise farm revenues.

5.4.5 Other simulations

Two other simulations were done in order to identify the optimal activity/technology combination at current resource levels: when the area under tea is fixed at its present acreage, and when tea is not grown. The results of these simulations are presented in appendix 5.1

The simulation on the optimal activity/technology combination when tea is not grown is necessary because the majority of households do not grow tea. Only 35% of households in farm type one, 25% in farm type two and 18% in farm type three have tea. As Imai (2003) observed, entering into tea production has barriers for households who are liquidity constrained because it requires a high level of initial cash investment and the benefits are not forthcoming until two to three years after establishment. On the other hand, for the households who already have tea, it is not possible in the short run to allocate the area under tea to other activities, hence the need to run the simulations when tea area is fixed at its current acreage. The results for both simulations confirm the results of section 5.4.2 that the current farmer practice dominates the optimal solution of farm type one and farm type two when excess labour cannot be hired out. It is interesting to note that for farm type two, when tea area is fixed at its current acreage, and with no off-farm opportunities, the optimal solution is exactly the same as their current practice.

5.4.6 Considerations

The improved fallow

The improved fallow practice does appear in any of the optimal solutions. This would appear strange at first instance. However, when it is considered that the main advantage of the improved fallow is low labour requirements (Place et al., 2002), and combined with the previous results, that, for all the farm types in Vihiga labour is not currently a constraint, then it is no longer strange. Though the improved fallow has relatively low labour requirements, it also has relatively low yields. With excess labour, it is rational for the households to pick technologies that are more labour intensive, especially if they give higher yields, rather than one like the improved fallow, which though it demands less labour gives lower yields. The improved fallow is more suitable for households who have relatively more land but are labour constrained. Place et al. (2002) note that feasibility and acceptability of improved fallow systems varies over different household types. Pisanelli et al. (2000), when carrying out improved fallow adoption study, found that households more likely to continue using improved fallows were in Siaya district rather than in Vihiga. Siaya district has relatively more land than Vihiga and relatively smaller household sizes (David, 1997; RoK, 2001), implying less labour per unit area. The results of the current study are therefore consistent with, and help explain the rationale of Pisanelli's findings.

One would expect that when the wage rate is increased, households will pick a technology with low labour requirements like the improved fallow and hire out the extra labour. However, simulations show that under high off-farm opportunities, as long as the wage rate is below ksh. 175, the model still puts all the land to the recommended practice.

Between wage rates of ksh. 175 and ksh. 195 the model predicts majority tea and some recommended practice. When the wage rate rises beyond ksh. 195 and all other factors remain the same, then the households abandon farming, and rely on labour revenue.

Maize and beans recommended practice

Maize and beans under recommended practice is the most remunerative practice at the 2001 maize output price of ksh. 11.2 per kg (ksh. 1008 per 90 kg bag). This price is relatively high when compared with other districts, mainly because Vihiga is a maize deficit district. Within the sample households the price ranged from ksh. 8.89/kg (800/bag[5.4]) to ksh. 13.3/kg (1200/bag). The minimum output price of maize that allows the maize and beans recommended practice to be the only one in the optimal solution is ksh. 9.80/kg; between the price of 9.80/kg and 9.00/kg the optimal solution has both the recommended practice and tea, and below ksh. 9.00/kg, there is only tea in the optimal solution. This implies that if the price of maize falls to below ksh.9.00/kg, then tea becomes the most profitable activity, implying that under no resource constraints households should then commit all their land to tea.

Even though the yield used in the recommended practice is the lower limit given by the research, this yield assumes that everything is done correctly, e.g. planting, weeding, and other operations are done on time. This may not always be possible under farmer conditions and hence that yield may not be attained. If prices remain unchanged, then the lowest yield (combined yield for two seasons) that allows maize and beans recommended practice to remain the most profitable is 3387 kg/acre (8366 kg/ha), which is 18% lower. In the event that the yields fall by more than 18%, then the model puts all the land to tea assuming no constraints. However, when compared to other maize and beans practices, the recommended practice remains the most remunerative even at half its yield.

Earnings from dairy

Many studies have shown that households that own cattle are less liquidity constrained than those who do not, and hence adopt more profitable practices (e.g. Imai, 2003; Dercon, 1998). It would therefore not be correct to end this chapter without mentioning earnings from cattle. Revenue from cattle in the area is mainly in terms of earnings from milk; cattle sales are very rare. Although Chapter 2 indicates that 89.9%, 88.7% and 38.5% owned cattle in farm types one, two and three, respectively, only 52%, 55% and 29% in farm types one, two and three respectively had income from milk during the reference year used in this study. The average annual earnings for households that sold milk are ksh. 9906, 16409, and 5529 for farm types one, two, and three respectively.[5.5] Comparing these results with those of Table 5.6, we can conclude that if all net earnings from milk can be injected into crop production, coupled with remittances, they will greatly ease the liquidity constraint for households who produce milk. However, the milk earnings come trickling in throughout the year and may not be there when inputs need to be purchased. In any case the cash constraint remains the same for the 48% in farm type one, 45% in farm type two and 71% in farm type three who have no revenue from milk.

Allowing the model to purchase inputs with revenue from tea

Having a cash crop should enable a household to use the revenues from the cash crop to purchase inputs for it and for other crops. We therefore experimented, allowing the model to purchase inputs from tea earnings. We do this under current resources with varying off-farm opportunities as in section 5.4.2 and therefore compare the results with those of Table 5.7. Revenue from tea has impact only where the model was not already committing all the land to the recommended practice. For all the farm types the model allows in just enough tea to generate the revenue required to purchase inputs but still commits the rest of the land to the recommended practice. Households who have tea should therefore be able to purchase their inputs from the tea earnings.

5.5 Discussion and conclusions

A household is liquidity constrained when it lacks finance from any source to undertake an investment that is most profitable at the prevailing input and output prices. In this chapter we investigated how much liquidity constraint matters to households in Vihiga in terms of determining their activity/technology choices and its impact on household objectives. A non-separable household model specified in a mathematical programming procedure was used for the investigations. It emerges that at the current resource levels (land, cash and labour) and assuming no off-farm opportunities, it is not possible to put all the land under the maize and beans recommended practice, which is the most profitable. We can therefore conclude that the households in the three farm types investigated are liquidity constrained. The assumption of no off-farm opportunities is reasonable given the current lack of non-

[5.4] One bag of maize is equivalent to 90kg.

[5.5] Milk earnings are total revenue from milk sold less cost of purchased inputs and of hired labour.

agricultural job opportunities, and the fact that the average household does not need extra labour (see Table 5.7 versus Table 5.9). Households in farm type two (medium farm size, low remittances and rich in labour) are the most constrained and can achieve only 52% of the potential farm revenue.

That households are liquidity constrained is not disputed because it has been demonstrated by several other studies in Kenya and elsewhere in Africa (Imai, 2003; Dercon, 1998; Freeman et al., 1998). In this study the degree to which the households are liquidity constrained, and hence the impact of easing their constraint, varies with their level of remittances. On the contrary, in Dercon (1998) and Imai (2003), lack of entry into higher return activities was caused by low endowments of land and labour and low initial asset holdings. In Freeman et al. (1998) on the other hand, the impact of credit varied with whether a household was credit constrained or not, with the highest impact obtained for credit constrained households. However, their definition of being credit constrained or unconstrained is rather subjective. A household was considered credit constrained if it had a loan and yet expressed willingness to borrow more at the current interest rates or had requested a loan, but the request had not been approved or it feared borrowing. None of these studies however, has indicated the exact magnitude and impact of the liquidity constraint as explicitly as done in the current study.

For the households to adopt more profitable and sustainable technologies their level of liquidity needs to be raised. According to Sanders et al. (1995), one important explanation for soil degradation in developing countries is the failure to provide sufficient access to resources. One way of dealing with the liquidity constraint is to open up opportunities for off-farm employment. The results show that off-farm opportunities have a great impact on the optimal solutions and consequently on farm revenues. The greatest impact is with farm type two households, who are able to raise their revenues by 144% when they can hire out all excess labour compared to when they cannot hire out any labour. Farm type two households are more reliant on the farm for survival and therefore more willing to hire out labour to raise extra revenue than their counterparts in the other two farm types. This result is supported by the results of Chapter 2, which showed that farm type two households derived most of their income from farming compared to the others. Shepherd and Soule (1998) also indicate that targeting interventions to low and medium resource endowment farmers will have much larger payoffs.

5.5.1 Possible sources of credit and off-farm earnings

Only 16.6 % of the households interviewed had obtained credit within a year preceding the interview (this credit was not limited to farming). Most of this credit was from cooperatives (51%) and from private money lenders (17%). The rest came from friends and relatives (7%), merry-go-round (7%), bank (3%) and other sources (14%). The cooperatives are mainly savings and credit cooperatives, which are associated with formal employment, meaning that the credit is only accessible to those who are employed. Moreover, such credit is usually not for farming.

Apparently banks play a very small role in offering credit to households in Vihiga. Freeman et al. (1998) report that, of the farmers who received loans for dairy production, only 20% received these from banks. This number is obviously higher than the 3% obtained in this study - Freeman's study was specific to dairy farming, and in a similar study area. Nonetheless, the percentage receiving loans from banks remains low. Could there be barriers in accessing formal credit particularly from banks? In the development literature, access to formal credit is often a positive function of income and wealth status (e.g. Jabbar et al., 2002; Dercon, 1998). Freeman et al. (1998) found that a farmer who already had credit was more likely to get credit than one who had not had credit before. In Salasya et al. (1998), lack of required collateral and unfavourable repayment conditions were reported to be major constraints to obtaining credit. Clearly, there are barriers for smallholders wanting to obtain credit to improve their farming, particularly formal credit.

