UNIVERSITY OF THE FREE STATE

MANAGING TRANSITIONS IN SMALLHOLDER COFFEE AGROFORESTRY SYSTEMS OF MOUNT KENYA

Sammy Carsan

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This thesis is dedicated to my children
Eddie and Talisha

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ABSTRACT

Coffee farming has been a major foundation of Kenya's rural highland economy for the last four decades or so. Over 600,000 smallholder farmers organized in 579 cooperatives are engaged in the subsector. Coffee was a major source of income, employment and food security until the late 1980's. Though Kenya produces some of the finest world coffee, the collapse of the International Commodity Agreement (ICA) on coffee and entry into the world market by major producers like Vietnam marked a near collapse of Kenya's coffee. Exports fell by over 50% between the year 2000 and 2010. This was accompanied by significant loss of productivity (declined to a meagre 200 kg/ha from 600 kg/ha). The situation has contributed to poor living standards in coffee growing areas. Interestingly, there are no credible alternative investments to merit the allocation of constrained farm resources to replace coffee growing. In addition, there are concerns that the current resource base can no longer support enhanced productivity.

This study used several research designs to investigate the performance of smallholder coffee agroforestry systems around Mount Kenya. More specifically, enterprise adoption and adaptation practices in the event of increased or decreased coffee production were researched. The evolution of coffee agroforestry systems was also evaluated and management of soil fertility determined.

Using coffee yields data obtained from 180 smallholder coffee farmers by stratified random sampling techniques, coffee farm typologies were identified. These farm typologies/categories were labeled as *increasing, decreasing* and *constant* - representing their historical trends in coffee production. These farms were then used to investigate current productivity behavior. Simple descriptive statistics such as means, range, counts, enterprise scoring, diversity analysis pair wise correlations and regressions were used to compare farmer enterprise intensification strategies. Results have showed that farms that are *decreasing* coffee production, though had smaller land sizes are not significantly different from those in the coffee *increasing* category. Further results showed similarities in farmer enterprise diversification strategies. Coffee was nonetheless declining in smaller farms compared to farm sizes where it was increasing. Results also showed that farms with increasing coffee yields are associated with productive milk enterprises. These farms appear to afford and benefit from larger amounts of fertilizer and manure application. Coffee declining farms view banana and maize as likely alternatives to coffee, perhaps in a strategy to secure household food security. The study has showed that land size, coffee production (number of bushes, cherry yields/Ha), livestock units, agroforestry trees, banana, maize value and nutrient inputs (manure and fertilizer) and labour costs are important factors to assess coffee farms productivity and distinguish farm types. Results have showed the importance of creating more awareness among policy makers in order to promote enterprises that are of interest to farmers.

This research also investigated tree diversity presently maintained by smallholders showing a shift in coffee cultivation practices. Trees on farm are traditionally appreciated for product benefits such as timber, fuel wood and food. They are also important for enhanced farm biodiversity and environmental services such as enhanced nutrient cycling. This study applied diversity analysis techniques such as species accumulation curves, rènyi diversity profiles and species rank abundance, to investigate farm tree diversity. At least 190 species were recorded from 180 coffee farms. For all the species enumerated, alpha diversity (H_0) = 5.25 and H_∞ = 0.89. Results showed that the 10 and 25 most abundant species comprise 75% and 91% of tree individuals present on farm, respectively. Results suggest that, though there is high abundance of tree individuals on farms they are of less richness and evenness. Species richness per farm was calculated at 17 species (15- 19.2, P = 0.95). *Grevillea robusta* was highly ranked in terms of relative density and dominance across surveyed farms at proportions of 41-42%. Tree species basal area distribution showed that fruit trees such as, *Persea americana, Mangifera indica* and timber species such as, *Cordia africana, Vitex keniensis* and *Croton macrostachyus* are the most dominant but are of lower relative density.

Species diversity analysis by coffee agro-ecological zones revealed that the upper-midland (UM) 3 is ranked significantly higher than UM2 and UM1. Results have implied that farmers with larger quantities of coffee (*Coffea arabica* L.) also retain more species diversity than farmers with stagnated production even though this evidence was inconclusive. Skewed patterns of species heterogeneity and structure among smallholder coffee plots provide indicators of divergent species cultivation. Tree species richness distribution between farms is strongly influenced by agro-ecological zones and presence of coffee cultivation. Only 22.5% of agroforestry tree abundance on farm was categorized as indigenous. Tree basal area ranking implied that fruit and native timber species are retained longer on coffee farms.

Finally, this study assessed the implications of recent changes in coffee cultivation on soil fertility management. It was hypothesized that significant soil nutrient exports have occurred from coffee systems and that present nutrient prevalence are unknown and likely to be poorly managed. The purpose of this research was to inform concerns that with poor soil fertility prevalence, coffee systems face a danger to deteriorate to low production systems. Near-infrared (NIR) spectroscopy was used to analyse soil constituent properties for some 189 soil samples collected on 94 farms (within coffee plots). One third of the samples were used to build calibration models giving correlation coefficients between measured and partial least square (PLS) predicted soil properties. Correlations were strong ($r > 0.70$) except for P, Zn and Na demonstrating the potential of NIR to accurately predict soil constituents. Principal component analysis (PCA) was then used to develop soil nutrient indices (principal components scores) to serve as representative soil nutrient prevalence indicators. PC scores were also used as dependent variables in regression analysis. Collected data is robust to show that soil organic C, total N and probably P were most deficient across the coffee sites surveyed.

Farmer nutrient application practices showed wide variability of fertilizer and manure use. Manure application is less than fertilizer and negatively correlated to farm size.

Estimation of manure use per household was however challenging due to quantification and timing aspects of application. Collated evidence showed that farmers with increasing coffee production were more likely to afford larger fertilizer and manure application. Overall results point out that smallholders deliberately concentrate nutrient application on farm enterprises with good market performance. Coffee cultivation has in the past benefited from fertilizer credit facilities from farmer cooperative movements and government bilateral programmes. Declined coffee production is therefore seriously jeopardizing the amount of fertilizer that can be loaned to farmers.

In conclusion, this study has identified a number of factors associated with smallholder decision making, resource use and enterprise adoption and adaptation behavior within coffee agroforestry systems of Mount Kenya. Research findings have allowed recommendations to be made on how best to promote farmer resource use, understand farmer decision making and enterprise choices that are of interest to farmers. The study has contributed to knowledge of farmer livelihood strategies when managing coffee farms in conditions of reduced profitability.

ACRONYMS

ACPC:	Association of Coffee Producing Countries
CAFNET:	Coffee Agroforestry Network
CEC:	Cation Exchange Capacity
CBD:	Coffee Berry Disease
CBK:	Coffee Board of Kenya
CRF:	Coffee Research Foundation
CLR:	Coffee Leaf Rust
DBH:	Diameter at Breast Height
EC:	Soil Electrical Conductivity
FCS:	Farmer Cooperative Societies
ICRAF:	International Centre for Research in Agroforestry
ICA:	International Coffee Agreement
ICA:	International Commodity Agreements
ICO:	International Coffee Organization
ILRI:	International Livestock Research Institute
NIR:	Near Infrared
RF:	Relative Frequency
RD:	Relative Density
RD:	Relative Dominance
TBA:	Tree Basal Area
UM:	Upper Midland
TLU:	Tropical Livestock Units
PC:	Principal Components
PCA:	Principal Component Analysis
PCR:	Principal Component Regression
PLS:	Partial Least Square
SL 28:	Scott Laboratories, Series No. 28
SL 34:	Scott Laboratories, Series No. 34
SLM:	Sustainable Land Management

CHAPTER 1

EVOLUTION OF THE SMALLHOLDER COFFEE SUB SECTOR IN KENYA

ABSTRACT

Coffee was a major source of farm income, employment and food security in Kenya until the late 1980's. The collapse of the International Coffee Agreement (ICA) precipitated an increase in production costs leaving many farmers exposed to the double tragedy of low income and low food availability. Coffee productivity by smallholders has therefore significantly declined or stagnated and even seems unresponsive to recent high prices offered in the international market. It's clear that more supportive policies are required to shift the present situation. Additionally, the impact of climate change, manifested in prolonged droughts and unpredictable rainfall episodes is likely to affect coffee fruiting and exacerbate pest and diseases incidence. This background chapter evaluates coffee production and marketing conditions experienced by thousands of smallholder growers in Kenya.

INTRODUCTION

Kenya's coffee systems are strongly associated with coffee growing as the main source of income since the country's independence in 1963. Arabica coffee (*Coffea arabica*) was successfully brought into Kenya around 1894 from neighboring German East Africa (now Tanzania) by Roman Catholic missionaries (Waters, 1972). Coffee cultivation was however reserved exclusively for European settlers. In 1933 coffee growing by African smallholders was piloted in small areas of Kisii, Embu and Meru under strict supervision (Barnes, 1979). The Native Grown Coffee Rules of 1934 stipulated coffee growing regulations. African coffee production was in fact considered experimental. Areas in which coffee cultivation was permitted were clearly defined by the director of agriculture. The gazettement of production areas was meant to ensure quality and to some extent quantity of coffee produce (Akiyama, 1987). Until 1950 planting was restricted to the altitude range of between 1645 to 1750 m above sea level on the slopes of Mount Kenya (Waters, 1972). Presently, over 90% of Kenya’s highland arabica are cultivated at altitudes ranging between 1400 m and 1950 m above sea level (Condliffe et al., 2008).

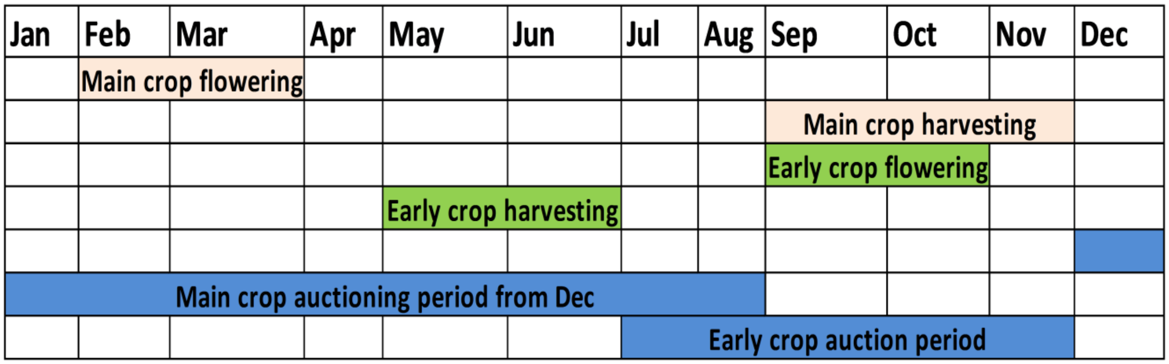
By 1952 there were about 11,864 farmers cultivating around 3,000 acres of coffee. Smallholder coffee cultivation accelerated after Kenya’s independence in 1963. Production increased at a rapid rate of 6% in the early 1960’s as some of the large estates were given up for sub-divisions to smallholders and un-favourable laws were lifted (Akiyama, 1987). Nonetheless, coffee cultivation by smallholders was by law restricted within cooperatives with government as a significant stakeholder so as to secure foreign exchange earnings and meet obligations entered into under the ICA that was politically negotiated. Coffee growing became the backbone of Kenya’s rural highlands economy. Until recently the subsector claimed to support over five million Kenyans both directly and indirectly as a result of forward and backward linkages. Coffee remained the nation’s top foreign exchange earner from independence in 1963 until 1989 when it was surpassed by tourism (Karanja, 2002). By 1978, the coffee sector accounted for 9.5 percent of GDP ($500 million in exports). By 2005, the revenues were only $75 million - a mere 0.6 percent of GDP (The World Bank, 2005). Coffee is presently ranked as the fifth foreign currency earner, after remittances from Kenyans abroad, tea, tourism and horticulture.

Unlike Ethiopia and Uganda, which are Africa's top coffee producers, Kenyan coffee output is under one percent of global production, but its beans are popular for blends and buyers have specific volume requirements (Ponte, 2002). On average, Kenya’s coffee fetches a 10% premium over standard arabica coffees from Central America and Colombia.

1.1 Coffee production

Presently, about 170,000 hectares is cultivated under coffee by over 600,000 smallholders organized in 569 cooperatives. Smallholders have farms of less than two hectares. There are 3270 estates with farms of between two to twenty hectares. Temperature extremes of less than 19 ^{o}C and well distributed rainfall favour coffee production. The rich volcanic soils in the highlands give Kenya's mild arabica coffee unique taste and aroma. Common varieties produced include: SL 28, SL 34 (Medium to high altitudes) K7 (lower altitudes) and Ruiru 11 (all altitudes) (CRF ud). The Ruiru 11 variety was introduced by the Kenya Coffee Research Foundation in 1985 as compact and disease resistant variety. The major coffee diseases in this area include coffee berry disease (CBD) (*Colletotrichum coffeanum*) and coffee leaf rust (*Hemileia vastatrix*) to a lesser extent.

In a normal year, farmers spray their crop against CBD from April. The main flowering period is between February and March while the early flowering period is September and October. The main cherry harvesting period is from September to November and early crop harvesting is during May to July (Figure 1). Coffee early auction is from July to August (Figure 1).



Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Main crop flowering										
								Main crop harvesting			
								Early crop flowering			
				Early crop harvesting							
											🟦
Main crop auctioning period from Dec											
						Early crop auction period					

Figure 1 Coffee production and auction market calendar

Changes in weather patterns related to climate change is affecting coffee flowering. Bushes are flowering when they should not and have coffee berries at different stages of maturity. This means farmers have to hire labor throughout the year to pick little quantities of coffee. Trees tend to have beans of all ages causing a problem of disease management, insect management and increased farmer harvesting costs (Reuters 2010). Further, due to the narrow range of temperature for coffee (19-25 ^{o}C) slight increases in temperature affects photosynthesis and in some cases, trees wilt and dry up especially in the marginal coffee zones. The most immediate solution recommended for farmers is to conserve whatever rainfall they receive through mulching, digging trenches to hold water, pruning, forking and planting shade trees (Reuters, 2010).

Coffee production has been on a constant decline over the past years. At independence (1963) coffee production was at 43,778 metric tonnes and rose up to 140,000 metric tonnes in 1987/88. Production has declined and stagnated at about 50,000 metric tonnes in the last few years (KNBS, 2010). The smallholder sector, which used to produce 2/3 of the quantity, is producing slightly over 50% of the current low production (Table 1). Yields have declined from approximately 600 kg/ha to below 400 kg/ha as the national average; smallholder production is indicated at about 200 kg/ha (Table 1).

Table 1 Coffee production in Kenya from year 2001-2007

	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07
Area in Hectares (Ha)						
Cooperatives	128	128	128	128	128	120.7
Estates	42	42	42	42	42	42
Total	170	170	170	170	170	162.7
Production (tonnes) ‘000						
Cooperatives	28.8	34	30	25.5	27	28.4
Estates	23.1	21.4	18.5	19.7	21.3	25.
Total	51.9	55.4	48.4	45.2	48.3	53.4
Average yield (kg/Ha)						
Cooperatives	198.8	265.8	234	199.2	211.3	235
Estates	537	509.9	439.8	469	506	595

Source: Coffee Board of Kenya cited by KNBS, 2010

An estimated 95% of the national production of coffee comes from the central parts of Kenya. In the area stretching from Nairobi to Muranga, coffee is grown in open sun plantations mostly with a small number of trees in the boundaries. Smallholder coffee systems are situated around the central highlands of Mount Kenya, in the Aberdare area, in the West of Kisii, Nyanza, Bungoma, in the Rift Valley in Nakuru, Trans Nzoia and in Taita hills, near Mount Kilimanjaro. The main production area between Mount Kenya and the Aberdare is between 1500 to 1600 m above sea level.

Open sun systems with multiple stems management is preferred as opposed to shaded coffee system to maximize yields (Kimemia, 1994). Single stem managed, shaded coffee under *Grevillea robusta* previously introduced in Kenya is not supported by formal extension services due to disease incident fears. Farmers nonetheless retain a wide variety of tree species on coffee farms such as *Grevilllea robusta, Vitex keniensis, Cordia africana, Trichillia emetica, Persea americana* and *Macadamia tetraphylla*. These species are not grown for shade coffee but rather for their various products and services.

A coffee crop takes over five years to attain full production. Production is generally labour intensive and involves appropriate land preparation, fertilizer application, pests and diseases control, irrigation, primary processing, secondary processing and facilities maintenance. To produce 400 kg/ha of clean coffee or 2870 kg/ha cherry, it costs about $531.31/ha ($ 0.181 kg of cherry) (KNBS, 2010).

1.2 Coffee marketing

Kenyan coffee is regarded as one of the best coffees in the World, traded under the ‘Colombian mild’s category. Coffee is mainly traded on the New York and London futures markets, which exert a strong influence on world coffee prices. Coffee prices are very volatile varying daily, hourly and even by the second, depending on factors such as the size of coffee stocks worldwide, weather forecast, insecure political conditions and speculation on the futures markets (ICO, 2010). Almost 99% of Kenyan coffee is exported and the domestic market only consumes less than 1% of the total coffee produced.

Coffee marketing is regulated by the Coffee Board of Kenya which also issues licenses for different categories of stakeholders in the industry including dealers, millers, roasters, packers, and warehouse license (EPZ, 2005). Coffee estates use licensed private milling and marketing agents to bring their coffee to the auction, while smallholder farmers are legally required to process and commercialize their produce through cooperatives (Mude, 2006). Farmers deliver their cherry to local factories for primary processing. Cherry for each grower is weighed and recorded. Cherry beans are sorted and pulped (coffee bean are removed from outer fruit). The beans are spread on drying beds and later stored in the form of ‘parchment coffee’.

The cooperatives and the estates then send their produce to commercial millers for milling and grading (Figure 2). Mills hull and clean parchment coffee to produce green (unroasted) coffee. The commercial millers then send graded coffee to marketing agents who prepare, classify the coffee, prepare catalogues and put a reserve price for the coffee auction through which all Kenyan coffee is sold (EPZ, 2005). The transaction between buyer and seller at the auction is often carried out on behalf of the cooperative by an agent hired by the miller. Once the coffee is sold, the miller deducts his share of the commission and sends the rest to the cooperative.

The larger cooperative management then deducts all of its operating costs including loan repayments, services and maintenance expenses, and other fees. The deductions are made from factory kitties as a proportion of each factory’s membership to the total (i.e. uniform deduction per cooperative member). The remaining funds are then distributed to factory managers who further deduct the costs of factory level operations then distribute the remaining money to farmers as their annual payment (Mude, 2006).

Coffee estates receive about 75% of the auction price and usually get paid within 14 days after selling. They have better access to credit, agricultural inputs and know-how than smallholders. Smallholder farmers also receive only 20% of the auction price and get paid only after up to 12 months (Mude, 2006). Over 90% of the traded coffee is the green (unroasted) coffee beans. The main traders of green coffee worldwide are the Neumann Gruppe GMBH, Volcafe, Cargill and E.D. & F. Man. (EPZ, 2005).

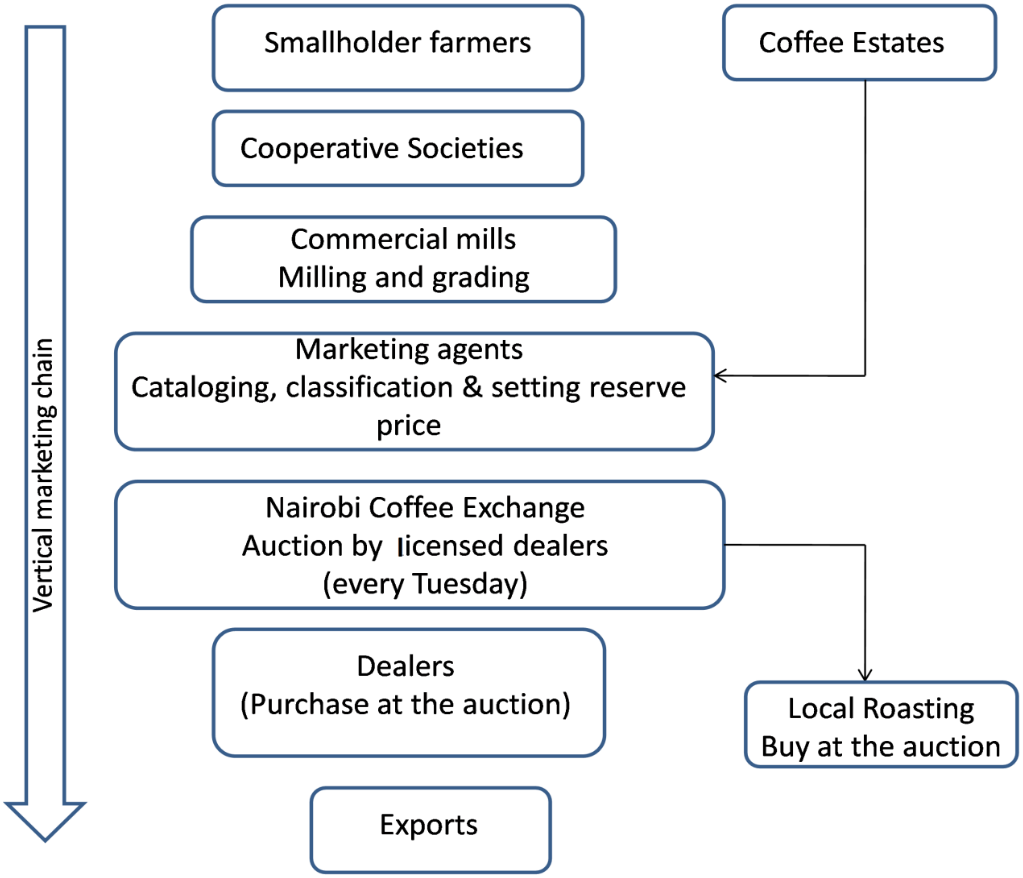


Figure 2 Coffee value chain system by smallholders and estates (adapted from: CBK 2010)

The coffee subsector underwent market reforms in the late 1990's. The World Bank (2005) argues that institutional structures that required smallholders to work through cooperatives reduced their revenues, without supplying quality services. The Bank recommended market liberalization to reverse this. They proposed the following steps in order to create a more open market-place:

a) Farmers require real time market information and the option to sell directly to consumers.
b) Marketing agents should provide information back to the producers to clarify the relationship between bean quality, liquor quality and price.
c) The requirement for farmers to discontinue the common coffee auction.
d) Government was required to review all licenses with the goal of abolishing many of them.

Coffee market liberalization has given smallholders greater control on production but at the same time enhanced moral hazards. For instance poor and good quality coffee cherries are often pooled together as quality is not necessarily related to payments. Further, smallholders are no longer keen to improve quality as there are no incentives to do so (Karanja and Nyoro, 2002).

1.3 Price volatility in the coffee industry

Coffee is a soft[1] commodity and is subject to extreme price volatility (Gilbert and Brunnette, 1998). The coffee value chain power shifts has significantly been influenced in two phases; during the International Coffee Agreement (ICA) regime (1962 to 1989) and secondly in the post ICA regime from 1989 to present. During the ICA era coffee markets were producer driven, while in the post ICA era, markets became buyer driven (Ponte, 2002). Producers no longer have much say in the present value chain (ICO, 2005). Previously, the International Coffee Agreement ensured high coffee prices between 1975 and 1989 but collapsed in 1989 leading to a decline in world coffee prices (Gilbert, 1996). When the agreements were in force, coffee market was regulated through a system of export quotas which were triggered when prices fell to significantly low levels. Gilbert and Brunette (1998) reported that the ICA may have raised producer

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[1] A soft commodity refers to commodities that are grown rather than mined such as coffee, cocoa, sugar, corn, wheat, soybean, fruit and others. The commodities are largely traded on the futures market.

prices by about 50-60%. Karanja and Nyoro (2002) report that Kenyan farmers benefited by 30% higher prices under the ICA trade regime.

While coffee growers used to capture about 30% of the value of the final retail price of coffee in 1975, by 2000, they captured just 10% as downstream players became increasingly consolidated (Talbot, 1997). In desperation, the coffee producer nations formed the Association of Coffee Producing Countries (ACPC) in 1993 as a lobby group, however the lobby has not managed any major impact on the world coffee trade.

During the 1990's, there were supply increases in the world coffee market, due to expansion of plantations in Brazil and Vietnam's entry into the market in 1994. As a result, by 2001, the world price of arabica coffee fell to below 60 cents a pound from highs of over $2 a pound precipitating a near market collapse (Akiyama et al., 2003; ICO, 2005). However in the recent past, world prices for quality coffee especially Colombian Milds arabica- produced mainly by Columbia, Kenya and Tanzania, quoted at the New York Futures market (used as references prices for Kenya coffee) has steadily increased (Figure 3).

Columbian Milds trades at higher price levels than the New York composite prices for all other coffee traded. Price indicators confirm that coffee markets reward quality. The period 2001 and 2004 however shows depressed prices below $100cents/lb, possibly due to supply gluts. Compared to robustas the arabica price trends show a sizeable price differential (premium) of about US$ cents 59.43 (s.d 34.63, n = 129) in the last ten years. Data however suggests substantial variation in premiums showing the cyclic and volatility characteristic of the world coffee market.

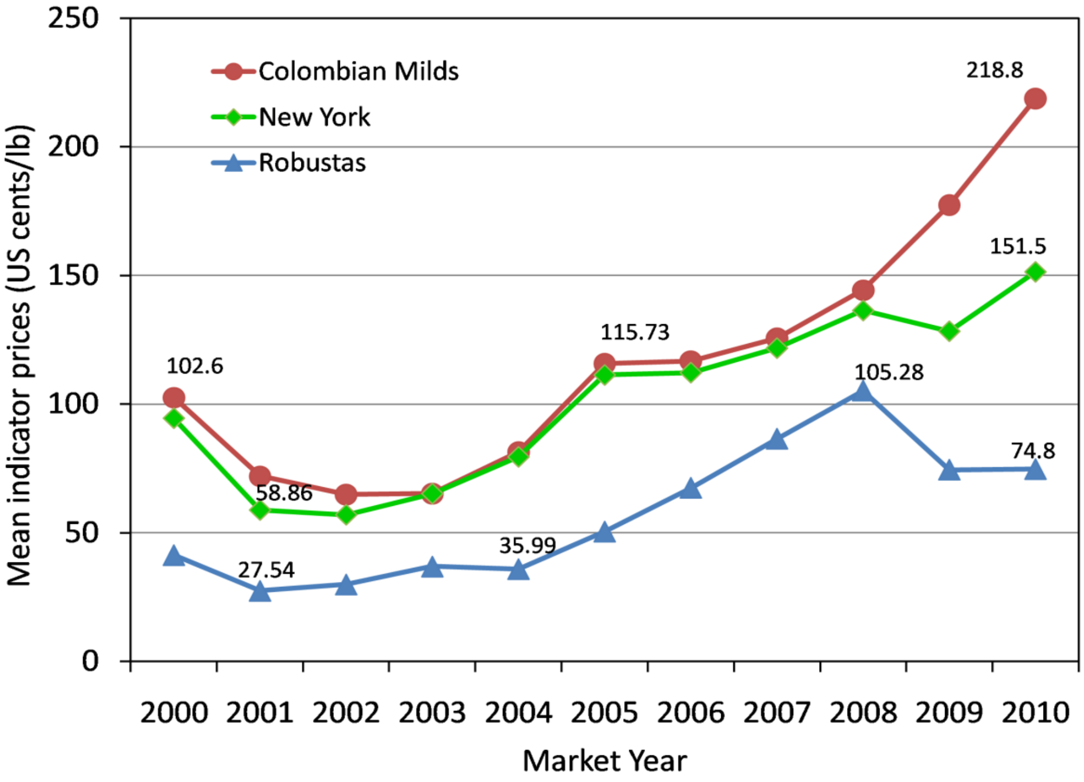

Figure 3 Mean price for Columbian Milds, New York Composite and Robusta coffee from 2000 to 2010 (Source: ICO, 2010)

The present free market environment and liberalization have nonetheless enhanced price volatility (Karanja, 2002). Higher international coffee prices do not readily translate to increased productivity. For instance, in Uganda when coffee production declined due to low market prices in early 2000, efforts to increase production have not been fruitful despite increased market prices (Baffes, 2006). Market liberalization is also blamed for exposing smallholders to higher price risks. Liberalization meant a significant reduction in public expenditure on agriculture which severely constrained the provision of essential services needed to promote the productivity of smallholder farms. The expectation that the private sector would take on these roles left behind by government and its agencies have only been fulfilled to a limited extent (Shepherd and Farolfi, 1999).

1.4 Coffee exports

Coffee used to be the most important foreign exchange earner representing 24% of total African agricultural exports during 1984-1986. This value decreased to only 11.5%, overtaken by cacao at 13.5%, by 1996-1998 (Ponte, 2002). In the period 1996-1998 coffee exports represented more than 50% of agricultural export earnings in five countries and more than 20% in nine countries (Ponte, 2002). Globally, coffee production in terms of exports by 2006 was dominated by Brazil (30%), Vietnam (15%) and Colombia (12%). Brazil is the largest arabica (*Coffea arabica*) producer in the world while Vietnam, is the world's largest robusta (*Coffea canephora*) producer (Condliffe et al., 2008; ICO, 2010).

Kenya's coffee exports have been erratic and downward trending. In figure 4 trends in export volume per thousands 60 kilo-bags of mild arabica coffee exported by Columbia, Kenya and Tanzania are shown. Kenya's exports fell by over 50% between the year 2000 and 2010. The country's world market share declined from 3.1% in 1986 to 0.6% by 2006 (ICO, 2010). Production has not yet managed to return to levels of previous years and cooperatives operate below capacity. Low prices paid to already indebted growers, are preventing them from meeting their maintenance charges and costs of agricultural inputs. Unless growers have access to adequate finance, production levels will remain at below the 1 million bag mark (ICO, 2010). Condliffe et al. (2008) report that the quality of Kenyan coffee could also be on the decline, making it harder for Kenya to demand a premium over commodity prices. About 20% of Kenya's coffee was premium grade in 1993; this proportion fell to about 10% by 2003.

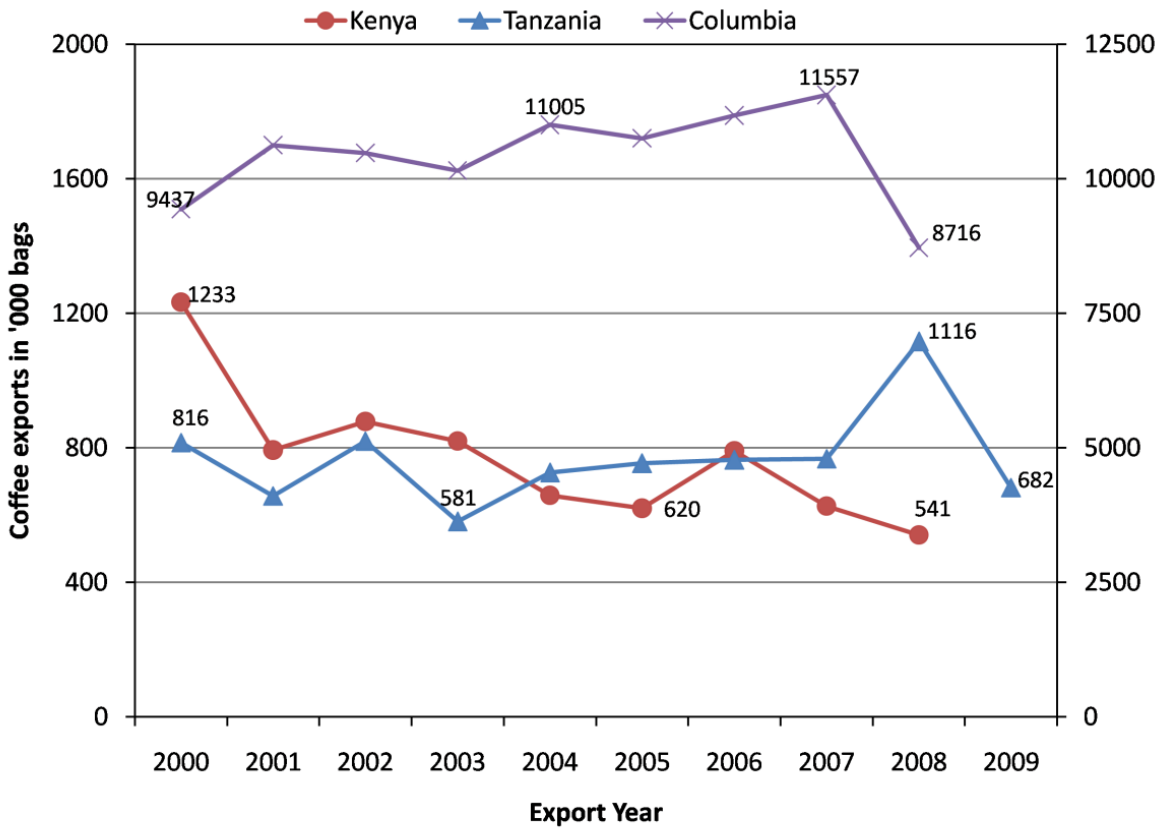

Figure 4 Columbian mild coffee exports by main exporter countries: Columbia, Kenya and Tanzania (Source: ICO statistics, 2010)

Kenya's coffee subsector is largely influenced by changes in the global coffee markets. However internal domestic factors such as production levels, quality and exchange rates play a crucial role in final price determination. These factors influence smallholder coffee productivity and farmer intensification strategies to cope with uncertain coffee markets, and ensure sustainability of other farm based enterprises including food production.

Where market liberalization has been favorable, there is evidence that total food production increases with increases in prices of export crops such as coffee (Shepherd and Farolfi, 1999). This is because food crops farming benefits from inputs such as fertilizer and pesticides secured through credit facilities to support export crops production. Secondly, as income from exports improves farmers devote less time from off-farm employment and more time is allocated to food production; and higher incomes from exports lead to higher investment in food and staple crops production (Karanja and Nyoro, 2002). Declining market trends are on the other hand proving to affect yields and family income directly. This is because farmers are not able to manage their coffee bushes due to lack of adequate income from the crop. Yields can therefore be regarded to make the difference between satisfactory income and poverty in coffee farming areas (Kabura-Nyaga, 2007).

A significant feature of the global coffee trade is the high market concentration of roasters and traders. Four large multinationals export more than half of the coffee consumed to the 25 main consumer countries. These companies are Jacobs/Kraft General Foods, Nestle, Proctor and Gamble and Sara Lee/DE. In Germany the big four control 86% while in The Netherlands, Sara Lee/De controls 70% (Karanja and Nyoro, 2002). According to ICO (2005), in the 90's coffee producing countries earned an estimated US$10-12 billion per year, while the value of retail sales in industrialized countries was about US$ 30 billion. Presently, sales exceed US$70 billion but coffee producing countries receive a meager US$ 5.5 billion per year (ICO, 2010).

1.5 DISCUSSION

The coffee subsector despite significant marketing challenges has provided livelihood support to thousands of smallholder farmers. Changes in commodity trade arrangements from international commodity agreements (ICA) to market liberalization shifted the coffee value chain power from producers to buyers. This has resulted in substantial erosion in smallholder profitability. It's no wonder therefore that even with price increases in countries like Kenya and Uganda it's difficult to stimulate more productivity as farmers remain cautious. Further, gains as a result of price increase do not translate to significant real incomes to make costs of inputs such as fertilizer and pesticides more affordable. Farmer cooperatives despite management inefficiencies have substantially supported access to credit and input facilities to members. These market instruments remain attractive to most smallholders and have contributed to stabilizing farmer productivity to some extent.

Coffee market liberalization though not fully adopted in the Kenyan coffee subsector have reduced government's role in the subsector and given farmers greater autonomy in coffee marketing (Shepherd and Farolfi, 1999; Karanja and Nyoro, 2002). However coffee marketing through a central auction still remains in force. Farmer cooperative societies are however free to elect their preferred coffee millers and marketing agents. Cooperatives management costs and indebtedness continue to exert enormous pressure on farmer earnings. All smallholders are legally bound to market their coffee through cooperatives. Growers whose land falls within a particular coffee society 'catchment' are required to register their membership (Mude, 2006). Many cooperatives however fall short of standards needed in financial and business management.

It has been difficult to stimulate coffee productivity due to factors such as costs of inputs and uncertainty in the market prices. Coffee yields have stagnated due to old coffee bushes. Re-investing in higher yielding coffee bushes could therefore improve production. Other factors such as poor road networks affect transport costs and foreign exchange rates affect net earnings by farmers.

Recent efforts to implement certification schemes for smallholder coffee growers have not really resulted in much added benefits. Preliminary assessment of certification schemes in Kenya have been showed to carry the risk of a top-down approach and do not always meet the main needs of farmers (Kirumba, 2011). As such, a more integrated approach is needed, which takes sustainability and the specific conditions under which farmers operate as its starting points.

Finally, the impact of climate change, manifested in prolonged droughts and extended rainfall episodes have influenced coffee fruiting. Changes in coffee fruiting have a direct impact on harvesting costs incurred by farmers. In addition, pest and disease management in coffee are likely to be negatively influenced (Reuters, 2010).

1.6 CONCLUSIONS

Smallholder coffee production and marketing is driven by a combination of local and international factors. Coffee prices have been improving in the recent past but farmer productivity has stagnated suggesting a need to consider more incentives to increase coffee production and offer farmers better security and stability. On the other hand getting alternative sources of income has been hard for farmers. In fact it’s not clear if farmers are presently able to expand coffee production areas due to their small land-holdings and large family sizes. It appears that increasing farm production and income can only be through land intensification, but this requires large capital investment which is limited.

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CHAPTER 2

TRANSITIONS IN SMALLHOLDER COFFEE SYSTEMS: THE ROLE OF AGROFORESTRY AS A LAND-USE OPTION AROUND MOUNT KENYA

ABSTRACT

This chapter highlights the role of smallholder agroforestry practices towards sustainable coffee production systems. Challenges related to family resource availability and declining living standards in cash crop growing areas are related to decisions at farm, national, regional and international circles. The adoption of farm enterprises is largely driven by resource availability and market value for major cash crops such as coffee. Interestingly, even with significantly reduced coffee profitability, few farming enterprises have emerged as credible substitutes to replace coffee. Serious concerns on the sustainability of current resource base within coffee systems due to environmental degradation have nonetheless been raised. Decisions on the change of farming activities in these systems will directly affect family income and living standards of many coffee producers. Strategies to improve smallholder well-being therefore require a better understanding of the existing resource capacities, their management as well as their contribution to coffee farming households. This chapter delineates the contribution of agroforestry often ignored by present agricultural policy, to improve smallholder overall farm productivity. The research motivation and objectives are outlined and the structure of the thesis is defined in this chapter.

2.1 Background

A multitude of smallholders in high potential parts of Sub-Saharan Africa are engaged in economic development through subsistence and export commodity production. It is estimated that 60% of all marketed agricultural outputs in these countries except South Africa, are by smallholders. In Kenya, coffee systems provide a good example of multiple cropping systems that support rural household needs of income and food provision. Reference to coffee systems in this study therefore does not imply coffee production solely but also other crops produced within the coffee agro-ecological zones.