There is then a need to invest in sustainable rural financial systems that target credit-constrained households who may not have access to bank or cooperative loans. The fact that 17% of the households who obtained credit got it from money-lenders[5.6] who usually charge very high interest rates shows the households' desperation to acquire credit. Previously there was the seasonal credit scheme (SCS) that gave loans specifically for maize production to farmers, through the Agricultural Finance Corporation (AFC). However, the scheme was conditional on a household having a minimum of 5 acres under maize, and that disqualified most of the households in Vihiga. A re-introduction of a similar scheme (SCS) but with terms that make it possible for smallholders to access the credit will be a step in the right direction. To improve on loan repayment, which was a problem in the previous scheme, there should be a system where the credit is given through

[5.6] Money lenders are individuals who give out short-term credit and usually charge very high interest rates. An informal contract is signed to seal the transaction between the lender and the borrower, and is usually witnessed by one or two other persons.

some local agency that is able to closely monitor the farmers. A possibility of the credit being paid back in kind (part of the produce) soon after harvesting, may enhance the repayment process further.

Another option is for households to open their own business (agricultural or non agricultural), but that too has barriers, because initial capital is required to start the business. Usually households use remittances to set up non-farm businesses and invest in education (Francis and Hoddinott, 1993). This means that households without remittances are unlikely to set up their own business. In Burkina Faso, prior wealth, especially cattle and established migration channels, is important for income diversification (Reardon et al., 1992). This again means that households with access to remittances and those currently owning cattle are the ones able to start their own businesses. However, self-employment can still be a viable option in Vihiga for poor households if they can access initial credit to start the businesses. For example, Atieno (1999) examining the "access of women in agribusiness trade" found that women who had credit had significantly higher weekly and monthly incomes. Some NGOs and farmers in Vihiga through activities like merry-go-rounds are promoting non-farm enterprises on a very small scale by giving soft loans. The government could strengthen and build on these efforts to promote the rural non-farm economy, which will help absorb some of the excess labour force. Other government projects such as building roads across the country should also target rural poor households who have excess labour to provide the non-skilled labour needed.

Earnings from livestock, particularly dairy, can also help ease the liquidity constraint and allow households make more profitable activity/technology choices. Projects that help develop the dairy industry in Vihiga and that can assist households who do not already have dairy cattle to purchase an initial stock of cattle will be useful.

In summary, all the households in the different farm types are liquidity constrained and so cannot allocate all their land to the recommended practice given their current resources. The degree to which they are constrained, and hence the potential impact of easing their liquidity constraint, varies based on their relative level of remittances. The analysis reveals that the level of remittances has an influence on the household behaviour such that households who have relatively high external remittances tend to work less and consequently adopt less optimal farming practices. In contrast households with relatively low external remittances spend more time working both on and off farm when opportunities are available, and adopt the most optimal technology/activity combinations given their current resources constraints.

Although the households need credit, there seem to be barriers in accessing the credit. Promotion of sustainable rural financial systems that can avail credit facilities similar to the former seasonal credit scheme, and that target households in farm type two (those with no or low external remittances) as of first importance, will be beneficial. In addition, promotion of small-scale non-farm business activities in the area by assisting the households to access initial capital to start off can help absorb some of the excess labour and raise remittances. Notably, if farm size were to decrease by 50%, then households in farm type three (smallest farm size) would not be able to survive on farming alone. Government policies that ensure land is not subdivided into very small plots are therefore necessary.

Appendix 5.1: Simulations with and without tea in cropping patterns

Table A5.1: Optimal activity/technology combination at current resource level when area under tea is fixed

	Farm type one			Farm type two			Farm type three		
Off-farm opportunities	None	Medium	High	None	Medium	High	None	Medium	High
Activity									
- MB-rec	0.41	1.21	1.21		1.01	1.01	0.59	0.67	0.67
- MB-cur	0.80			0.86			0.08		
- MB-man				0.15					
- Tea	0.59	0.59	0.59	0.59	0.59	0.59	0.24	0.24	0.24
Farm revenue	51,236	83,031	88,656	36,544	76,923	85,838	33,366	41,737	45,595
		(72,892)	(72,892)		(64,049)	(64,049)		(37,513)	(37,513)
Shadow values									
- Land	18.0	25.6	46.3	20.6	40.0	46.5	16.5	51.1	46.6
- Labour	0.28	1.01	0.88	0.13	0.81	0.88	0.40	0.70	0.88
- Cash	0.038	0.013	0.00	0.044	0.006	0.00	0.036	0.00	0.00

Household current resources are farm type one (Land = 1.80, labour = 80, liquidity = 12,680), farm type two (Land = 1.60, labour = 80, liquidity = 6950) and farm type three (Land = 0.91, labour = 43, liquidity = 10,940). Farm revenue = Net farm earnings including revenue from hired out labour. In brackets are net earnings from cropping only (less labour revenue).

Table A5.2: Optimal activity/technology combination at current resource level when tea is not grown

	Farm type one			Farm type two			Farm type three		
Off-farm opportunities	None	Medium	High	None	Medium	High	None	Medium	High
Activity									
- MB-rec	0.67	1.54	1.80	0.25	1.39	1.60	0.70	0.91	0.91
- MB-cur	1.13			1.35	0.21		0.21		
- MB-man		0.26							
Farm revenue	49,103	83,540	93,869	34,418	79,558	90,150	34,499	43,655	47,365
		(72,500)	(78,698)		(65,163)	(70,750)		(40,144)	(40,144)
Shadow values									
- Land	18.1	7.03	39.4	20.0	8.02	46.5	16.6	47.9	43.8
- Labour	0.27	1.30	1.02	0.12	1.27	0.88	0.39	0.77	0.94
- Cash	0.039	0.020	0.002	0.044	0.021	0.00	0.036	0.00	0.00

Household current resources are farm type one (Land = 1.80, labour = 80, liquidity = 12,680), farm type two (Land = 1.60, labour = 80, liquidity = 6950) and farm type three (Land = 0.91, labour = 43, liquidity = 10,940). Farm revenue = Net farm earnings including revenue from hired out labour. In brackets are net earnings from cropping only (less labour revenue).

Appendix 5.2: Cropping seasons

The first season starts in January with land preparation, which spills over into February. Planting starts late February and continues into March. Weeding begins in late March, with April being the main weeding month. Top-dressing of the maize crop is done in May, and June is a relaxed month with only harvesting of beans taking place. Activity increases in July when maize harvesting for all the maize production technologies except the recommended practice is done, and land preparation for the second season begins. The maize variety used in the recommended practice takes longer to mature and so is harvested in August, and that is also when land preparation for the second season begins. Second season planting for all technologies except the recommended practice is done in August and for the recommended practice it starts late August, but mainly in September. Weeding is in September and October for all the technologies. Harvesting is done in late November and early December, but for the recommended technology it goes on up to early January. Seed and basal fertiliser are therefore required in March for all the technologies, and in August for all technologies except the recommended practice, which requires these inputs in September. Fertiliser for top-dressing is required in May for the first season crop and in October for the second season crop. For all maize technologies the highest labour requirement is in August and September when land preparation, drying, harvesting and planting are going on almost simultaneously. Figure 1 below summarises the cropping calendar for the Vihiga households.

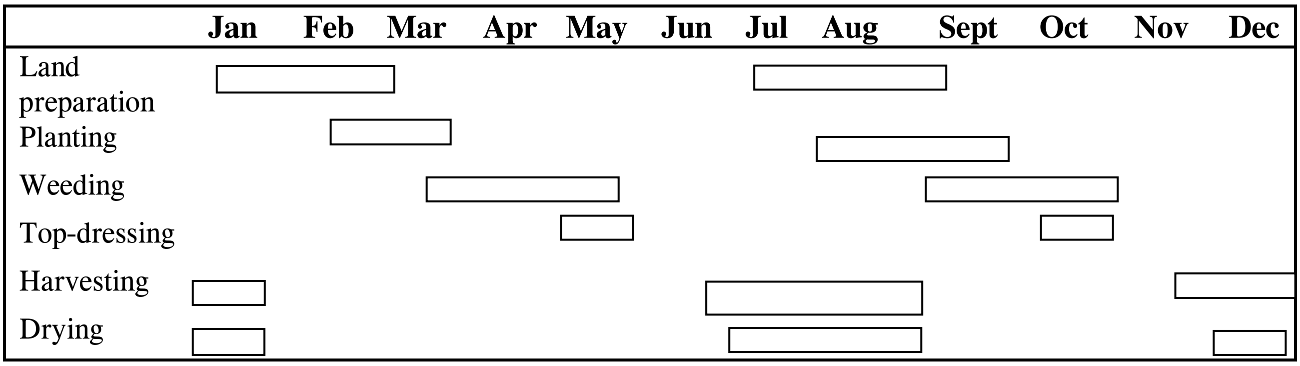

Figure A5.1: Seasonal calendar for maize and Bean production in Vihiga

Appendix 5.3: Labour requirements

Table A5.3: Seasonal labour requirements by the different activities and probability of getting hired

Season/Month	MB-rec	MB-cur	MB-fal	MB-man	Tea	Lprob
January	28.9	7.10	9.1	7.1	8.40	0.5
February	17.2	13.0	13.0	13.6	8.40	0.5
March	14.2	7.90	7.9	4.9	8.40	0.8
April	12.1	8.10	8.1	8.1	16.8	0.8
May	8.10	0	3.2	0	16.8	0.5
June	0	5.10	4.8	4.0	16.8	0.3
July	19.0	14.8	14.1	13.0	16.8	0.8
August	48.4	24.3	23.1	24.7	16.8	1.0
September	47.6	5.90	5.90	5.9	16.8	1.0
October	5.90	5.90	5.90	5.9	16.8	0.5
November	17.0	7.90	7.70	6.70	16.8	0.5
December	14.2	7.90	7.70	6.70	8.40	0.5

MB-rec = Maize and beans recommended practice; MB-cur is maize and beans current farmer practice; MB-fal = improved fallow; MB-man = manure practice; and Lprob is the probability of household labour getting hired.

Appendix 5.4: About the improved fallow

According to the information contained in Place et al (2003a), in Vihiga the fallows lasted 247 days (about eight months). The best practice is to inter-crop the trees with the long rain maize crop when the crop is maturing so that the trees do not interfere with maize performance – this is typically in May. In this study it is therefore assumed that the trees are planted in May. The maize is harvested in July/August and the trees remain on the land. This means that a second maize crop is not planted during the first year of the fallow. The eight months fallow period lasts until January when the trees are cut down and the biomass incorporated into the soil during land preparation for the next long rain season. Planting the long rain maize crop is usually done in February/March. The suggested practice is for farmers to grow maize for 3 seasons after cutting the fallow (a long rain, a short rain and a long rain, before inter-cropping the trees into the maize again. The maize and bean yields used are the sum of the three season harvests divided by two to give an average yield per year, and are as given in Rommelse, (2000) and Place et al. (2003a). The cost of maize and bean seed is not explicit (only a total cost of the inputs is given) in either Place et al., (2003a) or in Rommelse, (2000). It was assumed to be the same as the amount that the manure practice (2 kg/ha) improved maize seed, 26.9 kg/ha local maize seed and 37.8 kg/ha local bean seed.

Appendix 5.5: Labour for the improved fallow

Labour for the improved fallow is taken to be the same as that of the farmer practice except for the differences indicated. It is assumed that the households established the fallow in an existing maize field hence no additional labour for weeding. There are however three additional man-days for planting the trees assuming direct seeding is used (Place et al. 2003a). Labour for planting a maize/bean crop in the fallow system is less than that of the farmer practice because no fertiliser or manure is applied. Average planting labour as indicated by households who did not apply any fertiliser at planting is used for the improved fallow. Cutting the fallow means an extra 9.5 man-days, and the presence of stumps and roots on average means that an additional 10 md/ha is required for land preparation the season after cutting the trees. The fallow period takes two years but the input and output data are averaged over one year. During the second season when land remains fallow (not cropped) labour is saved, but so as not to interfere with labour constraint during the cropping months, all the labour for the one second season cropped is entered in the model. However to take account of the labour that is saved, half the second season labour is considered as a cost saved and entered as revenue for the improved fallow. Also considered as a cost saved is half of the labour for cutting the fallow, and half the additional labour for land preparation after cutting the fallow, because they are done in only one of the two seasons. Labour for harvesting and drying is increased or decreased by a factor of the ratio of the improved fallow yield to that of the farmer practice yield.

CHAPTER 6.

GENERAL DISCUSSION AND CONCLUSIONS

6.1 The problem

The basic subject analysed in this study is the use of soil nutrient management technologies by farm households in two regions located within the high potential areas of Kenya. Over 65% of Kenya's population live in the rural areas and rely on agriculture as their main economic base. Kenya's population is increasing and hence there is need for increased agricultural production. Meanwhile the increasing population has caused the farms to become very small due to continuous sub-division. Increasing production therefore means increasing the productivity of the land rather than area under cultivation. As a result farming has become more intensive both in terms of double cropping and inter-cropping, with hardly any fallows. Addition of soil nutrients to replace those removed by the crops is therefore paramount in order to maintain or increase productivity. However, it has been observed that households use fertiliser and other nutrient management technologies at much lower rates than considered sufficient. The crop yields are therefore much lower than potential yields. We analysed the issue of why so little fertiliser is used from various angles.

The use of fertiliser is often linked to the type of farm activities and so fertiliser use decisions are analysed alongside those of major crop outputs.

This chapter synthesises the preceding chapters by discussing the data used in the analysis, the methodologies followed and how the results of each method motivated the next approach. Section 6.2 synthesises the data, whereas in section 6.3 the methodological approaches and their results are discussed. The two regions investigated are compared in section 6.4 and innovative aspects of the study are outlined in section 6.5. Lastly, the policy implications are discussed in section 6.6.

6.2 The data

The study uses a detailed household level data set collected from a random sample of 296 households in Kiambu and 253 households in Vihiga with more detailed data on 175 of the 253. Detailed output and input data including labour collected at individual activity level for all the main farm activities made it possible to disaggregate the analysis to activity level, instead of aggregating output as is often done (see for example Chaudhary et al., 1998). Furthermore, the disaggregation of the data to activity level made it possible to simultaneously estimate the supply functions and hence capture the interrelationships between the different crops. Detailed data was also collected on household time allocation, including time spent on off-farm activities, and this made it possible in include in the analysis (mathematical programming model) the amount of household labour that was actually available for farming rather than the common practice of considering all adult members. The problem of lack of variability that is usually expected with cross-sectional data was partly dealt with by using the relevant farm gate prices rather than the retail price at which the item was bought/sold. To this end, transport costs were carefully collected for each item and added to/or subtracted from the price. More variability particularly in fertiliser prices comes about due to the presence of many retailers, and fertiliser being packaged in many different sizes ranging from 500 g to 50 kg (see Chapter 3). An assurance that the markets work is demonstrated in the Vihiga sample where the maize producer price (Chapter 3) is exactly the same as the maize consumer price (Chapter 5). The elasticities obtained in the analysis are comparable to those obtained in other studies that use time series data, showing the reliability of the current data set.

6.3 The methodological approaches and results

6.3.1 The dual approach

It was hypothesised that the price of fertiliser and output prices play a major role in the low level of fertiliser used by farm households. A standard production model was therefore used to investigate the role of price and other factors on the level of fertiliser used. Usually, in developing economies with market imperfections and transaction costs, a non-separable household model is recommended for analysing the farm production structure. However, the existence of a competitive fertiliser market and a market for outputs including food crops in the study areas made the adoption of a profit function plausible (see Chapter 3). Ranking of farm activities using farmers' perceptions and household farm data ensured that crop outputs included in the dual model are those most important to the households, namely; maize, potatoes, and kale. The perennial crop tea, though important, is not included in the dual model because only 13.5% of the households grow it. The dual model used in the analysis is that of restricted profit functions. Hotelling's Lemma was used to derive the input and output functions from the normalised quadratic profit function, and homogeneity and symmetry conditions were imposed. Furthermore, Heckman's two-stage procedure was followed to deal with the sample selection bias caused by not all households growing kale and or using fertiliser. The data (both input and output) used in the model is that specific to maize, potatoes and kale for Kiambu, and that specific to maize for Vihiga.

On the whole the results of the dual model are consistent with economic theory. In Kiambu there is an elastic and significant relationship between the price of fertiliser and the demand for it, with an elasticity of –2.44. The price of fertiliser also has a significant impact on maize and kale outputs, giving elasticities of -0.18 and -0.02 respectively. Similarly, the prices of maize and of kale significantly influence the demand for fertiliser with elasticities of 0.90 and 0.28 respectively. The results for Vihiga are similar to those of Kiambu in that the own-price elasticity for fertiliser is -1.88, whereas fertiliser price elasticity of maize output is -0.17. Apparently maize price has a bigger impact on fertiliser demand in Vihiga than in Kiambu with an elasticity of 1.58. Notably, the own-price elasticities for fertiliser obtained in this study are comparable to those previously obtained using time series data at the national level (see Gerdin, 2002).

The results suggest that if price of fertiliser is reduced, use of fertiliser will increase. However, what is striking about the results is that though the own-price elasticity of fertiliser is very high, its impact on the output quantities is small. Moreover, the fertiliser price elasticity on kale output is much smaller compared to that of maize or potatoes. Similarly, kale price has a much smaller influence on fertiliser demand compared to maize price. This is a surprising result because the activity ranking showed that kale is the most important crop in terms of income generation, whereas maize and potatoes are grown mainly for food supply. The reverse result should have therefore been expected. We were driven to think that there is more to the results than indicated by the elasticities, and so made further investigations. First we examined how fertiliser impacted on area allocated to the different crops.

Exactly how does a change in fertiliser price impact on the output levels? Is it via a reduction of the rate of fertiliser application hence lower yields, or is it via adjustment of area under the crops? The two results, whether change in crop area, or change in rate of fertiliser application, have different environmental effects. In the one case fertiliser per acre decreases implying more nutrient depletion, and in the other case, land is left fallow to replenish nutrients or put to use by other crops that perform better under low fertiliser application. This was investigated by applying the same model as used for output supply to crop area decisions. The results show that households respond to an increase in fertiliser price by reducing area under all the crops investigated. A 10% increase in the price of fertiliser led to a 5.05%, 4.58% and 8.99% reduction in maize, potato and kale areas respectively. The increase in fertiliser price also led to a reduction in outputs of 1.66%, 0.46%, and 0.17% for maize, potatoes and kale respectively. Notably, in all the three crops the decrease in crop area is greater than the decrease in output implying that the yields (output/unit area) of these crops increased. Because the amount of fertiliser used has reduced, it must be increased use of labour that leads to increase in yields. In Vihiga, unlike Kiambu, the increase in fertiliser price has only a minor impact on crop area (reduces by 0.96%), but the output decreases by 1.71%, showing that the maize yield decreases.

The impact of price changes differed for households in the different farm types (Chapter 2). Two distinguishable groups are identified in each of the regions in terms of their response to prices. One group consists of young and educated household heads who own small farms and are quite responsive to prices, whereas another group consists of old and uneducated households who own relatively larger farms and are less responsive to prices.

Of the dual model results (crop output and crop area) however, neither explains why fertiliser price has only a small impact on outputs, nor why fertiliser price has a higher elasticity in maize than in kale output. Nonetheless the crop area regressions allude to the fact that there must be another input that limits production besides fertiliser. A primal approach discussed in the next section was therefore taken to better explain the observed effects.