Coffee farming has nonetheless been the backbone of most rural highland economies in Kenya for the past three to four decades. Kenya's coffee and tea farming systems have been converted from natural forest vegetation (Kindt et al., 2007) thereby directly experiencing loss of important products and services such as firewood, timber and land for grazing and subsistence crops cultivation. The impact of converting natural forest to a coffee agroforestry system is yet to be clear. Nair (1990) has argued that inclusion of trees in farmland can change a farming system from one of decline to one of productivity as introduction of trees bring stability to the system.

Due to global natural resource degradation concerns, production of commodity crops such as coffee (*Coffea arabica*) and cacao (*Theobroma cacao*) are claimed to be more sustainable when practiced under complex agroforests as compared to pure monoculture plantations (Perfecto et al., 2005; Scroth and Harvey, 2007; Philpott et al., 2008). This special type of agroforestry is often characterized by forest-like structures involving a shade tolerant perennial crop such as cacao, coffee or canopy trees such as rubber (*Hevea brasilensis*) (Asase and Tetteh, 2010). In fact tree-crop systems have been showed to have a positive contribution to the environment and biodiversity preservation (Perfecto et al., 2005). Integration of diverse trees within coffee or cacao systems is now regarded as a form of intensification as planted trees can also be a source of products and services such as timber, fruits, firewood and enhance soil nutrient cycling.

More recently, Kenya's coffee farmers have been challenged by low coffee productivity[2] and income shortcomings due to a combination of factors affecting profitability. Low-input, family-based farming practices use limited resources in terms of technology, cash, and information in current production practices. This has forced many to become even more subsistence oriented rather than producing a surplus for the market. In addition impact of climate change is becoming more apparent as yields fluctuation persists due to unpredictable drought spells and the amount of rainfall received per season (Jamnadass et al., 2010). These challenges collectively influence smallholder production and income streams from traditional cash crops such as coffee, tea and cotton.

In parts of the Mount Kenya coffee systems, smallholders deliberately change their enterprises compositions on farm as a strategy to deal with some of these challenges (Carsan, 2007). These changes have involved adoption of agroforestry tree crops, food crops, horticulture and livestock on farm to balance provision of food and income needs. This type of farming practice is now commonly referred to as *coffee agroforestry* to depict the diversity of practices adapted on farm. Largely, the intensity of smallholder production is determined by available resource factors such as land, capital and labour (Chambers and Leach, 1989; Arnold and Dewees, 1998). It is therefore instructive to link farmer agronomic practices to factor availability. Smaller farm sizes can especially affect labour availability and overall agricultural production if they fail to fully support household's needs - family members tend to seek off-farm employment to supplement incomes or move out of farming when livelihoods improve significantly (Hazell et al., 2007).

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[2] Productivity: is the output of valued product per unit of resource input; common measures of productivity constitute yield or income per hectare or total production of goods and services per hectare (See Annex 1)

Future tree planting or non-planting within coffee system will nonetheless be influenced by socio-economic factors such as available land, expected market returns, farmers' beliefs, labour and access to planting material (Lengkeek and Carsan, 2004; Arnold and Dewees, 1998; Simons and Leakey, 2004). Moreover, the decisions of farmers to adopt tree planting are based on informal cost-benefit analysis to ensure they earn a livelihood in their real situations of existence and with limited resources. Often little is known about farmer perceptions on the value of trees and about the constraints they face in developing tree resources (Franzel, 2002). For instance, farmers already report increasing use of 'inferior' or mismatched species for fuel wood, timber, fruits and medicinal purposes (Muriuki, 2011). Ruf (2011) has warned that complex agroforests in cocoa systems of West Africa are likely to be displaced by less complex systems due to changes in factor availability especially land.

The purpose of this study was to characterise transitions among smallholder coffee producers of Mount Kenya, deemed to be at different but comparable trends in coffee production and related agricultural activities. This study investigated coffee farmers' enterprise adoption strategies; agroforestry tree diversity maintenance; and coffee farms land health status- depicted by soil nutrients prevalence under present management. It was anticipated that the study findings will provide better understanding of the implication of shifts in smallholder coffee production on future enterprise choices and sustainable resource use (land management strategies). The ultimate goal would be to better inform agricultural policies aimed at improving smallholder coffee productivity, incomes and living standards.

2.2 Why agroforestry in coffee systems?

Agroforestry has been described as the practice of integrating a range of trees with agricultural crop cultivation and other farm activities. The approach is adopted by millions of smallholders globally to meet their needs for essential resources such as food, medicine, timber, fuel, fodder and market commodities, and provides valuable environmental services such as soil fertility replenishment, water catchment protection, carbon sequestration, biodiversity conservation and landscape restoration (Garrity, 2004). Simons and Leakey (2004) demonstrate that farmers' interest and willingness to invest greater household resources in tree growing is indeed accelerated by scarcity of products from forests relative to the needs of an increasing population and relative to available substitutes.

Appropriate tree systems are perceived to maintain or improve soil fertility and soil productivity, to promote soil conservation, reduce soil degradation and achieve sustainable production (Falconer, 1990; Mucheru et al., 2007). Trees in agricultural landscapes offer soil protection from erosion and compaction, increased nutrient cycling and enhanced soil organic matter above and below-ground.

In Latin America, studies have shown that 'rustic-coffee systems' protect a greater diversity of ants, birds, and trees than open sun-coffee systems. Current knowledge claims that coffee agroforestry practices should be promoted, but not at the expense of remaining forest patches (Rappole et al., 2003; Perfecto et al., 2005; Philpott et al., 2008). Displacing natural ecosystems through clearing or replanting with crops and trees can result in variable levels of domestication of the original landscape and ecosystems (Asase and Tetteh, 2010). The effect of these conversions is presently not well understood.

Kenya's smallholder coffee systems are presently organized along combinations of annual crops/trees/livestock enterprises. Farmers' have basically shifted from subsistence, cereal – based farming systems to mixed – enterprise, market – oriented systems. Patterns of land use conversion to different crop choices appear to correspond to prevailing market signals. This study investigated whether tree growing on coffee farms is considered an investment opportunity in the Mount Kenya coffee farming systems showing different trends of increased or reduced coffee farming.

Participatory tree trials conducted on farms in the eastern parts of Mount Kenya, showed that farmers were willing to diversify and increase tree species planting on farm (Lengkeek and Carsan 2004; Lengkeek et al., 2006). However this was dependent on whether they have enough knowledge and information on how to generate income and food or even if a potential market would emerge for a given tree based technology (Lengkeek and Carsan, 2004). Preliminary farm tree inventories on the coffee and cotton land use systems showed that farmers tend to invest more on tree species such as eucalyptu*s* and grevillea considered to be fast growing and with fewer marketing regulations (Carsan, 2007).

Even though tree planting is not always ranked a first priority activity by farmers compared to food or cash crops or dairy farming activities; trees are revered for complementary roles in support of seasonal shortfalls of food and income as well as help reduce risk and lessen impact of droughts and other emergencies (Franzel and Scherr, 2002; Simons and Leakey, 2004). Trees fill farm niches in place of labour intensive annual crops when family labour is constrained offering landowners a low-cost opportunity to develop assets that often have long term benefits (Harrison et al., 2002).

Holding et al. (2006) report increased smallholder timber logging in coffee systems in parts of Mount Kenya following poor returns on coffee and subsistence crops such as maize and beans. Farmers frequently sell farm trees to meet household needs such as paying school fees, buying food and meeting other emergencies such as hospital bills. It is arguably true that poorer farmers are however under more livelihood pressure to harvest trees for income (Chambers and Leach, 1989; Muriuki, 2011). Increased farmer experimentation with trees for different end-uses remains an area of great interest.

Smallholders are therefore known to maintain a large diversity of tree species as part of their farming strategy and as investment to insure against future changes in market values or emergencies (Lengkeek et al., 2006; Scherr, 2004). Planting more than one species in sequential or simultaneous patterns tend to respond more to economic goal of increasing yields. Farmers tend to replace slower growing indigenous species with species such as grevillea and eucalyptus (See chapter 5). Further, various planting arrangements are adopted to maximize on available ‘planting holes’ per farm such as: line or block planting for timber species and mixed cropping with fruits and medicinals; or hedge and contour planting for fodder species (Simons pers. com). Table 2 provides a detailed evaluation of farmer tree adoption strategies within smallholder systems in response to their perceived resource position.

Table 2 A summary of the contribution of agroforestry trees in Kenya's smallholder coffee systems (source: own)

Tree portfolio in farming systems	**Changes in resources: land and labour**	**Farmer adaptation responses**	**Portfolio contribution**
Timber block, line planting	Reduced farm sizes & labour Higher efficiency on labour Declining, inaccessible forest plantations for logging	Over-harvesting of timber trees on farm Increased planting of fast growing timber trees e.g. *eucalyptus, grevillea, vitex, cordia* Replacements of native Spp. with exotics e.g. *eucalyptus, grevillea* Increased interest in tree enterprise development Less attention to perennial cash crops (coffee) Rural tree nurseries and tree seed trade Interest in species management for marketable products	Less capital, labour inputs compared to perennial cash crops Supplements forest resources (firewood, timber) with labour savings for women especially Accumulated capital in the long term
Fruits & nuts home garden, compound planting	Declining landholding sizes Reduced capital Reduced labour	Increased exotic fruit production for export and local market (avocado, mango, passion & macadamia) Over production of some fruits e.g. avocado (gluts) Variety agro-ecological zones mismatches Fruit marketing associations Fruit enterprise failures due to pest and disease e.g. citrus, passion, mango	High value market participation (exports) better returns accumulating capital Private sector involvement increasing capital Higher household, local and national level nutrition security supporting labour
Fodder hedgerows	Labour savings especially during drought seasons Small farm sizes Inaccessible forests for grazing Declining indigenous fodder species in intensive coffee systems	Fodder hedges on farm boundaries & contour edges for land care Increased planting of highly nutritive and yielding fodder shrubs e.g. Calliandra, Lucerne, Desmodium Drought tolerant species sought to save labour during drought seasons Preference for species with enough biomass for 'hay' making Fodder species seed trade e.g. Calliandra Multiple use of species e.g. sticks, firewood	Labour savings especially during drought season Savings when used as supplements for commercial feeds Land care roles when leguminous fodder used as hedgerows and for contour stabilization
Medicinal compound plantings	Declining land holding Loss of forests Loss of indigenous knowledge and species Low levels of labor well-being e.g. impacts of HIV/Aids	Interest in high value marketable species e.g. Prunus, Warburgia, neem, aloes, moringa, artemesia Species marketing not well developed Unclear formulation procedures often based on local knowledge Increase use for home therapies	Improved labour wellness when correctly used Improved indigenous knowledge repositories Savings when substituted to pharmaceutical products

2.3 Justification of the study

Overall, coffee agroforestry practices are characterized by complexities and competition for resource use which are the principles that most likely determine the profitability and sustainability of these systems (Sanchez, 1995). A high human population density in coffee systems has accelerated land fragmentation to allow space for settlement. There are concerns on land subdivision and degradation[3]. More importantly, loss of farm productivity means that farmers have to seek alternatives that can meet their food and incomes goals (see Annex 1).

In the Mount Kenya coffee systems, land sizes are presently about a third of the size they used to be during the 1978 national agricultural survey (Jaetzold and Schmidt, 2007). In Kirinyaga, one of the main coffee producing districts in Kenya, the average household farm size has decreased from 2.8 ha to 1.09 ha between 1978 and 2004, respectively. In Nyeri, farm holding size has decreased from 2.7 ha to 0.85 ha in 2004. While in Embu, available agricultural land per household of 4.44 persons is 0.6 ha per household. This clearly has serious implications on per capita land productivity with fertility depleted soils becoming rampant in the Districts (Jaetzold and Schmidt, 2007; Mucheru et al., 2007).

The present challenge is therefore to prescribe ways to adjust tree and annual cropping practices to form economical (profitable, diversified for risk) land use patterns for farmers given the available land and labor. This challenge comes against the backdrop of uncertain prospects of coffee and other farm enterprises. Productive enterprises in the eyes of smallholders must result in substantial food and income provisions to be acceptable. It is held that with reduced resources, smallholders will tend to search for other income sources such as off farm employment and may put available land into less labour demanding activities such as tree planting.

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[3] Land degradation: results of one or more processes that lessen the current and potential capacity of a soil to produce, quantitatively and or qualitatively, goods or services (FAO, 1989).

Productive and profitable annual, perennial and livestock enterprise choices are not a straight-forward decision. Farmers consider rationally, alternative enterprises to farm with the available resources such as land, labour and capital (Arnold and Dewees, 1998; Scherr, 2004; Holding et al., 2006). Coffee farming has previously been a prominent cash crop investment providing a source of income to thousands of smallholder farm families. The enterprise catered for school fees payments, food purchases and supported other farm enterprises such as maize farming and livestock production on farm. Loss of profitability in the smallholder coffee enterprise have therefore caused the suffering and disillusionment of farmers. In the Mount Kenya coffee region of Nyeri, Kirinyaga, Embu and Meru, farmers have recently neglected coffee tending with some cutting back bushes to allow for food crop production. Recent high food prices are also expected to stimulate a greater attention towards food crops cultivation. Farmers are also expected to invest more in dairy animals and keeping of shoats, pigs and rabbits which require minimum space. The integration of agroforestry trees to complement subsistence annual cropping has also become more prominent (see chapter 5 for current data).

Presently, there is limited knowledge available on the productive or economic efficiency of smallholder coffee agroforestry systems. Biophysical and socio-economic challenges have not been systematically investigated sometimes resulting in poor recommendations to address issues of sustainable production in the event of failure of major enterprises such as coffee. This study contributes to a better understanding of current position of farmer resources and their livelihood strategies in managing coffee farms around Mount Kenya. The role of traditional practices such as agroforestry in circumstance of declined farm productivity is brought to bear. Farmer orientation towards tree planting or non-planting, in coffee systems is examined. The study traces the evolution of smallholder coffee growing; present farm enterprise adoption and adaptation strategies; management of tree diversity on farm and the ‘health’ status of coffee land in the smallholder coffee areas of Mount Kenya.

2.4 Aims of this study and arrangement of the thesis

The main objective of this study was to investigate present farm production strategies adopted by coffee growers in the eastern parts of Mount Kenya in the light of constrained land resources and poor market returns in coffee growing. The following objectives were studied:

1. To investigate the evolution of the smallholder coffee subsector in Kenya and the improvement of the role of tree growing to livelihood and farming practices
2. To use a pre-determined functional typology of coffee farms to investigate farmer intensification decisions given their current resource position (e.g land size) and input and output relationships
3. To measure tree diversity on smallholder farms under '*increasing*' and/or '*decreasing*' coffee production trends, and different agro-ecological zones
4. To analyse the prevalence of coffee farms soil nutrient (fertility) under present coffee and agroforestry intensification practices.

2.5 Outline of the thesis

This work is presented in integrated chapter format, each chapter guided by the stated objectives. Each chapter follows specific methodologies and provides its own conclusions.

The introductory **Chapter one** traces the evolution of the coffee subsector in Kenya and its present situation as influenced by international and domestic marketing arrangements. Factors related to farmer cooperatives, productivity, markets and overall enterprise profitability are discussed.

Chapter two provides an overview of recent transitions experienced in the coffee subsector while identifying the role of agroforestry in supporting farmer production decisions to attain better incomes, sustainable production and improved standards of living.

Chapter three includes the research concept and the description of the study area. It presents recent data on the study area demographics, methods followed in data collection, processing and analysis. Details of the sampling strategy applied to select various units of analysis such as farmer households, coffee farms, and coffee societies are also presented.

Chapter four compares strategies used by three 'coffee farm typologies' to cope with declined coffee productivity and income levels. Farmer enterprise choices, resource position and analysis of input output relationships are demonstrated. Policy interventions are further recommended.

Chapter five reports on tree species diversity present on smallholder coffee farms. The importance and contributions of biodiversity in producing commodity crops such as coffee is illustrated. The chapter also illustrates farmer preferences on tree species going by the current tree abundance recorded on farm. Present farm tree populations are also shown to be dominated by a few exotic species.

Chapter six provides the status of soil fertility management in smallholder coffee farms with decreasing, constant or increasing coffee cultivation. Soil nutrient indicators are identified via Near Infra red (NIR) diagnostic tools and discussed. The chapter further highlights the role and likely implications of shifts in manure and fertilizer applications practices within coffee systems.

Chapter seven provides the overall conclusions and recommendations of the research.

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CHAPTER 3

RESEARCH METHODOLOGY

This chapter provides insight into how the study was conducted. It highlights the research design, methods of data collection, sampling and means to drawing key findings and conclusions.

3.1 Research approach

Smallholder coffee agroforestry systems are characterized as complex. To gain a good understanding of these systems, broad triangulated data gathering techniques were used. This study combined qualitative and quantitative research approaches. The two approaches are complementary, providing different perspectives and answering specific questions within any one broad area (Scrimshaw, 1990; Stern et al., 2004). This study investigated how smallholder farm productivity (yields, incomes, crop typologies, tree diversity, soil fertility and livestock composition) is influenced by socio-economic and biophysical factors associated with increased or decreased smallholder coffee cultivation around the Mount Kenya coffee systems.

Smallholders try to achieve their multiple objectives by using resources to which they have access to. ‘Household resource position’ has therefore been used to refer to household’s access to and/or possession of human capital (including knowledge, skill, health and labour availability), natural resources (land, trees and livestock), physical capital (agricultural implements, household assets), and financial assets (earnings, credit, savings, remittances) (Sen, 1982; Kragten et al., 2001). To optimally measure some of these variables it is important to note that household resources can nonetheless vary greatly within a community or even a village.

Following the “livelihood strategies” theory (Chambers and Leach, 1989; Scherr, 1995; Ellis, 1998) smallholders are seen as “welfare (utility) maximisers” who base their decisions – including the decision about how to use land – on the extent to which their potential alternatives fulfill their private household objectives. Farming households therefore invest in different activities in pursuit of the following objectives:

- secure provision of food and essential subsistence goods,
- cash for purchase of goods and services,
- savings (resources accumulated to meet future planned needs or emergencies) and,
- social security (i.e. secure future access to subsistence goods and productive resources).

Any evaluation of land use systems from the smallholder perspective should be made against the background of household objectives as identified in the livelihood strategies theory. This theoretical background supports the purpose of the study, mainly to investigate productivity of coffee agroforestry systems around parts of Mount Kenya considering their specific socio-economic and biophysical variables at the household and farm level. It was also held that though agroforestry has been promoted as a sustainable land use option for most tree crop systems, most policy makers, scientists and extension staffs dealing with agroforestry often ignore the fact that most agroforestry systems have evolved from local farmer practices. To contribute further knowledge, this study investigated the evolution of smallholder coffee subsector in Kenya; the typology and productivity of farmer enterprise carried on coffee agroforestry farms; implications of changing coffee production on tree diversity on smallholder farms; and coffee farms soil health status as influenced by shifts in coffee production. The connexions of the research activities with the conceptual frame underlying the livelihood strategies theory are shown in figure 5.

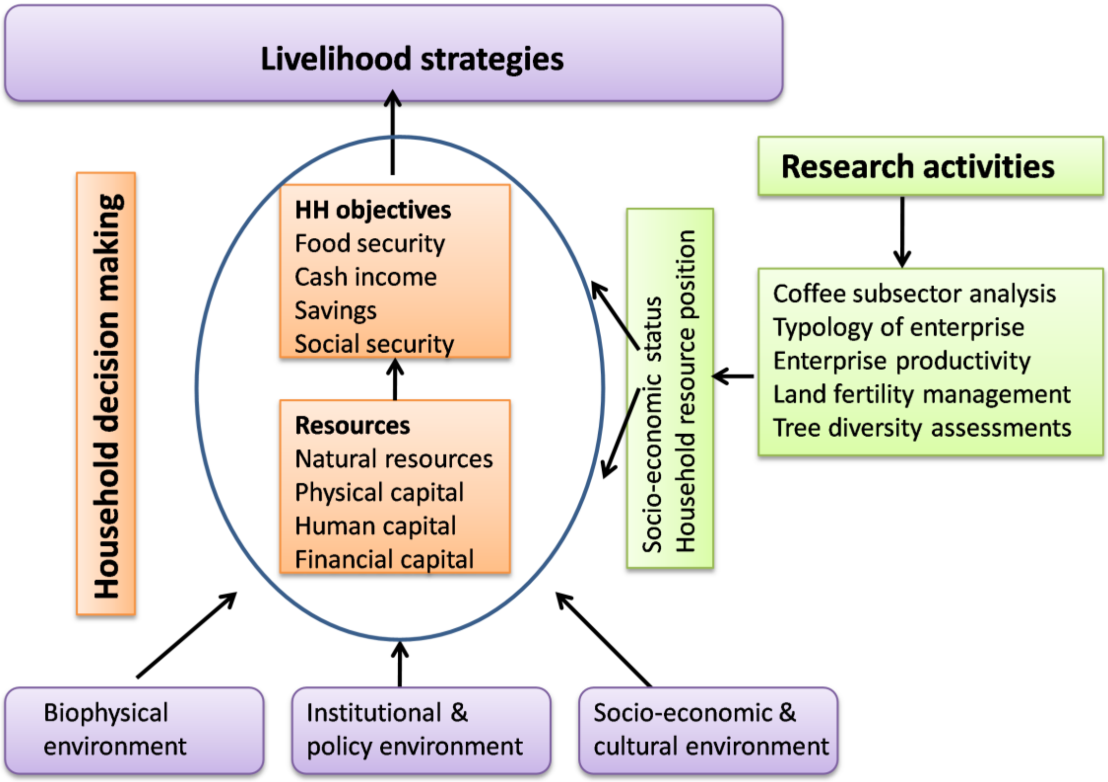

Figure 5 Factors influencing household decision making (Source: Kragten et al., 2001)

Qualitative methods were used to study intangible household factors such as socio-economic status (SES), gender roles and cross-generational attributes. When used along quantitative methods, the combined approach helped to interpret and better understand the complex reality of smallholder coffee agroforestry practices and more so, the implications of shifts in coffee production.

3.2 Study area

The Mount Kenya coffee systems was selected for this study as it is one of the largest smallholder coffee production area in Kenya. Three coffee production districts, namely Kirinyaga, Embu and Meru were selected as representative of smallholder coffee systems (Figure 6). These zones together with the western part of the country and the coast are the most arable.

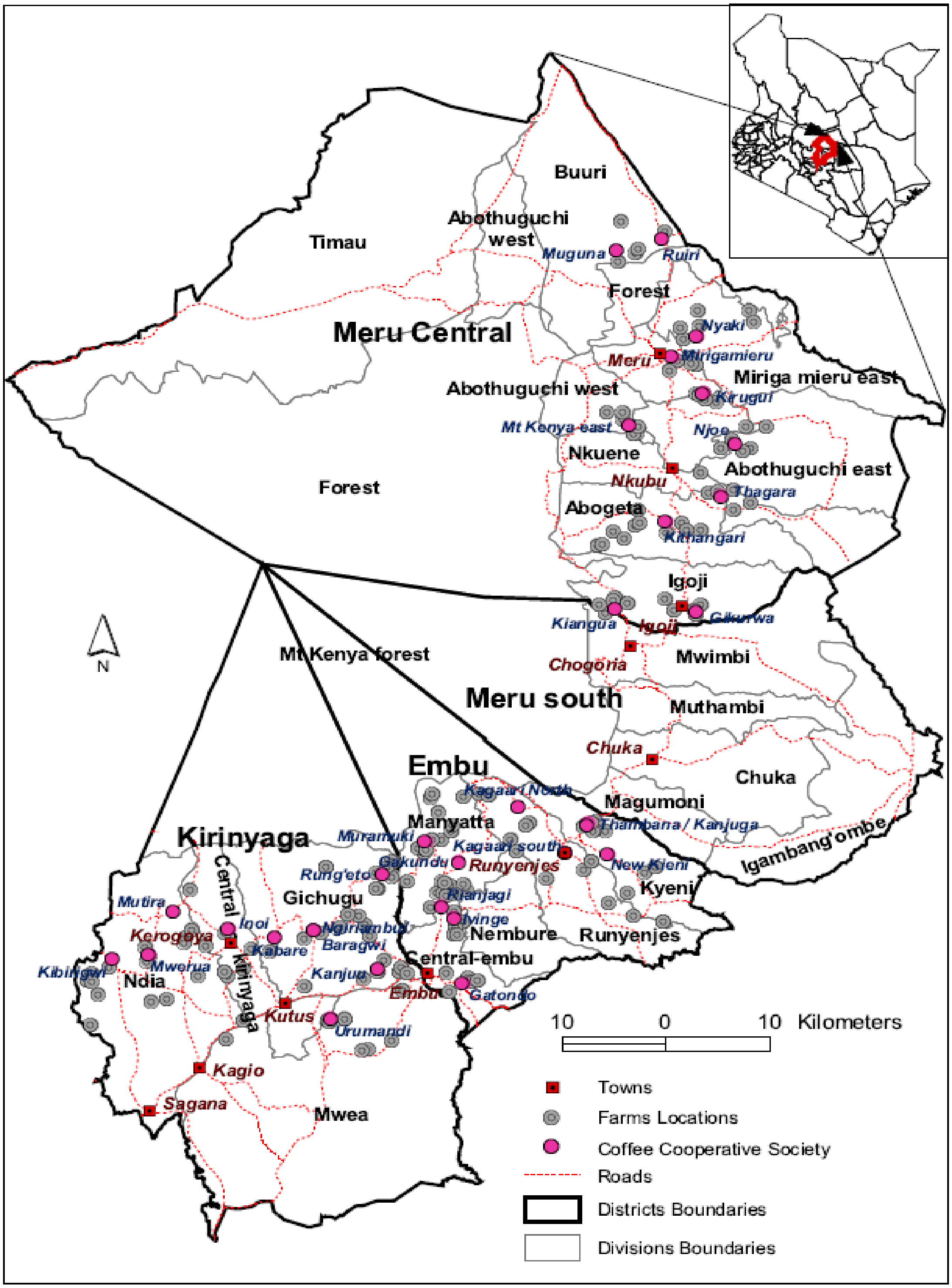

Figure 6 Surveyed parts of Meru, Embu and Kirinyaga districts

Coffee is grown in three agro-ecological zones namely, Upper midland one (UM1), Upper midland two (UM2) and Upper midland three (UM3). The zones are based on the FAO (1978) soil and agro-ecological zones (AEZ) classification of Kenya (Jaetzold and Schimdt, 2007). Each zone is defined based on climatic and edaphic requirements for recommended crops. Recommendations are meant to improve existing land use practices in order to increase productivity and limit land degradation (FAO, 1978; Bationo et al., 2006).

To a large extent, livelihood activities in the Meru, Embu and Kirinyaga coffee areas are dominated by smallholder farming. A diversity of staple crops such as maize, beans, banana, sweet potatoes and vegetables such as kales and tomato are cultivated in mixed cropping patterns. In addition, cropping systems are prominent with agroforestry tree growing for timber, fuel wood, fodder, and medicinals as windbreaks and boundary markers. Selected trees such as *Cordia africana* and *Grevillea robusta* have been valued for coffee shade. Livestock production involves intensive poultry keeping, dairying and limited piggery.

There however seems to be no systematic land use planning. Land is held under private tenure often with individual title deeds. Family households are densely scattered, especially in the upper midland coffee zones, in proximity to urban centres. The recent population census shows high population densities for Embu and Kirinyaga at 409 and 357 persons per square kilometer respectively (GOK, 2010). Meru central has a density of 194 persons per km^2 despite a similar population size with Kirinyaga however in the main coffee zone densities of up to 400 persons per km^2 are reported in the recent census.

Rainfall is of a bimodal pattern with long rains from March to May and short rains from October to December (Table 3). This allows two growing seasons. Most of the coffee growing zones are covered by well-drained extremely deep, dark reddish brown to dark brown friable and slightly smeary clay, with humic top soils suitable for growing coffee and tea (Table 3 and chapter 6).

Table 3 Detailed demographic and climatic features of the Meru, Embu and Kirinyaga study areas (Source: Sombroek et al., 1982; Jaetzold and Schmidt 2007; GOK 2010)

Location	Climate	Agricultural crops
Meru Central **Population:** 580,319 **No. Households:** 157,706 **Density:** 194 persons/Km^2 **Absolute poverty:** 41% **Total area:** 2,982 Km^2 **Area under coffee**: 18,650 Ha **Area under tea:** 4,900 Ha	**Mean rainfall**: 1250 -2500 mm/yr **Altitude:** 1280-1800 m **Mean temperature:** 17.6-20.6 ^{O}C **Soils**: moderately fertile, well drained, majority of volcanic origin- humic nitisols, ando-humic nitisols **Forest cover:** 1,030 Km^2 (Mt. Kenya, Imenti forests)	Maize, beans, Irish potatoes sorghum, millets, peas cowpeas, pigeon peas, garden peas, arrow-roots, cassava, yams tea, coffee, pyrethrum, cotton, tobacco, groundnuts bananas, mangoes, French beans, snow peas, baby corn and Asian vegetable
Embu **Population:** 296,992 **No. Households**: 80,138 **Density:** 409 persons/Km^2 **Absolute poverty**: **Total area:** 729.4 Km^2 **Area under coffee:** 8,499 Ha **Area under tea:** 4,234.8 Ha	**Mean rainfall**: 1000-1800mm/yr **Altitude:** 1200-1850m **Mean temperature**: 17.5^{o}C-20.7^{o}C **Soils:** volcanic foothill soils with moderate to high fertility, tend to become exhausted by permanent cultivation **Forest cover:** 210 Km^2 (Njukiri, Maraga, Kirimiri forests)	Maize, beans, bananas, Irish potatoes, yams, cassava, sweet potatoes and horticulture (passion fruits, cabbages, tomatoes, carrots and French beans)
Kirinyaga **Population:** 528,054 **No. Households:** 154,220 **Density:** 357 persons/Km^2 **Absolute poverty:** 35.6% **Total area:** 1,437 Km^2 **Area under coffee:** 14,000 Ha **Area under tea:** 5,500 Ha	**Mean rainfall:** 1200-2200mm/yr **Altitude:** 1000- 1850m **Temperature:** 19^{o}C - 20.6^{o}C **Soils:** moderately high to high natural fertility (Humic Nitisols), Acrisols appear in the southern and southeastern parts. They are acid soils with a low base status **Forest cover:** 350.7 Km^2 (Mt. Kenya forest)	Maize, Onions, French beans cabbages kales, onions, Tomatoes, sweet pepper, French beans, tea, Arabica coffee, bananas, yams, mountain paw paws, loquats, avocado, passion fruits, arrowroots

3.3 Data collection

This study involved a cross-sectional survey conducted in the main coffee growing parts in the southern (Kirinyaga), eastern (Embu) and Northern parts (Meru) of Mount Kenya (Figure 6). Several techniques were used to investigate households and farms within coffee systems. Focus group discussions were used to identify study target areas and listing of farmer cooperative societies to use as sampling frame. The technique was also used to build consensus with the management committee of the local farmer cooperative societies on the purpose of the research and its contribution. This usually involved face to face meetings to discuss the study approach and data requirements. Interviews with individual farmers were used to investigate household socio-economic status. This involved recording type of agricultural enterprise observed on farm by a farm walk. All types of livestock kept per household and all tree species on the whole farm were inventoried. Individual tree diameters at breast height (DBH) were recorded for all trees above one meter in height. Finally, for the selected sample of ninety farms soil samples were collected following prescribed procedure according to farm layout (see chapter 5 and Annex 15 and 16). A questionnaire tool, tree species inventories sheet and a soil sample collection sheet were used to record their respective data measurements (see Annex 11, 12). At the farmer cooperative society level, designed data recording sheets were provided (Annex 14).

3.4 Sampling strategy

The Mount Kenya coffee systems was selected due to its importance in smallholder coffee production. Farming practices are also comparable between farms but outputs are variable despite similar ecological settings. The zones are contrasted by their respective population densities, farm sizes and poverty levels indicated in national poverty surveys (KNBS, 1998). Stratified sampling was used to obtain the required sample sets. To capture the complexity of smallholder coffee agroforestry practices, three adjacent coffee districts were selected to situate this study. Figure 7 shows a summary of the planned sampling strategy.

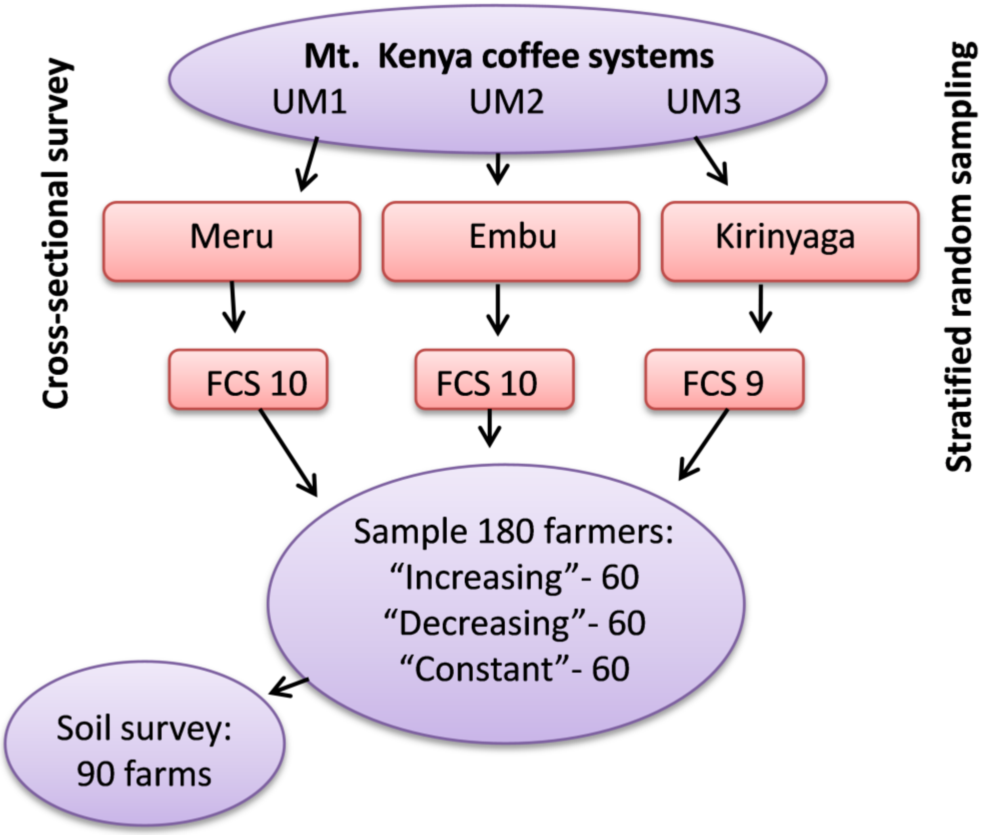

Figure 7 Farmer sampling strategy

Given the difficulty of obtaining accurate and reliable local sampling frame, several alternatives were considered. These included use of the Ministry of Agriculture (MoA) farmer catchment groups, use of local administration and use of local coffee society’s membership. The MoA and the local administration were however not used. They were found to be potentially biased and could not provide the required sample accuracy and representativeness. On the other hand, the Farmer Cooperative Societies (FCS) membership listing was adopted given their advantage of geographical area representation and relevance. Furthermore, all smallholder coffee growers in Kenya are legally bound to be members of cooperative unions due to economies of scale required to process and market coffee in the international markets. The FCS therefore provided a complete sampling frame of smallholder producers. This study sought to obtain a set of smallholder coffee farms and households as units of analysis. The sample of farms was based on historical coffee yield data from local FCS records. Yields (amount of coffee cherry in kilogramme) per farmer were obtained for the crop years 2000 to 2008/9. Three pre-determined farm categories namely *increasing*, *decreasing* or *constant* were identified to study transitions in coffee farming activities, involving both agroforestry and livestock keeping. These farm categories were regarded as a functional typology as they were supposed to reflect the dynamics of local coffee production. The required sample categories were described as follows:

a) *Increasing*: These were farmers/farms showing fairly consistent records of increased coffee yield deliveries to their local FCS in the crop years 2000-2008/9.
b) *Decreasing*: Farmers/farms showed consistent records of declining coffee yield deliveries to their local FCS for the crop years 2000-2008/9.
c) *Constant*: Farmers/farms whose yield production has stagnated for the crop years 2000-2008/9.

Simple trend analyses were applied on random sample sets in order to discriminate selected samples into the required categories. This approach was used rather than a random sample to study more closely the characteristic heterogeneity of present smallholder coffee farms. In order to successfully implement this sampling strategy using grass-root coffee FCS, the following steps were undertaken:

a) Visitations: The research team visited the Meru, Embu and Kirinyaga District Cooperative Office (DCO) for introductory discussions on the planned study objectives and to make formal requests to allow working collaboration with the coffee cooperative societies in the district.

b) Study area demarcation: Focused group discussions between the research team and the district’s coffee cooperative union advisory officers involved use of local maps to demarcate the main coffee growing zones served by their devolved farmer societies together with their constituent coffee factories. The coffee growing zones are mainly comprised of a humid Mid-Upper (MU) and sub humid

Mid-Lower (ML) zone. This zonation followed Jaetzold and Schmidt (2007), agro-ecological zone classifications. Up to five FCS's spatially covering the coffee zones were isolated. Contacts for the target FCS managers were obtained from the coffee union representatives to facilitate appointments and subsequent visits to the FCS offices. Geographical positions (GPS) recording was done for all the visited coffee societies.

c) Twenty nine FCSs, ten each in Meru and Embu and nine in Kirinyaga districts were selected to take part in the study (Table 4). Kirinyaga FCSs had the highest number of farmer membership - more than three times the membership reported for Meru and Embu. This was attributed to fewer subdivisions of coffee cooperative societies' taking place in Kirinyaga. The selected FCSs were used to provide a frame for farmer sample selection irrespective of their number of constituent coffee factories.