The dual model had other interesting results. Although it has been suggested that there is a positive relationship between cash crops and use of fertiliser on food crops (Jaeger, 1992; Govereh and Jayne, 2003), our results are to the contrary. Results of this study (Chapter 3) show that households with high acreages under tea and or coffee tend to concentrate on these crops and pay less attention to other crops. The amount of fertiliser used on maize, potatoes and kale is significantly lower for households who have coffee than for those who do not, and potato output is significantly lower for households who grow tea and/or coffee than for those who do not grow these crops. Moreover, this result is not peculiar to the current study, Strasberg et al. (1999) obtained similar results for sugarcane and food crops in Bungoma and Kakamega districts, and for coffee and food crops in Meru and Kisii districts. The plausibility of these results is strengthened by the fact that it is true for both the regions investigated.

Maize and potatoes are substitute crops but apparently kale is a complement crop to both maize and potatoes. While this seems inconsistent with expectation due to assumed competition for the same resources among the three crops, there is a possible explanation. The complementary relationship may be because many households are actually food importers so that higher prices for food crops (maize and potatoes) induce them to grow more of the cash crop (kale) in order to buy these foods. Besides, it may also be that high prices for maize and for potatoes coincide with better market conditions so that more/better opportunities exist for marketing of kale

Results of the dual model do not show organic manures to be substitutes to inorganic fertilisers as sometimes found (see for example Omamo et al., 2002). In both regions investigated, the application of manure has a complementary relationship with fertiliser, but the coefficient is not significant. It has a positive and significant relationship with maize output both in Vihiga and in Kiambu. This result is supported by the observation that organic sources of nutrients have technical or economic problems, making them not effective substitutes for inorganic fertilisers (see Place et al., 2003b; Palm et al., 1997). Moreover, in the study areas nitrogen and phosphorus are the principal constraints to yield increases (Shepherd and Soule, 1998), and organic sources contain negligible amounts of phosphorus, which therefore needs to be provided by inorganic fertilisers. Consequently, many of the organic sources are effective complements to inorganic fertiliser (Buresh et al., 1997).

6.3.2 The primal approach

The dual model result showed that fertiliser price has only a small impact on outputs and that the impact is bigger on maize than on kale output. We found this result rather surprising because kale is a cash crop and households tend to apply fertiliser more on cash crops than on food crops (see De Jager et al., 1998). A primal approach was therefore taken, seeking to unravel these observations. Response of the three crop outputs to four key inputs (crop area, manure, fertiliser and labour) was estimated in a quadratic production function. The obtained results are consistent with theoretical expectations. For example, all the linear terms except crop area and fertiliser in the kale equation are positive. Furthermore, monotonicity conditions are not rejected, as marginal products to all the four inputs for all the crops are positive. This is true for both the regions investigated.

The primal results help explain why the impact of fertiliser price on kale output was so low for the Kiambu households. They show that fertiliser is in fact important in the production of both kale and maize as shown by the marginal value product for fertiliser of ksh. 154 in kale and ksh. 146 in maize. The results, however, also show that kale output is very sensitive to labour. Further, there is a positive relationship between labour and fertiliser i.e. the marginal physical product of fertiliser in kale is higher when more labour is used. But the marginal value product for labour in kale production is very high compared to the wage rate (ksh. 373 versus 98.5) implying a labour market imperfection. It appears that labour is a limiting factor, which may be the reason for low fertiliser price elasticities in kale output obtained in the dual model. Additional fertiliser means more labour, yet labour is not available. Both maize and potatoes are less sensitive to the labour input (the coefficient in both crops is not significant) and the marginal value product of labour is much lower (ksh. 114 in maize and 155 in potatoes). In addition, the relationship between the marginal productivity of fertiliser and labour in maize is negative. Kale is more labour intensive than both maize and potatoes, as it requires constant picking to enable new leaves to grow.

An examination of the intensity of input use by the different outputs supports the dual model results of lower fertiliser impact on kale than on maize and potato outputs from another angle. Kale uses fertiliser more efficiently than both maize and potatoes, showing that when the price of fertiliser increases, a rational farmer diverts the fertiliser from maize and potatoes to kale, and hence a seemingly lower response for kale.

The positive marginal products for all inputs obtained in the primal model combined with the dual model results on prices (input price negative in both input and outputs equations, and output prices positive both for fertiliser demand and own output supply) confirm that the households have profit maximising behaviour. However, the primal approach shows another interesting result; the marginal value products for fertiliser are not commensurate with the price of fertiliser. The marginal value products for fertiliser in all the three crops are about 5 times larger than the price of fertiliser in Kiambu and over 2.5 times larger in Vihiga. This finding concurs with that of Karanja et al. (1999), on the productivity of maize, where they found that for every Kenya shilling spent on maize fertiliser, households got back ksh. 5.86 in value of maize output. Apparently, households find fertiliser more expensive than the market price indicates, because they possibly consider credit constraints and other costs like waiting and higher labour costs and risk. This result is true both for Kiambu and Vihiga households.

However, the same result on labour is different for the two regions. For Kiambu, the marginal value product for labour is still far above the market wage rate in the production of kale as already mentioned and it is lower but still above the wage rate in maize and potatoes. Interestingly, for Vihiga labour is not a constraint, in fact, the marginal value product is far below the wage rate (ksh. 16 versus 50.5), indicating that a reduction of paid labour will increase profit. This is strengthened by the fact that maize output is not sensitive to the level of labour. Neither the linear term of labour, nor the quadratic term is significant in the production function. The results mean that the market wage is far above the household's shadow wage. This implies some form of involuntary unemployment for the available household labour.

The optimal rate of fertiliser application for maize was derived from the primal model results, and they are comparable to the existing recommendations for both regions investigated, again showing that the current data set is reliable. For Kiambu we obtained an optimal fertiliser rate of 160 kg/ha of DAP, whereas the current recommendation is 200 kg/ha of NPK (20:20:0). The rate obtained for Vihiga is 165 kg/ha DAP and the current recommendation is 130 kg/ha DAP plus 141 kg/ha CAN. Most of the interviewed households do not top-dress the maize so an optimal rate for CAN could not be derived. The differences in the rates are due to the fact that the current study puts into consideration the other input levels available to the household, while the research recommendation considers fertiliser singly, assuming other inputs e.g. labour are at the optimum levels. The current results should therefore be more relevant to the farmers' conditions.

Because the households' shadow price for fertiliser is far above the market price, and we think that it is partly due to a liquidity constraint during the cropping season, we again made further investigation on how liquidity influences the households' technology choices. This was investigated in a mathematical programming set up for Vihiga (see next section).

6.3.3 The mathematical programming approach

Combined results of the dual and primal model showed that households find the price of fertiliser to be higher than the market price. We then hypothesised that this was partly due to credit constraints, considering that they have to pay for the fertiliser in advance of harvest. We therefore decided to investigate how much liquidity matters to the households' choice of soil nutrient technologies in one of the study regions (Vihiga). A non-separable household model was opted for to ensure that the expected link between household demand and supply of labour is captured. A link between the households' labour demand and supply was suspected because of the primal model result that labour was being applied far above the economic optimum level in Vihiga. The model was specified in a mathematical programming procedure that allowed for discrete choices among the technologies. Four soil nutrient management technologies applied on a maize/bean inter-crop, with production of a cash crop, tea, as a fifth technology were specified. The models were calibrated and solved using the General Algebraic Modelling System (GAMS).

The investigations were done for the three household types, obtained from the clustering procedure. Farm type one consists of households with relatively large farm size (1.80 acres), medium relative liquidity level (ksh. 12680) and a lower relative monthly labour force of 80 man-days. Farm type two has medium farm size (1.60 acres), relatively low liquidity level (ksh. 6950) and a relatively large monthly labour force (80 man-days). The third farm type includes households with small farm sizes (average 0.91 acres), relatively high liquidity (ksh.10,940) and a relatively medium monthly labour force of 43 man-days.

The results of the programming model confirm our hypothesis that households are liquidity constrained. They cannot at the current liquidity level commit all their land to the most profitable technology (recommended fertiliser levels). When there are no off-farm job opportunities, households in farm type one (largest farm size) require their current liquidity levels to more than double and that of farm type two (lowest liquidity level) to more than triple for them to adopt the recommended practice. The level of liquidity constraint varies based on the level of external remittances relative to farm size. For farm type three, which has the highest relative level of liquidity, the potential farm revenue declines by only 11% due to the liquidity constraint, whereas that of farm two, which has the lowest liquidity, declines by 48%, and that of farm type three declines by 30%.

Non-farm activities create additional income that can substitute for failing credit markets (Reardon et al., 1997b). The results show that the most constrained households (farm type two) can increase their farm revenue by 144% when they have an opportunity to hire out all their excess labour compared to when they cannot hire out any labour. That of farm type three, which is the least liquidity constrained, can increase by 31% and that of farm type one by 71%.

Another important result of the programming model is that households with low remittances are currently allocating their resources most optimally. This group, represented by households in farm type two and to some extent in farm type three, represents the majority of the households in Vihiga (see Chapter 2). Farm type two's current resource allocation is most optimal given their resources levels. Farm type three's is nearly optimal though they slightly deviate from the best solution. This result also confirms our assumption in using the dual model that households have a profit maximising behaviour, and is a further confirmation of the existing view that farm households are rational in their farming decisions.

Additionally, an important result from the programming model is that given the current land and liquidity levels, households in Vihiga do not require hired labour for farm activities. Their currently available household labour is sufficient. Moreover, the household labour is fully employed on the farm only two months in a year when farm activities are at their peak. This is a confirmation of the primal model result that labour is currently being applied at a higher than optimal level. The higher than optimal labour input is explained by the fact that there is more labour than can be used on the farm and yet there are no off-farm opportunities, so more is used on farm work.

6.4 Comparison of Vihiga and Kiambu

Households in both regions are similar in their response to prices as seen in the results of the dual model (Chapters 3 and 4). For example they are both price elastic in their fertiliser demand and in both regions the outputs are positively sensitive to output prices, and negatively sensitive to fertiliser price. Also in both regions households find the price of fertiliser much higher than the market price as indicated by the marginal value products. Furthermore, in both regions there is a negative relationship between acreage under strict cash crops and the level of fertiliser use on other crops and/or on food crop outputs.

However, several differences are observed between the two regions. The price of fertiliser is higher in Vihiga than in Kiambu such that on average a household in Vihiga pays ksh. 100 more for a 50 kg bag of DAP fertiliser. This difference is due to mark-ups on fertiliser price caused by their relative distance from the source rather than exorbitant profits by traders (see Wanzala et al., 2001). The price difference may partly be the reason for lower fertiliser adoption rates in Vihiga compared to Kiambu. For example, 89% of interviewed households use fertiliser in Kiambu versus 78% in Vihiga, and the rate of fertiliser application on maize in Kiambu is 63 kg/ha versus 29 kg/ha in Vihiga. For both regions, poor infrastructure contributes to increasing the size of the mark-ups by increasing transportation costs and losses. There is potential to reduce farm gate prices particularly in Vihiga and western Kenya as a whole by improving the infrastructure.

In Kiambu labour is a limiting factor, especially in kale production where it is the major constraint to the output level, more than fertiliser. On the contrary, in Vihiga the available household labour is more than sufficient and fertiliser level is the major limiting factor. This difference is clear when the marginal value product of labour versus the wage rate are compared in each region (see results of primal model). To support this point further, the household data reveals that the wage rate in Kiambu is almost double that of Vihiga (ksh. 98.5 versus 50.5). Kiambu being in the vicinity of Nairobi faces stiffer competition for farm labour with off-farm activities in the city. In Vihiga, on the other hand, there is little opportunity for off-farm employment.

Lastly, the incomes from the different farm activities are much higher for Kiambu compared to Vihiga. The biggest difference is with earnings from tea and from milk. Average tea earnings for those growing in Kiambu are ksh. 36,357 versus ksh. 20,073 in Vihiga, and the average dairy earnings are ksh. 36,885 for those with the enterprise in Kiambu versus ksh. 12,257 in Vihiga. This is despite the fact that the average area under tea and the average herd size are similar in the two regions. The different dairy breeds kept in the two regions can explain the variation in the milk earnings. In the Kiambu sample, only improved dairy breeds are kept, but the Vihiga households have mainly the local Zebu. The difference in tea earnings is however difficult to explain because Vihiga actually applies a higher fertiliser rate than Kiambu. This difference must have to do with other management practices, especially tea picking, which are possibly better done in Kiambu than in Vihiga. This does not however correspond with the fact that more labour is available in Vihiga.

6.5 Innovative aspects

There are several innovative aspects in the current study:

First, the study demonstrates the importance of assessing the effect of prices not only on output and input quantities, but in combination with the effect on area allocated to the crops. Unlike what has previously been assumed, that when price of fertiliser increases the rate of application goes down, the study shows that households respond by either reducing the crop area, but maintaining the rate of application, or by reducing the rate of fertiliser application or both. In some cases the yield actually increases as the area under the crop reduces. When only impact on output is analysed and not impact on crop area, the conclusions and recommendations can actually be different.

Secondly, the study shows the importance of carefully comparing empirical results with theoretical expectations. For example, when based on observed elasticities, the price of fertiliser does not seem to have a big impact on the output quantities, particularly kale output. However, further investigation by combining the results of the dual model with actual effects from the primal model shows that, though fertiliser is important in the production of kale, labour is a constraint, making the impact of fertiliser obscure. The marginal productivity of fertiliser is high when the labour input is high but the labour is not available.

Thirdly, the study puts fertiliser in the context of prices in the right framework, and derives the optimal level of fertiliser application that is not just based on biophysical conditions, but that considers the socio-economic conditions in terms of prices and other input constraints faced by the household. Furthermore, the study shows that fertiliser is not the most constraining input in the production of kale, but labour.

The fourth contribution is the quantification of the liquidity constraint for households with varying resource levels, quantification of its impact in determining the optimal activity/technology combination, and the potential impact of easing the liquidity constraint for households with different characteristics. Moreover, it shows that the level of remittances to a household affects their work effort in farming and their willingness to take up low paying off-farm jobs vis-à-vis consuming leisure. Furthermore, the study shows the minimum farm size that allows households with specific characteristics to subsist.

Fifth, two unique empirical results: one is the importance of kale to rural households in Kiambu. No study we know of has shown this importance. In most previous studies, kale is never mentioned, but is usually considered a minor and lumped together with others as horticulture, and when an emphasis is put on horticulture it is usually flowers. On the contrary, this study shows kale to be the most important crop for income generation to farm households in Kiambu, and by extension to households in other similar places. The other empirical result is the relative importance of various inputs in the different regions. By combining the dual model and the primal model the study finds that, whereas labour is the most constraining input in one of the regions, it is in abundance in the other region, showing that different policies are required for the two regions. Kiambu is located close to Nairobi city, so the labour shortage may be due to competition between farm work and off-farm job opportunities.

The current study also demonstrates that heterogeneity of the farm households matters in their response to policy instruments. When analysis is based only on whole samples without classifying households into groups with similar characteristics, one gets average impacts that are underestimated for some groups and overestimated for some other groups, and do not represent any particular group. For the two districts we have studied, there are two distinct groups of farm households that respond quite differently to changes in prices in their production decisions.

The study also finds that the use of fertiliser is very low, and the analysis shows that this low use can be attributed to labour scarcity in Kiambu, but even more to shadow prices of fertiliser being higher than actual observed prices. The high shadow prices are attributable to liquidity constraints particularly at planting time.

Lastly, the results of this study show that currently, although there is some addition of nutrients to replace those being mined by the crops at plot level, the rate of application is far below the recommended rate, to be effective. The results therefore imply that households are not currently farming sustainably in terms of nutrient management, confirming earlier observations on the soil nutrient management debate.

6.6 Policy Implications

Several policy implications come out of the present study.

The disparity in average fertiliser price between Kiambu and Vihiga found in this study is not due to exorbitant profits by traders, but due to costs incurred during transit. Reducing distribution and other transit costs will reduce the fertiliser price at the farm level and make fertiliser use more profitable, and hence increase its use especially in regions situated further from the source. This in turn will increase productivity, reduce poverty and make systems more sustainable. An efficient transport system should therefore be a priority goal, in addition to improving the infrastructure, especially roads.

Kale makes a substantial contribution to household income in Kiambu. There is a need to look into ways and means of improving its production and marketing, as this will increase rural incomes in Kiambu and other similar places. It is important to consider the fact that kale, like many horticultural crops, is perishable, hence improved infrastructure and transportation are necessary if its marketing is to be facilitated. Development of marketing channels and provision of marketing information to households will be useful.

Labour is limiting agricultural production in Kiambu but not in Vihiga. This points to different policy implications for the two regions in terms of agricultural research. In Kiambu it is important for agricultural researchers to concentrate on technologies that are labour saving due to the competition on the labour market with off-farm activities in the nearby Nairobi city. In Vihiga on the other hand, labour intensive technologies/activities such as horticulture and dairy that are remunerative ways of employing the excess household labour may be useful. But these crops will require a ready market if households are to benefit from them.

Relaxing the liquidity constraint of households is necessary for adoption of more remunerative production technologies and alleviation of poverty. To increase smallholder access to credit, the government should invest in more informal financial institutions that have greater contact with the households. Improvement of the dairy sector in Vihiga may, if profitable, help ease the liquidity constraint. Additionally, for Vihiga and similar areas, a policy towards the creation of rural non-farm activities is most needed. A viable option is investing in rural micro industries and self-employment opportunities.

Farms in Kenya are continuing to become smaller and smaller because of the increasing population and the prevailing inheritance norms. The current study finds that if farm size were to decrease by 50%, and there are no remittances, then households similar to those of farm type three (farm sizes averaging 0.91 acres (0.37ha)) in Vihiga will not be able to meet their minimum consumption requirements from farming alone. This is true even if they were to adopt the most remunerative technology. This implies a need to look into the prevailing customs on land inheritance and subdivisions.

Suggestions for further research

It is not clear from the current study whether the labour shortage in Kiambu is because there is no labour available for hiring in, or because of a liquidity constraint during the cropping season that makes households unable to hire in labour. Further research is required to make this clear before making conclusive recommendations.

It is not clear why kale is so important in Kiambu, and not in Vihiga. Even though Vihiga is far from Nairobi, it is close to the city of Kisumu, which should provide a market for kale or other vegetables. In examining the optimal technology and activity choices in Vihiga, there was no sufficient data on kale or any other vegetable to enable its inclusion in the model. Further research on this discrepancy will be useful.

Several factors may cause the farmers' shadow price for fertiliser to be higher than the market price, e.g. credit constraint, risk and waiting costs. In this study we only investigated the credit constraint. Further investigations on the role played by other factors, for example risk, may be useful.

Main conclusions

In conclusion, increasing the level of fertiliser use will have a substantial impact on the output of all the crops analysed, as indicated by their marginal value products. This is true for both regions investigated, but with a larger impact in Kiambu. However, the study confirms previous observations that households are using much lower levels of fertiliser than is optimal.

Households are sensitive to prices in their fertiliser use decisions. Fertiliser price and output prices, particularly of maize, can be effective to stimulate households to increase their level of fertiliser use as shown by the observed elasticities. Other important factors affecting the use of fertiliser on the crops analysed are farm size and livestock ownership with a positive influence, and area under coffee, with a negative influence in Kiambu. In Vihiga the other important factors in addition to prices are farm size and education level, both with a positive influence. Organic manures have a complementary but not significant relationship with inorganic fertiliser in both regions.

In terms of response to price incentives in their demand for fertiliser, the households divide into two groups mainly defined by age, education level and farm size. The young, educated and with relatively small farms are very responsive to prices, whereas the elderly, uneducated and with relatively larger farms are less responsive to prices.

From the observed elasticities for the Kiambu sample, fertiliser appears not to have a big impact on crop outputs, particularly of kale. However, further investigations show that for increased productivity of fertiliser in kale, more labour is required, but labour is constraining, making the impact of fertiliser obscure. Secondly, kale uses fertiliser more intensively than maize or potatoes and hence when the price of fertiliser increases, less fertiliser is purchased, but it is diverted from maize and/or potatoes to kale. Otherwise fertiliser is important in the production of kale.