Table 4 Farmer Cooperative Societies sampling frame

Region	Selected No. of FCS	Membership	Membership/FCS	No. of factories
Embu	10 (N=25)	16613	1661	9
Kirinyaga	9 (N=15)	51434	5143	10
Meru	10 (N=34)	18741	1748	14
Total	**29**	**86788**	**2751**	**33**

N = no. of FCS per region

d) It was reported that FCS operations are presently autonomous and approval for study collaboration should involve discussions with individual FCS secretary managers. In at least three occasions the research team was required to make presentations to the society's management committee to whom the secretary manager's report in order to clarify the purpose of the study. In all the visited FCSs there was willingness and interest to participate in the research. There was however a common request to provide feed-back on study findings and especially the soil analysis reports.

e) FCSs management was requested to provide their membership records on coffee cherry delivery (in Kilogrammes) from the year 2000 to 2008/9. Sample selection involved random FCS member's selection in the categories *'Increasing' 'decreasing'* and *'constant'* covering historical trends in coffee production. Coffee yields records per farmer were considered on a yearly basis. Coffee fruiting has a phenological trend of 'good' and 'bad' years which was born in mind during sample preparation by assessing overall total production records for and between societies. This exercise was achieved with relative degree of ease depending on the state of individual FCS data management. For FCSs that had computerized their records, sample selection was less tedious. However most societies still use manual filing systems where hard copy records had to be manually perused to obtain the required sample records.

f) Data compilation from the various FCSs was mainly done by their secretary managers who are responsible for the day to day running of the society affairs. In some instances, the FCS clerical staffs were involved in the compilation. Data were recorded on prescribed data sheets (Annex 14). Prior discussions with FCS staff responsible for data compilation was undertaken to explain the search procedure. In order to ensure bias was adequately managed blind farmer selection was undertaken through use of FCS membership numbers other than names of farmers. Practical demonstrations on how to compile the data by searching records most fitting the required categories was undertaken.

g) Using complete FCS membership records, a sample of five farmers was randomly drawn for each category - 'increasing', 'decreasing' and 'constant'. A total sample of 15 farmers was assembled per FCS. Before assigning a sample to the prescribed categories simple trend analysis of their cherry delivery records was undertaken. The exercise involved observation of data records to make a good judgment on real trends. Most data recorders put very strict measures to fit the categories prescribed. For instance in one FCS the response returned was that the categories were not available. In this instance, more guidance discussion was provided on the steps to draw a sample record. A two week period was allowed for data assemblage especially where records were stored in hard copy files.

h) Sample selection from societies in the same region was often done concurrently. This ensured timeliness as several alternative sample sets were always available for farm visits and eventual data collection. Contacts for data recording assistants were taken for purposes of follow-ups and backstopping on the data recording exercise. Meru and Kirinyaga had four FCS, while Embu had three FCSs with incomplete cherry data for the required time frame. They nonetheless had at least five years of data considered a useful minimum to observe production trends for the required farmer category.

i) After ensuring sample sets were ready at the FCS level, there was a ‘researcher stage’ of sample selection where only two farmers most fitting the study categories were selected based on simple trend analysis of cherry delivery records for at least the past five years. A sub-set of six farmers was therefore selected for interviews per FCS. A total of 180 farmers, 60 each from the three coffee regions were selected from the 29 FCS. Meru region is larger geographically with more coffee factories and FCSs. In instances where there were mistakes of misplaced entries, this was rectified by either returning to the FCS for extra sample records or by re-aligning category entries. A summary of the implemented sampling plan is shown in Table 5.

Table 5 Summarized sample selection by stratification

Coffee region (covering: MU & ML coffee zone)	Selected FCS/region	Stratified No. of FCS/coffee zone	**No. of Sample/ FCS level	*No. of Sample/FCS (Researcher level)	Total samples for interviews
Kirinyaga	9	MU-zone=5 ML-zone=4	Increasing=5 Decreasing=5 Constant=5	Increasing =2 Decreasing=2 Constant=2	6*9FCS + 6 from ML FCS (60 farmers)
Embu	10	MU-zone=5 ML-zone=5	Increasing=5 Decreasing=5 Constant=5	Increasing=2 Decreasing=2 Constant=2	6*10FCS (60 farmers)
Meru	10	MU-zone=5 ML-zone=5	Increasing=5 Decreasing=5 Constant=5	Increasing=2 Decreasing=2 Constant=2	6*10FCS (60 farmers)
Totals	29		Sample/FCS= 15 farmer records	Sample/FCS= 6 farmer records	Total sample= 180 farmers

* MU- mid to upper coffee zone; ML- mid to lower coffee zone; **most fitting record per prescribed coffee cherry deliveries strata i.e. increasing, decreasing & constant. Six additional farmers were included from the mid lower zone of Kirinyaga area which was under-represented.

j) Other complimentary data were requested from FCSs including: society membership statistics, number of affiliated factories per society, total coffee cherry production per FCS, coffee price payment per society from the year 2000 to 2008 and number of coffee bushes per farmer. The latter variable was however found to be poorly captured at the coffee society level and was instead obtained from individual farmers visited for interviews. Finally, in order to assess how smallholder coffee farming practices are influenced by external factors such as transport, the time taken by farmers to access their local town centres was estimated in minutes (Figure 8).

k) Eventually, FCS officials were requested to accompany the research team during farm visits to help with target farmer introductions and to facilitate creating rapport and a friendly environment to conduct interviews and farm assessments. FCS affiliated factories provided the link with the sample farmers since this is the primary point of membership registration. There were a few instances of poor farmer identification especially where the members had passed away and the registers were not yet updated. In some of these instances the families had not changed their registry details with the society yet. In other instances the coffee plot had already been sub-divided to siblings therefore the name did not match farm ownership. A map of the coffee societies and study locations used for interviews is displayed in Figure 8.

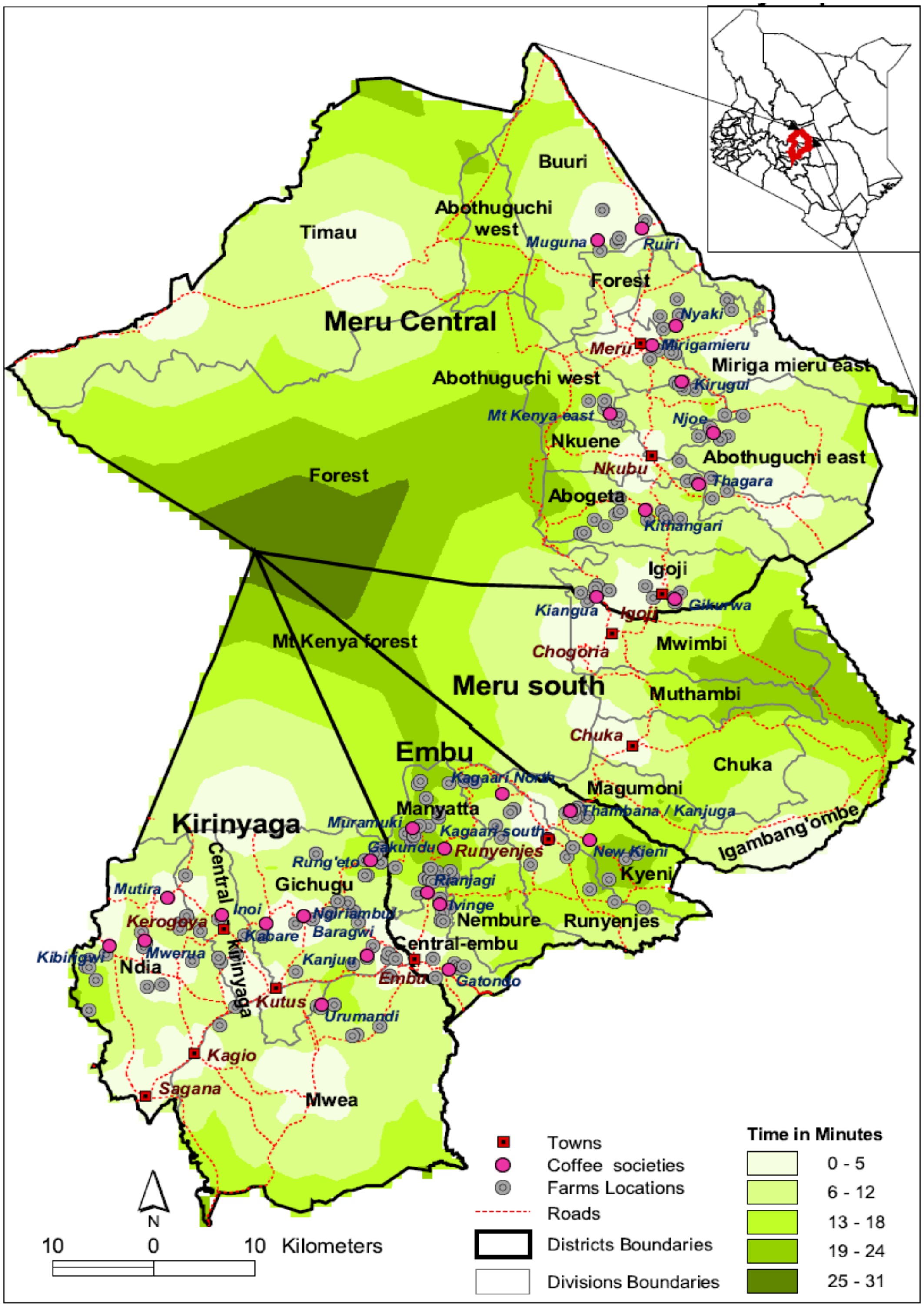

Figure 8 The Mount Kenya coffee system and the surveyed coffee factories and farms.

3.5 Farm surveys

Data collection activities undertaken during the survey of the selected farm-households covered:

a) Household socio-economic interviews on choices and size of crops cultivated, kinds and quantities of livestock kept and tree farming and products marketing activities
b) An entire farm tree inventory and biomass measurements
c) A random soil sample collections on farm plots for basic soil fertility analysis
d) Coffee society's data on the amount of coffee production for the last 10 years, prices paid, number of active society membership and gender composition.

Overall, the decision to use the FCS approach as a sampling strategy followed some assumptions such as:

a) FCS membership are spatially representative of typical coffee smallholders per selected study strata
b) FCS coffee production records mirror transitions behavior in smallholder coffee agroforestry systems
c) Farmer records maintained at FCS accurately represent real production efforts by individual member farmers
d) That if sample selection is based on actual records of farmer coffee produce then biased sample selection would be minimized

3.6 Drawbacks of using the farmer cooperative membership as a sampling frame:

a) Several FCSs were found not have adequate data sets necessary to conduct trend analysis in order to discern the required sample farm categories. Loss of data was sometimes associated with the concerned FCS management politics. In at least three instances records were missing after FCSs splits and consequent change in management. Newer FCSs therefore had data covering only the period of their existence for instance two FCSs were only four years old therefore providing data for only this time-frame. Most of these societies reported difficulties in accessing data from their former unions once the splits had occurred. In another situation, one FCS in Embu had lost most of their data files in fire incident.

b) The central record keeping system at coffee union level, previously enforced under law is no longer in practice following the coffee subsector reforms (market liberalization). Farmer records at the union level (usually at the district), are therefore severely affected and are no longer up to date. Visited FCSs are autonomous and see little need to report their operations to their umbrella union. The individual FCSs deal directly with coffee millers when marketing their coffee, unlike in the past where the unions marketed coffee on behalf of the FCSs.

c) A few of the FCSs reported illegal selling of coffee cherry by members to middlemen hence reduced portions are received at their factories. Though rare, the practice was attributed to households facing serious income constraints especially during recent droughts or in instances where farmers have little produce and wanted to avoid installment payment for input loans. Secondly, there were incidences of land subdivision but the same farmer account was still used to sell coffee. These factors tended to influence the coffee cherry data reflected at the society's records.

d) Farmer samples for the "increasing" category were in some instances found to be members of the FCSs management committee, creating some misgiving regarding the sample. The FCS management committee is often constituted by 'role model coffee farmers' with high levels of coffee production.

3.7 Data analysis

Collected data was analyzed following qualitative and quantitative techniques. These analyses are presented per study chapter/objectives. Each objective had specific but often interlinked analytical requirements. The following types of analysis have been completed:

a) General linear regressions (Gill, 2000) to show rates of change in coffee production amongst *increasing*, *decreasing* and *constant* farmer categories together with an overview on the performance of the smallholder coffee subsector.
b) Analysis on the typology of enterprise portfolio adopted by farmers at different level of coffee production. Investigations on production factors such as land size have been analysed to show kinds and sizes of farmer enterprise selection, and factors influencing adoption and adaptation. The analysis enabled an evaluation of likely intensification strategies with coffee and other enterprise such as banana and maize.
c) Characterization of tree diversity maintained in smallholder coffee agroforestry systems - this involved showing amounts and diversity of tree adoption amongst increasing, decreasing and constant coffee farmer categories and within different coffee agro-ecological zones.
d) Estimate agroforestry tree stocking volumes as related to other economic activities including annual crop farming, livestock keeping and off-farm employment activities.
e) Soil nutrient prevalence in smallholder coffee farms of Mount Kenya were analysed and most limiting nutrient identified. Implications of nutrient inputs via chemical fertilizers and animal manure were assessed and related to socio-economic constraints especially land size.

Data entries and management was undertaken using Microsoft *Excel* 2007. After data cleaning, coding and standardization, data was subjected to reliability tests visually using histograms and box and whisker plots to detect influence of extreme values. The extreme values were checked for source of error. If the values were realistic, they were retained but otherwise were corrected by replacing them with arithmetic mean.

Multivariate analysis involved various descriptive statistics such as means, frequency counts and percentages (Gill, 2000; Stern et al., 2004).

Details on types of analysis executed are presented under the research methodology section of each chapter. Multivariate data analysis involved use of several statistical packages such as PASW statistics 18 (2009), GenStat Release 12.1 (2009); *BiodiversityR* based on *R* statistical software version 2.11.1 (2010); and *the unscrambler version 9.2*. Camo Process As (2006).

3.8 CONCLUSIONS

Smallholder coffee agroforestry systems are uniquely complex. Farmer practices are nested in indigenous knowledge, socio-cultural values, biophysical factors and current household resource position. To adequately characterize systems productivity, composite variables measuring these elements have to be gathered. Further, there is need to exercise flexibility in data collection and collation to involve multiple data collection instruments and techniques. Finally, selection of an appropriate sampling frame is critical in rural settings which often have poor formal record keeping practices. Use of existing farmer organizations such as the coffee cooperative societies membership was shown to be a useful approach to test different sampling opportunities as may be required. Clearly, sampling exercises can be challenging, time consuming and requiring participatory approaches to execute.

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CHAPTER 4

DETERMINING ENTERPRISE DIVERSIFICATION TYPOLOGIES BY SMALLHOLDER COFFEE FARMERS AROUND MOUNT KENYA

ABSTRACT

Improved understanding of the main drivers that influence productivity patterns in smallholder coffee farming systems can help better target agricultural innovation. The purpose of this study was to investigate if smallholders with decreasing or increasing coffee production around Mount Kenya invest in enterprise intensification and diversification strategies such as with maize, banana, livestock and agroforestry trees. Using functional typologies of smallholder coffee farms determined *a priori*, coffee yield data from 180 farms was used to identify and analyse productivity on farms with *increasing, decreasing* and *constant* coffee production trends. Simple descriptive statistics such as means, range, counts, enterprise scoring, diversity analysis, pair-wise correlations and general linear regression analysis were used to compare farm typologies.

Results show similarities in smallholder farm diversification strategies; coffee production is nonetheless declining in smaller farm sizes compared to farm sizes where it's increasing. Data suggest that on decreasing coffee, farmers with smaller land size diversify into crops such as banana and maize probably in a strategy to secure household food security. Results showed that smallholders expanding coffee production are also associated with productive milk enterprises. Analysis was consistent that, land size, coffee production (number of bushes, cherry yields/Ha), livestock units, trees, banana, maize value, nutrient inputs (manure and fertilizer) and labour costs influence coffee farms productivity and are useful indicators to distinguish farm typologies. In conclusion, this study highlights the importance of increased awareness by policy makers on coffee production trends and the need to promote enterprises that are of interest to farmers.

INTRODUCTION

Smallholder farming systems in sub-Saharan Africa are situated in diverse biophysical and socio-economic environments (Tittonell et al., 2010). Within localities and villages, households differ in resource endowment, production orientation and objectives, ethnicity, education, past experience and management skills (Crowley and Carter, 2000) and in their attitudes towards risks. Rural families therefore tend to develop different livelihood strategies driven by opportunities and constraints encountered in such environment (Ruben and Pender, 2004; Stroebel, 2004). Largely, agro-ecology, markets and local cultures determine different land use patterns and agricultural management practices across regions. Improved understanding of the main drivers that influence patterns of households diversity and in turn livelihood strategies and farming objectives can help better target agricultural innovation (Tittonell et al., 2010). Land users are known to make decisions about their environment influenced by political and institutional restrictions at local, regional and international levels (Lambine et al., 2003; Carmona et al., 2010).

Land use patterns form a farming system that can be described as socially built systems associated with farm assets and location assets, often situated between social and biophysical environments. Beets (1990) has described farming systems as a unit consisting of a human group (households) and the resources it manages in its environment.

In the region of this study, farming systems correspond to groups of smallholder farms that share generally similar resource bases, enterprise patterns, livelihood styles and constraints for which similar development strategies are pertinent (Valbuena et al., 2008; Van de Steeg et al., 2010; Carmona et al., 2010). Farming systems interface the relations between farmers and the landscape by integrating biophysical, economic, social, cultural and political factors that constrain or promote land use and land cover change (Shepherd and Soule, 1998; Duvernoy, 2000). In the densely populated highland

and midland coffee systems of East Africa, variability in the drivers of agricultural systems have resulted in different land uses that range from strongly market-oriented smallholder coffee, tea and dairy systems, through semi-commercial cereal/legume-based systems, to subsistence oriented systems based on crops such as maize and beans (Place et al., 2003; Tittonell et al., 2005a).

Livelihood strategies to cope with limited access to resources (land, labour, monetary) have shown that these are not only restricted to alternative methods of farm management and/or choice of production activities. Off- and non-farm opportunities can also provide alternative or complementary livelihood options (e.g. Tittonell et al., 2005a; Barret et al., 2006). Household categorization can therefore help target agricultural innovations, and more importantly inform farmer decision making processes with regard to enterprise diversification and considered levels of investments (Stroebel, 2004; Lengkeek and Carsan, 2004). Diversity in farming systems are commonly evaluated using farm typologies or even land cover characterization approaches (Duvernoy, 2000). A farm typology has been defined as a tool to simplify the diversity of farms and farming strategies in a given area, by characterizing different groups of farms based on a specific criterion. The majority of these typologies take the production system into account since production decisions have an obvious influence on a farms economy and its impact on the environment (Duvernoy, 2000; Köbrich et al., 2003; Keating et al., 2010).

Previous studies have used various criteria and methods to link farming typology to the extent of soil fertility degradation (Carter 1997; Shepherd and Soule, 1998; Waithaka et al., 2007). Other farm clustering approaches have used household wealth or resource endowment indicators, to undertake farm classifications. These constitute examples of structural household typologies. More appropriately, classification that takes into account the dynamics of production orientation and livelihood strategies have been shown to improve categorization (Mettrick, 1993). This approach is regarded as functional typology.

The current study used the functional typology approach to understand the diversity and productivity of farming strategies used by smallholder coffee growers of Mount Kenya. It was held that in order to measure implications of changes in coffee production and better target agroforestry related innovations; a farmer classification strategy would help avoid making blanket recommendations. This was further expected to inform enterprise choices amongst coffee farmers assumed to have heterogeneous farming practices.

It was therefore hypothesized that smallholders with decreasing or stagnated coffee yield production will invest in more enterprise intensification/diversification options such as with maize, banana, livestock and trees. Conversely, smallholders with increased coffee yield production will invest in fewer crop intensification enterprises such as banana, maize and trees. In order to test these hypotheses, coffee farmers showing different trends in coffee production over a period of eight years categorized as, *increasing, decreasing* or *constant* (to denote their coffee production trends over the years) were studied. It was held that smallholders under each category/typology exhibit different or unique behavior in terms of enterprise adoption to complement coffee farming.

To characterize productivity on the identified farm typologies, input-output relationships for key enterprises present on farms were analysed. Enterprises such as maize, banana, and livestock are farmed together with coffee at different but unclear intensities. The cropping strategy involves short term/annual cropping, intermediate cropping and longer term perennial enterprises. This study therefore sought:

(i) To identify factors associated with smallholder household typologies showing increasing, decreasing or stagnated trends in coffee production

(ii) To determine enterprise diversification/intensification strategies used by smallholder coffee farmers, under conditions of reduced or increased coffee production

(iii) To investigate use of inputs such as manure, fertilizer and labour under conditions of smallholder enterprise diversification/intensification.

4.1 MATERIALS AND METHODS

4.1.1 Study area

Livelihoods in the study area (Figure 9) are presently dominated by mixed farming activities. A diversity of food crops such as maize, beans, banana, sweet potatoes and vegetables such as kales, tomato and others are intensively produced. Farm cropping systems are also prominent with agroforestry tree growing valued for timber, fuel wood, fodder, medicine, windbreaks and as boundary markers (Lengkeek and Carsan, 2004). On the other hand, livestock production involves intensive poultry keeping, dairying and limited piggery.

Land is held under private tenure often with individual title deeds. Family households are densely scattered all over, especially in the upper midland coffee zone in proximity to urban centres. Recent population census has showed high population densities for Embu and Kirinyaga at 409 and 357 persons per km^2 respectively (GOK, 2010). Meru central has a density of 194 persons per km^2 despite a similar population size with Kirinyaga; however in the main coffee zone, densities of up to 400 persons per km^2 were reported in the latest census (GOK, 2010).

Rainfall is of bimodal pattern, with long rains from March to May and short rains from October to December. This allows two growing seasons. Most of the coffee growing zones are covered by well-drained extremely deep, dark reddish brown to dark brown friable and slightly smeary clay, with humic top soils suitable for growing coffee and tea.

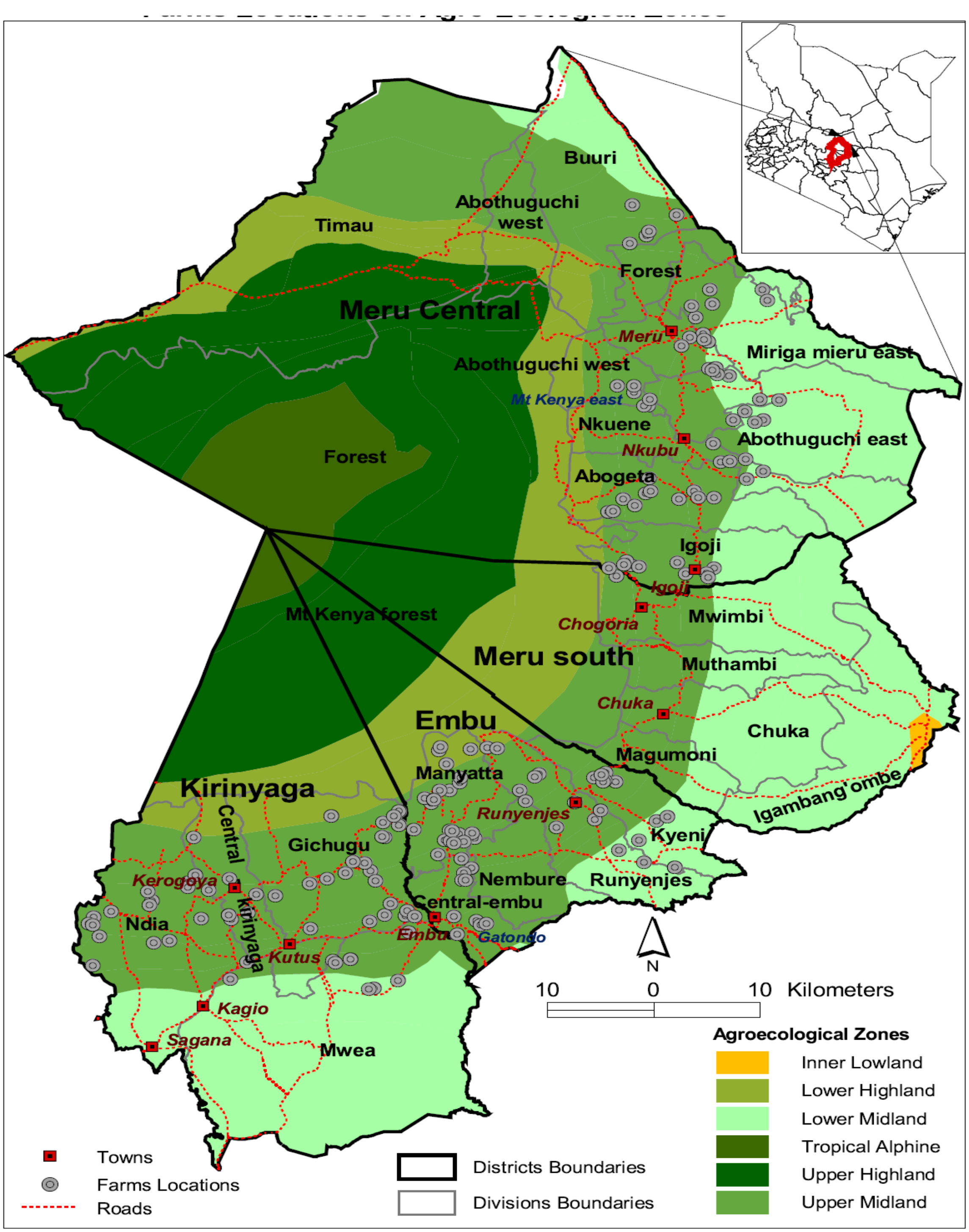

Figure 9 Eastern and central parts of Mount Kenya: Map indicating surveyed farms around Meru, Embu and Kirinyaga coffee zones

4.1.2 Coffee cultivation

Kenya's Coffee Research Foundation (CRF), provides broad guidelines for coffee cultivation. Four major varieties namely, SL 28, SL 34, K7 and Ruiru 11 are cultivated in the surveyed region, depending on altitude and precipitation (Table 6). Coffee diseases, mainly coffee berry disease (CBD) and coffee leaf rust (CLR) are also major considerations of choice varieties. Ruiru 11 is the latest variety developed by CRF with a high productivity and disease resistance. Its adoption has however been low due to high costs of planting material and inputs, while some farmers feel it's not tolerant to drought conditions. Field observations during this study recorded interest by farmers to vegetatively graft the Ruiru 11 cultivar onto the SL varieties.

Smallholder cherry productivity remains poor compared to the CRF recommended levels due to inputs and market constraints (Table 6). Many farmers also do not adhere to recommended spacing regime and often have larger densities per hectare to maximize productivity.

Table 6 Coffee varieties cultivated in the surveyed region (Source: CRF, 2010)

Coffee variety	Cherry productivity	Coffee bushes ha^{-1}	Recommended zones
Scott Laboratories, Series no. 28 (SL 28)	8.52 kg cherry/tree 1.8 tons/ha	Spacing: 2.74 X 2.74m Density: 1330 tree/ha	Medium to high altitude zones without serious leaf rust
Scott Laboratories, Series no. 34 (SL 34)	6.11 kg cherry/tree 1.35 tons/ha	Spacing: 2.74 X 2.74 m Density: 1330 tree/ha	High altitude with good rainfall
K7 selected at Legetet Estate, Muhoroni (French Mission Coffee)	9.05 kg cherry/ tree 2.01 tons/ha	Spacing: 2.74 X 2.74m Density: 1330 tree/ha	Low altitude coffee areas with serious CLR
Ruiru 11	8.39 kg cherry/tree 4.6 tons/ ha	Spacing: 2 X 2m Density: 2500 trees/ha	All coffee growing areas. Resistant to both CBD and CLR.

CBD-Coffee Berry Disease, CLR-Coffee Leaf Rust

4.1.3 Classification of farming systems

A common draw-back of typologies is that the majority do not account for the spatial linkage in which land-use decisions are applied (Carmona et al., 2010). In this research, the farm typology approach was applied at the household level where coffee farmers/farms were characterized with respect to their historical trends in coffee production. Grouping smallholder coffee farms according to their trends in coffee yields production was held to convey overall farmer productivity behaviour especially with regard to intensification/diversification strategies.

Local farmer cooperatives societies (FCS) who legally do primary processing and marketing of smallholder coffee were used to obtain coffee yield production data at the farm level. Ten FCSs were selected per district covering the different coffee growing zones namely, the upper midland one (UM1), upper midland two (UM2) and upper midland three (UM3). FCSs management usually represented by secretary managers were requested to provide records of their members' coffee cherry delivery to serve as a sampling frame to draw a random sample for interviews. A random set of six farmers were selected per FCS for interviews and farm assessments. Selected samples were exceeded by three farmers for Meru central which occupies a larger geographical area compared to the other coffee zones under study. FCSs were further requested to provide historical coffee cherry production records on the selected sample of farmers for data analysis at a later stage.

A cross-sectional survey was then conducted on 180 households occupying three coffee zones of Mount Kenya (Figure 9). These zones are regarded typical representation of smallholder coffee-agroforestry systems in Kenya. Chapter 3 provides a detailed description of the methodology followed.

4.1.4 Household survey

The selected farms were surveyed during the months of June to October, 2009. Survey questionnaires (Annex 13, 14, 15 & 16) were designed to capture biophysical, socio-economic and managerial aspects of each farm. A team of three individuals were recruited to administer questionnaires. Socio-economic and farm management information including characteristics of the household head (name, age, gender and marital status) and family size, land size, labour availability, distance to nearby markets, number of coffee plants, number of agroforestry trees planted, amount of cereals (maize) and banana produced and sold, vegetable farming, livestock rearing and amount of inputs (manure, fertilizers, hired labour) used were collected. In addition, an interactive tool (*bao game*) was used to facilitate collection of qualitative information quantitatively, with regard to score ranking of farmer preferences for adopted farm enterprises. Franzel (2004) has shown merits on the use of *bao game* techniques to record qualitative data to qualify different criteria over abstract recording of information using questionnaires only. The *bao* technique has the advantage of enhancing farmer accuracy and objectivity as it facilitate respondent's verifications of scores based on different criteria at hand. Farm walks and observation schedules were undertaken to record types of cultivated agricultural crops and agroforestry trees species present on individual farm plots.

After introduction and discussions with potential respondents on the purpose of the survey, respondents were requested for a brief farm walk also to indicate the boundaries of their farm plots. This helped build rapport with respondents as the research team appreciated farming activities on farm. One member of the research team was dedicated for household interviews to ensure consistency of recordings, while the other two members of the team carried out farm walks recording and measuring present agroforestry enterprises (agricultural crops, trees) on the entire farm plots. Simultaneous data collection enhanced timeliness in surveying coffee farms and conducting household interviews especially where sample farms had huge land sizes.

Collected data were keyed in standard computer spreadsheet (Microsoft Office Excel, 2007). Data management for subsequent analysis followed standard ICRAF's data management guidelines (Muraya et al., 2002; Stern et al., 2004).

4.1.5 Data analysis

Qualitative and quantitative approaches were used to analyze collated information. Keyed data were cleaned for errors, coded and formatted for multivariate analysis using *PASW statistics 18* (2009) and *GenStat Release 12.1* (2009). Simple descriptive statistics such as means with standard deviations were used to profile household and coffee farms characteristics. Variables such as intensity of coffee bushes and/or yields reported per farm, quantity of agroforestry trees (density and tree basal area), value of maize and banana crops and reported value of inputs such as fertilizer, manure and labour used by farmers were used to analyse farm intensification practices. Using historical coffee yields data from the year 2000-2008, rates of coffee yield production was analyzed per farm category - *increasing, decreasing* and *constant.*

General linear regressions were used to assess effects of coffee production trends (constant, decreasing and increasing) on selected variables shown to have strong association using pair wise correlations. Fisher's Least Significance Difference (LSD) was then used to assess mean differences of the response variates among the farm categories. Response variates such as cherry value ha^{-1}, coffee bush ha^{-1}, maize value ha^{-1}, banana value ha^{-1}, avocado trees ha^{-1}, fertilizer kg ha^{-1}, labour costs ksh ha^{-1} and non labour costs were transformed to take care of observed skewness. Normality test such as Shapiro-Wilk and plotting of simple histograms were used to assess skewness on these variables.

To determine levels of farmer enterprise diversification present on the different types of smallholder coffee farms, Simpson Index of Diversification (SID) was calculated on agricultural crops recorded per farm and for the surveyed region. Additionally, commodity crops rank abundance per farm was calculated for the entire surveyed region. This result was compared to farmer ranking of the present enterprise on farm. Farmer preference rankings were scored on a scale of 0 to 5 and treated as ordinal [4] rather than interval data. The distance between the scores was held to be indeterminate. A follow-up analysis involved records of farmer preference counts on possible substitute crops for coffee. Analysis of farmer preference on likely substitutes for coffee was done following simple response counts and percentages. All livestock keeping activities such as cattle, piggery, shoats and others were converted into single variable per household, termed Tropical Livestock Units (TLU)[5] to allow ease of making comparative analysis.

4.2 Theoretical model

The purpose of this study was to explore factors that will have the most significant impact on farmer intensification practices given the current losses in smallholder coffee productivity. In order to develop useful forecasts, econometric modeling approaches were followed using general linear regressions (Gill, 2000).

Coffee production is regarded as a major smallholder economic activity undergoing important transitions owing to challenges experienced in international markets. Domestically, changes are accelerated by inter-generational factors and resource constraints pertaining to inputs requirements such as fertilizer and pesticides. The older generations of coffee farmers are being inherited by a younger generation with a different set of farming goals. Competition on land use for higher and faster return activities such as horticulture and dairy are emerging. There are also land constraints occasioned by chronic land subdivision practices, due to a growing human population. To understand current farmer productivity circumstances, coffee bushes cultivated per hectare and cherry yields (kg) produced per hectare were established as useful

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[4] Ordinal data means that the answers are in some order, but says nothing about the distance between the ordered items. Interval data means there's an equal distance - cognitively - between the scores

[5] 1 TLU represents 250 kg of livestock live weight

indicators to assess smallholder coffee farms productivity. The size of coffee enterprise adopted is assumed to influence the size and composition of other enterprises carried by smallholders.

In economic theory, coffee production can be seen as a function of traditional inputs such as capital (K) and Labour (L) (Williams, 1972). The flow of capital services is assumed to be proportional to coffee yields. If the coffee industry is competitive, for profit maximization, the marginal cost for inputs, i.e. MPP_k = c/P and MPP_L= W/P. Where MPP = marginal physical product, c = rental cost of capital, w = wage rate and P = price of output.

In large scale farming, mathematical programming is frequently applied in farm planning. These tools allow determination of an optimal allocation of land, labour and capital, given a set of goals (e.g. maximisation of income and leisure and minimisation of risk) and constraints (e.g. labour and land) (Barnett et al., 1982).

Smallholders operate under imperfect market conditions driven mainly by buyers. Coffee marketing under cooperative arrangement has recently been shown to suffer from serious inefficiencies further complicating future viability of smallholder coffee farming (Mude, 2006). For instance most cooperatives operate at below capacity and are highly indebted with only a few farmers servicing their operational costs and long standing credit facilities.

4.3 RESULTS AND DISCUSSIONS

4.3.1 Coffee farm typology

Smallholder coffee production records from the year 2004 to 2008 define trends per farm category. The *increasing* farm category appears to have higher fluctuations with the year 2008 showing pronounced yield production. The *constant* and the *decreasing* farm types, showed fairly consistent yield production trends per farmer for the period under consideration (Figure 10I). Calculated rates of change in coffee yields showed that the increasing farm category produce more than three times the average rate of the coffee decreasing farms. The constant farms types showed insignificant rate of change in production, but a higher production rate than the decreasing farms. Mean production values confirm stagnation trends (Figure 10II). There was significant evidence to show that using coffee yields per farm was successful in depicting desired farm categories for this study, as distinct farm types that can mirror other farmer enterprise management behavior.

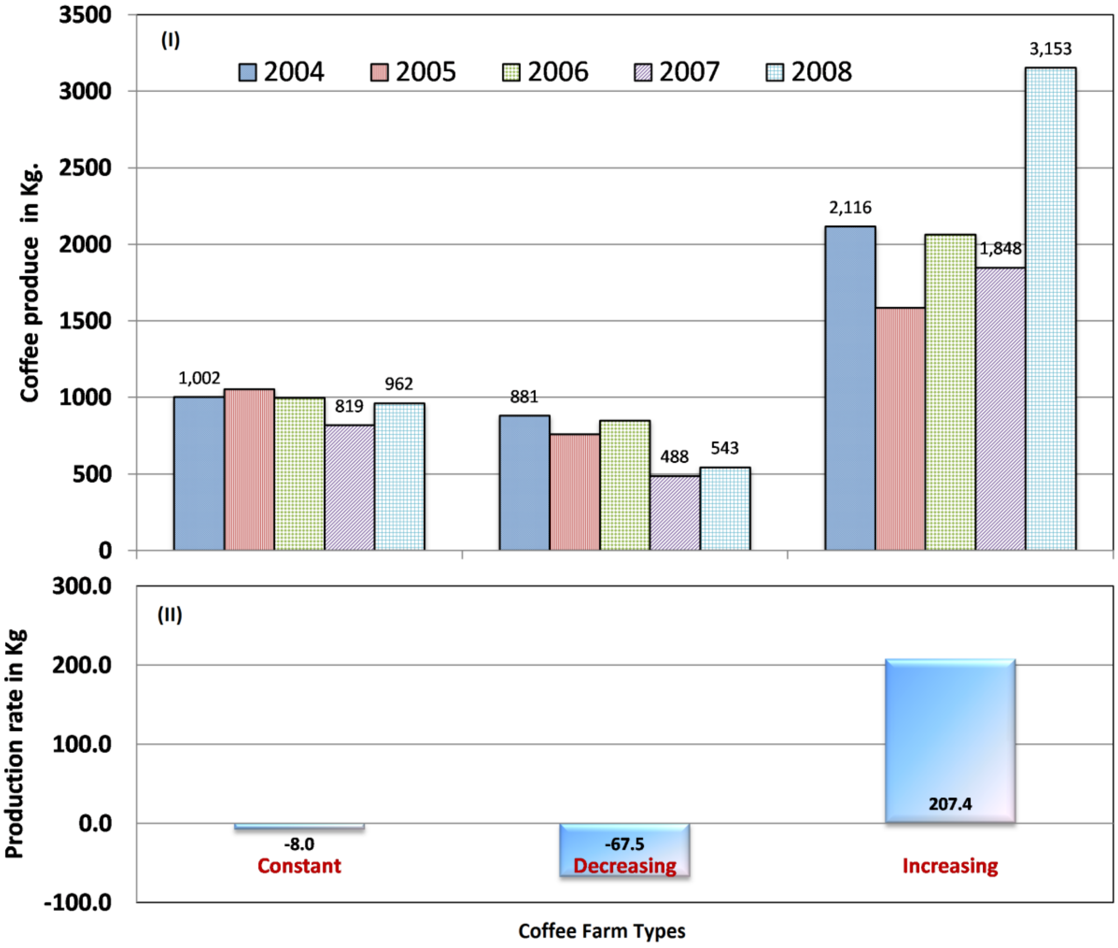

Figure 10 Farm types (constant, decreasing and increasing) (I) average coffee production and (II) mean rates of change from year 2004-2008

4.3.2 Household characteristics

Smallholders in the surveyed coffee region cultivate an average farm size of 1.2 ha (s.d = 1.04; n = 180). The smallest farm sampled was 0.05 ha and the largest farm was 6.9 ha. Coffee household heads are elderly at an average age of 58 years (s.d = 13.43; n = 180). Results showed that farmers had an average of 550 coffee bushes per hectare (s.d = 539.4; n = 180), producing a mean of 4.3 (s.d = 3.21; n =180) kg cherry per bush. The coffee decreasing farms had mean cherry production of 3.8 (s.d = 3.7) kg per bush while the increasing ones have a mean of 4.63 (s.d = 2.53) kg per bush. On per hectare basis, coffee decreasing farms reported coffee mean yields of 1657 (s.d = 1740) kg/ha while the increasing and constant categories had a mean of 2483 (s.d = 1901) and 2183 (s.d = 2052) kg/ha (Table 7). Results further showed a corresponding mean rate of cherry value obtained by farmers across the three farm categories. Conversely, the average value of banana per hectare for the coffee decreasing farms was Ksh 57,806 (s.d = 105,745), compared to Ksh 48,463 (78,453) and Ksh 28416 (s.d = 35,768) for the constant and the increasing farm types (Table 7). Reported maize value showed similar patterns of value distribution.