If the market price of fertiliser and of the outputs is considered, the results show that households could profitably increase their level of fertiliser use on all the crops examined. Apparently, however, the households' shadow price of fertiliser is much higher than the market price, and/or the outputs shadow prices are much lower than the market prices. This is because households consider other costs such as credit constraints and possibly risk. Further investigations show that households are indeed liquidity constrained. The level of the constraint varies with different household types based on the level of their external remittances relative to farm size. Relaxing the liquidity constraint for all the household types is necessary for increased use of fertiliser and adoption of the most profitable activity/technology.

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SUMMARY

In Kenya, most of the agricultural production is concentrated in the medium and high agricultural potential areas. The population of Kenya is increasing, and as a result these high potential areas are becoming more and more densely populated. Meanwhile, the increasing population implies that there is increased demand for food. Currently most of the food is locally produced and mainly from the high potential areas. Increasing agricultural production therefore means increasing land productivity on mainly small-scale farms. Low soil fertility is one of the major obstacles to increased agricultural productivity by smallholders. This is compounded by the fact that due to the population pressure, there is an increase in cropping frequencies, but with little or no addition of soil nutrients.

The increasing intensification is likely to result in serious strains on the soil in terms of nutrient depletion, leading to further reduction in yields if it is not accompanied by addition of soil nutrients. In order to encourage farm households to increase their use of soil nutrient replenishing technologies, and hence their agricultural production, it is important to understand their resource limitations and other factors that influence their farming decisions. Understanding these factors and limitations will help policymakers and development agencies to provide sufficient and appropriate institutional support, and design policies that lead to improved soil nutrient management

This study investigates why farm households use so little fertiliser and yet its use has been shown to be profitable. It further examines how this low use of fertiliser impacts on productivity and household objectives of smallholders in Kenya. The investigations are carried out in two regions, Vihiga district of Western Kenya, and Kiambu district of Central Kenya. Both of them fall within the high agricultural potential, high population density areas, but are different in their socio-economic characteristics such as market access, and their socio-cultural backgrounds. A cross-sectional household level data set collected through a formal survey using pre-tested structured questionnaires is used for the analysis. Various methodological steps are employed to increase the reliability of the information generated and to arrive at clear and reliable conclusions.

Households are known to be heterogeneous in their resource endowment, their objectives and their access to markets and other institutions. Their response to technologies and policy incentives are therefore different. To deal with the heterogeneity issue, descriptive statistics, cluster analysis and fuzzy clustering are employed in **Chapter 2** to classify the sample into groups of households with similar characteristics, referred to in this study as farm types. The classification yielded three groups in each of the two study

districts. Several variables are used in the clustering, but the classification is mainly driven by farm size, age of the household head and education level of the household head. The first group consists of elderly and educated household heads who own medium size farms. The second group consists of elderly and uneducated household heads who own relatively large farms, whereas the third group is composed of young and educated household heads with the smallest farm sizes. Interestingly, similar groups (with similar characteristics) are obtained for both regions investigated. The fuzzy clustering adds value to the characterisation process through group membership values assigned to each household. Membership values are particularly useful for household modelling purposes where, instead of modelling a non-existent average household, the model can be based on households that best fit the groups they belong in i.e. those with high membership values. The farm types generated form a basis for analysis in subsequent chapters.

Understanding what influences household decisions on fertiliser is key to formulating policies that encourage households to increase its use. In **Chapter 3** fertiliser use decisions are analysed alongside decisions on crop outputs (maize, potatoes, kale). These crops are the most important to the households as identified through a ranking process based on farmer perceptions and restricted activity profit. Kale, a green vegetable of the cabbage family, but whose leaves do not form a head, is the most important crop in terms of income generation. This is an outcome that was rather surprising because kale is considered a minor crop and in analyses is usually lumped together with others as horticultural crops. It was similarly surprising that tea was not among the three most important crops to the households in Kiambu. Though tea generates high income for the households that grow it, it is grown by only 13.5% of the sample. This is possibly due high initial investment costs coupled with the fact that benefits will not be forthcoming until two to three years after planting.

The analysis was done using a normalised quadratic profit function and Hotelling's Lemma was applied to derive the input and output equations. Heckman two-step procedure and Seemingly Unrelated Regression (SUR) are used in the estimation. Results show that demand for fertiliser is responsive both to its own price and to output prices with elastic own price demand. They suggest that if the price of fertiliser is decreased and/or output prices increased, use of fertiliser will increase. For both regions investigated, households in the different farm types differ in their response to prices, with the farm type comprising young and educated household heads, with small farm sizes being the most responsive. Unlike other findings, the results of this study show that households with a large area under traditional cash crops (tea and coffee) tend to concentrate on them and hence use less fertiliser on other crops. Furthermore, the results reveal that maize and potatoes are substitute crops but kale is a compliment to both of them. Organic manures act as complements to inorganic fertilisers. It is notable that although the quantity of fertiliser used increases with farm size, the rate of application (kg/ha) reduces. Other important variables explaining fertiliser use are livestock numbers with a positive impact in Kiambu, and education level with a positive impact in Vihiga.

An increase in fertiliser and output prices may impact on crop outputs either through a reduced rate of fertiliser application that leads to low yields, or through adjustment of the crop area. In **Chapter 4** the same model used for crop outputs in Chapter 3 is applied to crop area to investigate the impact fertiliser price has on crop area allocation. Households respond to increases in fertiliser price not only by reducing the rate of fertiliser application, but also by reducing area under all the three crops investigated. In Kiambu it results in an increase in crop yields, possibly due to increased rate of use of other inputs, but in Vihiga the yield of maize declines. Similarly, an increase in output prices leads to an adjustment in crop area. For example, an increase in the price of potatoes leads to a decrease in area under maize and vice versa. Increase in kale price on the other hand leads to an increase, both in area and production of all the crops.

We also examined the impact of a change in prices on household restricted profit and find that among the outputs in Kiambu, kale price has the greatest impact as expected, whereas among the input prices the wage rate has the greatest impact. In Vihiga the price of maize has the greatest impact on the household profit.

Simulations with the dual model showed that though the effect of fertiliser price on outputs is statistically significant, the impact on output levels, especially on kale output, is small. This seemed surprising because kale is a cash crop and maize and potatoes are food crops. Further analysis, however, shows that kale uses fertiliser more efficiently than do maize and potatoes, so that, when the fertiliser price increases, less fertiliser is purchased, but it is diverted from maize and potatoes to kale. Hence the small impact of fertiliser price on kale.

To explain the results of the dual model further, and present a clearer picture of the estimated effects we also take a primal approach where a quadratic production function is estimated. The results of the production function comply with monotonicity conditions. The production of kale is very sensitive to the labour input as shown by a high significance level, but the fertiliser input is not significant. By taking the first derivative of the production function with respect to fertiliser and to labour, the marginal productivity of the two inputs is calculated. The results show that fertiliser is currently applied at a much lower level than is optimal. Interestingly, both fertiliser and labour have very high marginal value products in kale production, indicating that the households' shadow price for these inputs is much higher than the market price/wage. The results further show that the marginal productivity of fertiliser in kale is higher when more labour is used. But due to labour market imperfections, labour is possibly not available for hiring in, which may be partly the reason why fertiliser price has only a small impact on kale output. The optimal fertiliser application rates in maize are derived given other input levels, and the obtained rates are comparable to the existing recommendation.

The marginal value product for fertiliser in Vihiga is also higher than the market price, though comparatively lower than that of Kiambu. A major difference however is in the marginal productivity of labour, which for Vihiga maize production is much lower than the wage rate, implying that the households' shadow wage is much lower than the market wage. This is attributed to lack of off-farm opportunities to absorb the excess household labour.

That the marginal value products for fertiliser are higher than the market price implies that households are considering other costs that we do not observe. One of the costs may be due to a liquidity constraint during the cropping season. In **Chapter 5** we therefore investigate how much liquidity matters to the households in one of the regions in determining their activity/technology choices. Four soil nutrient management technologies are considered in relation to a maize/bean inter-crop for each of the farm types, with production of tea being the fifth technology. A non-separable household model where production and consumption decisions are inter-dependent is used for the investigations. The results show that all the three farm types in Vihiga are liquidity constrained, with the level of the constraint varying across the farm types. Some households require their current liquidity level to triple to adopt the most profitable technology.

We then explore the possibility of increasing farm revenues through a re-allocation of the currently available household resources. We find that households in farm type two (those with the lowest liquidity level) are currently allocating their resources optimally. Farm type one (largest farm size, medium remittances and low labour) can slightly improve on their allocation, whereas farm type three (smallest farm size, high remittances, medium labour) deviates considerably from the optimal allocation. Moreover, the results confirm the theory of the drudgery-averse peasant in that those in need of extra income (who have lower remittances) work more and consume less leisure than those with higher remittance levels. Possibilities of off-farm jobs will have a large impact on farm revenues and on the cropping patterns, particularly for households in farm type two.

Another important result in Chapter 5 is that given the current resource levels (land and remittances), households in all the three farm types of Vihiga do not need hired labour for farm work, implying that agricultural off-farm opportunities are rare in the area. Lastly, in Chapter 5 we also show that if farm size were to be reduced by half, households with the smallest farm size (farm type three) would no longer be able to subsist on farming alone.

In **Chapter 6** the data used, the methodologies followed and their results are synthesised and discussed. It shows how the results of one approach motivated the next approach. On the whole, results of all the chapters combine to give a good picture of the key factors that influence household decisions on use of fertiliser on the various activities. Fertiliser is important in the production of all the crops analysed, but is used at a much lower than optimal level. This low use is because households are liquidity constrained and hence their implicit fertiliser price is much higher than the market price. Also, increased productivity of fertiliser requires that more labour is used, but labour for hiring in is not available in sufficient amounts.

The main policy implications are that kale, a vegetable, is very important in generating farm income for the Kiambu households and hence improving its production and marketing is attractive. Improving the infrastructure and transport system will increase fertiliser use in areas far from the source. In terms of encouraging households to increase their level of fertiliser use, there is a need to target two different types of households: the young and educated with small farms who are quite responsive to prices, and the elderly and uneducated, with relatively larger farms who are not very responsive to prices. Relaxing the liquidity constraint is in all cases necessary for increased use of fertiliser.

DUTCH SUMMARY (NEDERLANDSE SAMENVATTING)

In Kenia is de meeste landbouwproductie geconcentreerd in de middel- en hoog-potentiële landbouwgebieden. De populatie in Kenia groeit, waardoor de hoog potentiële landbouwgebieden dichtbevolkt raken. Daarnaast betekent een groeiende populatie ook een groeiende vraag naar voedsel. Momenteel wordt het merendeel van het voedsel lokaal geproduceerd in de hoog-potentiële gebieden. Een toename in landbouwproductie leidt daarom tot een toename in de productiviteit van met name kleinschalige boerenbedrijven. De weinig vruchtbare grond is één van de grootste obstakels voor een verhoogde productiviteit op de kleine boerenbedrijven. Dit wordt nog gecompliceerd door het feit dat door de bevolkingsgroei de oogstfrequentie omhoog gaat, terwijl er weinig of geen toevoeging aan bodemnutriënten is.

De toenemende intensivering zal de bodem uitputten, hetgeen zal leiden tot een afname in de opbrengsten als er geen bodemnutriënten toegevoegd worden. Het is belangrijk om een indruk te hebben van tekorten aan middelen en andere factoren die invloed hebben op de belissingen die boeren nemen. Met deze kennis is het beter mogelijk de boeren aan te sporen om meer gebruik te maken van technologieën waarmee hun grond verrijkt kan worden, zodat hun productie kan toenemen. Deze kennis zal ook beleidsmakers en ontwikkelingsorganisaties helpen om voldoende en geschikte institutionele support te bieden en beleid te ontwikkelen dat zal leiden tot beter gebruik van de bodemnutriënten.

Deze studie onderzoekt waarom boeren weinig mest gebruiken, terwijl het gebruik daarvan aantoonbaar profijtelijk is gebleken. Er wordt ook onderzocht in hoeverre het lage mestverbruik de productiviteit en de doelstellingen van de kleine boerenhuishoudens in Kenia beïnvloedt. Twee regio's in Kenia zijn onderzocht: Vihiga, een district in West Kenia en Kiambu, een district in centraal Kenia. Beide regio's vallen onder de gebieden met een hoge bevolkingsdichtheid en hoog-potentiële landbouwgrond. De gebieden verschillen echter in sociaal-economisch opzicht, zoals de toegang tot de markt en sociaal-culturele achtergrond. Voor de analyses is gebruik gemaakt van een dataset, die is verzameld middels een survey onder landbouwhuishoudens waarvoor een vooraf geteste vragenlijst is gebruikt. Om de betrouwbaarheid van de informatie te verbeteren en om duidelijke en

betrouwbare conclusies te trekken, zijn verschillende methodologische stappen ondernomen.

Het is bekend dat huishoudens heterogeen zijn in hoe ze met hun inkomsten omgaan, in hun doelstellingen en in hun toegang tot markten en andere instellingen. Daarom is hun reactie op technologieën en aanmoedigingsbeleid verschillend. Om meer inzicht te krijgen in dit heterogeniteitsprobleem worden in **Hoofdstuk 2** beschrijvende statistieken gegeven en een cluster analyse en fuzzy clustering uitgevoerd. Met deze analyses wordt de steekproef geclassificeerd in huishoudensgroepen met dezelfde eigenschappen, die in deze studie boerderijtypes genoemd worden. De classificering resulteerde in drie groepen in elk van de twee districten. Hoewel verschillende variabelen in de clustering gebruikt zijn, is de classificering vooral gebaseerd op boerderij-grootte, leeftijd van het hoofd van het huishouden en opleidingsniveau van het hoofd van het huishouden. De eerste groep bestaat uit oudere en opgeleide hoofden van het huishouden die een middelgrote boerderij bezitten. De tweede groep bestaat uit oudere niet-opgeleide hoofden van het huishouden die een relatief grote boerderij bezitten. De derde groep is samengesteld uit jonge en opgeleide hoofden van het huishouden die de kleinste boerderijen bezitten. Het is interessant dat voor beide onderzochte regio's dezelfde groepen (met vergelijkbare eigenschappen) gevonden zijn. Door de toekenning van waarde van groeplidmaatschap aan elk huishouden, geeft de fuzzy clustering meerwaarde aan het indelingsproces. De waarden van groepslidmaatschap zijn vooral bruikbaar bij het modelleren van de doelstellingen van het huishouden, waar in plaats van een niet-bestaand gemiddeld huishouden, het model gebaseerd kan worden op huishoudens die het best passen bij de groep waar ze toe behoren (de groep met hoge waarden voor lidmaatschap). De geformuleerde boerderijtypes vormen de basis voor de analyses in de volgende hoofdstukken.

De sleutel tot het formuleren van beleid dat huishoudens aanmoedigt meer mest te gebruiken, is het begrijpen van zaken die invloed hebben op de beslissingen van het huishouden ten aanzien van mestverbruik. In **Hoofdstuk 3** worden mestverbruik tezamen met de beslissingen ten aanzien van gewasopbrengsten (maïs, aardappelen en kool) geanalyseerd. Gebaseerd op een ranking van de percepties van de boer en de gelimiteerde opbrengst van activiteiten, blijken deze gewassen het belangrijkst te zijn voor de huishoudens. *Sukuma wiki*, een groene koolsoort waarvan de bladeren geen krop vormen, is het belangrijkste gewas in termen van opbrengst. Dit is een verrassende uitkomst, aangezien dezekool als een mindere soort beschouwd wordt en het in analyses vaak over één kam geschoren wordt met andere tuinbouwgewassen. Het is ook verrassend dat in de huishoudens in Kiambu thee niet tot de drie belangrijkste gewassen behoort. Hoewel thee een hoog inkomen genereert voor de families die het verbouwen, wordt het bij slechts 13,5 procent van de steekproef verbouwd. Dit komt waarschijnlijk door de hoge initiële investeringskosten en het feit dat er pas na twee of drie jaar na aanplant inkomsten gegenereerd kunnen worden.

De analyse is uitgevoerd door gebruik te maken van een kwadratische productiefunctie en het toepassen van Hotelling's Lemma voor het verkrijgen van input- en outputvergelijkingen. Heckman's tweestapsprocedure en Seemingly Unrelated Regression (SUR) zijn gebruikt voor de schattingen. De resultaten laten zien dat de vraag naar mest bepaald wordt door de prijs van mest en de output-prijzen, met een elastische vraag naar de prijs van mest. Dit suggereert dat als de prijzen van mest afnemen en/of de prijzen van output toenemen, het gebruik van mest zal toenemen. In de beide onderzochte regio's verschillen de boerderijtypes in hun reactie op prijzen, waarbij de sterkste reactie komt van het boerderijtype dat bestaat uit jonge en opgeleide hoofden van het huishouden met kleine bedrijven. In tegenstelling tot andere bevindingen, toont deze studie aan dat huishoudens met veel grond met traditionele exportgewassen (zoals thee en koffie) zich concentreren op deze gewassen en daarom minder mest gebruiken voor de andere gewassen. Verder laten de resutaten zien dat maïs en aardappelen substituten zijn, terwijl *sukuma wiki* een complementair goed voor maïs en aardappelen is. Organische mest is een complementair goed voor niet-organische mest. Het is opmerkelijk dat hoewel de hoeveelheid mest toeneemt met boerderij-grootte, de hoeveelheid toegevoegde mest per hectare (kg/ha) afneemt. Andere verklarende variabelen zijn de hoeveelheid dieren op de boerderij, hetgeen positief gerelateerd is aan mestverbruik in Kiambu en opleidingsniveau dat positief gerelateerd is aan het mestverbruik in Vihiga.

Een verhoging van prijzen van kunstmest en van outputs kan gewasopbrengsten beïnvloeden, of door verlaging van kunstmestgebruik dat leidt tot lagere oogsten, of door aanpassing van de gewasoppervlakte. In **hoofdstuk 4** is hetzelfde model als gebruikt voor gewasopbrengsten in hoofdstuk 3, toegepast op gewasareaal, om de invloed van kunstmestprijs op toewijzing van arealen aan gewassen te onderzoeken. Huishoudens reageren niet alleen op verhogingen in kunstmestprijs door minder kunstmest toe te dienen, maar ook door de arealen van alle drie de bestudeerde gewassen te verkleinen. In Kiambu resulteert dit in hogere hectareopbrengsten, misschien door een verhoogd gebruik van andere inputs, maar in Vihiga nemen maïsopbrengsten per hectare af. Op dezelfde wijze leiden hogere outputprijzen tot aanpassingen in gewasoppervlakte. Hogere aardappelprijzen leiden bijvoorbeeld tot een verkleining van maïsareaal, en hogere maïsprijzen tot een verkleining in aardappelareaal. Een verhoging van de koolprijs leidt aan de andere kant tot toenames zowel in areaal als ook in productie van alle gewassen.

Wij onderzochten ook de invloed van prijsveranderingen op winsten van huishoudens, hun variabele kosten buiten beschouwing latend. Wij vonden dat in Kiambu met betrekking tot de outputs de koolprijs zoals verwacht de grootste invloed had, en van de inputprijzen het loon de grootste invloed heeft. In Vihiga heeft de maïsprijs de grootste invloed op de winst van de huishoudens.