The average number of agroforestry trees and tree basal area for the constant and decreasing farms were similar, whereas the increasing farms had fewer than 200 tree stems per hectare (Table 7). High value tree crops such as macadamia, avocado and mango had tree densities of less than twenty trees per hectare even though they are often assumed to be potential substitutes for coffee. Macadamia was more highly stocked at 19 trees ha^{-1} compared to mango (9.83, s.d = 17.4) and avocado 6.52 (10.96). Average fruit yield production per tree for these tree crops was: mango 200 fruits/tree/year; avocado 250-300 fruits/tree/season and macadamia 50-80 kg/tree/year. Results showed that fruit tree stocking rate was small on farms however yield production per tree was higher compared to coffee presently grown at a higher density. Macadamia is a particularly important cash crop receiving greater attention by smallholders due to affordable management requirements compared to coffee.

Macadamia nuts have fewer post-harvest losses on storage, handling and transportation compared to fruits such as mango and avocado.

Analysis of livestock farming practices measured as a single variable - tropical livestock units (Table 7), showed that on average the constant farms had 5.38 (s.d = 5.5) units compared to 4.21 (s.d = 4.9) and 3.87 (s.d = 2.9) units for the decreasing and increasing farm categories. Results nonetheless showed that average milk value sold per day for the coffee increasing farms was Ksh 152 (s.d = 143.8) compared to Ksh 118 (s.d = 119.4) and Ksh 94 (s.d = 112.4) for the constant and decreasing farms. Coffee decreasing farms had fewer units of dairy cattle compared to the other farm categories (Table 7).

Table 7 Transformed and non-transformed descriptive data variables on the surveyed coffee farms

	Coffee farm categories				Coffee farm categories		
Non-Transformed	**'Constant'**	**'Decreasing'**	**'Increasing'**	**Transformed farm data**	**'Constant'**	**'Decreasing'**	**'Increasing'**
farm data variables	**Mean (s.d)**	**Mean (s.d)**	**Mean (s.d)**	**variables**	**Mean (s.d)**	**Mean (s.d)**	**Mean (s.d)**
Family size	4.9(2.5)	4.8(2.2)	5.3(2.2)	Family size	-	-	-
Land size (ha)	1.3(1.3)	1.1(0.84)	1.4(0.97)	Land size (Ha)	-	-	-
Food crops							
Maize value ha^{-1}	17843(17955)	19098(19138)	14769(13594)	Sqrt Maize value Ha^{-1}	131.3(55.67)	134.8(52.88)	114(50.11)
Banana value ha^{-1}	48463(78453)	57806(105745)	28416(35768)	Sqrt Banana value Ha^{-1}	166(145.8)	175.5(167.9)	134.2(102.9)
Coffee production							
Coffee age years	35.23(12.96)	37.7(12.43)	33.7(11.97)	Coffee age (Yrs)	-	-	-
Cherry/bush (Kg)	4.4(3.2)	3.84(3.7)	4.63(2.53)	Ln Cherry/bush (Kg)	1.29(0.69)	0.92(1.1)	1.37(0.68)
Cherry yields Kg ha^{-1}	2183(2052)	1657(1740)	2483(1901)	Sqrt Cherry yields Kg Ha^{-1}	42.07(20.51)	35.92(19.31)	46.77(17.34)
Cherry value ha^{-1}	61180(58526)	47220(49604)	69587(54482)	Sqrt Cherry value Ha^{-1}	224.6(109.5)	191.8(103.1)	245.5(97.26)
Coffee bushes ha^{-1}	499.7(379.1)	569.6(694.5)	601.6(497.4)	Ln Coffee bushes ha^{-1}	6.00(0.69)	6.02(0.77)	6.25(0.544)
Livestock keeping							
TLU Ha^{-1}	5.38(5.5)	4.26(4.9)	3.87(2.9)	Sqrt TLU Ha^{-1}	2.07(1.09)	1.72(1.13)	1.79(0.82)
Milk value day^{-1}	118(119.4)	94(112.4)	152.3(143.8)	Ln Milk value day^{-1}	4.28(1.25)	3.94(1.34)	4.52(1.31)
Tree crops							
AFT ha^{-1}	229(223)	202(152)	182(99)	Ln AFT Ha^{-1}	5.20(0.73)	5.13(0.66)	5.13(0.54)
AFT Vol. ha^{-1}	30.4(20.4)	34.4(38.1)	32.4(21.6)	Ln AFT Vol Ha^{-1}	3.59(0.46)	3.59(0.60)	3.62(0.50)
Macadamia trees ha^{-1}	18.04(27.6)	16.89(19.81)	13.52(18.02)	Sqrt Macadamia trees Ha^{-1}	3.16 (2.90)	3.32(2.40)	2.89(2.29)
Mango trees ha^{-1}	10.54(24.53)	7.57(8.678)	5.65 (9.68)	Ln Mango trees Ha^{-1}	2.77(0.58)	2.77(0.43)	2.65(0.40)
Avocado trees ha^{-1}	5.956(8.41)	7.580(15.77)	4.064(4.123)	Ln Avocado trees Ha^{-1}	2.69(0.37)	2.73(0.42)	2.61(0.25)

Data transformations: Ln-Logarithm(x); Sqrt- Square root(x)*$^{0.5}$; Crop values are in Kenya Shillings (1 US$ = Ksh 80); Kg=Kilogramme; AFT=Agroforestry trees; TLU=tropical livestock units; TBA=tree basal area; s.d=standard deviation

4.3.3 Input sizes and types- labour, fertilizer and manure

The amount of inputs such as fertilizer, manure and labour applied per farm were used to compare farm typologies. Results showed wide disparities of inputs applications. Fertilizer application for all farms surveyed was recorded at a mean rate of 255 kg/ha while manure application rates were estimated at 7856 kg/ha. Labour expenses (not costing family labour) were estimated at Ksh 8931/ha (Table 8). Between farm categories, fertilizer application was on average bigger among the coffee increasing farms compared to farms with stagnated production (Table 8). Manure application was similarly largest among the coffee increasing farms on average (Table 8).

Table 8 Fertilizer, manure and labour application rates per coffee farmer categories: 'constant', 'decreasing' & 'increasing'

Farm categories **Inputs variables (n)**	Mean (s.d)	Minimum-Maximum
Constant		
Fertilizer kg/ha (55)	211.9 (150.7)	6.25-750
Manure kg/ha (49)	7008 (5567)	409.5-24000
Labour costs (Ksh)/ha (45)	7266 (6762)	481.6-25716
Decreasing		
Fertilizer kg/ha (53)	231.4 (142.4)	6.67-625
Manure kg/ha (49)	7857 (7779)	875-32000
Labour costs (Ksh)/ha (50)	7873 (6463)	164.7-26602
Increasing		
Fertilizer kg/ha (56)	320.8 (186.2)	37.5-875
Manure kg/ha (53)	9092 (7030)	223.2-31920
Labour costs (Ksh)/ha (53)	10409 (7393)	141.1-32216
All farmers		
Fertilizer kg/ha (164)	255.4 (167.3)	6.25-875
Manure kg/ha (151)	7856 (6605)	223.2-32000
Labour costs (Ksh)/ha (148)	8931 (7517)	141.1-33962

Labour costs were on average highest among coffee increasing farmers compared to the constant and decreasing ones. Statistical differences for the means of the different variables are tested in section 4.3.8 using general linear regressions.

4.3.4 Smallholder enterprise diversification

Farm crop enterprises recorded within all surveyed coffee farms showed a diversity of 7.1 (s.d = 1.71). The farm with the least crop diversity had two crop types while the farm with highest diversity had 12 agricultural crop types. The ten most prevalent agricultural crops on smallholder coffee farms represent 88% of all crop types surveyed on all farms. These crops were maize, beans, banana, avocado, macadamia, mango, beans, papaw, Irish potatoes and Khat (Table 9).

Table 9 Farmer preference scores on major enterprises on farm. Enterprises were arbitrary selected given their prominence on surveyed farms.

	Percentage (%) of farmers allocating an enterprise given score (5 = Highest score; 0,1 = lowest score)						
Farm enterprises (N)	**5**	**4**	**3**	**2**	**1**	**0**	Total
Coffee (180)	**52**	20	18	9	1	-	100
Livestock (166)	**52**	24	14	7	2	-	100
Maize (165)	30	14	25	20	10	-	100
Trees (156)	**44**	14	21	16	4	1	100
Banana (154)	31	15	27	18	9	1	100
Beans (129)	27	14	21	19	19	-	100
Tea (36)	28	**31**	31	11	-	-	100
Potato (36)	19	17	28	25	11	-	100
Vegetables (31)	32	16	26	10	13	3	100
Fruits (26)	19	23	19	23	15	-	100
Macadamia (24)	13	17	**58**	4	8	-	100
Napier (21)	**43**	29	10	14	5	-	100
Cajanas (17)	12	18	6	24	**41**	-	100
Catha edulis (12)	25	**33**	-	25	8	8	100
Cowpeas (6)	-	-	-	**33**	**67**	-	100
Cassava (5)	20	-	20	20	**40**	-	100
Sweet potato (4)	25	-	-	-	**75**	-	100
Yams (3)	-	**33**	-	-	**67**	-	100
Arrow roots (3)	-	**33**	-	-	**67**	-	100
Black beans (3)	**33**	33	-	-	33	-	100
Sorghum (3)	-	-	33	33	33	-	100
All enterprises	37	18	21	15	9	0.00	100

N = number of farms surveyed. Percentages in **bold** shows the highest score attributed to an enterprise

For all the major enterprises present on farm, farmers were asked to score for favorite enterprise. A scale of zero (0) to five (5) was used to represent the least favorite to the most favorite enterprise for addressing household requirements. Table 9 shows the percentage of farmers allocating each enterprise their considered score-rank. Coffee and livestock have a tied preference and are confirmed as a premier choice for more than 50% of respondent farmers. Agroforestry trees and napier grass were also regarded to be highly important (scored 5) by 43-44% of the farmers interviewed. Banana, maize, black beans and vegetables constitute a crops cluster shown to be of similar, high importance by at least 30-33% of the respective farmers interviewed. Tea, khat and tuber crops (yams, arrow roots) were scored (score 4) as the second most important crops by a 30-33% of interviewed farmers; while macadamia was scored of medium importance (score 3) by 58% of the interviewed farmers. The lower score for macadamia is perhaps due to a drop in the nut prices in the recent past.

Some of the crops apportioned a low importance (score 1) by a majority of farmers were cajanus, cowpeas, cassava, sweet potatoes, arrow roots, black beans and sorghum. These crops show a huge distance margin with the highly important enterprises. Though cultivated on farm by some farmers, most respondents reported that these enterprises just complement household food needs and offer little surpluses for income generation. Overall, the percentage of farmers apportioning the surveyed enterprise the low importance (score 0) were insignificant mathematically.

4.3.5 Enterprise presence

Findings on enterprise presence counts on smallholder coffee farms can be matched with enterprise preference scoring. The most abundant commodity enterprises on farm (Figure 11) were also score-ranked highest. However though fruits such as avocado, macadamia, mango, and papaw record a high presence count on farm, a high rank score was elected by only 20-23% of surveyed farmers an indication of some disconnect. Vegetables were also scored highly by over 30 percent of farmers but showed low presence on farm. A further indication of varied farmer adoption practices can perhaps be due to recent prolonged droughts.

There is a steep drop in the enterprise presence counts after the first eight popular enterprises, suggesting a wide disparity (unevenness) of farmer adoption of different enterprises for diversification/intensification purposes. Scoring for some of the seemingly miscellaneous enterprises helped identify growing appreciation for enterprises such as *napier* and khat. The constant farm categories showed higher presence of livestock, banana and avocado compared to the other farm categories. The coffee increasing farm categories showed a lower banana presence but higher livestock presence. The coffee decreasing farm category show a lower enterprise presence overall.

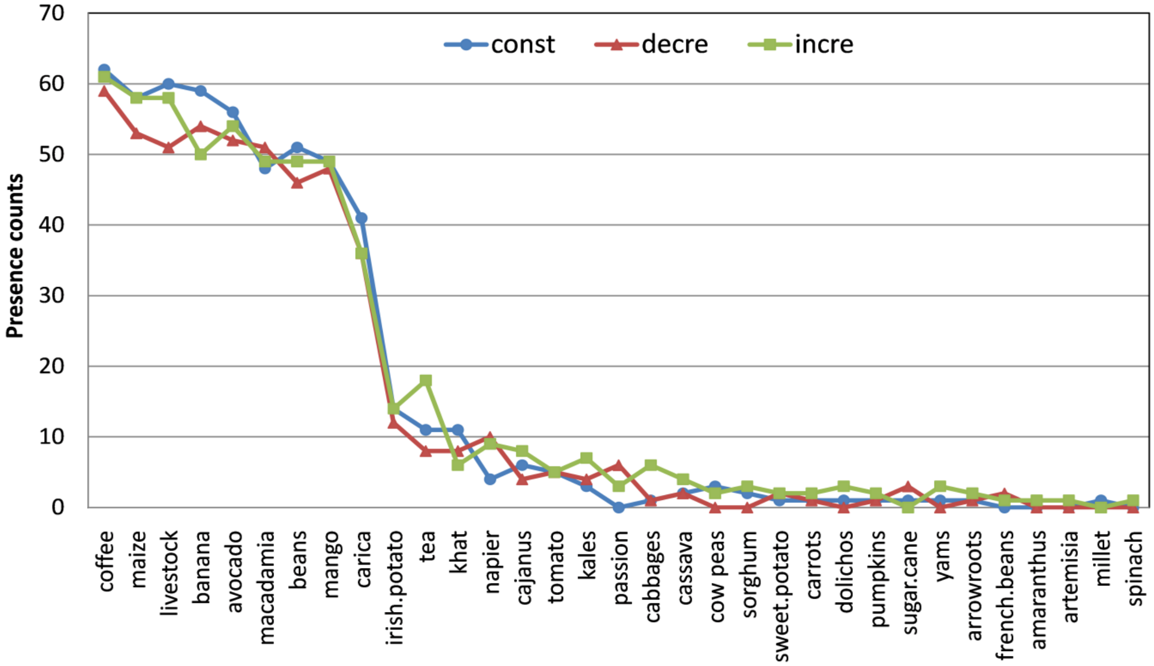

Figure 11 Smallholder farms enterprise presence counts for the constant, decreasing and increasing farm categories

4.3.6 Farmers preferred substitutes to coffee

Given the prevailing challenges facing coffee production such as price volatility, farmers were asked to name farm enterprise they considered likely alternatives to coffee. At least 23 (11%) of the respondents reported to never have thought of any alternatives to coffee; some 55 (25.5%) farmers reported that bananas would be a suitable alternative.

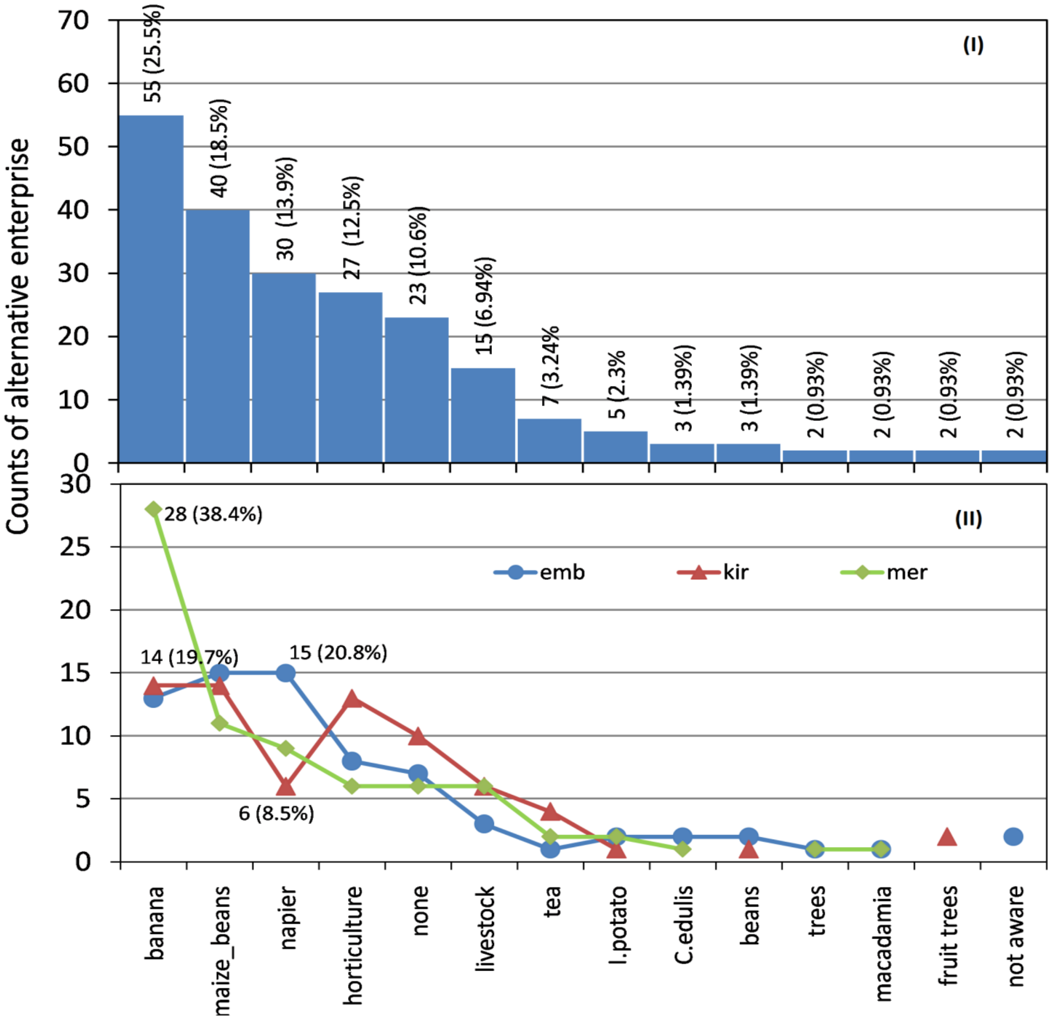

Figure 12 (I) Farmer preference counts on enterprises seen as an alternative to coffee for the entire survey area (II) Comparison between regions on farmer preferences on enterprises

Another (40) 18.5% of the respondents proposed maize and beans as possible alternatives while 30 (14%) respondents preferred napier, implying enhanced dairy keeping as possible alternatives (Figure 12I). Data comparisons between coffee districts clearly showed that banana is the most preferred alternative for the Meru region but is less favoured in Embu and Kirinyaga regions rivaled by maize and beans (Figure 12II). There is a high preference for napier grass (implying dairy keeping) for Embu and high preference for horticulture (mainly tomato, kales) for Kirinyaga (Figure 12II).

4.3.7 Factors driving smallholder enterprise choice

To assess the relationship between various factors having a role in smallholder enterprise productivity pair-wise correlation was assessed on selected variates at 5% significance level. Variables measuring farm resource size such as land size, family size, agroforestry tree ha^{-1}, tree basal area ha^{-1}, cherry production, coffee bush ha^{-1} and livestock enterprise TLU ha^{-1}, milk value day^{-1} were tested for association (Table 10). Additionally, farm inputs variables such as manure, fertilizer and labour costs were correlated with other variables used to assess farm production (Table 11).

Results showed some evidence that maize value obtained per hectare is negatively correlated to household size and land size. Maize is the staple food for most households and extensification is constrained by input costs. There is some evidence that maize value significantly increases with higher tree basal area (TBA), number of coffee bushes and banana value per hectare. A higher banana value ha^{-1} suggests that more inputs can be afforded for maize production. It also in a way complements maize as the main staple food crop. Moreover, a high banana value is positively associated with the size of tropical livestock units kept per hectare. This is perhaps due to the fact that banana stems are valued as fodder supplement for livestock kept under zero grazing systems. Correlation of banana value with family size, land size, agroforestry tree ha^{-1} and coffee bushes ha^{-1} returned an expected negative correlation, even though not significant at 0.05 level.

Table 10 Pair-wise correlation matrix on key variables used to assess smallholder coffee farm productivity

Productivity variables		**FS**	**LS**	**AFT**	**TBA**	**CB**	**CY**	**BV**	**MV**	**TLU**	**MT**	**CD**	**MS**	**MkV**
Family size	**FS**	1												
Land size (ha)	**LS**	0.1459	1											
AFT ha^{-1}	**AFT**	-0.1045	**-0.2792**	1										
TBA ha^{-1}	**TBA**	0.0054	**-0.2308**	**0.3827**	1									
Coffee bush ha^{-1}	**CB**	-0.1128	**-0.2607**	0.0875	**0.3214**	1								
Cherry Yields ha^{-1}	**CY**	-0.0784	**-0.283**	0.0094	0.0432	**0.4321**	1							
Banana Value ha^{-1}	**BV**	-0.0765	-0.1323	-0.0114	0.0016	0.0031	0.0529	1						
Maize Value ha^{-1}	**MV**	**-0.1615**	**-0.1703**	0.0139	**0.2072**	**0.2956**	0.0584	**0.1775**	1					
TLU ha^{-1}	**TLU**	0.0412	**-0.3374**	0.0777	**0.2225**	**0.1949**	**0.4032**	0.1464	0.1154	1				
Macadamia ha^{-1}	**MT**	-0.0413	**-0.274**	**0.2954**	**0.1794**	0.1103	0.1062	-0.0251	-0.0689	**0.1944**	1			
Crop diversity	**CD**	0.0322	**0.2609**	0.0115	0.0573	**-0.1754**	-0.0995	-0.0169	-0.0746	**-0.2434**	-0.0827	1		
Milk sold (Ksh) day^{-1}	**MS**	-0.0694	0.0137	-0.0806	-0.0696	0.0963	**0.2787**	0.135	0.0294	**0.3586**	-0.0513	0.0139	1	
Milk value (Ksh) day^{-1}	**MkV**	-0.0166	0.1043	-0.0787	-0.0533	0.0739	**0.2389**	0.1196	0.0157	**0.371**	-0.0645	0.0403	**0.9621**	1

Coefficients in **bold** significant at 0.05 level (two-sided test of correlations); AFT = agroforestry trees; TLU = tropical livestock units; TBA = tree basal area

Table 11 Pair-wise correlations for selected variables used to assess farmer input-output relationships

Input Variables		**FS**	**LS**	**Fert**	**Man**	**Lab**	**Mkt**	**CD**	**CS**	**MkV**	**TLU**	**BV**	**MzV**
Family size	**FS**	1											
Land size (ha)	**LS**	0.1016	1										
Fertilizer Kg ha^{-1}	**Ft**	-0.0128	**-0.2308**	1									
Manure Kg ha^{-1}	**Mn**	0.0232	**-0.2951**	**0.2855**	1								
Labour costs ha^{-1}	**Lb**	-0.1342	-0.0986	**0.4759**	**0.2899**	1							
Market distance	**Mkt**	**0.188**	-0.0179	-0.0574	0.0652	-0.1084	1						
Crop diversity	**CrD**	0.0312	**0.245**	**-0.1874**	-0.1222	-0.0644	-0.0679	1					
Coffee bushes ha^{-1}	**CoS**	-0.1277	**-0.2608**	**0.549**	**0.3004**	**0.1995**	-0.0197	-0.1746	1				
Milk value day^{-1}	**MkV**	-0.0358	0.0878	0.136	0.0302	0.1387	0.0774	0.0007	0.058	1			
TLU ha^{-1}	**TLU**	0.0666	**-0.325**	**0.3348**	**0.3608**	0.1516	0.0689	**-0.1941**	**0.2066**	**0.4012**	1		
Banana value ha^{-1}	**BV**	-0.0699	-0.185	0.052	0.0836	0.1254	-0.1389	-0.0266	0.0121	0.069	0.1421	1	
Maize value ha^{-1}	**MzV**	**-0.1856**	**-0.2095**	**0.3329**	0.0558	0.1521	-0.1121	-0.056	**0.3086**	0.0004	0.1318	0.1522	1

Coefficients in **bold** significant at 0.05 level (two-sided test of correlations); TLU = tropical livestock units

Results showed that reduced land size accelerates intensification (i.e. value per hectare) using agroforestry trees, coffee bushes, banana, maize and livestock enterprises. Crop diversification is significantly enhanced by bigger land sizes. Higher coffee and livestock intensity nonetheless significantly reduces agricultural crop diversity on farm while a higher maize and banana value will also reduce farmer crop diversification even though analyzed data is inconclusive. Finally, crop diversity is reduced by lower labour costs and market distance even though collected evidence was not significant.

Key input applications such as fertilizer, manure are significantly constrained on large farm sizes. Labour inputs are shown to be constrained even though not significantly. However labour costs can significantly affect fertilizer application rates implying higher costs could seriously influence farm nutrient status. Labour costs as expected were positively related to the number of coffee stems per hectare. Other results showed a negative correlation between farmer labour expenditure and distance to the nearest market outlet and levels of crop diversification even though not significant at 0.05 level. Fertilizer application rates increases significantly with the number of coffee stems per farm, maize value realized per hectare and amounts of manure applied per hectare. Distance covered by households to the nearest market showed a negative correlation with fertilizer application rates even though not significantly. Fertilizer application was also reduced by higher crops diversity within smallholder farms. On the other hand, data revealed that manure ha^{-1} is positively associated with labour expenditure per hectare, coffee bushes ha^{-1}, livestock units' ha^{-1} and banana value ha^{-1}. Like fertilizer, manure application is significantly reduced with higher agricultural crop diversification.

4.3.8 General linear regression analysis

The effects of present coffee production trends and farm size on smallholder farm intensification were investigated using a general linear regression model (Table 12). The effects of coffee production trends were modeled using the farm categories- 'constant', 'decreasing' and 'increasing' as predictor variates. Farm size (ha) was then added to this 'trend' model to assess its effects as it was found to be significantly associated with most variables. Coefficients of the model containing farm size were then used to analyse differences between the three coffee production trends. Response variates selected for regressions were identified by pair-wise correlations (Table 10 and 11). These were coffee bush ha^{-1}, fertilizer kg ha^{-1}, labour costs Ksh ha^{-1} and non labour costs Ksh Yr^{-1}, tree volume $farm^{-1}$, avocado tree ha^{-1} and milk value sold day^{-1} (transformed by natural logarithm, Ln) and cherry value ha^{-1}, maize value ha^{-1}, banana value ha^{-1} and TLU ha^{-1} (transformed by taking square root). Shapiro-Wilk tests for normality on all variables showed $P < 0.001$ suggesting they were unlikely from a normal distribution hence the transformations (Royston, 1993).

The 'constant' farm category was fixed as the model reference/constant. Fisher's Least Significance Difference procedure was then used to compare significant differences between coffee production categories at $P < 0.05$ and $P < 0.1$ level. Models regressing cherry value ha^{-1}, milk value sold day^{-1}, fertilizer Kg ha^{-1}, non-labour costs Yr^{-1} and avocado tree ha^{-1} against coffee production trends were significant at 0.05 level. Regressions models on coffee bush ha^{-1}, labour costs Ksh Yr^{-1} and maize value ha^{-1} were significant at 0.1 level. All the models showed that farm size effect was highly significant at $P < 0.05$ except for avocado tree ha^{-1} (Table 12).

Results showed significant differences between farm categories considering outputs such as cherry value ha^{-1}, milk value sold per day, number of avocado trees ha^{-1} and inputs such as fertilizer applied in Kg ha^{-1} and labour and non labour costs per farm per year. Measures of intensification such as tropical livestock units ha^{-1}, maize value ha^{-1}, banana value ha^{-1} and agroforestry tree volume $farm^{-1}$ were however not significantly different for farms with the different coffee production trends.

Table 12 General linear regressions coefficient for various 'intensification' variables against farm categories and farm size

	Coefficients of independent variables					
	Coffee production trend			P-value for the model assessing 'trend effect'	Farm size (Ha) (P-value for farm size effect	R^2 for model containing 'trend' and farm size effects
Response variables	Model constant	Increasing	Decreasing			
Ln Coffee bush ha^{-1}	6.320	0.29**	0.012^{++}	0.095	-0.269 (<.001)	0.182
SQRT Cherry value ha^{-1}	262.9	26.9^{++}	-35.2$^{\#}$	0.018	-32.19 (<.001)	0.132
Ln Milk value sold day^{-1}	3.657	0.5**	-0.191^{++}	0.011	0.004 (0.029)	0.035
Ln Fertilizer Kg ha^{-1}	5.302	0.641***	0.085^{++}	0.004	-0.228 (0.002)	0.097
Ln Non-labour costs Yr^{-1}	8.357	0.568**	-0.236^{++}	<0.001	0.304 (<.001)	0.167
Ln Labour costs KshYr^{-1}	7.951	0.426*	0.090^{+}	0.086	0.515 (<.001)	0.166
SQRT Maize value ha^{-1}	143.20	-15.53	2.72^{+}	0.072	-9.960 (0.009)	0.051
Ln Avocado tree ha^{-1}	2.711	0.0233^{++}	-0.1281$^{\#\#}$	0.042	-0.008 (0.746)	0.019
Ln tree volume farm^{-1}	3.020	0.158*	0.0635	0.110	0.407 (<.001)	0.414
SQRT TLU ha^{-1}	2.440	-0.214	-0.371$^{\#\#}$	0.144	-0.312 (<.001)	0.106
Manure Kg ha^{-1}	17147	-2591	-5285	0.181	- 3710 (<.001)	0.140
SQRT Banana value ha^{-1}	201.20	-25.9	5.6^{+}	0.273	-29.93 (0.003)	0.047

Least significant differences between farm categories: Increasing versus Constant (*); Increasing versus decreasing (+); Decreasing versus constant (#). Significant different level: P<0.01(*** +++ ###); P< 0.05(** ++ ##); P<0.1 (*+ #); Data transformations: Ln = Natural logarithm base e(x+10); SQRT = Square root(x)*$^{0.5}$

Coffee bushes ha^{-1} for farms with increasing coffee production was significantly different from the constant and decreasing ones ($P < 0.05$). In fact results showed that on average farms increasing coffee farming have 17% ($P < 0.05$) more coffee bushes ha^{-1} than constant farms and 5.5% ($P < 0.05$) more bushes compared to the farms on a decreasing trend. Though coffee bushes ha^{-1} on coffee decreasing farms were 12.3% higher than the constant ones, data analysis did not show evidence of significant differences.

In terms of cherry value ha^{-1}, results were robust to show that cherry value for the increasing farms are significantly different ($P < 0.05$) from those of decreasing farms but not so for the constant farms. In fact cherry value for the coffee decreasing farms was significantly lower ($P < 0.1$) compared to the constant farms. Analysis showed that both cherry value ha^{-1} and coffee bushes ha^{-1} are significantly ($P < 0.001$) lower in bigger farm sizes measured in hectares. This is perhaps due to the high costs of labour and non-labour inputs required for coffee farming at larger scale.

Farm intensification with dairy farming activities revealed that milk value sold per day for the coffee increasing farms were significantly different from the constant and the decreasing ones. Farms switching to increased coffee production trends recorded a 22.5 % ($P < 0.05$) higher milk value sold per day compared to the constant farms; and a 38.3 % ($P < 0.05$) higher value compared to the coffee decreasing farms. The coffee constant farms recorded a 20% higher milk value compared to the coffee decreasing farms. This finding was however not statistically significant at 0.1 level. Results showed that milk outputs could nonetheless be increased with bigger farm sizes.

On the other hand, avocado fruit farming, popular in smallholder coffee systems showed a significantly higher (31.8%, $P < 0.05$) tree intensity per hectare for farms with constant/stagnated coffee production trends compared to the increasing ones. Avocado trees per hectare were significantly higher (46.4%; $P < 0.05$) in coffee decreasing farms compared to the increasing farms. Results however showed that avocado intensification is significantly reduced in bigger farm sizes. Other results showed that total tree volume maintained on farm though not different by farm categories would be significantly increased by bigger farm sizes.

Coffee farms intensification using maize (maize value ha^{-1}) and banana (banana value ha^{-1}) were not different by farm categories but showed declining and increasing trends for farms with increasing and decreasing coffee production trends. Results further showed that larger farm sizes would significantly decrease maize ($P = 0.027$) and banana ($P = 0.020$) value per hectare. Both enterprises have a fairly high input demand. Results demonstrated that fertilizer application (Kg ha^{-1}) were significantly higher (33.9 %) for the coffee increasing farms compared to the constant farms; and 27.9 % higher compared to the coffee decreasing farms ($P < 0.05$). Fertilizer application on the coffee decreasing farms were 8.4 % higher compared to the constant farms. This finding was nonetheless not significantly different.

Measurements of non-labour input costs such as pesticides, seeds and others, showed that, coffee increasing farms record significantly higher costs compared to the constant farms (14.2 %, $P < 0.05$) and 12.9%, ($P < 0.05$) more costs compared to the decreasing farms. The coffee decreasing farms recorded lower non labour costs though higher (1.44 %; $P > 0.1$) than the constant farms. Coffee farms further showed a significantly high labour costs (30.2%) incurred per year for farms showing increasing coffee production compared to the constant ones; and 24.4% more costs compared to farms on a decreasing trend ($P < 0.1$). Labour costs for the decreasing farms were 7.7 % higher but not significantly different from the constant ones.

Results confirmed expected trend that bigger farm sizes will significantly increase costs of labour and non-labour costs and more specifically reduce fertilizer application rates per hectare. Manure application was also found to decline significantly with bigger farm sizes. In fact all farm types whether increasing or decreasing on coffee production had declining manure application rates perhaps suggesting its limited use compared to chemical fertilizers. These results were however not statistically different.

Hypothetically data analysis and field observations provide insight on cropping strategies that can meet household requirements at different time scales - short, intermediate and long-term. Cropping choices can therefore be further analysed from a farmer perspective on the role of coffee as the usual traditional cash crop. Field observed examples of farmer enterprise choices that were held as complementary to coffee are shown in Table 13.

Table 13 Smallholder cropping strategies under different time scales

Cropping time-scales	Example of farmer enterprise system	Role of coffee as a complementary crop
Annual cropping system and semi-annual cropping	Maize-beans (cereal based) Tomato, kales (vegetable)	Mixed cropping on coffee plots Coffee may be cut back awaiting price improvements Inputs obtained from coffee market instruments e.g. stabex used to improve food crops Land productivity increased by mixed cropping with coffee
Intermediate cropping patterns	Banana Passion fruits,	Possible replacements of coffee crop Change of land ownership to younger farmers with little appeal on coffee Reduced coffee crop size relative to enterprise of choice Reduced manure application on coffee Land productivity may be improved when passion is cropped within coffee plot
Longer term perennials	Coffee, macadamia	Higher inputs access (fertilizer, pesticides) obtained from market instruments Size of coffee plots are being maintained, few expand or may change varieties Farmer have lower pressure for land subdivision as siblings have urban employment Low consideration for alternative crops Farmers are ‘model coffee producers’ with leadership roles in local coffee cooperative societies

4.4 DISCUSSION

Uncertainty in coffee profitability has been contributed by buyer driven chains with producers having little influence in the market chains. This situation suggests that farmers can expect persistent price fluctuations. Though it's clear that at a micro-level, diversified farm enterprises are part of farmer risk avoidance strategies there are challenges to prescribing credible alternative to coffee or enhancing coffee productivity.

Development of successful smallholder coffee productivity forecasts requires identification of factors that influence changes in agronomical practices. Smallholders are nonetheless heterogeneous and show complexities of farming practices (Stroebel, 2004). Previous empirical studies have used data collected from random samples to analyze and construct farm typologies (Valbuena et al., 2008; Carmona et al., 2010; Titonnell et. al., 2010). In this study, a sampling strategy that characterized existing farm typologies was used to determine farmer enterprise adoption behaviour. Essentially, farmer historical coffee production records were used to depict production trends as increasing, decreasing or maintaining more or less the same level of production. Data sources to categorize sample farmers were mainly from coffee cooperatives societies. Using simple descriptive statistics such as means with standard deviations, paired correlations and general linear regressions, performance of farms showing different coffee production behavior were made.

Results were clear that smallholder farms intensification is aligned to farmer coffee production decision on whether to increase or decrease coffee production. To some extent other farm enterprise productivity and diversification pursuits are also pegged on this behavior since farm productivity was shown to be strongly associated with labour and non labour inputs including fertilizer affordability. Marenya and Barret (2009) have showed that in Western Kenya, smallholder production response to fertilizer at the levels they can afford do not justify application.

The differentiation of coffee productivity in terms of coffee bushes ha^{-1} and cherry value ha^{-1} between the farm categories revealed that the coffee increasing farms were significantly different from the constant and decreasing farms however there were weak differences between the constant and the decreasing farms. These results are suggestive of farmers' uncertainty on future coffee production. Results demonstrated that farm output measures such as cherry value ha^{-1}, the number of high value tree crops such as avocado ha^{-1} and milk output sold per day as useful indicators depicting farm productivity differences. These differences are in addition reinforced by farmer inputs affordability particularly on fertilizers, labour and other non labour inputs such as pesticides and seeds.

Results comparing the constant, decreasing, and increasing farm categories were inconclusive on the hypothesis that smallholders with stagnated or decreasing coffee yield productivity record higher enterprise intensification rates with maize, banana, livestock and agroforestry trees. Analysis showed that farmers decreasing coffee production realize significantly lower cherry value and have smaller farm sizes and households; but larger banana and maize value which were however not significantly different to the other farm categories. Milk value sold per day was also on the decline per unit suggesting lesser dairy keeping activities compared to the coffee increasing farms. The size of agroforestry tree volumes was slightly bigger than other farm categories. Further, these farmers incur lower labour costs, have lower manure application rates and not much dairy production. They nonetheless appear to use a higher diversity of crops to substitute decreased coffee farming.

On the other hand, farmers interested in expanding coffee production are cushioned to some extent by productive milk enterprises. They also have larger land areas which allow them to have some diversity of other crops without impinging on coffee. They can afford higher fertilizer application and labour costs somewhat subsidized by larger household sizes. Comparatively, evidence suggests that coffee decreasing farms seem to be shifting more into banana and maize than farmers who are expanding coffee production. For these farmers, maize and banana are seen as alternatives. In fact banana has a much higher value on coffee decreasing farms than those expanding the coffee enterprise.

There is evidence of farmer response to shrinking farm sizes and lost coffee yield productivity. Findings suggest that farmers with larger farm sizes are more likely to maintain and increase their investment in coffee enterprise, especially if they also have other important income sources like milk. On the other hand, coffee is decreasing on smaller farms suggesting that with greater land subdivision there is greater farmer interests on other crops like banana and maize unless profitability for coffee were to increase. Smaller farmers inadvertently face more challenges to maintain coffee production instead opting for other crops that provide food security. These farmers also show higher levels of livestock keeping and agroforestry trees to serve as self- insurance for the household. In self-insurance, people exchange some forgone expected earnings for reduced income variability by selecting a portfolio of assets and activities with a low or negative correlation of incomes.

Overall farm typology analysis confirm that farmers rationally allocate assets across activities to equalize marginal returns in the face of quasi fixed complementary assets (e.g land) or mobility barriers to expand existing (farm or non-farm) enterprises (Barrett, 2001). For the poorest this may mean highly diversified portfolios with low marginal returns, or desperation led diversification (Reardon et al., 2000; Barrett et al., 2006).

4.5 CONCLUSIONS

This study has provided insights on farmer strategies to meet household requirements in circumstances of uncertainty for major cash crop farming such as coffee. Land size, coffee production (number of bushes, cherry yields ha^{-1}), livestock units, agroforestry trees, banana, maize value and nutrient (manure and fertilizer) and labour and non labour inputs were identified as significant factors that influence coffee farms productivity behaviour and can therefore distinguish farm typologies. Though farm diversification strategies are found to be similar especially in terms of agroforestry activities, it is apparent that coffee production is decreasing in smaller farms compared to where it is increasing. It is also clear that inputs such as fertilizer application are tremendously reduced with declining coffee production raising concerns that smallholder coffee farms could decline to low productivity systems. On the other hand continued farm subdivisions and unprofitability could seriously curtail increased coffee production. Farmers with small farm sizes and declining coffee production are interested in other crops such as maize and banana that perhaps offer food security but may not ensure land health. These trends would probably change with a high profitability shift in coffee. It is therefore critical that policy makers are aware of these trends in order to support enterprises that are attractive to farmers. This study nonetheless did not show clear alternatives to coffee farming even though dairy farming seem to be associated with increased coffee production, perhaps due to bigger farm sizes.

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CHAPTER 5

IMPLICATIONS OF DECREASED COFFEE CULTIVATION ON TREE DIVERSITY IN SMALLHOLDER COFFEE FARMS

ABSTRACT

African smallholder farming systems are known to maintain a large diversity of native tree species on farm. A shift in coffee cultivation by smallholder producers is however suspected to influence the available tree diversity on farm. To provide current knowledge on how tree diversity is maintained under present coffee production practices within different agro-ecological zones, this study surveyed 180 farms to determine the diversity of available tree species. Farms were categorised according to their trends in coffee production such as, *increasing*, *decreasing* or *constant*. Tree diversity analysis was done using species accumulation curves, rènyi diversity profiles and species rank abundance. Quasi-Poisson generalized linear regressions were used to elucidate richness and abundance difference by farm categories. Results showed that tree diversity per farm was not significantly different by farm types. Tree individuals within coffee plots among the coffee *increasing* farms, were significantly higher than those in the *decreasing* farms ($P = 0.05$) and those of the constant farms. Farm size had a significant effect on tree richnness, abundance and tree volume/basal area on farm. Shannon diversity index for the *decreasing* farms was nonetheless higher than for the *decreasing* farms. There was strong evidence ($P < 0.001$) that species richness in the coffee zone, UM3, is significantly different from those in UM1 and less so ($P = 0.0169$) from those in UM2. Rènyi diversity (H_0) ordered as follows: UM3 ($H_0 = 4.86$; richness = 128) > UM2 ($H_0 = 4.71$; richness = 110) > UM1 ($H_0 = 4.58$; richness = 98). UM3 had the largest proportion (45%) of the most abundant species and hence most un-even. *Grevillea robusta* was highly ranked in terms of relative density and dominance across farm plots at proportions of 41-42%. In conclusion, results suggest that farmers with larger levels of coffee (*Coffea arabica* L.) cultivation tend to retain more tree abundance though not necessarily of high richness on farm. Species richness was more strongly influenced by type of agro-ecological zones.

INTRODUCTION

Smallholder coffee agroforestry systems around Mount Kenya are typical example of tree rich agro-ecosystems. Derived largely from moist intermediate forests, coffee farms adjacent to forests often contain tree species richness depicting close association with species composition in the natural forests (Lengkeek et al., 2006; Kindt et al., 2007). Coffee agroforests have been shown to be instrumental in protecting biodiversity and assist in alleviating negative effects of deforestation (Perfecto et al., 1996). Peeters et al. (2003) have observed that complex agroforests complement ecological services similar to those provided by natural forests, such as soil protection through nutrient cycling; water retention and carbon capture. More importantly, cultivation and retention of naturally regenerated trees in coffee landscapes, which comprise a significant land-use system in the tropics and sub tropics, can serve as biological corridors between protected forest areas and farming landscapes (Schroth and Harvey, 2007).

Recent field evidence suggests that structurally complex habitats also support a more diverse fauna (Perfecto et al., 2005). For instance, in Latin America, ‘rustic’-coffee systems contain a great diversity of ants, birds and trees compared to sun-coffee systems (Rappole et al., 2003). In Brazil, agroforests have been shown to accumulate intact ant communities that provide natural pest control saving farmers on pesticide use. Harvey et al. (2008) and Chazdon et al. (2009), illustrate that conservation approaches that build alliances between ‘human-modified landscapes’ and protected areas tend to enhance biodiversity and to promote sustainable livelihoods.

Lengkeek et al. (2005), report that farmers can also benefit culturally by maintaining biological diversity of tree species that ensure productivity and sustainability of their agroforestry systems. Genetic variation in agricultural landscapes made up by variation between and within species, helps farmers to manage their inputs in more efficient ways (Dawson et al., 2009). For instance, a mix of fast growing and slow growing indigenous timber species can be retained for different market opportunities such as sawn wood markets; as well as domestic consumption like house building and firewood requirements. In addition, fruit tree species with different fruiting phenology can better contribute to household food security and income (Dawson et al., 2009).

In line with this knowledge, approaches such as shade coffee certification have been advocated to promote preservation of coffee systems biodiversity (Philpott and Dietsch, 2003). In these schemes, coffee consumers are impressed on the value of ‘shade coffee’- coffee grown under tree canopy as opposed to ‘sun coffee’- coffee grown without an over-storey. Where practiced, for instance in the Veracruz region of Mexico, shaded coffee establishment involves placement and maintenance of young coffee plants under a canopy provided by one or two tree species (Rappole et al., 2003). In Kenya, tree planting within coffee plots is prominent, though not necessarily for shade but for tree products and services. Different tree species are cultivated in mixed or line planting patterns commonly as boundary markers.

Determining what kind of tree canopy management contributes to biodiversity conservation is critical for increasing consumers’ confidence in shade coffee certification schemes (Perfecto et al., 2005). For instance, some plantations in Central America use low density of heavily pruned *Inga* or *Erythrina* trees which may not be as effective at preserving biodiversity compared to ‘rustic’ plantations that mimic structural complexity of forests (Perfecto et al., 2005). In order to raise the ‘attractiveness’ of shade coffee certification programs, Philpott and Dietsch, (2003) have recommended provision of financial incentives to farmers to maintain biodiversity-rich shade farms that also preserve adjacent forest fragments. To keep farmers from converting more forest to shade coffee, they recommend only certifying farms that are ten or more years old. The relative impact of converting natural forest to agroforestry systems has nonetheless not been compared in many agricultural landscapes (Fitzherbert et al., 2008; Asase and Teteh, 2010). From a conservation perspective, coffee agroforestry systems should be promoted, but not at the expense of remaining forest patches (Rappole et al., 2003; Philpott et al., 2003; Perfecto et al., 2005).

Though studying all the factors influencing biodiversity in coffee systems is challenging, useful lessons from similar agroforests such as cacao (*Theobroma cacao* LINN.) and rubber (*Hevea brasilensis* Muell. Arg) can be inferred. These systems have been showed to offer more sustainable production systems than pure plantations systems (Perfecto et al., 2005; Asase and Teteh, 2010). Like coffee, cocoa production systems are nonetheless being replaced by land-use systems of lower biodiversity value for instance, in indigenous territories of Talamanca, Costa Rica, despite efforts to promote cocoa agroforestry as conservation tool (Schroth and Harvey, 2007).

Challenges that negatively affect the promotion of coffee and cocoa agroforests include; fears of pest and diseases prevalence; expanded human population with accompanied demand for land; demand for expanded food crop production, integration of indigenous communities into the cash economy, low prices and poor market prices for cocoa and coffee (relative to alternative crops).

In order to promote biodiversity in smallholder coffee agroforests of Mount Kenya, current vegetation with floristic and structural complexity should be enhanced. It is clear that intensification of the systems with other land uses such as annual cropping usually involving maize, beans and banana may not be compatible with biodiversity preservation. Consequently, farm tree domestication activities that enhance farm tree planting and natural regeneration and at the same time enhance farmer benefits such as provision of wood and fruits or are beneficial to fauna can have positive impacts on biodiversity. There are concerns that trees in coffee systems are propagated with few germplasm sources that are in close vicinity such as neighboring farms implying that similar patterns of tree diversity on farms can persist since inter and intra-specific tree diversity is eventually decreased (Lengkeek et al., 2005).

Few studies are available to show how tree diversity in high potential farming systems such as Mount Kenya can contribute to biodiversity enhancement with direct benefits to the farmer. Knowledge gaps abound on farm tree species choices, management strategies and conservation within fragile habitats and niches. More so, there is need to understand how indigenous species on farm may be managed in a context of changing land use decisions to cultivate or not cultivate coffee and food crops such as maize frequently affected by commodity market shocks.

Summarizing patterns of species diversity in relation to the most important factor structuring plant communities would therefore help reveal the basic patterns of variation. A small and un-even, tree species population in a given farming landscape may be dysfunctional by hampering gene migration within a given tree population thereby increasing chances of genetic erosion (Dawson et al., 2009). There is however no available evidence to indicate minimum tree densities to be maintained at a given farming landscape (Lengkeek et al., 2006; Kindt et al., 2007).

The first objective of this study was to investigate agroforestry tree species richness maintained by coffee farmers under changing coffee yield production trends categorized as *increasing*, *decreasing* or *constant*. The second objective was to determine tree diversity patterns maintained under the different coffee agro-ecological zones (Upper midland 1), 2 and 3 around Mount Kenya. Thirdly, the study sought to determine *gamma* diversity for the Mount Kenya coffee system.

It is anticipated that this study findings will contribute towards better awareness among agricultural practioners and policy makers on the availability and contribution of tree diversity in smallholder coffee farms. An understanding of the structure and densities of tree population on farm is especially useful in determining the viability of trees on agricultural landscape even for conservation. Further, findings could also inform strategies towards establishing farm based or the so called decentralized tree germplasm sources by identifying available tree species diversity and their distribution on coffee farms.

5.1 CONCEPTUAL FRAME

Recent studies on shade coffee document the biodiversity benefits of coffee agroforestry in various geographic locations. In Mexico, Peeters et al., (2003) report that diverse shade vegetation yield complimentary products, such as fruits, timber and firewood, which diversify the diet and stabilize incomes for smallholders. The values of these products have sometimes been found to outweigh gains from coffee sales. For instance, Beer et al. (1998) shows that coffee estates producing 1380 pounds of coffee ha^{-1} and shaded with *Cordia alliodora* (R & P) Oken, a timber species, have higher profits if coffee price sinks below 60 US$/100 pounds. Peeters et al. (2003) reports that coffee shaded with any density of *Cordia alliodora* has better benefit/cost ratio than in un-shaded coffee estates, although coffee yields are lower. In Costa Rica, studies have shown that one hectare of coffee plantation with diverse shade vegetation covers all the necessities of timber, firewood and fruits for a seven-person peasant family. Simplifying these plantations is reported to be economically disadvantageous even if coffee production increases (Peeters et al., 2003).

Quantifying direct benefits households can anticipate from cultivating a diversity of agroforestry trees can contribute towards preserving and protecting individual species and their ecosystems (Purvis and Hector, 2000). Comparative measurements of diversity for multiple locations, groups or times can help answer crucial questions about how diversity arose and how we might best act to maintain it (Humphries et al., 1995; Purvis and Hector, 2000). Conceptually, plant diversity can be related to productivity at different scales: global, regional and experimental (Purvis and Hector, 2000). Figure 1 shows a schematic presentation of these relationships. At a global scale, from high latitude to the tropics, plant diversity in large areas is positively related to increasing productivity (Figure 13I). At regional level, (Figure 13II) plant diversity in small plots is frequently negatively related to increasing productivity, often as part of a larger unimodal distribution of diversity. The number of species will at a given scale relate to several factors such as their size. Hence in ecology studies it’s important to consider the number of individual plants sampled, spatial heterogeneity and competitive exclusion as productivity increases.

Experimental manipulation of plant diversity within habitats (Figure 13III) reveal that although relationships vary, productivity tends to increase with diversity owing to increasing complementarities or positive interactions between species and the greater likelihood of diverse communities containing a highly productive species.

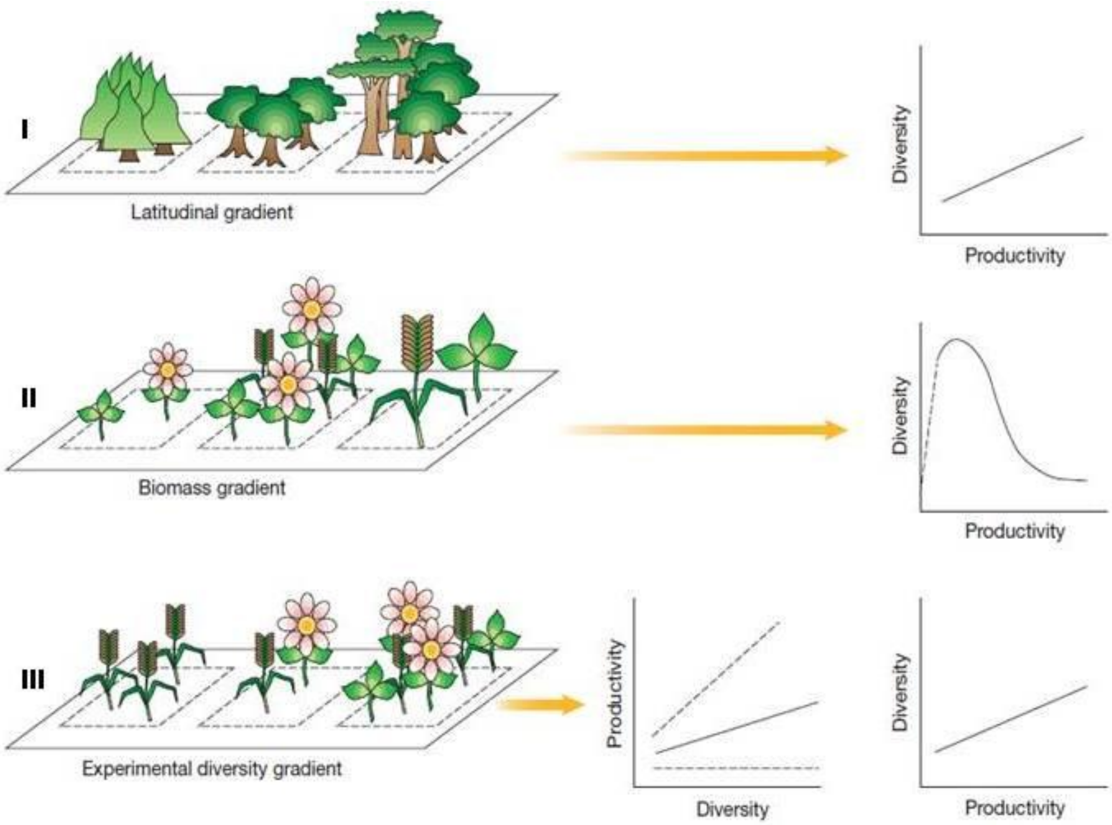

Figure 13 Plant diversity and productivity at different scales (Source: Purvis and Hector, 2000)

In manipulation experiments, biodiversity is the explanatory variable and productivity the response, whereas in observational studies the relationship is usually viewed the other way round as illustrated in Figure (13 III). Abiotic variables may be responsible for large-scale variation. Nonetheless, evaluation of large or small - scale effects differ according to species and given field situation.

Benchmarking genetic diversity among the farm tree communities has been poorly understood aspects for diversity estimation. It is further, not clear to what extent smallholders are willing to conserve tree diversity due to resource constraints such as available land per household and possible benefits that can be accrued (Lengkeek and Carsan, 2004; Simons and Leakey, 2004). The importance of on-farm tree inventories lies in the information they reveal on the density and the level of aggregation of tree species in farmland. They can also provide insight on the connectivity, levels of out-crossing and possible inbreeding depression of farm tree population (Dawson et al., 2009).

Finally, available literature provides useful perspectives for interpreting species richness data in natural systems. The relation of species richness to species succession stage, abundance and composition are shown as important in biodiversity analysis (Grime, 1983; Jongman et al., 1995). For instance large changes in species richness at a certain stages of the succession does not necessarrily mean large compositional turnover, since compositional turnover mean a change in species abundancies which may be uncorrelated with the presences or absences of species.

5.2 MATERIALS AND METHODS

Many factors, such as environmental variation, history of a site and dispersal ability of different species can be responsible for structuring tree assemblages (Spies, 1998). Species diversity implies the number of categories that can be differentiated and the proportions (or relative abundance of the number of individuals in each category (Kindt and Coe, 2005). In more elaborate systems, at least three measures are used to determine diversity: *alpha* diversity (species richness of standard site samples), *beta* diversity (differentiation between samples along habitat gradients), and *gamma* diversity for a geographic area (differentiation between areas at larger scales) (Bond, 1989).

Species richness and evenness are common methods of quantifying biodiversity even though quantification is always done with loss of some information (Humphries et al., 1995; Jongman et al., 1995). Species richness refers to the number of species in a community; while evenness refers to how species abundances (e.g. the number of individuals, biomass, and cover) are distributed among the species (Ludwig and Reynolds, 1988). In forestry, species richness is often regarded as the most important component of alpha diversity. Tree diversity inventories are therefore useful in characterizing the demographic shortcomings of agroforests that may underlie the system (Dawson et al., 2009).

The frequency distribution of species abundances is considered a fundamental characteristic of tree assemblage structure (Sizlinga et al., 2009). Generated species abundance curve show a *log-normal* distribution. Relative abundance is an interplay of many more or less independent factors. On the other hand tree basal area distribution, matches a *geometric distribution* of species abundance. This model is known as the *niche pre-emption hypothesis.* It assumes that with limited environmental resources the most dominant species pre-empts a large fraction of the resources, the next most successful species pre-empts a smaller fraction of the remaining resources and so forth (Ludwig and Reynolds, 1988).

In this study, tree species counts and tree basal area (tree cross-sectional area at breast height) are used to analyze tree diversity patterns in smallholder coffee farms. Diversity is assessed by calculating certain values of inventoried trees (Githae et al., 2007; Ambinakudige and Sathish, 2009), these are: relative frequency (Rf), which is the number of farm plots in which a species occurs divided by the total number of occurrences in plots; Relative density (Rd), which is the number of individuals of a species divided by the total number of individuals of all species; relative dominance (RD), which is the basal area of a species divided by the sum of all basal areas for all species; and importance value (Iv) which is calculated by the summation of Rf + Rd + RD.

5.2.1 Study area

This study was conducted within the Mount Kenya, smallholder coffee systems (see chapter 3). The larger Mount Kenya forest biosphere is separated from the coffee zone by a belt of tea. This biome is a world heritage site exhibiting rare fauna and flora. Some 882 plant species, belonging to 479 genera and 146 families have been identified in this ecosystem. Eighty one high altitude plants are endemic to this system (UNEP, 2005). Three coffee agro-ecological zones namely the upper midland one (UM1), 2 and 3, constitute the main coffee agro-ecosystems in Kenya (Jaetzold and Schmidt, 2007). Altitude for coffee growing ranges from 1200 to 1750 m above sea level. The lower altitude works better if precipitation is above 1200 mm. Annual mean rainfall is between 1200 and 1800 mm. Mean temperature range is 18.9 to

20.7 °C. A small change in diurnal temperature range is anticipated due to prevalent cloud cover and minimum temperatures compensating for any rises (Jaetzold and Schimdt, 2007).

The soils are mainly ando-humic nitisols and humic andosols, developed on tertiary basic igneous rocks. They are characterised by dark reddish brown, to dark brown colours, with good drainage and extremely deep profile (FAO, 1978). Soil fertility is however on the decline due to recurrent permanent use over the years with little recycling of nutrients (see chapter three). Present land use activities other than coffee production involve growing of vegetables such as French beans, snow peas, cabbages, kales, bananas, fruits such as passion fruits, avocado, mangoes and food crops such as maize, beans, Irish potatoes. In the upper midland zone (UM 1), tea cultivation is also undertaken to a lesser extent. Livestock keeping forms an important part of smallholder farming. Pure and improved crosses of dairy cattle such as Ayrshire, Guernsey and Friesian are raised under zero grazing units. Some farmers also keep bulls (local zebu or crosses) for draft power and serving their cows.

The Mount Kenya coffee zones are largely of high agricultural potential characterized by high human settlement. Population density exceeding 400 persons per square kilometer in parts of Embu and Meru central have been recorded (GOK, 2010). Possible population pressure is driving significant land-use change possibly influencing farmer land access, availability, and intensification practices.

5.2.2 Farm plots sampling frame

A total of 29 farmer cooperative societies (FCS) effectively covering the coffee production zone of North-Eastern and Southern Mount Kenya was used to select farmers. Random samples of 180 farm plots were surveyed during the months of June to August 2009. Farmer coffee cherry production records were collated at the FCS level and used to categorize sample farm plots into three groups according to their ‘coffee trends’ as either *‘increasing’, ‘decreasing*’ or `constant’ (see details in chapter 2). The three types of farm plots were compared and contrasted with respects to levels of tree diversity maintained. Farm sizes and their slopes were assumed to be similar in most coffee zones and therefore not considered during sample selection. Coffee, banana and maize farming were assumed to be the most dominant agricultural cropping patterns present in the Mount Kenya coffee system. Household interviews, using close and open ended questionnaires were further used to collect additional farm plot data such as on tree planting practices, farmers' age, family size, land size, and size of the coffee enterprise.

The study used ground based methods to enumerate tree species present in smallholder coffee farms. Tree basal area mensuration (tree cross-sectional area measured at breast height) was also undertaken. All trees greater than or equal to 5 cm diameter at breast height (DBH) were in fact enumerated. DBH's were readily measured using calibrated tree diameter tapes. Trees were defined as all woody perennials growing to over 1.5 m tall, including exotics (Beentje, 1994; Brown, 1997). Local names of tallied trees were recorded from farmer interviews. All enumerated trees were identified to the species level according to Beentje (1994) or Maundu and Tengnäs (2005). Coffee plants were not classified as agroforestry trees. Two persons were required to undertake tree inventories by farm walks; simultaneously recording species presence counts and DBH readings. Farmers' were requested to facilitate marking-out of plots boundaries and in species identification in local dialects.

5.2.3 Diversity analysis

Recorded tree species information was termed as 'coffee farm trees assemblage' and tabulated into an ecological data matrix. This was subjected to diversity analysis using *BiodiversityR* (Kindt and Coe, 2005), based on *R* statistical software version 2.11.1 (R Development Core Team 2010).

Species patterns are used here to refer to the spatial dispersion of a species within a given farm and the relationships among many species between farms (Ludwig and Reynolds, 1988). To investigate species aggregation and levels of dominance, rank abundance curves and Rènyi diversity profiles were analyzed. Tree abundances (number of individuals) and basal area (stems area) distributions were calculated to assess structural complexity and heterogeneity of present farm tree populations

(Jongman et al., 1995). All calculations were based on species frequencies. Tree diversity was assessed by calculating Shannon and inverse-Simpson diversity indices (Annex 5).

In order to assess tree diversity among farm categories, districts and the different coffee agro-ecological settings, Rènyi profiles were used to rank sites from low to high diversity (Kindt and Coe, 2005; Kindt et al., 2006). Rènyi profiles are curves used to provide information on richness and evenness; they are essentially one of the diversity ordering techniques (Jongman et al., 1995; Kindt and Coe, 2005). The profile is calculated from the species proportion and alpha parameter as follows:

$$H_\alpha = \frac{\ln\left(\sum_{i=1}^{s} p_i^{\alpha}\right)}{1-\alpha}$$

$$p = proportions\ of\ each\ species$$

Rènyi species diversity ordering for all enumerated species was plotted at scale values of: 0, 0.25, 0.5, 1, 2, 4, 8 and ∞ as prescribed in *BiodiversityR* (Kindt and Coe 2005; Jongman et al., 1995). The values are based on parameter 'alpha'. The profile value, alpha = 0 provide information on species richness- it equals the logarithm of species richness (H_0 = ln(S). While the profile value, alpha (∞) = *infinity* provides information on the proportion of the most dominant species- it is calculated as the logarithm of 1/proportion of a given species. In summary, Rènyi diversity profiles calculation includes:

H_0 = Ln (Species richness)
H_1 = Shannon diversity index
H_2 = Ln (Simpson^{-1})
H_∞ = ln (Prop Max^{-1})

Finally, to analyse tree richness and evenness in the different coffee agro-ecological zones and coffee farm categories surveyed, sample based species accumulation curves were plotted. Species accumulation curves show species richness for combinations of sites (in this case farms). These curves portray the average pooled species richness for all sites together. Average pooled species richness is calculated because different sites combinations have different species richness (Kindt and Coe, 2005). Quasi-Poisson regression modeling (with a log-link) was used to assess effects of coffee production trends and farm size on tree diversity, tree volume, coffee bush and enterprises such as the number of livestock units on farm. The Bray-Curtis and Kulczynski distances were calculated for academic purposes to examine species composition for the Meru, Embu and Kirinyaga coffee regions as they are held to be ecologically similar.

5.3 RESULTS

5.3.1 Farm characteristics

A total of 35820 trees were enumerated from 180 coffee farms. Surveyed farms on average contain 199 (172.6 - 221.5, $P = 0.95$) trees; 90 to 100 of the trees are maintained within coffee plots per farm. Mean species richness per farm was 17 species (15.7 to 18.2 species; $P = 0.95$). While average tree biomass volumes accumulated per farm was calculated at 36.31 m^3 (31.1- 41.5 m^3, $P = 95\%$). Data analysis showed that only 22.5% of the tree individuals counted on farm was of indigenous origin. The total area surveyed (combined sample farms) was 224.5 hectares. Farms are on average about 1.2 ha (1.1- 1.4 ha, $P = 0.~95$) with a family size of about 5 persons (4.7- 5.4, $P = 0.95$). Household heads are aging at a mean age of 58 years.

Farmers own about 4.0 tropical livestock units (TLU), and cultivate about 545 (470.8-619.9, $P = 0.95$) coffee bushes per hectare; coffee cherry production is 4 kg per bush. Data analysis showed that coffee bushes distribution on farm is skewed with some 156 (75%) farmers growing between 500 and 750 bushes (Figure 14I). About 40 (22%) farms produce coffee cherry at between 2000-5000 kg ha^{-1} $year^{-1}$ indicating possibilities of high yield production; some 110 (60%) farms reported yields of 1000-2000 kg of cherry ha^{-1} $year^{-1}$ (Figure 14II). Besides coffee, 57.8 % (n = 96) and another

42.2% (n = 70) of the surveyed farm households produce maize as the main staple food crop in polyculture or monocrop systems.

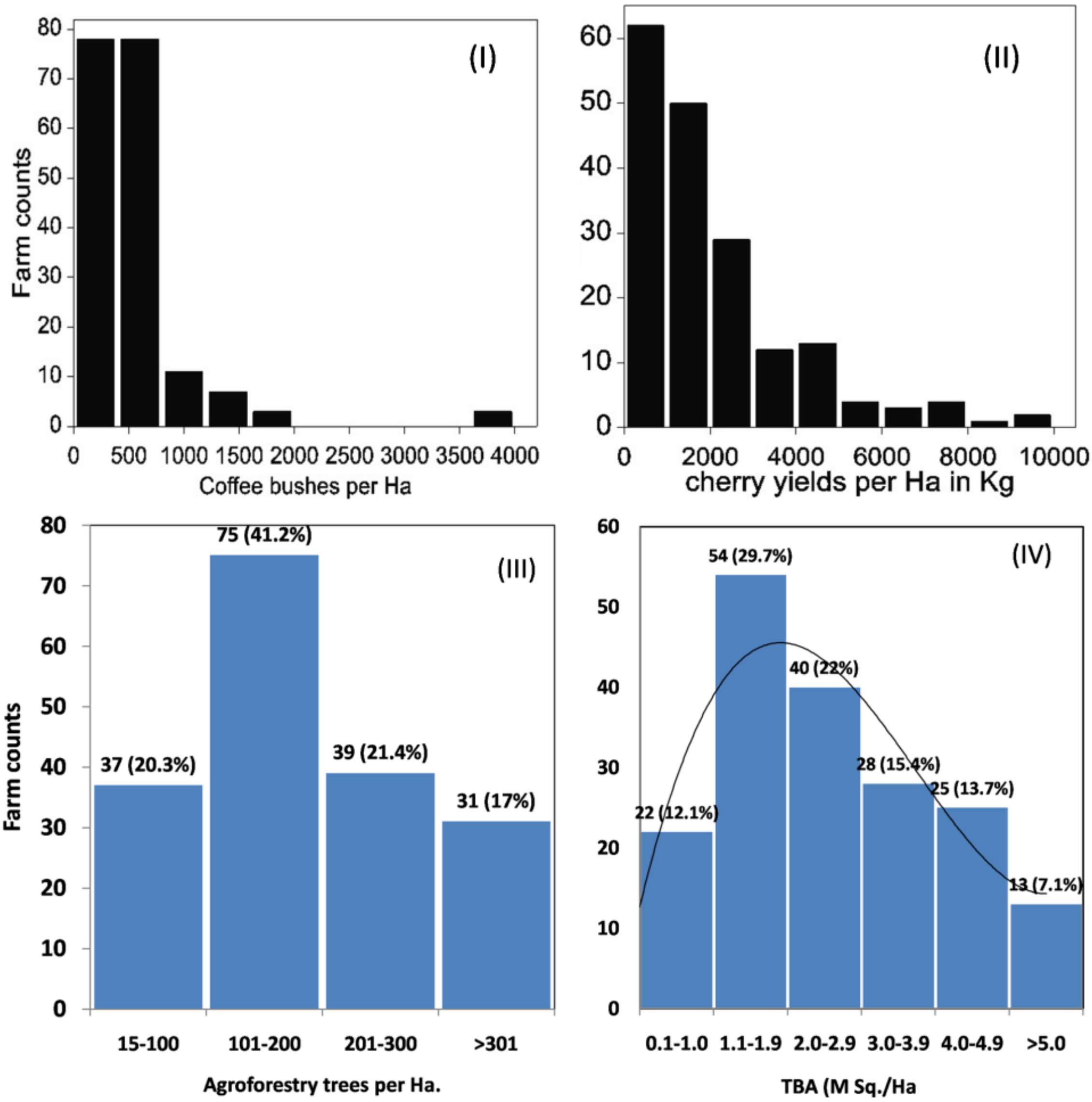

Figure 14 (I) & (II) show coffee productivity distribution in terms of bushes per hectare and Kg cherry per hectare for surveyed smallholder farms. (III) & (IV) histograms showing tree densities and tree basal area distribution in the surveyed farms

The majority of the studied farms, 75 (41%) had a tree density of 100-200 trees ha^{-1}. Analysed data showed that the lower (15-100 trees ha^{-1}) and higher (200-300 trees ha^{-1}) tree density distribution occur in similar proportions of the farms (30%) (Figure14III). Analysis on the distribution of tree sizes measured as tree basal area

(m^2) ha^{-1}, showed that some 54 (30%) of farms contained tree basal area of 1.1-1.9 m^2 ha^{-1} while 40 (22%) of the farms have tree basal area distribution class of 2.0-2.9 m^2 ha^{-1}.

A large tree basal area of between 3 to 5 m^2 ha^{-1} was recorded on 66 (35%) of the surveyed farms. The smallest tree basal class was at 0.1 to 1 m^2 ha^{-1} and accounted for 12% of recorded tree stems on all farms (Figure 14IV). In summary, about 80% of the farms surveyed showed tree basal area class distribution of between 0.1 to 3.9 m^2 ha^{-1}. Mean tree volumes available within coffee farms was calculated at 36.31 m^3 (31.1-41.5 m^3, P = 95%).

5.3.2 Tree species diversity by coffee farm types

Increasing or decreasing trends in smallholder coffee production was hypothesized to influence tree species diversity maintained on coffee farms. Data analysis showed that species richness between farm categories were on average largest for the coffee *decreasing* farms followed by the *increasing* and the *constant* ones (Table 14). The Shannon diversity index measure was consistent with this observation. Average species richness per farm within a category was nonetheless highest for the coffee increasing farm category followed by the decreasing and the constant ones. The inverse-Simpson index was more consistent with this observation (Table 14).

Table 14 Coffee farms categories and tree diversity characteristics.

Farm category (n)	Farm size Ha. (s.d)	Richness (mean)	Abundance (mean)	Shannon index	Inverse – Simpson index
Constant (60)	1.18 (1.216)	110 (14.4)	10079 (168)	2.59	4.93
Decreasing (60)	1.12 (0.916)	145 (17.9)	11149 (186)	2.79	5.49
Increasing (60)	1.37 (0.979)	141 (18.4)	14592 (243)	2.72	5.51
All farms (180)	1.22 (1.04)	190 (16.9)	35820 (199)	2.76	5.4

n-no of farms; s.d-standard deviation

5.3.3 Tree (*alpha*) diversity analysis by coffee farm category

Plotting sample based species accumulation curves and rènyi diversity profiles for the *increasing, decreasing* and *constant* coffee farm categories showed overlapping species richness patterns for the *increasing* and *decreasing* farms (Figure 15). Respective sites could not be ordered from low to high diversity. Rènyi profiles confirmed that coffee *decreasing* farms had higher levels of tree diversity compared to the coffee *increasing* farms. The profile values for alpha = 0 (H_0) is the logarithm of species richness. The value H_1 is calculated directly as Shannon index and the alpha value = 2 is the logarithm of the reciprocal Simpson diversity index. The alpha value = infinity (H_∞) provides information on the proportion of the most abundant species.

For this study, both the species accumulation curve, (Figure 15i) and rènyi profile (Figure 15ii) show that farms whose coffee production has more or less remained constant had smaller tree species richness, but greater species evenness.

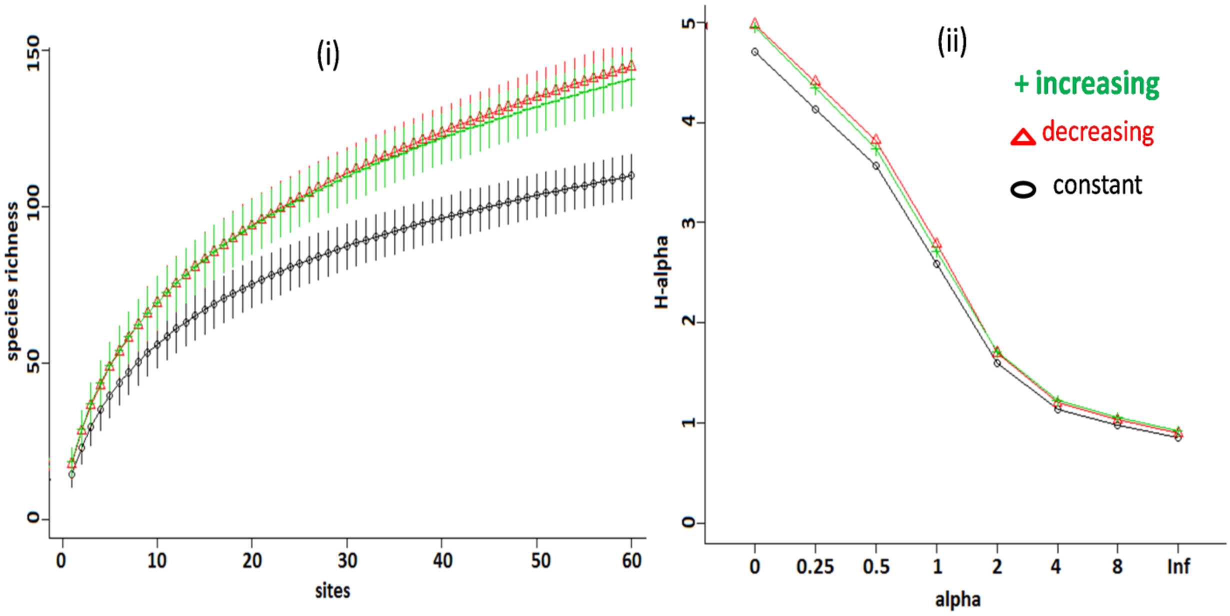

Figure 15 Species accumulation curves (i) and (ii) Rènyi profiles for coffee farm categories: increasing, decreasing and constant

Rènyi profile showed that proportions of the most abundant species for the *increasing* and *decreasing* farm categories were similar at 40%. The *constant* farm category had higher proportions of the most dominant species at 43% (Table 15).

Table 15 Calculated alpha diversity indices from the constant, decreasing and increasing rènyi profiles

Farm category	Species richness (H_0)	Shannon index (H_1)	inverse Simpson (H_2)	Proportion (%) of most abundant species (H_∞)
Constant (n = 60)	110	2.59	4.93	0.43
Decreasing (n = 60)	145	2.79	5.48	0.41
Increasing (n = 60)	141	2.72	5.51	0.40
All farms (n = 180)	190	2.76	5.40	0.41

High alpha values indicate higher species richness, conversely; low *infinity* values indicate a higher proportion of the dominant species. Examining tree diversity by Shannon and inverse-Simpson diversity indices showed values of 2.59, 2.79 & 2.72 and 4.93, 5.49 & 5.51; for the *constant* (n = 60), *decreasing* (n = 60) and *increasing* (n = 60) farm categories, respectively. Rènyi diversity order showed that tree species evenness was higher in the *constant* farm category compared to the *decreasing* and *increasing* categories (Figure 15ii).

5.3.4 Effects of coffee production trends on tree diversity

To investigate the effects of coffee production trends (increasing, decreasing, and constant) and farm size on tree diversity, number of coffee bushes and livestock units on farm, quasi-Poisson generalized linear regression model (with log-link) was used (Table 16). The model was preferred instead of a simple linear regression analysis (Annex 3) as it was found to fit the largely non-random, count data well. Furthermore, simple linear regression model was found inappropriate when predicting parameters with non-negative values such as tree richness and abundances (Kindt and Coe, 2005).