Simulaties met het duale model lieten zien dat, hoewel het effect van kunstmestprijs op opbrengsten statistisch significant is, de invloed op de opbrengstniveaus, vooral die van kool, klein is. Dat lijkt verbazend, omdat kool een handelsgewas en maïs en aardappelen voedselgewassen voor eigen gebruik zijn. Verdere analyse toont echter dat kool kunstmest efficiënter benut dan maïs en aardappelen, zodat, wanneer de kunstmestprijs stijgt, minder kunstmest wordt gekocht, en het gebruik op maïs en aardappels naar kool wordt omgebogen. Vandaar de kleinere invloed van kunstmestprijs op kool.

Om de uitkomsten van het duale model nader te verklaren en een duidelijker beeld van de geschatte effecten te schetsen, gebruiken we ook een primale benadering waarbij een kwadratische productiefunctie geschat wordt. De uitkomsten van deze productiefunctie voldoen aan monotoniciteitscondities. De productie van kool is gevoelig voor arbeidsinput, hetgeen blijkt uit een hoge significantiegraad, maar kunstmesttoevoer is niet significant. De marginale productiviteit van kunstmest en arbeid is berekend door de eerste afgeleide van de productiefunctie met betrekking tot beide inputs te nemen. De uitkomsten tonen dat het huidige niveau van kunstmesttoediening onder het optimale ligt. Interessant is, dat zowel kunstmest als ook arbeid hoge marginale waarde opbrengsten hebben in de koolproductie, wat aangeeft dat de schaduwprijs van huishoudens voor deze inputs veel hoger is dan de marktprijs, respectievelijk het loon. De uitkomsten tonen verder dat de marginale productiviteit van kunstmest in kool hoger wordt wanneer meer arbeid wordt gebruikt.

Maar doordat de arbeidsmarkt imperfect is, is er misschien geen arbeid te huur. Dit kan een deel van de reden zijn waarom kunstmestprijs slechts een kleine invloed heeft op de opbrengst van kool. De optimale niveaus van kunstmesttoediening in maïs zijn afgeleid, gegeven de niveaus van andere inputs, en de verkregen niveaus zijn vergelijkbaar met de bestaande aanbeveling.

De marginale productiewaarde van kunstmest in Vihiga is ook hoger dan de marktprijs, hoewel zij lager is dan in Kiambu. Een groot verschil ligt echter in de marginale productiviteit van arbeid. Deze is voor maïsproductie in Vihiga veel lager dan de loonvoet, wat inhoudt dat het schaduwloon van huishoudens veel lager is dan de marktprijs voor arbeid. Dit komt door het gebrek aan mogelijkheden buiten het bedrijf om het arbeidsoverschot van huishoudens op te nemen.

Dat de marginale productiewaarde van kunstmest hoger is dan de marktprijs, betekent dat huishoudens andere kosten ervaren dan wij waarnemen. Een van deze kosten zouden liquiditeitsbeperkingen tijdens het groeiseizoen kunnen zijn. In **hoofdstuk 5** bestuderen wij daarom hoe belangrijk liquiditeit is voor de huishoudens in een van de gebieden voor hun activiteit/technologiekeuzes. Vier technieken om voedingsstoffen in de bodem te beheren zijn voor elk van de boerderijtypes onderzocht in relatie tot een gelijktijdige mengteelt van maïs en bonen, met theeproductie als vijfde techniek. Een niet-separeerbaar huishoudensmodel waar productie- en consumptiebeslissingen onderling afhankelijk zijn is gebruikt voor het onderzoek. De uitkomsten tonen aan, dat alle drie boerderijtypes in Vihiga qua liquiditeit beperkt zijn, waarbij de mate van beperking varieert tussen de boerderijtypes. Van sommige huishoudens zou het liquiditeitsniveau moeten verdrievoudigen voordat zij de meest winstgevende technologie kunnen toepassen.

Wij hebben de mogelijkheden onderzocht om landbouwopbrengsten te verhogen door een herbestemming van de nu beschikbare hulpbronnen van de huishoudens. Wij vinden dat huishoudens in het boerderijtype twee (die met het laagste liquiditeitsniveau) hun hulpbronnen nu optimaal toewijzen. Boerderijtype een (grootste boerderijen, middelmatig bijdrageniveau van gemigreerde verwanten, lage beschikbaarheid van arbeid) kunnen hun toewijzing iets verbeteren, terwijl boerderijtype drie (kleinste boerderijen, hoog bijdrageniveau van migranten, middelmatig in arbeid) aanzienlijk afwijkt van de optimale toewijzing. Bovendien bevestigen de uitkomsten de theorie van de gesloof- afkerige boer in dat zij die extra inkomen nodig hebben (die minder bijdragen van gemigreerde verwanten krijgen) meer werken en minder vrije tijd gebruiken dan degenen met hogere bijdrageniveaus. Arbeidsmogelijkheden buiten de boerderij zullen een grote invloed hebben op inkomsten uit het bedrijfen op teeltpatronen, vooral voor huishoudens in boerderijtype twee.

Een andere belangrijke uitkomst in hoofdstuk 5 is dat onder de huidige hulpbronnenniveaus (land en bijdragen van migranten), huishoudens in geen van de drie boerderijtypes in Vihiga agrarische loonarbeid nodig hebben, wat inhoudt dat landbouwmogelijkheden buiten de eigen boerderij in de regio beperkt zijn. Tenslotte tonen wij in hoofdstuk 5 ook aan, dat wanneer boerderijgrootte gehalveerd zou worden, huishoudens met de kleinste boerderijen (boerderijtype drie) niet meer in staat zouden zijn om van landbouw alleen te leven.

In **hoofdstuk 6** worden de gebruikte data, de gevolgde methoden en hun uitkomsten samengevoegd en besproken. Het laat zien hoe de uitkomsten van de ene benadering hebben aangezet tot de volgende benadering. In totaal geven de uitkomsten van alle hoofdstukken same`n een goed beeld van de kernfactoren die huishoudensbeslissingen over kunstmestgebruik op gewassen beïnvloeden. Kunstmest is belangrijk voor de productie van alle geanalyseerde gewassen, maar het gebruiksniveau ligt onder het optimum. Dit lage gebruik komt doordat huishoudens liquiditeitsbeperkingen kennen waardoor hun impliciete kunstmestprijs hoger is dan de marktprijs. Bovendien vereist een hogere productiviteit van kunstmest dat meer arbeid wordt gebruikt, maar er zijn niet voldoende arbeidskrachten beschikbaar.

De belangrijkste beleidsimplicaties zijn dat *sukuma wiki*, een koolgroente, zeer belangrijk is voor de landbouwinkomsten van huishoudens in Kiambu, en daarom is het verbeteren van de mogelijkheden voor productie en verkoop ervan aantrekkelijk. Verbetering van infrastructuur en transportsysteem zal kunstmestgebruik in ver van de bron gelegen gebieden verhogen. Om huishoudens aan te moedigen meer kunstmest te gebruiken moeten twee doelgroepen worden onderscheiden: de jonge, opgeleide met kleine boerderijen die vrij sterk reageren op prijzen, en de oudere, niet opgeleide met betrekkelijk grotere boerderijen die niet sterk reageren op prijzen. De liquiditeitsbeperking verminderen is in alle gevallen noodzakelijk voor verhoogd kunstmestgebruik.

Completed training and supervision plan

Name of the course	Department/ Institute	Year	Credits
I. General part			
Techniques for writing and presenting a scientific paper	Mansholt Graduate School (MGS)	2003	1
Time planning and Project management	Graduate school of Production Ecology and Resource Conservation (PE&RC)	2003	1
II Mansholt Specific part			
Mansholt Introduction course	Mansholt Graduate School	2003	1
Multi-disciplinary seminar	Mansholt Graduate School PhD day	2004	1
Operational Tools for Regional Land-use Analysis: A hands on course.	Graduate schools of PE&RC and MGS	2001	2
III. Discipline-specific part			
Bio-economic Modelling	Mansholt Graduate School	2002	1
Econometrics 2	Wageningen University - General Economics group	2001	4
Farm household economics	Wageningen University - Development Economics group	2001	4
Information and decision making in Agriculture	Wageningen University - Business Economics group	2001	4
Current issues in Development Economics	Netherlands Network of Economics (NAKE)	2003	2
Efficiency and Productivity Analysis – Non-parametric Approaches	Mansholt Graduate School	2003	2
Presentations at international conferences:			
Paper presentation	2ND Development Dialogue, Institute of Social Sciences (ISS)	2004	1
Poster presentation	European Association of Agricultural Economists (EAAE) 85th Seminar, Florence, Italy	2004	1
Total (min. 20 credits)			**25**

1 credit represents 40 hours.

Curriculum vitae

Beatrice Dorna Sakwa Salasya born in Mumias, Kenya on 29th June 1958 is a graduate of Nairobi University where she obtained a BSc degree in Agriculture in 1986 and an MSc degree in Agricultural Economics in 1992. Before joining Nairobi University, she attended the then Egerton College (now Egerton University), where she obtained a Diploma in Agriculture with distinction.

After graduating from Egerton she worked with the Ministry of Agriculture based in Mosop division, Nandi, before embarking on the BSc training in 1983. From 1986 to date she has worked at the Kenya Agricultural Research Institute (KARI) based in the Kakamega Regional Research Centre. Between 1999 – 2000 while on a leave of absence from KARI, she worked as a research officer (Agricultural Economics) with the International Livestock Research Institute (ILRI) in Nairobi, Kenya

Beatrice was awarded a PhD scholarship through a collaborative research project between her employer (KARI), Wageningen University, ILRI, and ICRAF. The project: "*System prototyping and impact assessment for sustainable alternatives in mixed farming systems in high-potential areas of Eastern Africa" (PROSAM),* is an ecoregional project funded by the former International Services for National Agricultural Research (ISNAR). She registered for the PhD training at Wageningen University in January 2001, initially at the Laboratory of Soil Science and Geology and later transferred to the Development Economics group. During the period of the PhD study she was attached to the International Livestock Research Institute as a graduate fellow on the PROSAM project.