Table 16 Quasi-Poisson generalized model (with a log-link) to assess effects of 'coffee production trends' and 'farm size' on trees, coffee bushes and livestock on farm

Response variates per farm	Model assessing effects of coffee production trends: 'constant', 'decreasing', 'increasing'				Model assessing effects of coffee production trends and farm size				
	Model constant (antilog)	**Decreasing**	**Increasing**	**% variance accounted**	**Model constant** (antilog)	**Decreasing**	**Increasing**	**Farm size**	**% variance accounted**
Tree abundance	5.26	-0.053	0.148	1.33	4.86	0.003	0.129	0.273^{***}	
	(192)	(0.95)	(1.160)		(129.02)	(1.00)	(1.14)	(1.32)	24.25
Tree richness	2.76	0.06	0.143	1.38	2.51	0.090	0.120^{*}	0.183^{***}	
	(16)	(1.07)	(1.153)		(12.31)	(1.09)	(1.13)	(1.20)	20.99
Trees in coffee plot	4.45	0.06^{+}	0.241^{**}	3.28	4.53	0.042	0.103^{**}	0.214^{***}	
	(86)	(1.06)	(1.27)		(92.76)	(1.04)	(1.11)	(1.24)	22.17
Exotics abundance	5.04	-0.13	0.104	1.45	4.98	-0.039	0.040	0.267^{***}	
	(154)	(0.88)	(1.11)		(145.47)	(0.96)	(1.04)	(1.31)	18.67
Indigenous abundance	3.66	0.203	0.327	1.49	3.75	0.135	0.148	0.327^{***}	
	(38.7)	(1.22)	(1.39)		(42.52)	(1.14)	(1.16)	(1.39)	16.26
Tree volume (m^3)	3.47	0.032	0.267	1.84	3.46	0.073	0.134^{**}	0.407^{***}	
	(32.26)	(1.03)	(1.31)		(31.82)	(1.08)	(1.14)	(1.50)	40.37
Tree basal area	0.96	0.05	0.24	1.79	0.98	0.059	0.106^{*}	0.330^{***}	
	(2.62)	(1.05)	(1.26)		(2.66)	(1.06)	(1.11)	(1.39)	32.36
No. of coffee bushes	6.08	0.0015^{+++}	0.535^{***}	10.89	6.20	0.030^{+++}	0.246^{***}	0.289^{***}	
	(435.5)	(1.0)	(1.71)		(492.75)	(1.03)	(1.28)	(1.34)	30.90
Tropical livestock units	1.39	-0.086	0.114	1.31	1.38	-0.033	0.044	0.187^{***}	
	(4.03)	(0.918)	(1.12)		(3.97)	(0.97)	(1.04)	(1.21)	10.92

Notes: All the models showed that the response variates had a dispersion of >1 suggesting they were not randomly distributed. Farm trends 'constant' and 'decreasing' were interchangeably fixed as reference levels to detect differences between all possible categories. Significant differences between farm categories are represented by signs in brackets: Increasing versus Constant (*); Increasing versus decreasing (+); Decreasing versus constant (#). Significant different level applied were: P<0.01(*** +++ ###); P< 0.05(** ++ ##); P<0.1 (*+ #)

A suitability assessment of Poisson and quasi-Poisson models revealed that regressions with Poisson model was inappropriate as the dispersion of the variates was fixed at 1, whereas the response variates studied had a dispersion parameter >1, suggesting that individuals were not randomly distributed but clumped.

To compare effects of ‘coffee production trends’ and ‘farm size’ between farm categories, increasing, decreasing and constant; the categories ‘constant’ and ‘decreasing’ were fixed as references in sequential regressions. Results showed that present trends in coffee production had no effect on tree richness and abundance on farm. When combined with ‘farm size’ effect, results showed some evidence ($P < 0.1$) that tree richness was higher on farms with increasing coffee production compared to the constant ones. Analysis showed strong evidence ($P < 0.05$) that increasing coffee production trends influences current tree abundance within coffee plots, different from the constant and decreasing farms.

There were no significant effects on coffee production trends on the abundance of exotic and indigenous trees on the whole farm. The regression coefficient for exotics was nonetheless negative for coffee decreasing farms suggesting possibilities of fewer exotic trees when coffee production declines. Other results showed that present tree volume and basal area on farm is significantly different for farms with increasing coffee compared to the constant ones. It was clear that farm size has a strong effect ($P < 0.001$) on tree volumes and basal area available on farms.

Results further confirmed that coffee bushes were different between the coffee increasing farms compared to the constant and the decreasing ones ($P < 0.001$). The number of bushes in the decreasing farms were however not different from the constant ones. Finally, results showed that the number of livestock units on farm was not influenced by current trends of coffee production; however decreasing coffee production (negative co-efficient) could contribute to declining livestock units. By and large, results showed that farm size significantly influences (large % of variance accounted for during regressions) tree diversity, tree volumes, number of coffee bushes and livestock unit on coffee farms.

5.3.5 Tree (*beta*) diversity analysis by coffee agro-ecological zones

Smallholder coffee cultivation around the surveyed region is limited to three agro ecological zones namely; upper midland (UM) 1, 2 and 3. These zones were hypothesized to influence coffee production and tree species diversity given their biophysical gradient. UM1 is topographically higher in altitude and experience the highest precipitation compared to UM2 and UM3. Data analysis showed significant differences in tree diversity patterns for the three zones surveyed. Species accumulation curves showed the size of species richness was as follows; UM 3 > UM2 > UM1 (Figure 16i). Accumulation curve for UM3, relative to 2 and 3 was nonetheless represented by a smaller sample hence the curve showed a steeper trend (Figure 16i). The finding that species richness in this zone is greater compared to the other zones are therefore interpreted with caution. Spatially, UM3 constitutes a relatively smaller area under coffee farming. The studied sample was smaller since only farms with coffee cultivation activities were considered for this study.

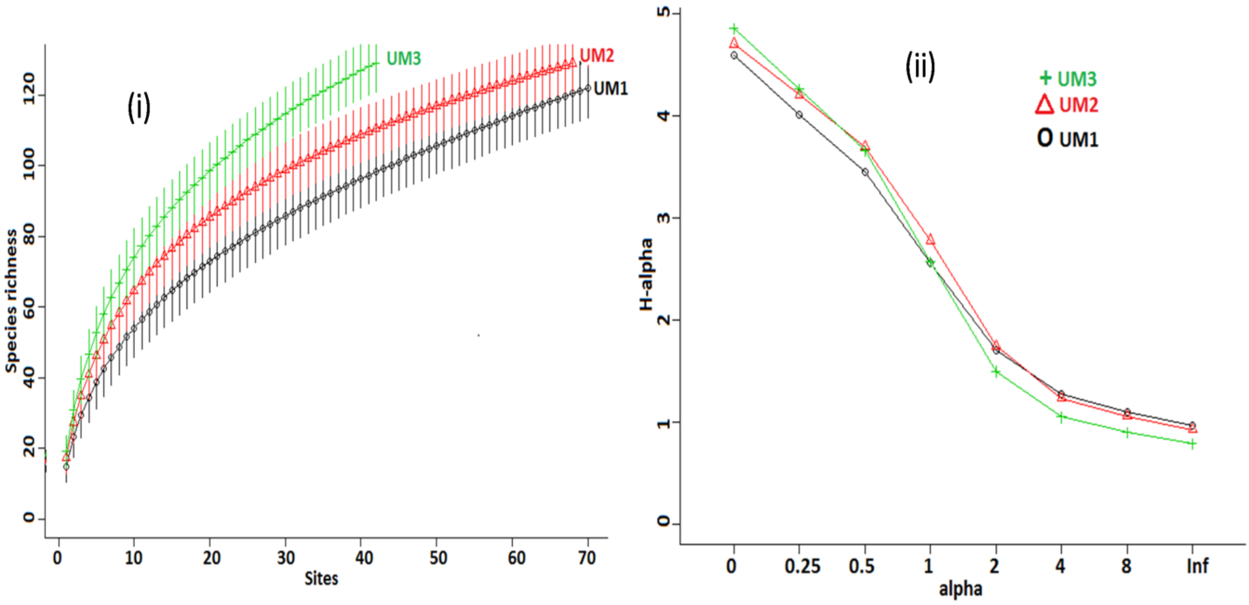

Figure 16 Sample based tree species accumulation curves (i) and rènyi diversity profiles (ii) by coffee agro-ecological zones, UM1, UM2 and UM3

Rènyi diversity profiles were found to be intersecting suggesting that surveyed coffee zones could not be ranked from low to high diversity (Figure 16ii). Alpha values plotted at scale of 0, 1, 2 and ∞, were nonetheless examined for species richness and dominance/evenness (Table 17). Rènyi diversity order confirms observations made on plotting species accumulation curves. Alpha diversity (H_0) ordered as follows: UM3 (H_0 = 4.86; richness = 128) > UM2 (H_0 = 4.71; richness = 110) > UM1 (H_0 = 4.58; richness = 98). H_1 was directly calculated as Shannon index. It was highest for UM2 (2.78) and similar for UM1 (2.56) and UM3 (2.57). Inverse Simpson index (H_2) was; UM3 (H_2 = 5.69) > UM1 ($H2$ = 4.23) > UM2 (H_2 = 4.17) (Table 17; Annex 4). The profile value for *alpha* = ∞ showed that UM3 had the largest proportion (45%) of the most abundant species and was most un-even. UM1 had the smallest proportion of the abundant species (38%) and therefore relatively more even (Table 17). Rènyi profiles on species evenness show that systems with high dominance are less even.

Table 17 Calculated species diversity indices for the UM 1, 2 & 3 rènyi profiles

AEZ	Species richness (H_0)	Shannon index (H_1)	Inverse Simpson (H_2)	Proportion (%) of most dominant species (H_∞)
UM1 (n=70)	97.72	2.56	4.23	0.38
UM2 (n=68)	110.53	2.78	4.17	0.40
UM3 (n=42)	128.99	2.57	5.69	0.46
All farms (n=180)	190	2.76	5.40	0.41

Investigating effects of the different ecological zones on tree species diversity on farm using a linear regression model (see Annex 3) confirmed that tree richness is significantly different between the present zones (P < 0.001). There is strong evidence (P < 0.001) that species richness in the coffee zone, UM3, is significantly different from those in UM1 and less different (P = 0.0169) from those in UM2. Results on regressing tree abundance per farm on the different agro-ecological zones showed evidence (P = 0.0037) of differences between the three zones. There was strong evidence (P = 0.0014) that tree population size in the UM3 was significantly different from those in UM1. There was nonetheless no evidence (P = 0.593) to show that tree abundance in the coffee farms of UM2 differ from those in the zone, UM1.

Data analysis to assess whether indigenous tree abundance differ by coffee zones showed a significant model ($P = 0.002$). Results revealed strong evidence ($P < 0.001$) that zone, UM3 differ from zone UM1; invariably there was weak evidence ($P = 0.096$) that zone, UM2 differ from UM1 and UM3. Interestingly, when exotic tree abundance on farm was regressed on the coffee zones, results showed a weak model ($P = 0.0479$). There is not strong evidence ($P = 0.0269$) that exotic tree species abundance in the zone, UM3 are significantly different from those in UM2 and UM1. There was no evidence, that average exotic tree populations in UM2 are different from farms in the zone UM1 or UM3. Other results showed that on average farm sizes were not significantly different ($P = 0.395$) between the present coffee zones.

5.3.6 Tree diversity (*gamma*) for the Mount Kenya coffee ecosystem

A total of 165 species were identified belonging to 127 genera and 56 botanical families from all the sampled farm plots together (see Annex 2). Some 23 dialect names of species could not be confirmed using local species identification knowledge and relevant species literature. The most abundant taxa counted were; *Grevillea, Eucalyptus, Macadamia, Mangifera, Cordia, Carica, Persea, Catha, Cupressus,* and *Bridelia.* The best-represented botanical families by species counts (in brackets) were: Fabaceae (20), Rubiacea (10), Euphorbiaceae (10), Moraceae (8), Rutaceae (7), Combretaceae (7), Anacardiaceae (7), Myrtacea (6), Apocynaceae (6) and Meliaceae (5) (Figure 17I). Twenty six families are represented by only a single species while some 17 families are represented by two to four species. Only 11 families are represented by five or more species counts (Figure 17II).

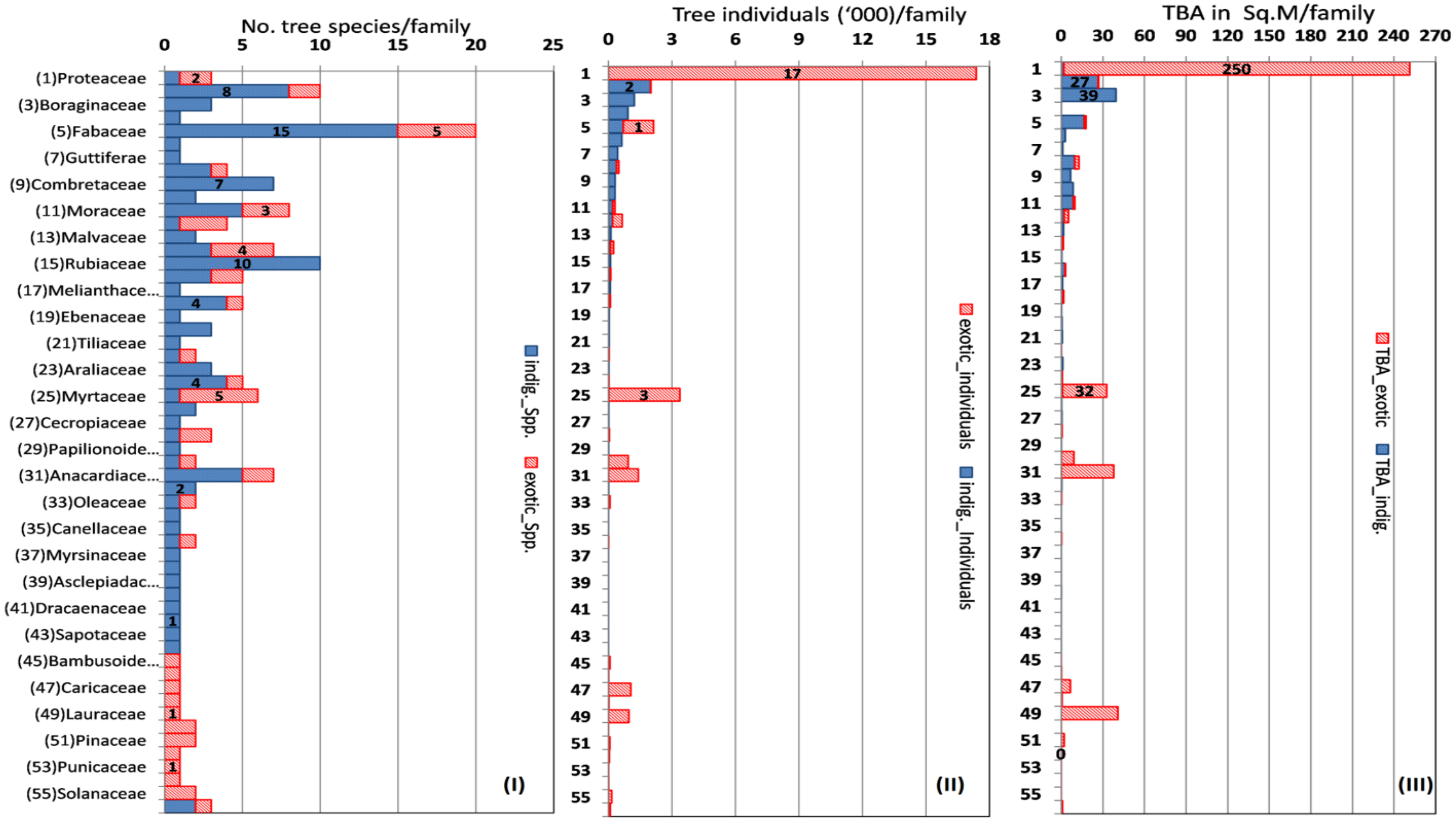

Figure 17 Surveyed plant families comparing distribution of indigenous and exotics by: (I) species (II) tree individuals per species and (III) tree basal area (TBA)

The most abundant indigenous species (Figure 17I) were found in the family Fabaceae (15), Rubiacea (10) and Euphorbiaceae (8); while most exotics were present in the family Fabaceae (5); Myrtaceae (5) and Rutaceae (4). In terms of tree individuals abundance, the family Proteaceae had the most individuals (more than 17,000) represented by only 2 exotic species (Figure 17II). Their cumulative basal area was 250 m^2 (Figure 17III). While, the highest number of indigenous tree individual surveyed were only 2000 in the family Euphorbiaceae. The other highest exotics individuals were present in the family Myrtaceae, with over 3000 individuals (Figure 17II). Only the indigenous tree species in the family Boraginaceae had a tree population of basal area of more than 30 m^2. On the other hand, exotic tree species in the families, Myrtaceae, Anacardiaceae and Lauraceae each contained tree basal area of more than 30 m^2 (Figure 17III).

5.3.7 Tree species abundance and basal area distribution

Using rank-abundance curves to assess tree diversity in the surveyed area, showed a wide curve on species abundance counts suggesting higher evenness and density for selected tree species (Figure 18I). On the other hand, analysis showed that tree basal area distribution had a steep curve suggesting greater un-even abundance among coffee farms (Figure 18II). This comparison is however provided with caution as only trees with more than five centimetres in diameter were enumerated for basal area ranking.

The 10 and the 25 most abundant species by ranking account for 75% and 90% of all available trees on farm respectively. Data therefore reveals high prevalence of popular tree species on farm. Invariably, the 10 and the 20 most abundant species by tree basal area ranking accounted for 81% and 90% of available tree basal area per farm. This could be showing high farm dominance by a few tree species. At the 25th species ranking, only 92% tree basal area abundance is accounted for, indicating little basal area is added by the next additional species inventoried per farm (Figure 18(ii), Table 18).

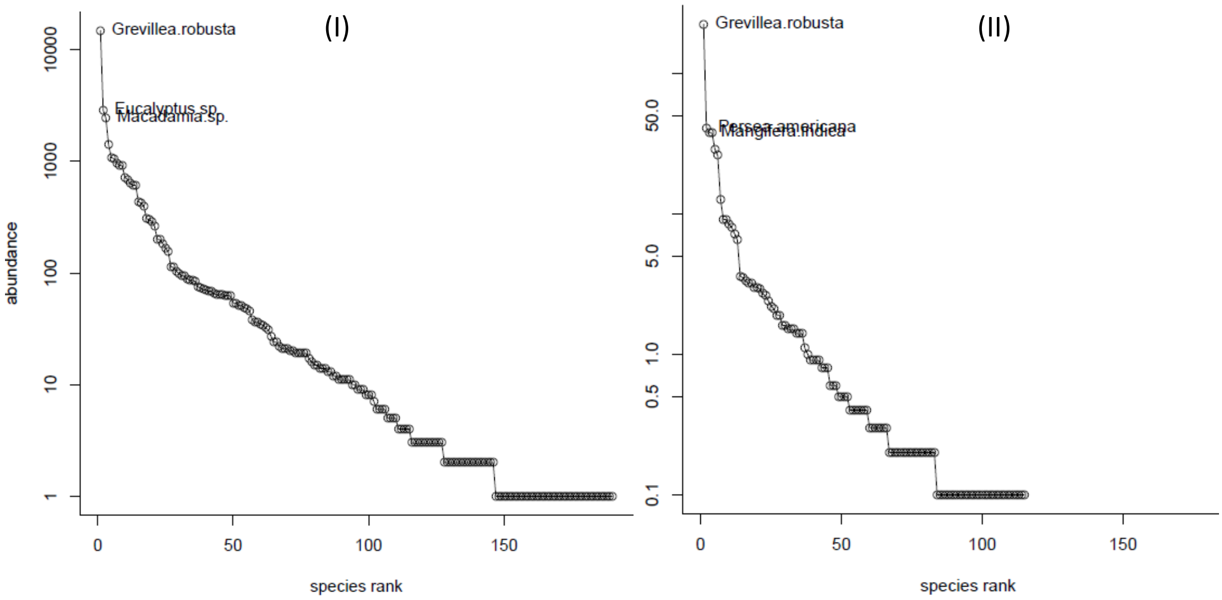

Figure 18 Rank-abundance curves: (I) species relative densities, and (II) species dominance (basal area)

Results proof the high abundance observed for some taxa, but if the individuals were small sized then dominance were low. For instance relative densities for *Eucalyptus sp. Macadamia sp. Carica papaya* and *Catha edulis* are ranked high; however their dominance is relatively low displaced by species of larger basal area such as *Persea americana, Mangifera indica, Cordia africana, Croton macrostychyus* and *Vitex keniensis* (Table 18).

Additionally, though *Croton macrostachyus* and *Vitex keniensis* are ranked among the top ten in terms of dominance, they are low in relative density ranking. In fact, among the native species, only *Cordia africana, Catha edulis* and *Bridelia micrantha* are ranked highly in terms of relative densities on farm. Field observations noted substantial quantities of *Cordia africana* and *Bridelia micrantha* on farm largely derived from wildlings (natural regeneration) often dispersed by birds, other than deliberate farmer planting. *Catha edulis* is however widely cultivated particularly in the Meru-Embu coffee region as a cash crop to complement coffee earnings.

Table 18 Species relative density (counts) and dominance (tree basal area distribution) for the ten most abundant tree species in smallholder coffee farms of Mount Kenya

Rank abundance by tree counts (Relative density)				Rank abundance by tree basal area (relative dominance)			
Rank	**Species**	**Abundance**	**Proportion (%)**	**Rank**	**Species**	**Abundance**	**Proportion (%)**
1	*Grevillea robusta*	14923	41	1	*Grevillea robusta*	223.3	41.9
2	*Eucalyptus sp.*	2877	7.9	2	*P. americana*	40.9	7.7
3	*Macadamia sp.*	2445	6.7	3	*Mangifera indica*	37.7	7.1
4	*Mangifera indica*	1402	3.9	4	*Cordia africana**	37.5	7.1
5	*Cordia africana**	1086	3	5	*Eucalyptus sp.*	28.8	5.4
6	*Carica papaya*	1059	2.9	6	*Macadamia sp.*	26	4.9
7	*P. americana*	969	2.7	7	*C. macrostachyus**	12.7	2.4
8	*Catha edulis**	921	2.5	8	*B. micrantha**	9.1	1.7
9	*C. lusitanica*	920	2.5	9	*C. lusitanica*	9.1	1.7
10	*B. micrantha**	722	2	10	*Vitex keniensis**	8.4	1.6

*indigenous species

Grevillea robusta recorded high species abundance and basal area distribution at 41-42%. The species can be regarded as the most evenly distributed on farm even though it has a low conservation value being an exotic. The smaller sized but higher density species enumerated were regarded as recent farmer tree planting preferences as compared to the bigger sized material retained longer on farm. The most dominant species besides *Grevillea robusta* are fruits trees such as *Persea americana* and *Mangifera indica*; and some indigenous tree species less frequently felled. The latter could be attributed to government regulations on felling indigenous species.

5.3.8 Species richness in the surveyed area

To demonstrate species richness for the entire surveyed area, sample based species accumulation curves were plotted to show richness for combinations of sites (Figure 19). Results are based on possible combinations of the 180 farms surveyed for tree species diversity.

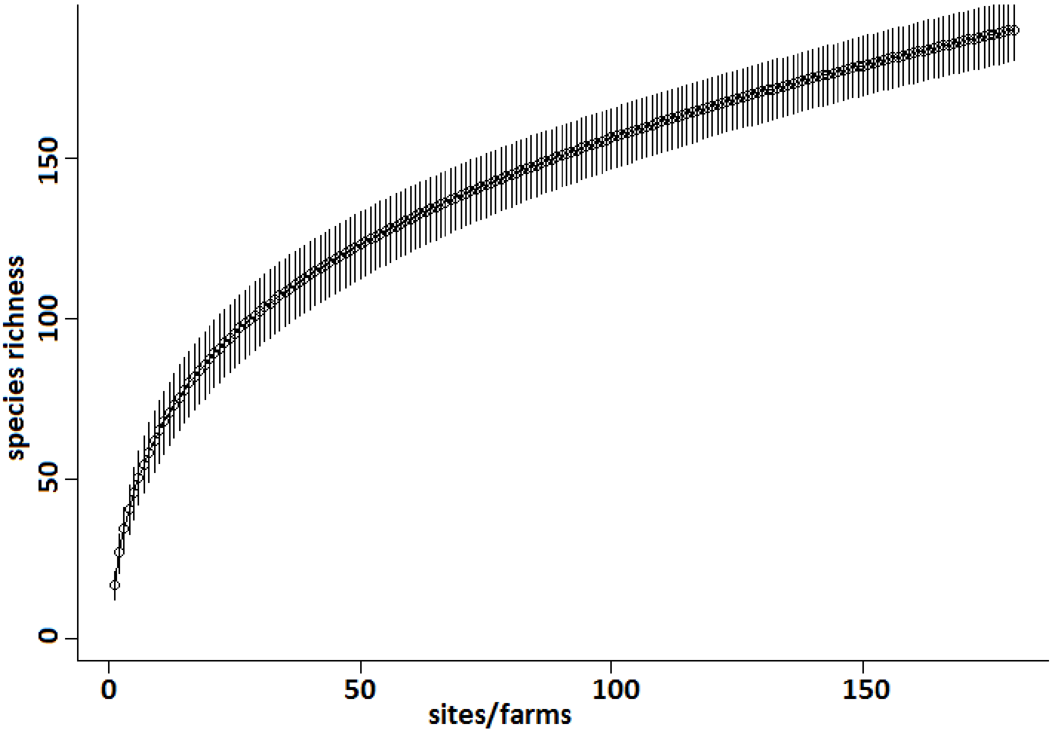

Figure 19 Sample based species accumulation curve for the surveyed areas of Embu, Meru and Kirinyaga. Error bars indicate standard deviations by chance at 95% level.

Species richness calculations are based on exact calculations for the average species per combined farms/sites. The relationship between the mean and variance or the number of individuals per sampling unit is influenced by the underlying dispersal of the population (Norton, 1994). Extrapolations of confidence intervals show little evidence that sampling more farms would exhaustively provide a complete record of species available in the surveyed area (Figure 19).

For all inventoried species, alpha diversity (H_0) was = 5.25 (richness = 190 species; n = 180) and infinity (H_∞) = 0.89. The slightly low H_∞ value indicates that most surveyed sites have high proportions of the most abundant (41%) species, while the high value of H_o means a fairly high level of species richness for all sites together. Shannon-Weiner richness index (H_1) value for the surveyed area was 2.76, while inverse-Simpson diversity index ($1/D$) was calculated at 5.39. The Shannon evenness measure ($j´$) value was 0.526. The evenness measure assumes a value between 0 and 1, with 1 being complete evenness (Magurran, 2004). Data therefore suggests moderate levels of species evenness across the surveyed area.

Investigating diversity between the main coffee regions, results showed that species richness (H_0) is highest in Meru (4.9; richness = 134), followed by Kirinyaga (4.7 richness = 110) and then Embu (4.6; richness = 99). Moreover, the Kirinyaga coffee region was showed to have a high proportion of the dominant species (54%; H_∞ = 0.6) compared to Embu (35%; H_∞ = 1.05) and Meru (33%; H_∞ = 1.10). Shannon (H_1) and Simpson (H_2) diversity indices however showed higher diversity for Meru (H_1 = 2.98; H_2 = 7.61) followed by Embu (H_1 = 2.66; H_2 = 6.35 and Kirinyaga (H_1 = 2.22; H_2 = 3.28) in that order.

5.3.9 Species diversity prediction

Extrapolated species richness for the entire coffee system surveyed using the first order and second order Jackknife, Chao and Bootstrap methods, was in the range of 215 to 292 species (Table 19). Bootstrap estimate suggests that sampling captured about 89% of the species while Jackknife 2 estimate indicates that sampling efforts captured 66% of the species. Plotted species accumulation curves indeed showed reduced variability on species presence after 150 sites combinations (Figure 19); implying lower species richness is captured by extra sampling effort. The sampling strategy used to survey coffee farms can therefore be regarded to have worked fairly well having recorded a species richness of 190 species.

Table 19 Species richness prediction for the entire survey area

Prediction method	Species richness (all sites combined)
Chao	285
Bootstrap	215
Jackknife1	251
Jackknife2	292

5.3.10 Species composition between coffee regions

As expected, there are dissimilarities in species composition between the three coffee sub-regions in spite of the dominance of few species at the farm level. The

Bray-Curtis and Kulczynski distances were used to calculate differences in species composition. Sites that share most species have a small score, while sites with few species in common have a large ecological distance score. In the current data, the Bray-Curtis and Kulczynski distances show strong species composition similarities between Embu and Kirinyaga, but weak similarities with Meru coffee region. Meru and Kirinyaga species composition are more similar than between Meru and Embu (Table 20). This result is interesting, as geographically, Embu lies in closer proximity to Meru than Kirinyaga.

The distance parameters are calculated from differences in abundance for each species. For purpose of this analysis, the data matrix was transformed logarithmically to lessen influence of dominant species.

Table 20 Calculated species ecological distance matrix between Embu, Kirinyaga and Meru coffee regions

Bray-Curtis distance			**Kulczynski distance**	
Coffee regions	Embu	Kirinyaga	Embu	Kirinyaga
Kirinyaga	0.274		0.273	
Meru	0.362	0.358	0.358	0.349

5.4 DISCUSSION

Agroforestry tree species assemblages in smallholder coffee systems depict interesting heterogeneity patterns. Farmer adopted cropping practices have a major influence on species richness. This is in contrast to natural forests, where abiotic factors such as local variation in soils, moisture, and tree stand have been shown to drive heterogeneity (Spies, 1998). Species aggregation patterns may however be a product from within community interaction. Summarizing pattern of species diversity in relation to the most important factor structuring plant communities can help reveal the basic patterns of variation (Ludwig and Reynolds, 1988). When a species environment is fairly similar, such as in the coffee growing zones, diversity is called ‘pattern diversity’ (Preston 1948; Spies, 1998).

This study focused on the Mount Kenya coffee zones recently converted from natural forests (in the last 100-150 years). Coffee farm categories - *increasing, decreasing* and *constant* determined by historical coffee production trends were analysed for the available tree species diversity. Studied farm types were significantly different in terms of coffee yield production and the number of coffee bushes cultivated per farm. Agroforestry tree richness and abundance per farms was however not significantly different by the categories. Further, data analysis showed tree individuals maintained within coffee plots per farm were significantly higher in the coffee *increasing* farms than the *decreasing* ones. This suggests a possible decrease in tree abundance if coffee crop would be reduced on farms. Results further showed that more than 50% of trees on the surveyed farms are planted within coffee plots.

Farm size between the *increasing* and *decreasin*g farms was not significantly different even though on average, the coffee *increasing* farms are slightly bigger. Farm size may therefore not necessarily determine levels of tree abundance and richness adopted on farm. Rènyi diversity analysis showed that the *increasing* and the *decreasing* farms have similar levels of tree richness and abundance but higher than the constant farms. The coffee increasing farms on average have higher tree abundance of similar diversity with the coffee decreasing ones confirming that high levels of tree abundance do not necessarily imply high level of species richness.
The coffee stagnated farms showed a higher percentage of the most abundant species perhaps suggesting increased preference of certain species such as Grevillea that was found to be more abundant.

Though high species richness is recorded in the surveyed coffee farms, this study confirms uneven species distribution within and between farms (Kindt et al. 2007). This is probably accelerated by recent market induced changes in agriculture and the preference of farmers towards fast growing exotics. Analysed data is consistent on rarity of native species as compared to exotics across surveyed farming landscape. Further, tree basal area distribution even for the dominant species is steeply variable and uneven among farm plots. This finding suggests increased tree harvesting going hand in hand with tree species replacement planting.

Coffee plots contain more than half (58%) of all trees present per given farm plot. Any significant changes in coffee cultivation among farmers will therefore influence the number of agroforestry trees on farms. Inconclusive evidence suggests that smallholders with decreased or stagnated coffee production due to reduced coffee bushes adopt more annual crops and maintain lesser tree richness. Data implies changes in species selection over time with farmers preferring more exotics than indigenous species to plant on their farm plots. *Grevillea robusta* is the most abundant and dominant species on coffee farms at proportions of 41%.

The presence of indigenous species per farm plot account for about 78% of the recorded richness, however they are of low, uneven distribution between farms posing serious demographic implications with regard to genetic integrity. Only *Cordia africana, Croton macrostachyus, Bridelia micrantha* and *Vitex keniensis* ranked among the 10 most abundant tree species in coffee farm plots. Overall 10 and 25 of the most abundant species by ranking, account for 75% and 90% of available trees respectively. Results suggest farmer reliance on relatively few species choices for tree replacements on farm. It is not clear the extent to which the larger enumerated tree diversity contributes to households' livelihood needs and ecological functions owing to their limited quantities on farm. For instance, though *Croton macrostychyus* and *Vitex keniensis,* are ranked among the top ten in dominance among native species, they are low in relative densities indicating a low presence of young tree population. Lower densities of the native species could therefore influence their genetic integrity in the long run as farmers tend to propagate materials from limited mother trees on farming landscapes.

Overall, results suggest possible loss of species richness from all study regions. A low pattern of richness is shown to be associated with higher adoption of exotic species.

For instance, species richness is highest in Meru (H_0 = 4.9), followed by Kirinyaga (H_0 = 4.7) and then Embu (H_0 = 4.6). Invariably, the proportion of species domination for Kirinyaga was 54%; Embu, 35% and Meru, 33%. The results however show an exception when species richness is assessed by the different coffee *agro*-ecological zones. UM3 contains the highest species richness (H_0 = 4.91) but also has the highest proportions of the dominant species (H_∞ = 0.77; 46%). UM1 has the lowest richness (H_0= 4.5) but has the least domination by popular species (H_∞ = 1.0; 36%). This zone perhaps has fewer tree compositional changes due to lower reliance on trees compared to the more prevalent cash crops including tea and horticulture in some sections. The UM3 on the other hand has fewer cash crops and more annuals perhaps indicating that more tree abundance and richness are retained to complement economic benefits.

In terms of species composition, Meru and Kirinyaga coffee sub-regions show similarities, however there are dissimilarities with Embu, despite geographical proximity. The significant proportion of dominant species could be associated with germplasm access, and propagation related constraints influencing farmer species choices. Largely, planting material for native species is lacking (Lengkeek and Carsan, 2004). Native species are also widely perceived as slow growing with most species spontaneously inherited from natural regeneration. Further, Grime (1983) reported that a decrease in community niche space can reduce the number of species due to ecophysiological constraints. Species with different competitive abilities in relation to these resources/factors divide the niche space in hierarchical manner (Ludwig and Reynolds, 1988).

At the botanical families' level, results revealed skewed patterns of distribution. Though 56 families were recorded, only 18.5% (11 families) are represented by more than five species. Nearly half 48%; (26 botanical families) are represented by a single species while 35% (17 botanical families) are accounted by two to four species. Presence of a large diversity of plant families, though of skewed distribution, is an indicator of the potential of coffee system as a reservoir for species diversity on farm. Despite larger indigenous species records in the families Fabaceae, Rubiaceae and Euphorbiaceae, they are of low individual and tree basal area presence in the surveyed farms. On the other hand, there are fewer exotic species with larger tree population (individuals) and tree basal area per family suggestive of expanded cultivations of selected exotic species. The family Proteacea and Myrtaceae contain the most available exotic tree population in the surveyed farms.

Tree species balance at the botanical family level is often ignored during prioritization of domestication activities. How this can be promoted or improved for purposes of meeting livelihood and conservation objectives, remain an important research issue. Further, trees in coffee agroforests are largely propagated from germplasm sources in close vicinity such as neighbor farms. Long term performance of agroforestry tree population in agricultural systems has therefore been a matter of concern. A small uneven, tree species population in agricultural landscapes may be dysfunctional by hampering gene migration within a given tree population increasing chances of genetic erosion (Dawson et al., 2009). There is however is no available evidence to indicate minimum tree densities to be maintained at a given farming landscape (Lengkeek et al., 2005; Kindt et al., 2006).

Mapping and monitoring tree diversity at the farm level is therefore critical in coffee agroforestry systems so as to understand performance of tree population especially for germplasm provisioning and their future productivity and adaptive capacity. Towards this end, agroforestry systems can be used to protect biodiversity and alleviate the negative effects of deforestation by stimulating natural forest cover through cultivation of trees with agricultural crops and may serve as biological corridors between protected areas and non-protected areas (Schroth and Harvey, 2007). Understanding patterns of tree diversity maintained in smallholder systems provides useful indicators on their productivity assuming that the most diverse systems are also the most productive.

5.5 CONCLUSIONS

Intensification of coffee farms with high value agricultural enterprises other than coffee will most likely shift tree species richness in these farms. This study has shown significant presence of exotics such as: grevillea, eucalyptus, macadamia, mango and avocado indicative of farmer preferences. It is clear that this transition will be accelerated by decreased coffee cultivation. The reason is that farms immediately adopt short returns cropping practices to ensure their food security and incomes. Adoption of fast growing exotic trees is displacing indigenous species such as *Croton macrostychyus* and *Vitex keniensis*. *Cordia africana* however has significant abundance within coffee systems perhaps due to its excellent compatibility qualities with coffee and crop polycultures. Tree abundance and basal area distribution, show small-sized tree diversity and high relative densities suggesting rapid tree compositional turnover which imply changing patterns and structure of tree population on coffee farms. This study has shown that smaller farm size tends to reduce tree size on farm. Small tree size diversity, unevenly distributed among farms, has implications if farm tree populations are to be considered for germplasm provisioning (possible low viability). Further, botanical families are skewed, showing patterns of distribution that perhaps have been ignored during prioritization of species for domestication activities. Policy incentives that would promote greater benefits from indigenous trees will encourage farmers to retain or plant more of these species. If current trends are unchecked there are risks of lost tree diversity or poorly performing tree population maintained on smallholder coffee farms.

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CHAPTER 6

IMPLICATIONS OF CHANGES IN COFFEE PRODUCTIVITY ON SOIL FERTILITY MANAGEMENT BY SMALLHOLDER COFFEE FARMERS

ABSTRACT

Land fragmentation, over cropping, soil erosion, low fertilizer and manure inputs have raised concerns that coffee farms around Mount Kenya could rapidly decline to low production systems. Significant nutrient exports occur through coffee, horticulture and food crops commonly cultivated. Smallholder decision-making on soil fertility management is poorly understood, even though it is a key determinant of the 'health' status of their land. Near-infrared spectroscopy (NIR) diagnostic techniques were used to study soil properties obtained from 94 coffee farms. At least 189 soil samples randomly collected from coffee plots were scanned for constituent properties. One third of the samples were identified using Kennerd and Stone algorithm to aid in calibration. These reference samples were analyzed for fertility by wet chemistry methods. Partial least square (PLS) regression was used to run calibration models, giving correlation coefficients between the measured and PLS predicted soil properties. Results showed strong correlations with all soil properties ($r > 0.70$) except for P, Zn and Na confirming the potential of NIR to accurately predict soil constituents. Principal component analysis (PCA) was then used to develop three soil nutrient indices (principal components scores) for the surveyed farms. Collected data was reliable to show that soil organic C, total N and P were the most deficient across surveyed coffee farms. B prevalence (which is often ignored as a useful indicator of soil fertility) was identified as a useful nutrient to monitor acidification in coffee farms and possible effects on the quality of coffee berries. Results from farmer interviews confirm low rates of manure and fertilizer application. Finally, results demonstrate the use of NIR techniques to rapidly and cheaply characterize the nutrient status of smallholder farm. A useful hypothesis formulated is that smallholders target nutrient application on farm crops with good market performance.

INTRODUCTION

Coffee systems in the Mount Kenya region comprise an important smallholder agricultural production area in Kenya. Intensive cropping patterns with cash crops (such as coffee), cereal crops, vegetables and agroforestry trees form the economic foundation for farmers in these systems. Though the largely volcanic soils have provided a fertile resource base, increased land fragmentation, over cropping, and soil erosion have raised concerns on the future productivity of these systems. Low soil nutrient levels have been associated with low fertilizer inputs, over cropping, soil dehumification and mineralization (Sanchez, 2002; Tittonell et al., 2005; Muchena et al., 2005). These factors combined have resulted in declining yields and even crop composition on farms. Farmer efforts to improve soil fertility involve manure and chemical fertilizer application albeit below recommended rates (Palm et al., 1997; Omamo et al., 2002; Swift and Shepherd, 2007). Nutrient depletion rates are farm specific, depending on the way each particular field has been managed over decades. Nutrient depletion can produce negative on-farm side effects and exacerbates off-farm externalities (Place et al., 2005). On-farm effects include less fodder for cattle, less fuel wood for cooking, and less crop residues and cattle manure to recycle nutrients. These effects often increase runoff and erosion losses because there is less plant cover to protect the soils (Sanchez et al., 1997).

Africa loses about 4.4 million tonnes N, 0.5 million tonnes P, and 3 million tonnes K every year from its cultivated land. These rates are several times higher than the continent’s annual fertilizer consumption, excluding South Africa: 0.8 million tonnes N, 0.26 million tonnes P, and 0.2 million tonnes K (Sanchez et al., 2002). Yet analyses of soil fertility management in Africa often fail to account for links between soil fertility depletion and factors related to smallholder oriented production patterns that dominate the continent’s rural landscapes (Carter, 1997; Omamo, et al., 2002; Swift and Shepherd, 2007).

Research and development efforts in the context of Sustainable Land Management (SLM[6]), need to focus on how to improve smallholder land quality (soil quality), as soil can be seen as the most important natural capital owned by smallholders. New strategies must ensure continued crop productivity in circumstances of low household incomes to secure nutrient inputs. Agroforestry has been proposed as a form of land intensification that offers farmers low cost options to improve their land quality by integrating soil enriching trees that fix atmospheric nitrogen or through biomass transfer (Swift and Shepherd, 2007). There are however bottlenecks in selecting species, and designing systems and management regimes, that optimizes the efficiency of environmental resource capturing and use in a sustainable manner (Huxley, 1996).

In order to identify strategies that could support maintenance of land quality within intensive smallholder coffee systems, this study sought to determine soil quality (nutrient level indicators) and variability on small farms in three coffee producing areas around Mount Kenya, where declined income from coffee is suspected to influence farmers' purchasing power for fertilizers, manure and other inputs. The hypothesis followed is that, given the declined incomes from coffee farming, there are intra-household variability in soil nutrient management influencing nutrient prevalence, and subsequently cash and food crops productivity. Though smallholder heterogeneity is a given, in terms of production practices, the maintenance of land quality acts as a common denominator that significantly influences farmer decisions on crop enterprise. In fact, productivity decline recorded in subsistence crops is often closely related to a decline in cash crops since invariably, inputs used on cash crops are shared for subsistence food crop production, therefore indirectly supporting their production. In situations where farmers continuously maintain low inputs, the system risks decline to an overall low production system (Place et al., 2005; Sanchez, 2010).

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[6] Sustainable land management (SLM) can be defined as the use of land resources such as soils, water, animals and plants for the production of goods - to meet changing human needs – while assuring the long-term productive potential of these resources, and the maintenance of their environmental functions (SLM-IM Guidelines, ud)

Therefore both land-use and soil management influence the amount of nutrients in soils in many ways, positively as well as negatively. Intra-household differences were therefore assessed and indicators for the prevalence of farm soil nutrients developed to characterize smallholder managed soils in coffee systems on the eastern slopes of Mount Kenya. A description of organic and inorganic fertilizer inputs further help capture the position of households in accessing key nutrients inputs via fertilizers and/or animal manure.

6.1 CONCEPTUAL FRAME

Factors most likely to determine soil nutrient flow and out-flows can be divided into both biological and ecological (biophysical) factors, and socio-economic factors (Swift and Shepherd, 2007). The biophysical factors are climatic, biological, physical and chemical characteristics of soil, and the topography, altitude, temperature and biodiversity (De Jager et al., 1998). Soil fertility loss and land degradation in high potential systems are often associated with high human population pressure (Carter, 1997; Sanchez et al., 1997). However this observation is also disputed (Omamo, 2002) where small intensified farms are also associated with higher organic and inorganic nutrient inputs. Cultivation of small farm sizes with similar crops such as maize and other high input crops can however lead to soil nutrient ‘mining’ and loss of productivity (Smaling et al., 1997; Shepherd and Walsh, 2007). The difference of mineral and organic fertilizer inflows and out flows through harvested products and crop residues removed in a system has been termed as partial nutrient balance. Conversely, full nutrient balances involve environmental nutrients flows such as from wet/atmospheric deposition, nitrogen fixation and sedimentation; whereas outflows occur by leaching, gaseous losses, and soil erosion (Cobo et al., 2010).

The high cost of inorganic nutrients especially chemical fertilizers, in Africa, viewed as the highest across the world often reduces its use (Mwangi 1996; Omamo, 2001; Odendo et al., 2007). However, with the right incentives, for instance government market liberalization, fertilizer use in Kenya and Ethiopia virtually doubled between the early 1990’s and late 2000’s (Odendo et al., 2007; Haggblade and Jayne, (u.d))(See Annex 8). Though raising fertilizer use does not automatically contribute to smallholder productivity, poverty reduction, or national food security, there is consensus that raising fertilizer use in a cost-effective way is essential to meeting these objectives (Omamo et al., 2002; Haggblade and Jayne, (u.d)). At least 55% and 34% of smallholder farmers in Malawi and Zambia respectively use fertilizer, with mean application rates of between 24 and 29 kg/ha (Table 21). Ethiopia and Tanzania have relatively little state involvement in output markets and are directly or indirectly involved in the distribution of fertilizer. Mozambique and Uganda have very low fertilizer use (Nkonya et al., 2005). Kenya has a relatively liberalized fertilizer markets and state involvement is mainly in supporting and stabilizing maize prices. Overall fertilizer application remains low on per hectare basis across the six countries analyzed (Table 21). For Kenya it's less than half of the recommended rate (Ngoze et al., 2008; Mwangi, 1996). See Annex 6 on Kenya's fertilizer consumption.

Table 21 Country categorization of fertilizer and food market policy conditions, 2005-2008 (Source: Haggblade and Jayne, (u.d))

		Fertilizer markets	
		Direct state interventions	**Relatively little direct state intervention**
Output markets	Direct state intervention	Malawi – 55% (29 kg/ha) Zambia – 34% (24 kg/ha)	Kenya – 70% (34 kg/ha)
	Relatively little direct state intervention	Ethiopia – 25% (17 kg/ha) Tanzania – 12% (9 kg/ha)	Mozambique – 5% (4 kg/ha) Uganda – 6% (2 kg/ha)

% of farmers using fertilizer (2005 mean kg/hectare application rate)

Although manure is often recommended as a substitute to chemical fertilizer, it rampantly has a low adoption among smallholders due to accessibility reasons and labor related costs for application (Tittonell et al., 2005; Waithaka et al., 2007; Nkonya et al., 2005). Interestingly, smallholder decision making processes on input-output relationships are often poorly understood, leading to poor recommendations on soil quality management. Often, effects of economic losses from cash crops are readily linked to aspects of household well-being and rarely on soil fertility management.

Coffee cultivation around Mount Kenya has had a significant influence on farmers' incomes for at least forty five years. Its reliance on international market performance and heavy government control however has important impacts on levels of returns. The government has traditionally supported the subsector with hopes of accumulating taxes and enhancing foreign exchange. However in the last two decades, returns from coffee farming have significantly dissipated with many farmers opting for alternative cash crops or increased food crop cultivation. Nonetheless, some farmers are resilient and remain 'loyal' to coffee cultivation.

This study assessed soil nutrient status in the Mount Kenya coffee systems with a history of dependence on coffee cultivation as the main cash crop. Farmer participation in cash crop marketing arrangements has to a great extent facilitated their access to fertilizer inputs not only for coffee but also for food crops like maize (Yamano et al., 2003). In circumstances where markets for coffee decline, tremendous shocks in terms of inputs that can be afforded are anticipated. Indirectly, nutrient inputs for food crops such as maize and beans are affected significantly. Some of the likely scenarios likely to emerge in smallholder systems with regard to coping with input challenges are presented in Figure 20.

Basically soil nutrient inputs are naturally affected by the soil parent material - in the Mount Kenya area rich basaltic parent material, volcanic in origin, provides a rich nutrient base for the newly weathered soils. There however concerns of exacerbated soil erosion due to cultivation on steep slopes, with poor adoption of soil conservation measures (Ngoze et al., 2008).

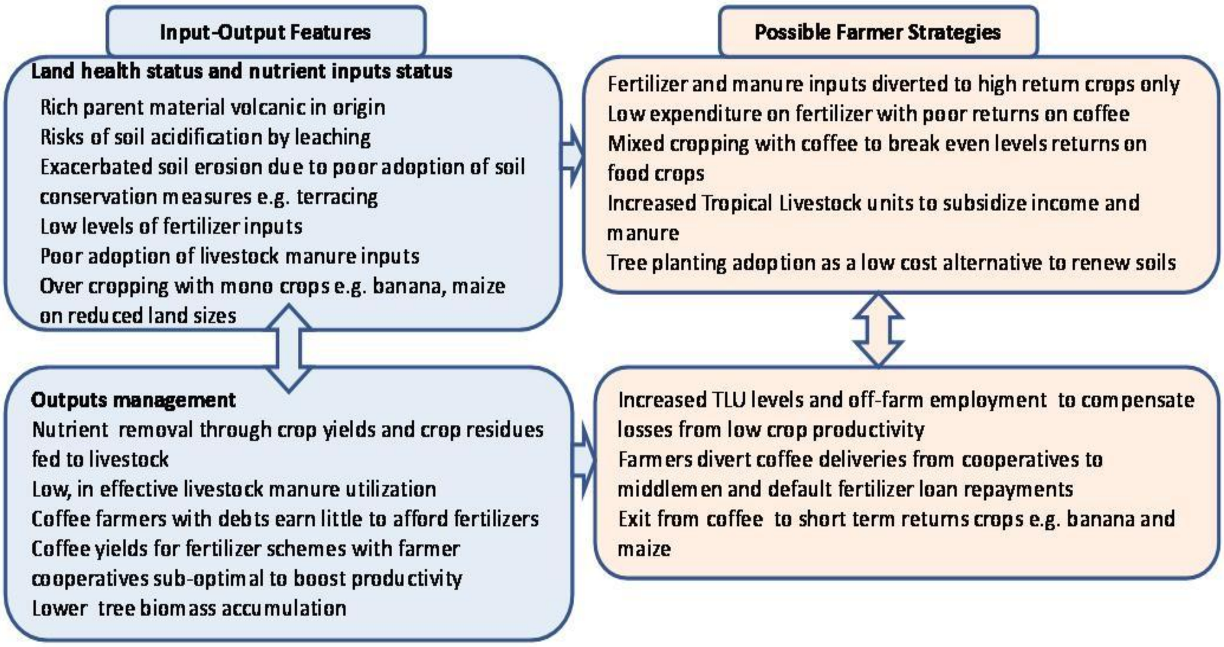

Figure 20 Schematic overview of inputs-outputs features influencing soil nutrient prevalence in small coffee farms around Mount Kenya

Further, in most smallholder farms in Africa, crop residues are not returned to the field where they were produced because they are used for cattle fodder, fencing, or cooking fuel, resulting in a virtual complete removal of P accumulated by crops for human nutrition (Sanchez, 2002; Muchena et al., 2005; Nkonya et al., 2005). P in cereal crops and grain legumes is accumulated in the grain and removed from the field at harvest. While grain harvest is desirable, soil erosion is environmentally dangerous since eroded nitrates and P-enriched topsoil, can cause eutrophication of surface waters (Smaling, 1997; Swift and Shepherd, 2007).

Farmer organic inputs can however be ineffective. One of the main arguments against the use of organic inputs is their low nutrient concentration in comparison to inorganic fertilizers (Palm and Nandwa, 1997). Animal manure and plant material contain 1 to 4% N (10-40 g N kg^{-1}) on a dry weight basis, while inorganic fertilizers contain from 20 to 46% N (200 - 460 g N kg^{-1}) and are already dry. To haul 100 kg N required for a 4 t ha^{-1} of maize crop, it would take 217 kg of urea or 201 of leaf biomass with 80% moisture and a 2.5% (25 g N kg^{-1}) N concentration on a dry weight basis. Fertilizer use is therefore the obvious way to replenish the depletion of soil nutrients and indeed has been responsible for a large part of the sustained increases in per capita food production in Asia, Latin America, and the temperate region, as well as in the commercial farm sector in Africa (Sanchez, 2002; Omamo and Mose, 2001; Waithaka et al., 2007).

Though most smallholder farmers in Africa appreciate the value of fertilizers, they are seldom able to apply them at the recommended rates and at the appropriate time because of high costs, lack of credit, delivery delays, and low and variable returns (Sanchez, 2010). Fertilizer application is reported to be highest in highland systems such as the coffee systems where this study was carried (Omamo, 2001; Odendo et al., 2007). More recently, fertilizer access by coffee growing farmers is linked to yield deliveries and coffee market prices. Farmers who accumulate debts therefore continuously access smaller and smaller fertilizer quantities from their cooperatives.

The conceptual frame presented here suggests that farmer nutrient application strategies target only high value cash and food crops. Effects of poor yields from coffee can therefore depress fertilizer inputs. Farmers will tend to enhance coffee growing with mixed cropping practices in order to utilize available nutrient. Another strategy is increased livestock keeping for income and manure. Furthermore, agroforestry tree planting is adopted as a low cost investment to utilize available land, perhaps also utilize below surface soil nutrients which are recycled on top soil by leaf litter for instance by use of *Faidherbia albida* (ICRAF, 2009).

In economic theory, farmer expenditure on fertilizer and manure nutrient inputs can be related to total expenditure of income. This is demonstrated through Engels's expenditure curve[7] (Figure 21); where, y denotes expenditure on fertilizer and χ the total income (Lewbel, 2006). The postulated model therefore assumes non linear reciprocal predictors as follows:

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[7] An Engel's curve is the function describing how a consumer's expenditures on some good or services relate to the consumer's total resource holding. Prices are fixed, so $qi = gi(y,z)$, where q_i is the quantity consumed good i, y is income, wealth or total expenditures on goods and services and z is a vector of other characteristics of the consumer such as age and household composition (Lewbel, 2006). The goods are usually aggregate commodities such as total food, clothing or transportation.

$\hat{y}_1 = b_1 + b_2\,(1/\chi_1) + \mu$………………………………………………………………(1)

The commodity, in this case nutrient inputs carry certain features such as: there is a critical threshold level of income below which the commodity is not purchased; the threshold is at level - *(b_2/b_1);* Secondly, there is a satiety level of consumption beyond which smallholders will not go no matter how high the income goes. This level is the asymptotic (limit value) *b_1* (Figure 21).

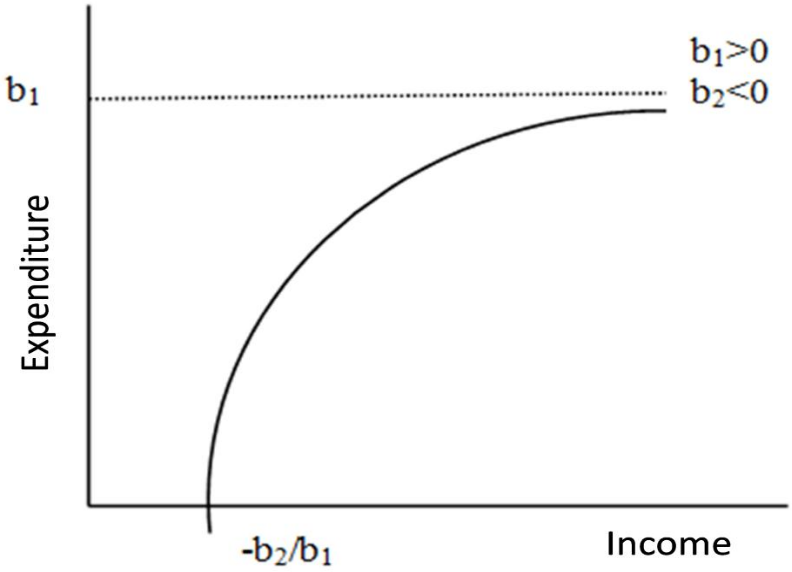

Figure 21 Engels expenditure curve on soil nutrient inputs

In this study, several socioeconomic variables were assembled to characterize farmer nutrient management. These were: the cost incurred on fertilizer and manure inputs; size of coffee yields; banana and maize yields per year; the size of the livestock enterprise; size of agroforestry tree biomass; land size; family size and presence of off-farm employment per household. Rapid NIR soil tests data for primary, secondary and micro-nutrients were characterized and soil fertility indices developed to show current nutrient status per coffee farm. It was anticipated that the biophysical soil assessment combined with characterization of household and farm related variables will improve current understanding of soil nutrient management at the household level as opposed to analysis at a large geographical scale.

6.2 MATERIALS AND METHODS

6.2.1 The study area

The eastern, windward slopes of Mount Kenya, comprising of Meru, Embu and Kirinyaga districts were selected for this study. These zones are of high potential for coffee production and record some of the highest smallholder agricultural outputs in Kenya (Jaetzold and Schimdt, 2007). The key 'coffee constituencies' selected for this study include: Kerugoya-Kutus, Gichugu (Kirinyaga); Manyatta, Runyenjes (Embu) and North, South, and Central Imenti (Meru). Population pressure in these areas is high and poverty levels are severest in Embu (Table 22). According to the Kenya poverty survey, the numbers of individuals below the poverty line in the coffee constituencies are 47%, 44% and 55% for Kirinyaga, Meru and Embu respectively (CBS, 2008).

Table 22 Constituency poverty level estimates (Source: CBS, 2008)

Coffee region	Constituency	Estimated population (from 1999 census)	Estimated No. of poor individuals	Poverty Incidence (% of individuals below poverty line	Constituency National Poverty rank(1=richest; 210=poorest)
Kirinyaga	Gichugu	117270	40249	34	23
	Kerugoya/Kutus	101859	33525	33	20
Embu	Manyatta	136124	72236	53	101
	Runyenjes	131182	76533	58	120
Meru	South Imenti	151806	65473	43	52
	Central Imenti	123961	53999	44	56
	North Imenti	209242	92374	44	60

Sampling sites varied in altitudes from 1140 m to 1750 m above sea level representing a gradient in mean annual temperature between 17.5 ^{o}C and 20.7 ^{o}C, and mean annual precipitation ranging between 1200mm and 1800 mm. The soils are mainly humic nitisols - well drained, extremely deep, dusky red to dark reddish brown, friable clay, with acidic humic top soil. A detailed description of site characteristics such as soils, climate, geology and land-use, are described in Jaetzold and Schimdt (2007).

6.2.2 Farmer sampling strategy

Household sampling involved stratification techniques in three coffee districts of Embu, Meru and Kirinyaga. Coffee regions largely fall under three agro-ecological zones namely; Upper midland one (UM1), Upper midland two (UM2) and Upper midland three (UM3) according to the FAO soil and agro-climatic zones classification of Kenya (Jaetzold and Schimdt, 2007). Therefore for each zone, existing farmer cooperative societies were identified and approached for collaboration in the study. At least 10 farmer coffee cooperative societies per district were approached to provide a sampling frame covering their respective coffee producing regions.

The coffee societies were requested to provide farmer membership records to be used as a sampling frame. Farmer membership accounts detailing amounts of coffee yield deliveries, payments and credit profiles are maintained by the societies. Written request to the society’s management committee was often required to state the purpose of the information sought. In a few instances, the research team was required to hold meeting with the management committee to discuss the purpose of the study. Most of the societies readily gave consent to collaborating in the study on meeting their requirements. Findings from the study and especially on the soil test data were requested once the exercise was complete. Confidentiality of farmer account information was assured to the management committee. For instance names of respondents would be replaced with identification codes after data entry for subsequent analysis.

Random sample farmers were selected a *priori* in three farmer categories, labeled ‘increasing’, ‘decreasing’ and ‘constant’ according to their levels of coffee cherry delivery for the period 2000-2008. Soil sampling and household interviews were conducted for a farmer category in 10 coffee societies, for a total of 30 farmers per district and a total of 90 farmers for the surveyed region. Meru however has a larger area and three additional societies were approached for sampling. Soil sample collection was conducted following a pre-determined random sampling scheme according to the approximate shape of the farm parcel (Stern and Coe, 2004). The procedure involved demarcating a 5m X 5m quadrat per farm. Quadrat placement per farm was roughly determined by farm dimensions considered as either 'thin rectangular' or 'square shaped'. Transects from the centre of a given farm were used. Assuming a determined random bearing and taking a randomly specified percentage distance to the edge of the farm, a site for soil sample collection was defined by a quadrat. Quadrat placement was flexible and could be moved up and down a land slope depending on site conditions.

Four soil samples were collected per quadrat in the depths of 0-20 cm and 20-40 cm using soil augers. These were later pooled to obtain a composite of two samples, per depth per farm. Brown bags were used to collect samples before processing for laboratory analysis. Sample identification information labels showing farmer name, depth of sample, date of collection and type of crop on the sample plot were shown on each sample. A total of 189 soil samples were collected even though only 180 samples were desired. Five extra farms were sampled in the event of poor handling or loss of samples during field work. Only one sample was lost therefore providing nine extra samples which were included in the analysis. A map of the Eastern slopes of Mount Kenya and random farms selected for soil sample collection are presented in Figure 22.

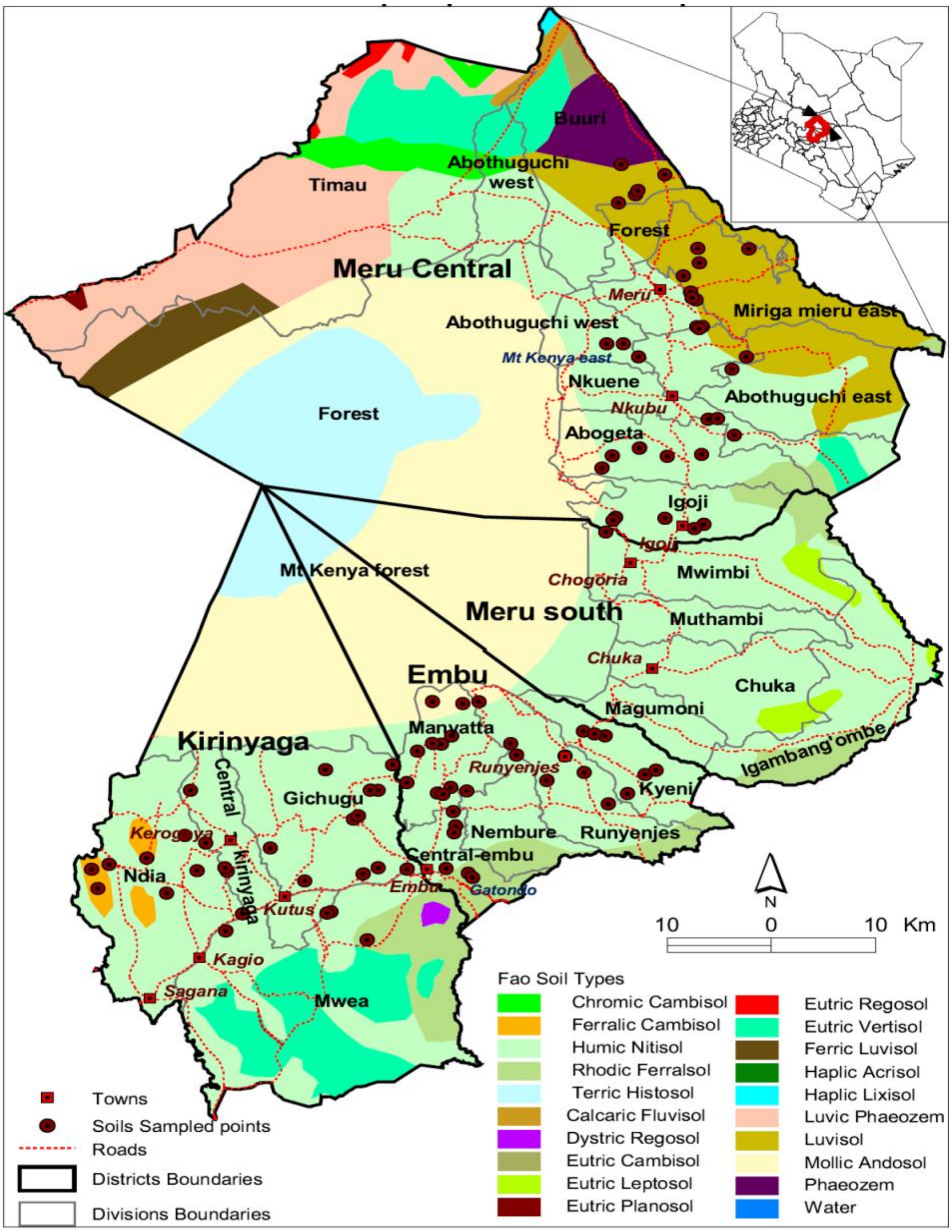

Figure 22 Map of Eastern Mount Kenya coffee region showing soil sampled coffee farms

6.2.3 Soil and farm parcel assessments

A rapid assessment of collected soil samples for soil nutrient constituents was done using Near Infrared (NIR) spectroscopy with a third of the sample analyzed by wet chemistry as reference. Inputs, accessibility and applications with respect to soil quality management were obtained from households, and used to map factors that could influence soil nutrient status. Household interviews were used to collect data on land management strategies, data on coffee cherry production, food crop yields and costs of manure and chemical fertilizers applied. Other assembled variables were: tree basal area (m^2), tree volumes (m^3) and calculated TLU. These were correlated with nutrient input and output to explore their inherent correlations. The following section describes the steps followed on the NIR approach so as to analyze soil constituents and subsequent development of soil nutrient indices.

6.2.4 Near Infrared (NIR) spectroscopy

NIR spectroscopy is a rapid non-destructive technique recently adopted for diagnostics of soil chemical constituents (Shepherd and Walsh, 2007). NIR has been widely used in pharmaceutical and industrial applications for quality control. The technique show efficiency and cost effectiveness when analyzing organic and mineral composition of soils (Janik et al., 1995; Shepherd and Walsh, 2002). The theory provides that derived soil properties may be correlated with the infrared spectra of constituent components, and the covariance between soil properties and spectra then modeled by partial least square (PLS) loadings and scores. Factors and scores are derived independently for each soil property using PLS regressions. This study used PLS for the qualitative and quantitative study of the prevalence of nutrients in soils by classifying soil spectra and associated major nutrient elements by their PLS loadings and scores as described by Shepherd and Walsh (2002). The next sections demonstrate how NIR diagnostics steps were carried out to analyze soil samples from small coffee farms in three districts of eastern Mount Kenya.

6.2.5 Sample preparation for NIR spectroscopy

Collected soil samples, in the 0-20 cm and 20-40 cm depths were processed to obtain only two samples per farm in the respective depths. Processing work involved soil samples air drying and sieving through a 2 mm sieve. A clean wooden rolling pin was used to crush course soil material. Samples for laboratory analysis were sub-sampled using the cone and quarter method. Processed samples were assigned unique identification for purposes of referencing and then uploaded into ICRAF’s soil laboratory database. A total of 189 soil samples were processed.

Soil sample scanning was done using a Fourier Transform Near Infrared spectrometer (FT-IR) at wavebands of 4000 cm^{-1} to 12820 cm^{-1}. Samples were loaded into glass petri-dishes and scanned in 30 seconds. The resulting spectral signature display the amount of energy absorbed at each wavelength, responding especially to the soil organic matter and mineral composition content of a given sample. Spectra data is multivariate in nature and highly multi-collinear, which makes it difficult to be analyzed by parametric techniques. Peaks in the regions where absorption features were found characterize the resulting spectral signature. However noise gets registered due to instrumental noise and drift, light-scatter and path-length variations that occur during measurements (Shepherd and Walsh, 2002).

Selected sample spectral signature and demarcated noise free region is shown in Figure 23. Significant levels of redundancies (noise) in spectral data results in sub-optimal calibration models to predict constituents in a sample. This is because Partial Least Squares (PLS) assumes spectral errors are normally distributed throughout the spectral region. The spectral signatures were therefore assessed for ‘noise’ regions which were ‘cut off’ so as to remain with data points with significant information levels. A more accentuated ‘noise free’ spectral signatures for a sample in the selected spectral region is shown in Figure 24.

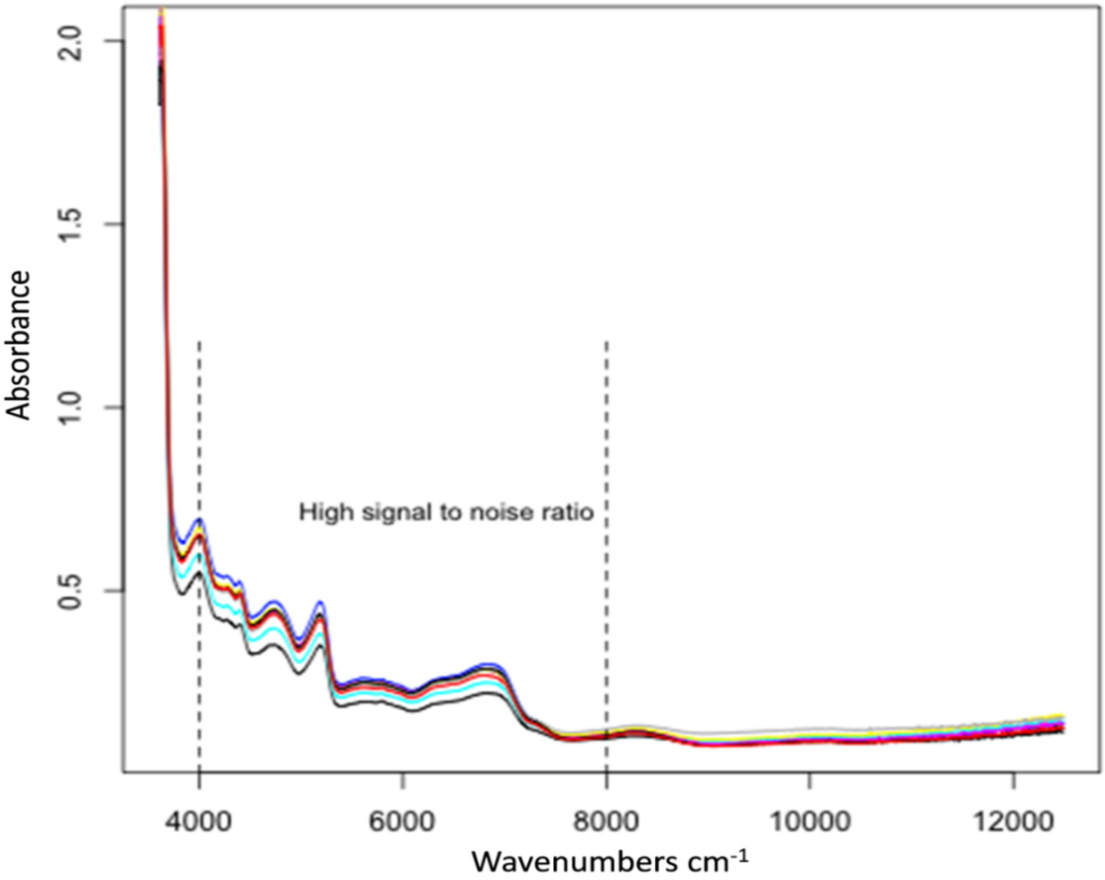

Figure 23 NIR spectral signatures on selected sample sets showing varied absorbance at w4000 –w8000 cm^{-1}

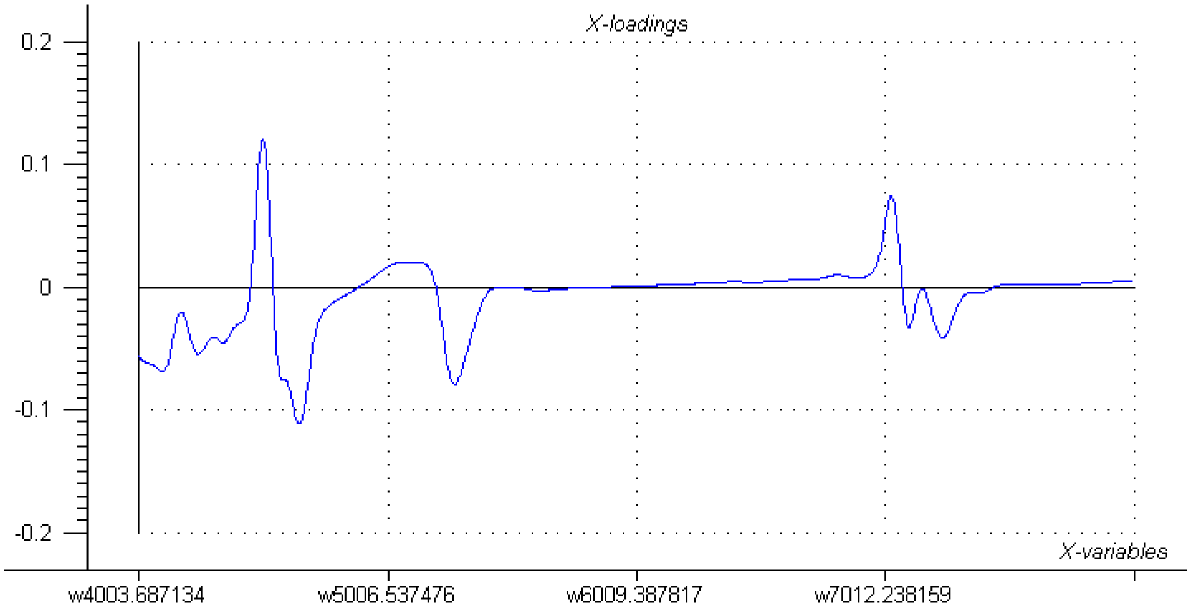

Figure 24 Selected 'noise free' spectra region (w4000 - w8000)

6.2.6 Reference samples and calibration instruments

When transmittance spectra are converted to absorbance, spectra noise is no longer constant. This is accentuated in cases where there are large variations in absorbance (Haaland and Jones, ud). Precision of calibration predictors (spectral data) is therefore improved by Kennerd and Stone algorithm procedure using *R* statistical software. One third of the 189 samples were deemed a suitable calibration set following ICRAF's standard procedure (Shepherd and Walsh, 2002). The algorithm was prescribed to collate 63 reference samples (one third of total samples) from the entire spectral space based on their relative variation.

Selected samples were submitted for wet chemistry analysis adhering to the standard soil fertility analysis package by ICRAF for 17 soil properties, namely: pH, available P, exchangeable K, total N, organic C, Mg, Ca, Na, Mn, S, Cu, B, Zn, Fe, Al, cation exchange capacity (CEC) and soil electrical conductivity (EC), (ICRAF, 2001).

6.2.7 Spectrometric calibration

Measured soil property values from the wet chemistry procedure were calibrated to the first derivative of their reflectance spectra using PLS regression. PLS is a chemometric method to derive prediction models for specific compounds from spectroscopic data (Haaland and Jones, ud). Full-hold-out-one cross-validation was done to prevent model over-fitting. PLS regression was applied in constructing linear predictive models for the 17 soil properties based on their spectra. The multivariate calibration technique used was principal component regression (PCR), where the *X*-scores are chosen to explain as much of factor variation as possible. In this case the standard reference analysis by wet chemistry was related to their constituent NIR spectra (Shepherd and Walsh, 2007). This is achieved indirectly by extracting latent variables from the reference sample factors and responses - in this case the analyzed 14 soil mineral properties together with three fertility factors, CEC, PH and EC. The approach yields information in the direction of the factor space (Janik et al., 1995; Shepherd and Walsh, 2007). The 17 factor models were then used to predict properties for the 189 soil sample sets. Regression analysis was by *R* statistical software with cross-checks using *The Unscrambler* software (CAMO, 2006). The calibration model for C failed to yield consistent outputs using *The Unscrambler*.

Model calibration sets were assessed based on the coefficient of determination (r^2) and the number of principal components (PC). Model reliability was further assessed on data transformation by natural log and square root.

To ensure the integrity of selected models, calibration models were built both in statistical software *R* and *The Unscrambler*. Table 23 shows calibration models constructed in *R* and in *The unscramber*. Data transformation was not useful when using *The Unscrambler.* Model results however, suggest using natural log for P, S, Zn could yield slightly better models with r^2 improved from 0.16 to 0.65 for P; from 0.41 to 0.52 for S; and r^2 0.59 to 0.62 for Zn, using *R*.

Primary nutrient N, calibrated well, while P and K calibrated poorly in *R* but showed fair improvements with *the unscramber* on the respective natural log (r^2 = 0.71; *PC* = 7) and square root (r^2 = 0.71; *PC* = 6) transformation. The C calibration model was satisfactory in either transformation but optimized with natural log. Secondary nutrient models calibrated well except for S, while the precision for micro-nutrients models was reasonable with the exception of Na, Cu and B the latter showing higher levels of PCs. Soil PH calibrated well, while CEC showed reasonable results with *the Unscramber*. Cross checks on outputs for most of the models in *R,* showed slightly higher PCs than in *the Unscrambler.*

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Table 23 Calibration models showing precision assessed by three methods of data transformations

	Primary nutrients				**Secondary nutrients**			**Indicators**				**Micro nutrients**			
Transformation	**N**	**P**	**K**	**C**	**Ca**	**Mg**	**S**	**CEC**	**PH**	**Al**	**Na**	**Mn**	**B**	**Fe**	**Zn**
***R* software**															
None (r^2)	0.85	0.16	0.32	0.78	0.78	0.86	0.41	0.67	0.74	0.77	0.54	0.86	0.74	0.5	0.59
None (PC)	20	3	2	8	15	13	5	10	11	12	7	13	11	6	12
Lnlog (r^2)	0.81	0.65	0.34	0.79	0.85	0.76	0.52	0.52	0.73	0.82	0.14	0.55	0.75	0.51	0.62
Lnlog (PC)	16	8	8	8	14	12	5	10	13	15	2	11	14	7	10
SQRT(r^2)	0.83	0.44	0.33	0.79	0.89	0.87	0.47	0.62	0.72	0.79	0.09	0.55	0.79	0.51	0.66
SQRT PC	16	5	9	8	15	14	5	10	12	15	2	9	14	8	0.12
The Unscrambler															
None (r^2)	0.79	-0.4	0.23	0.8	0.76	0.85	0.53	0.75	0.8	0.83	0.107	0.7	0.79	0.67	0.67
None (PC)	8	1	2	7	9	11	5	8	8	10	2	5	11	6	11
Lnlog (r^2)	0.81	0.71	0.27	0.85	0.89	0.86	0.62	0.71	0.74	0.82	0.18	0.7	0.82	0.72	0.76
Lnlog (PC)	12	7	2	8	12	12	5	9	8	12	2	4	11	7	9
SQRT (r^2)	0.82	0.59	0.71	0.85	0.92	0.88	0.59	0.74	0.79	0.83	0.18	0.71	0.83	0.71	0.73
SQRT PC	8	4	6	8	15	10	5	9	11	12	2	7	14	6	9

None-no data transformation; Lnlog-natural logarithm; SQRT- square root; PC-principal components

Overall data transformation by natural log showed slight benefits for calibration instruments, considering r^2 and PC values, and was therefore used to predict nutrient composition for the spectra data set. Shepherd and Walsh (2007) confirm that IR spectroscopy in soils show variable performance when predicting for nitrates and soil available P and K tests, however soil reflectance responds well to key soil properties that respond to P availability in crops such as mineralogy, organic matter, clay content and microbial activity.

6.2.8 Data analysis

Soil test data were submitted for principal component analysis[8] (PCA), to obtain a smaller number of artificial variables (called principal components) that account for most of the variation in the analytical sample (Stern and Coe, 2004). Data reduction procedures are useful to remove redundant (highly correlated) variables from the data and obtain a smaller number of uncorrelated variables. PCA was used to develop soil nutrient indices (principal components) representative of all the soil samples collected. Essentially, principal components (PC) show levels of soil nutrient prevalence between farms.

Descriptive and exploratory approaches are used to analyse the relationships between derived soil PC scores (PC1, PC2 and PC3- the dependent variables) and composite smallholder household socio-economic variables such as farm size, amount/value of fertilizer and/or manure applied, tropical livestock units estimates (TLU), number of coffee bushes, size of tree volumes, and value of maize yield produced per year. SPSS version 15 was used for biophysical and socio-economic multivariate data analysis. PCA on soil test data was executed using *the unscrambler version 9.2* or with *R* software.

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[8] Principal component can be defined as a linear combination of optimally-weighted observed variables. The words “linear combination” refer to the fact that scores on a component are created by adding together scores on the observed variables being analysed (Stern and Coe, 2004)

6.3 RESULTS

6.3.1 Determining soil nutrient indices

Data values for the seventeen soil properties (pH, P, K, N, C, Mg, Ca, Na, Mn, S, Cu, B, Zn, Fe, Al, CEC and EC subjected to a principal component analysis, showed high extracted communality estimates (Annex 7). [9]Communalities (always equal to 1) indicate the amount of variance accounted for in each variable. The score for all properties was 0.70 to 0.92; except for, K and Zn, which were 0.51 and 0.55; and S and P, which were 0.62 and 0.64 respectively (Annex 8). This confirmed that extracted components represent the studied variables well.

The principal axis method was used to extract components, followed by a varimax (orthogonal) rotation. Only the first four components displayed eigen-values (accounted variance in the original variables) greater than 1 (PC4=1.8; PC3= 2.04; PC2= 2.74; PC1=6.8). Results from the scree plot also suggest only the first four components were meaningful; these were therefore retained for rotation. Extracted principal components (1 to 4) accounted for 78.3% of total variability in the submitted data dimension (Annex 7). The rotations maintain the variation explained by extracted components and is spread more evenly over the components, making the rotated matrix easier to interpret that the un-rotated one. In Table 24 a comparison of the rotated and un-rotated extraction matrix is demonstrated.

The rotated component matrices showed better clarity and were used to determine what the components represent. Using a cut off value of 0.65, a variable item was said to load to a given component if the factor loading was 0.65 or greater for that component, and was less than 0.70 for the other principal components (PC). From this criterion the following was deduced:

i. PC1 is strongly correlated with B, Ca, Mg, Al, Mn, pH, CEC, S, Zn and is therefore a good indicator of these soil properties

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[9] Initial communalities are estimates of the variance in each variable accounted for by all components. For principal components extraction, this is always equal to 1.0 for correlation analyses. Extraction communalities are estimates of the variance in each variable accounted for by the components.

ii. PC2 is most highly correlated to organic Carbon, N and P is a useful indicator of these properties

iii. PC3 is highly correlated to Fe and Cu only

iv. PC4 is highly correlated to Na only (however not considered in subsequent analysis owing to poor calibration with spectra).

Table 24 Principal components extraction: comparison of the rotated and un-rotated extraction

Component Matrix (No rotation)					Component Matrix (Rotated)				
	Components					Components			
Variables	**1**	**2**	**3**	**4**	**Variables**	**1**	**2**	**3**	**4**
pH	**0.900**	0.097	-0.136	-0.109	**B**	**0.904**	0.000	-0.312	-0.095
Al	**-0.897**	0.105	0.058	0.261	**Ca**	**0.880**	-0.055	0.141	0.186
C.E.C	**0.881**	0.092	0.121	0.150	**Al**	**-0.823**	0.448	-0.070	-0.064
Ca	**0.878**	0.216	0.107	-0.046	**C.E.C**	**0.822**	-0.072	0.020	0.374
Mg	**0.876**	0.078	-0.163	0.006	**pH**	**0.811**	-0.304	0.244	0.203
B	**0.764**	-0.022	0.536	-0.229	**Mg**	**0.753**	-0.289	0.233	0.310
Mn	**0.659**	-0.254	0.516	-0.205	**Mn**	**0.752**	-0.135	-0.467	-0.079
S	**-0.628**	-0.447	0.015	0.167	**S**	**-0.685**	-0.069	-0.384	-0.003
K	0.579	0.083	-0.174	0.377	**Zn**	**0.654**	0.297	0.026	0.190
Zn	0.566	0.337	0.318	0.132	**C**	-0.152	**0.939**	-0.065	-0.128
P	-0.069	**0.770**	0.082	0.199	**N**	-0.156	**0.926**	-0.009	-0.120
Cu	0.038	**0.636**	-0.486	-0.243	**P**	0.078	**0.667**	0.435	0.067
N	-0.445	**0.620**	0.516	0.219	**Fe**	0.109	-0.027	**0.858**	0.115
C	-0.451	**0.592**	0.567	0.222	**Cu**	0.055	0.076	**0.817**	-0.158
Fe	0.204	0.576	**-0.621**	-0.042	**Na**	0.035	0.020	0.063	**0.959**
Na	0.329	-0.029	-0.248	**0.868**	**EC.S.**	-0.198	0.214	0.387	**-0.781**
EC.S.	-0.455	0.449	-0.034	**-0.660**	**K**	0.407	-0.088	0.172	0.558
Extraction Method: Principal Component Analysis					Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization				

This suggests that soil nutrient prevalence in the smallholder coffee systems are better characterized focusing on soil bases, and B, organic C, and total N level, with indications of available P and prevalence of Fe, and Cu micronutrients only.

Further, for each variable item and each component, a component score is computed by multiplying the items standardized variable values by the component's score coefficients. The resulting component score variables (PC scores) are representative of, and are used in place of, the seventeen measured soil property variables with approximately 20% loss of information. PCA scores have previously been used directly for discriminating samples into groupings. Bivariate principal component score maps have been used to reveal clustering of samples or separation into classes (Janik et al., 1995). An example of a principal component score map obtained with *the unscrambler*, for PC1 and PC2 is showed in Figure 25. The next section discusses the relevance and application of the PC scores in this study.

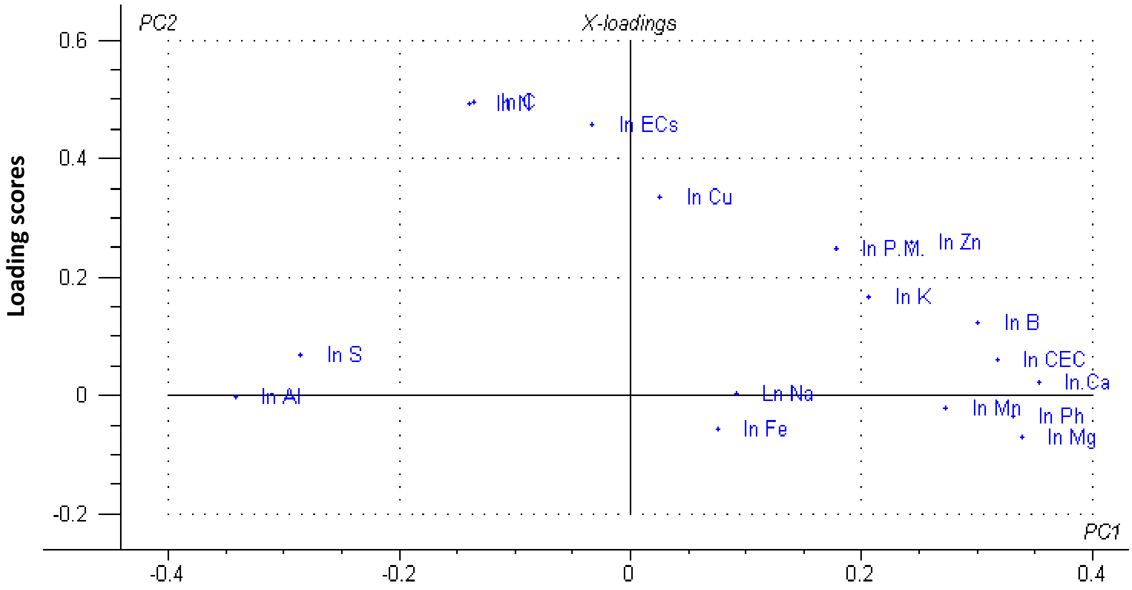

Figure 25 Principal component loading scores

6.3.2 Principal components - scores validity

Principal components (PC1, PC2 and PC3) versus representative soil properties showed strong correlation. PC4 was omitted since a poor PLS regression model to calibrate Na was obtained casting doubt on its prediction. Al is positively correlated to PC1 and was included to show its score against PC1. Organic C and N are strongly correlated to PC2; while Fe is strongly correlated to PC3. Pearson correlation on all the properties is statistically significant (P = 0.00). A correlation of the PC scores with respective soil properties is shown in Table 25. Decreasing PC1 scores indicate high prevalence of soil bases while increasing PC2 and PC3 scores relate to increasing organic C, N; and Fe prevalence respectively. Scatter plots of the PCs against representative soil properties is presented in Figure 26.

Table 25 Principal components (PC) scores correlation to representative nutrients

Principal component Score	Soil properties (n=189)			
	Al	**B**	**Ca**	**Mg**
PC1 correlation	0.55 (0.00)	-0.33 (0.00)	-0.47 (0.00)	-0.57(0.00)
	C	**N**	**P**	
PC2 correlation	0.904 (0.00)	0.854(0.00)	0.514(0.00)	
	Fe	**Cu**		
PC3 correlation	0.82(0.00)	0.68 (0.00)		

(**) Correlation is significant at 0.01 level (2 tailed)

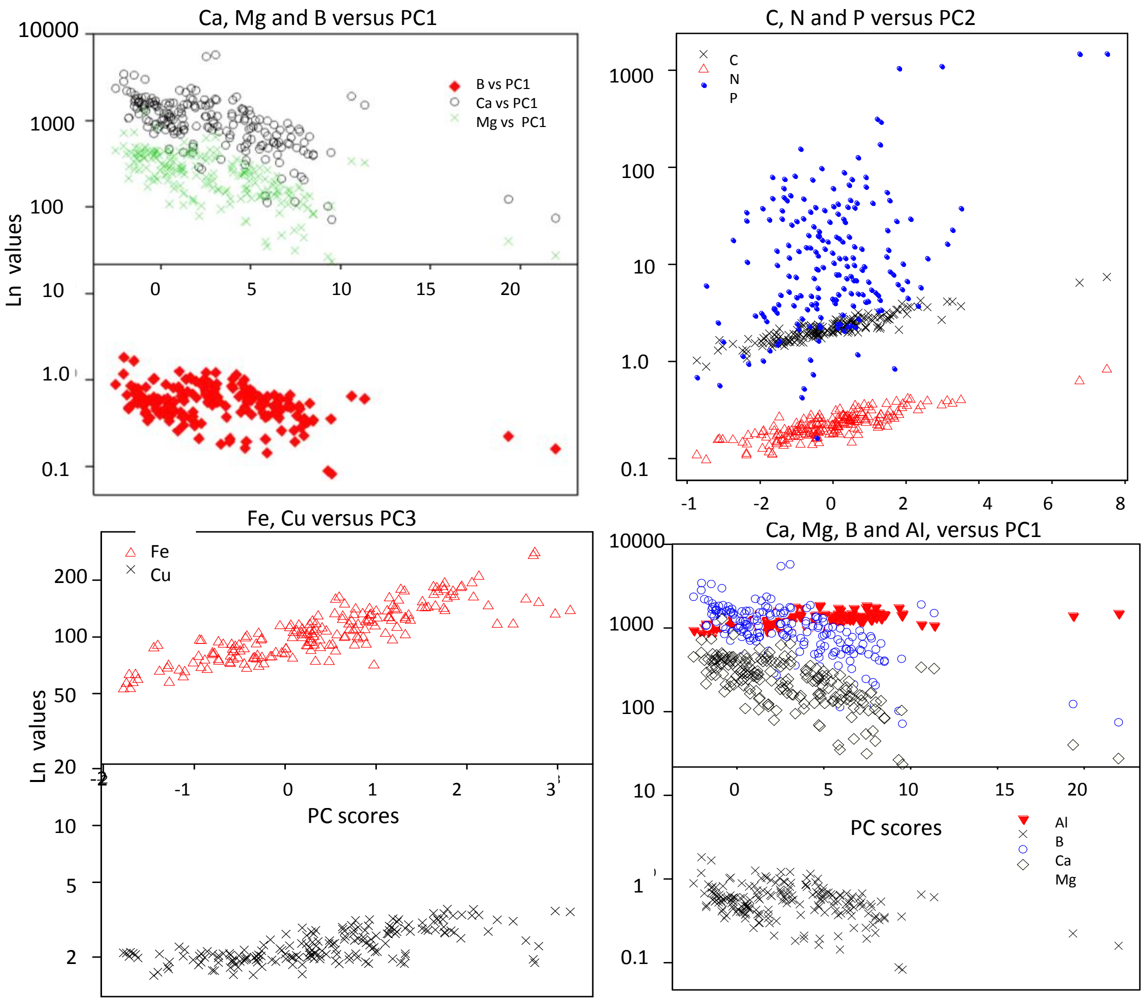

Figure 26 Scatter plots showing PC1, PC2 and PC3 scores and related soil properties

6.3.3 Nutrient prevalence in small coffee systems

Data on soil nutrient prevalence is represented by principal components scores for all soil properties described. These were: PC1 (soil bases and B), PC2 (organic C, total N and P) and PC3 (Fe and Cu). The PC and constituent nutrients are interchangeably used in describing soil fertility characteristics of the coffee farms. Indicator scores were derived by observing entire PC scores range and visually demarcating scores as low, moderate and high as shown in Table 26.

Table 26 Derived soil nutrient prevalence indicator scores

Nutrient indicators	Indicator scores		
	high	moderate	low
PC1 (Ca, Mg, B)	<0.0	0.1-5.0	>5.0
PC2(Org. C, N, P)	>2.0	0.1-2.0	<0.0
PC3 (Fe, Cu)	>2.0	0.1-2.0	<0.0

Analysis of soil nutrients prevalence using the identified indicators (Table 27) showed 64% of the soil test samples had high bases content; only 18% of the samples showed high organic C content, total N, Fe and Cu. Results showing high bases content were contrary to expectation, as many of the locations experience high rainfall with potential leaching. The high score indicates reasonable nutrients stocks in spite of permanent cultivation practices. Reduced rainfall patterns in the past two years may also play a contributing factor.

Further analysis showed that nearly half (46%) of the samples tested for organic C and total N, had low levels of these soil properties. This is perhaps indicative of available P even though spectra analysis showed high variability. Shepherd and Walsh (2007) have showed that P dynamics in soils are complex, as they involve both chemical and biological processes with long-term effects of sorption (fixation) and desorption (release) processes. Also low concentration and low solubility of P in soils frequently make P a limiting factor (Sanchez, 2002).

Data suggests C, N and P are by far the most deficient minerals in small coffee farms as compared to bases at 24% of the samples and Fe, and Cu, at 30% of the samples.

A substantial number of samples record moderate nutrient prevalence especially for Fe and Cu (40%), soil bases and B (33%) and organic C and N (28%). This would suggest that a fairly sizeable number of coffee farms are of average fertility but face possible soil texture and structure degradation due to deficient organic C (organic matter), N and P content.

Table 27 Soil nutrient prevalence in sampled smallholder coffee farms

	Soil nutrients prevalence (all sampled farms)					
Nutrients Indicators	**Low**		**Moderate**		**High**	
	Sample (%)	% of PC	Sample (%)	% of PC	Sample (%)	% of PC
PC1 (soil bases, B)	24.4 (n=52)	35.9	32.8 (n=94)	55.0	64.2 (n=43)	70.5
PC2 (Org. C, N)	46.0 (n=98)	67.6	27.5 (n=79)	46.2	17.9 (n=12)	19.7
PC3 (Fe, Cu)	29.6 (n=63)	43.4	39.7 (n=114)	66.7	17.9 (n=12)	19.7
All	100 (N=213)	146.9	100 (N=287)	167.8	100 (N=67)	109.8

n= no of samples, PC = principal components

Mean nutrient levels show bases, Ca and Mg were high at 1111 ppm (s.d = 769) and 269 ppm (s.d = 166) respectively, while B levels are low at a mean of 0.58 ppm (s.d = 0.26). Organic C, total N percentage and P were 2.28 % (s.d = 0.77), 0.23 % (s.d = 0.08) and 49 ppm (s.d = 188) respectively. A high standard deviation for P showed wide variability across the samples. Average Fe and Cu prevalence were of moderate levels at 111 ppm (s.d = 38) and 2.3 ppm (s.d = 0.48) respectively. Soil tests on aluminum toxicity showed a high mean of 1240 ppm (s.d = 208). This value was expected especially for the upper midlands zones of coffee bordering tea, due to exacerbated bases leaching.

Box and whisker plots on the soil test scores for the three study sites (Embu, Kirinyaga and Meru) are presented in Figure 27. Soils in Embu are severely leached of bases with no samples recording ‘high’ nutrient content (PC1 score < 0). Box and whisker plots nonetheless showed that bases variability (inter-quartile range) was not much (Figure 27); at the third quartile, bases score was > 5, an indicator of severe bases deficiency widespread on farms. At the first quartile, PC1 score is about

4.8 indicating a slight improvement of bases levels but perhaps tending more to degradation.

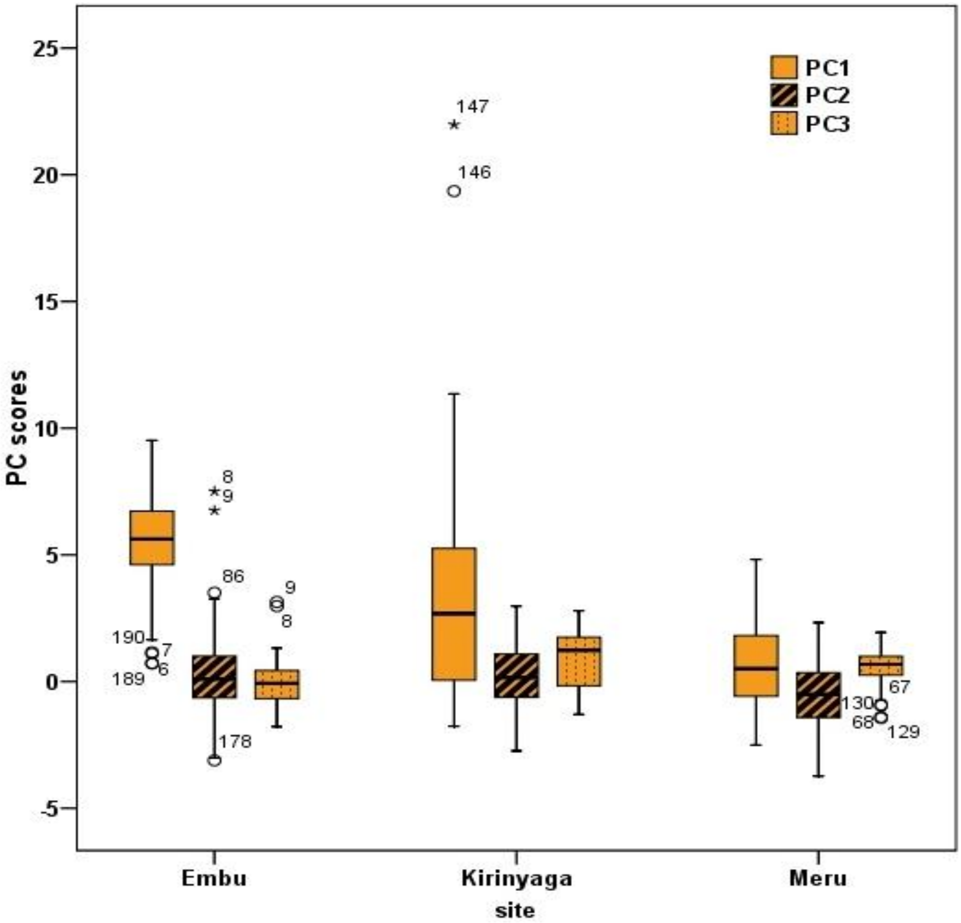

Figure 27 Soil nutrient indicators (PC scores) for Embu, Kirinyaga and Meru coffee systems

Soil bases in Kirinyaga samples are most variable with two farms (outliers) showing excessive score values and hence extremely low bases and severe soil acidification. However the first quartile of the indicator value was less than zero, while at the third quartile, PC1 score was about 5 showing a substantial prevalence of moderate levels of bases. The maximum score value for Kirinyaga was about 12 showing a higher, low level of bases than Embu at a score of 9. Meru recorded the strongest bases prevalence with PC1 score of zero at half quartile and a maximum score of 4.9 for farms with lower bases (Figure 27).

Organic C and total N percentage showed similar variability across the three sites. At the second quartile, all the sites recorded an approximate score value of less than zero, indicating low nutrient prevalence. The maximum score value was approximately 3.5 and the minimum was about -3.0. Analysis of Fe and Cu prevalence for Kirinyaga showed a score of 1.5 at the second quartile, while Embu showed a score value of approximately zero. Meru showed the smallest variability at the second quartile at an approximate score value of one (Figure 27). Comparison of soil fertility by the three farm categories *constant, decreasing* and *increasing* showed more or less similar patterns (Figure 28).

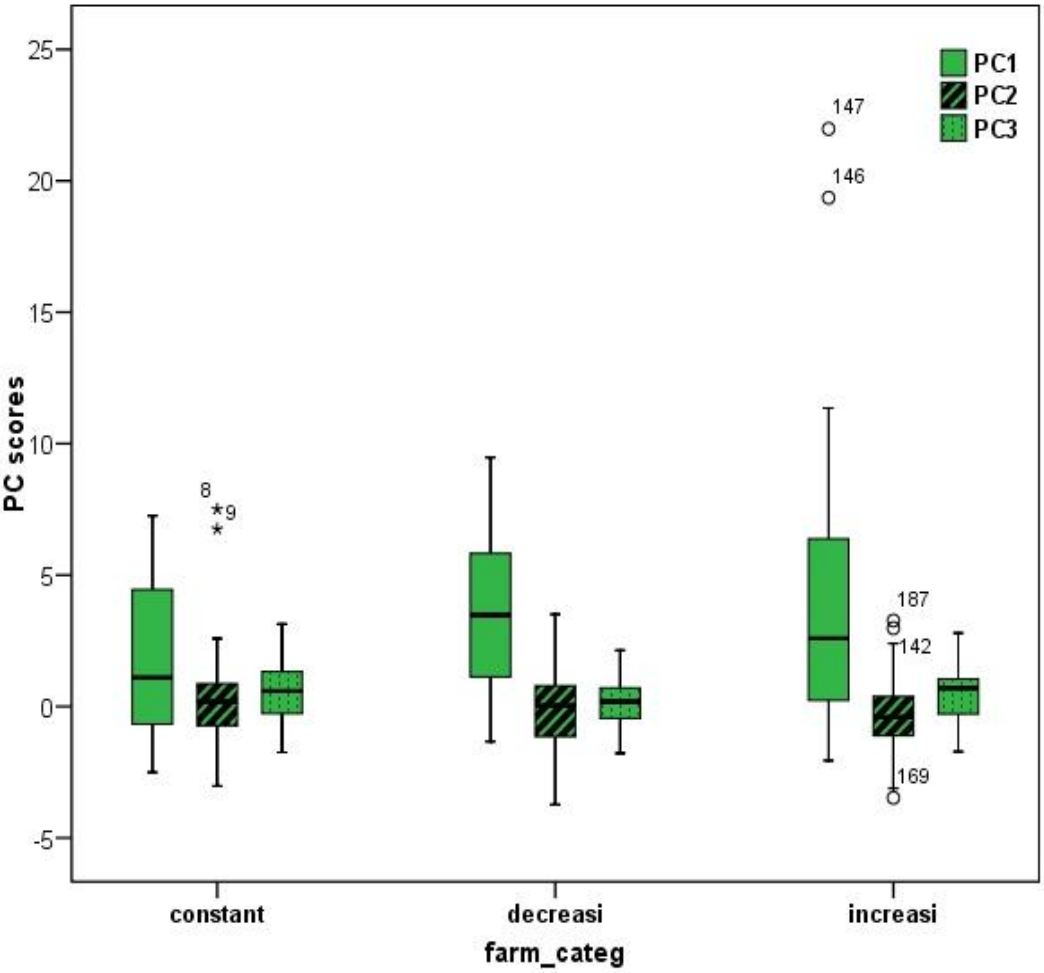

Figure 28 PC scores for the ‘constant’, ‘decreasing’, ‘increasing’ farm categories

Coffee *decreasing* farms showed PC1 score value of 2 at the first quartile suggesting only moderate contents of basic soil properties; while for the *increasing* and *constant* categories the score value was about -1 at the first quartile suggesting that fewer than 25% of farms in these farm categories had high bases and low Al prevalence.

The coffee *increasing* and *decreasing* farms had a PC1 score of > 5 at the third quartile suggesting very low bases and B content, but a high prevalence of Al. The *constant* farm category had a score of 4 at the third quartile implying relatively moderate levels of soil bases and Al. PC2 (Organic C and total N percentage) showed high variability in the *decreasing* farm categories with a maximum of about 3 and minimum score of about -3.5.

The coffee *increasing* farms showed a PC score of < 0 at the second quartile suggesting these farms have low organic C, N and P prevalence. All farm categories showed PC2 score of about 0.1 suggesting only slightly moderate prevalence of organic C, N and P, at the third quartile. PC3 (Fe and Cu) score variability, though not of interest, showed low nutrient prevalence for these nutrients at the first quartile and just moderate levels at the third quartile.

6.3.4 Surveyed households and farm parcel characterization

Typical small coffee farms are characterized by multiple crop and animal enterprises. Some socio-economic characteristics of the surveyed households are presented in Table 28. Results showed that heads of households are aging at a mean age of 59 years (s.d = 14); a family size of five persons; and farm parcel of about 1.2 hectares (s.d = 1.04). There are about 540 coffee bushes per household producing about 4.4 kg of coffee cherry per bush.

Calculated TLU are at a mean of 4 (s.d = 2.6) indicating a relatively strong preference for livestock farming. Fertilizer and manure application are widely variable per household demonstrating steep differences in nutrient application rates and perhaps varied challenges in nutrient accessibility.

Coffee, maize and banana cultivation form important farming activities carried out in mixed cropping or small monoculture patterns. Soil nutrient assessment as expected show variable soil fertility by the farm parcel surveyed. The next section quantifies rates of animal manure and fertilizer application from the surveyed households.

Table 28 Summary of the socio-economic features of smallholder farmers

Household & farm parcel characteristics	Mean	Standard Deviation	n
Farmer age	59	14	94
Family size	5.02	2.22	94
Farm parcel in hectares	1.24	1.04	94
Number of agroforestry trees	193	137	94
Tree Basal Area (TBA) in M^2	2.97	2.19	94
Tree volume per farm parcel (m^3)	37	35	94
Number of coffee bushes	537	497	93
Cherry yield per bush (Kg)	4.4	3.3	93
Value of banana yields produced per yr (US$)	575	780	75
Value of banana yields for home use (US$)	177	168	71
Value of maize yields per year (US$)	258	285	87
Value of maize yield for HH use per yr (US$)	137	108	87
Fertilizer costs for maize alone per yr (US$)	37.84	32.96	67
Tropical Livestock Units (TLU) estimates per HH	3.99	2.64	89
Value of livestock products consumed daily (US$)	0.77	0.68	94
Amount of fertilizer applied per farm (Kg)	286	257	88
Value of fertilizer used per year (US$)	177	157	88
Amount of manure applied per farm (Kg)	8960	9060	84
Value of manure applied per farm per yr (US$)	230	276	83
Soil bases prevalence (PC1 score)	2.78	3.54	94
Organic carbon, Nitrogen % prevalence (PC2 score)	0.31	1.55	94
Iron (Fe) & Copper (Cu) prevalence (PC3)	0.44	1.03	94

Key household variables for the three farmer categories studied are presented in Table 29. The mean age of heads of households was highest for the constant farmer category and slightly lower in the *increasing* and lowest in the *decreasing* category. This could be considered as an indication that younger farmers are currently not interested in coffee production. Farm sizes were similar in the constant and decreasing categories at about 1.1 ha while the increasing category shows larger farm sizes of approximately 1.6 ha. Cultivated coffee bushes were similar in the *constant* and *decreasing* categories at about 420 and 440 bushes, with reported subjective yields of 1740 kg and 990 kg respectively. The *increasing* farmer category has about 750 (s.d = 660) coffee bushes yielding 3390 kg of cherry (s.d = 2393).

Estimated input costs were highest for the *increasing* farmer category and lowest for the *decreasing* category, perhaps indicating farmers are still in a stage of selecting alternative high value crops after reducing the size of the coffee crop. Input cost estimates showed a high standard deviations suggesting severe disparities in reported costs.

Table 29 Descriptive variables for three farmer groupings (according to coffee production)

Farmer category	Statistics	HH Age	Farm size	Family size	Coffee bushes	Cherry yield (Kg)	No. Af trees	Tree diversity	TLU	Inputs costs/yr
Constant	Mean	62	2.59	4.82	423	1742	158	16	3.09	11698
	SD	16	2.34	2.18	319	1323	89	5.20	1.30	11724
	n	33	34	34	33	33	34	34	32	30
Decreasing	Mean	56	2.70	4.77	448	989	187	17	2.96	7471
	SD	14	2.24	2.161	404	817	121	10.19	1.43	9469
	n	29	30	30	30	30	30	30	28	26
Increasing	Mean	58	3.97	5.50	752	3386	239	20	3.38	17904
	SD	12	2.93	2.32	661	2393	182	8.05	1.12	24633
	n	30	30	30	30	30	30	30	29	29

HH=house head; Af=agroforestry; TLU= total livestock units; SD=standard deviation, n=sample size, costs in Ksh.

6.3.5 Manure application

Estimating the application of animal manure was challenging as application is dependent on many factors. Most farmers who have cattle readily obtain manure from their zero grazing units; however it's never enough to apply to the whole farm. Sometime slurry from zero grazing units is directly furrowed to adjacent farm sections, mainly with banana crops, eliminating the labour of collection and spreading. Manure application demands labour for digging manure piles, collecting and spreading on the farm. Storage is often done in the open, in a section of the homestead, and is prone to nutrient leaching during rainy season. Animal waste is often mixed up with feed residues especially napier and maize stovers. When purchased manure cost is inflated due to high transport charges. Application has therefore remained less frequent compared to inorganic fertilizers occurring in intervals of one to three years.

Interviewed farmers prioritize manure application on coffee (82%) and food crops such as maize (67%), and banana 48% (Table 30). Whole farm application is seldom done with only 1.7% of the farmers surveyed taking that approach. About 13% of the smallholders interviewed did not apply any manure on their farms.

Table 30 Farmer priority crops for manure application

Type of crop	Responses count		Percent of farmers (n=181)
	N	Percent	
banana	86	18.3%	47.5%
beans	12	2.6%	6.6%
coffee	149	31.7%	82.3%
horticulture	26	5.5%	14.4%
maize	121	25.7%	66.9%
napier	15	3.2%	8.3%
potato	26	5.5%	14.4%
tea	8	1.7%	4.4%
no application	24	5.1%	13.3%
whole farm	3	0.6%	1.7%

6.3.6 Fertilizer inputs

Compound fertilizers, nitrogen-phosphorous (NP); nitrogen, phosphorous and potassium (NPK) and straight fertilizers (calcium ammonium nitrate, urea) are commonly used albeit in smaller than optimal quantities. Straight fertilizers contain one nutrient while compound fertilizers contain two or more nutrients. The two main basal fertilizers used were NP and NPK compounds. The former are mainly used for planting of cereal crops (maize) and horticultural crops, while NPK is mainly applied on coffee and tea.

Straight fertilizers such as CAN and urea are used for top dressing. Commercial types of NP compounds include Diammonium phosphate (DAP) 18.45.0, 23.23.0 and 20.20.0. The NPK types mainly used are 17.17.17 and 25.5.5 + 5S, with the latter mainly used in tea growing. Common fertilizer types[10]used by farmers in Kenya are shown in Appendix 5.

Data analysis by ranking of the quantities of fertilizers used per household per year, showed that the NPK compounds were the highest followed by the straight types and then the NP compounds in the mean rate of 190 kg, 118 kg and 80 kg respectively (Table 31). The unit cost of the three fertilizer groups do not show much difference, approximated at about US$ 0.50 per kilogramme. Expenditure on basal fertilizers was nonetheless twice that of straight fertilizers. This is perhaps due to the practice of many farmers of applying fertilizer only once, during planting. Overall, data revealed wide variability in amounts of fertilizer applied and expenditure irrespective of types accessed.

Many factors could be attributed to this observation; chief among them fertilizer costs and returns from cash crops are correlated as shown in the previous sections. On the other hand, data have showed high amounts of fertilizer use indicating improved fertilizer accessibility by some farmers and perhaps raised awareness on the nutrient status of their land. An estimated quantity of fertilizer accessed by farmers and costs-expenditure (for the different types) is shown in Table 31.

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[10] Every inorganic fertilizer has a particular grade. The fertilizer grade refers to the percent nutrient content of nitrogen, phosphorus and potassium. Nitrogen is expressed in % N, phosphorus as % phosphate (P_2O_5) and potassium as % potassium oxide (K_2O). In Kenya, it is mandatory that this N-P-K (i.e. N-P_2O_5-K_2O) information be displayed on the outside of each fertilizer bag. For example, the fertilizer 17-17-17 contains 17% nitrogen, 17% P_2O_5 and 17% K_2O, the remaining 49% is filler material.

Table 31 Quantity and costs of basal and straight fertilizers used by surveyed farmers (n =173)

Type of fertilizer	Minimum	Maximum	Mean
NP compounds (Kg)	3	2400	79.5 (s.d = 200; n=148)
NP compounds cost (Ksh)	180	21000	3759.8 (s.d = 3714; n=148)
NPK quantity (Kg)	10	1200	191.0 (s.d = 217; n=117)
NPK cost (Ksh)	550	49300	8724.4 (s.d 8858; n=117)
Straight fertilizers (Kg)	1	650	118.0 (s.d= 110; n=149)
Straight fertilizer cost (Ksh)	150	36000	5139.4 (s.d = 5160; 149)

s.d = standard deviation; 1US$ =Kenya shilling (KES) 80; Kg = kilogramme

Fertilizer prices were similar across the three studied regions. Like manure, fertilizer applications appear to be rationalized between the many crops cultivated on farm. Food crops like maize, Irish potatoes and cash crops such as coffee and tea appear to receive more attention for fertilizer application. Others are horticultural crops such as tomato, French beans, cabbage and passion fruit. Percentage counts on farmer choice of crops for fertilizer application across the different fertilizer groups are summarized in Table 32. Coffee and maize are the highest fertilized crops by all the fertilizer types reported, except that NPK is more preferred on coffee and the NP compounds on maize.

Table 32 Percentage counts of farmers using basal and straight fertilizers per crop (n = 173 farmers)

Priority crop	NP compounds	NPK	Straight fertilizer
coffee	24.9% (43)	54.3% (94)	79.2 % (137)
maize	72.8 % (126)	11.0% (19)	56.1% (97)
horticulture	14.5% (25)	9.2% (16)	16.2% (28)
beans	8.1% (14)	0.6% (1)	3.5% (6)
Irish potato	17.3% (30)	1.2% (2)	2.9% (5)
tea	1.2% (20	19.7% (4)	2.3% (4)
banana	4.0% (7)	3.5% (6)	1.2% (2)

*Number in brackets () represents farmer counts. Large counts attributed to cross application in the many crops

6.3.7 Factors influencing fertilizer and manure nutrient inputs

Organic and inorganic nutrients application practices in smallholder farms is influenced by diverse household socio-economic factors. Examining correlations between the value of fertilizer and manure applied show interesting correlations, even though it may not entirely explain the relationship of the correlations (Table 33). The value of fertilizer applied has a significant positive correlation with farm size, costs of straight fertilizers, yield value of coffee, maize and banana, value of manure used, tree volume (m^3) on farm and tree basal area. Though not statistically significant, data showed a negative correlation between the cost of fertilizer and manure applied per kilo per hectare, cherry (in kg) per hectare, tree volume (m^3) per hectare and tree basal area (m^2) per hectare. Manure applied in kilogramme per hectare showed significant correlation with the amount of basal fertilizers applied per hectare, manure costs, and coffee cherry produced per hectare.

Table 33 **Correlation between fertilizer and manure application, and variables of selected households/farms**

Factor	Correlation	Variables
Fertilizer cost(US$)/per year	**.575** (.000)**	Farm size (ha)
	.478 (.000)**	Yield value (coffee + maize+ banana)
	.465 (.000)**	Cost of manure used/ farm (US$/yr)
	.385 (.000)**	Tree volume on farm (m^3)
	.269* (.014)	Maize yields value (US$/yr)
	.243* (.022)	Total tree basal area on farm (M^2)
	-.015 (.893)	Cherry produced (Kg/ha)
	-.019 (.871)	Manure used (Kg/ha)
	-.082 (.447)	Tree volume (m^3/ha)
	-.169 (.116)	TBA (m^2/Ha)
Manure applied (kg/ha)	**.498** (.000)**	Basal fertilizer applied (Kg/ha)
	.414 (.000)**	Coffee cherry produced Kg/Ha
	.056 (.627)	Basal fertilizer cost US$
	-.079 (.543)	Yield value (coffee + maize+ banana)
	-.200 (.080)	Maize yields value yr us
	-.219* (.047)	TBA (m^2/Ha)
	-.224* (.042)	Tree volume on farm (m^3)
	-.332* (.011)	Fertilizer costs for maize US$/yr
	-.334 (.002)**	Farm size Ha.

**correlation is significant at 0.01 level (2-tailed); *correlation is significant at 0.05 level (2-tailed)

There is a negative correlation (statistically significant) between manure application, and tree basal area, tree volume, fertilizer cost for maize and farm size. This perhaps is due to targeted application practices practiced by farmers. Trees on farm do not receive any manure application directly unlike crops, while larger farm sizes have much smaller proportionate application compared to the smaller farms. Interestingly, there was no significant correlation between the size of TLU versus the amount of manure applied, perhaps confirming the limited use of manure or it's availability on farm.

6.4 DISCUSSION

Soil fertility between smallholder farms is widely varied - large quantities of nutrients from small farm parcels are lost through coffee exports, given that inadequate quantities of manure and fertilizer are presently used to replenish the soil. Sanchez (2002) estimates a high mean depletion rate of 22 kg of N; 2.5 kg of P, and 15 kg of K are lost per hectare per year, on cultivated land over the last 30 years in 37 African countries. This is equivalent to an annual loss of US $4 billion in fertilizer. In Western Kenya, 80% of the land by smallholders, mainly under maize cultivation is extremely deficient in P.

Results suggest that nutrient prevalence is closely related to farmers' choice of crops and its market performance. Farmers in coffee systems source nutrients from fertilizers and animal manure to target crops such as coffee, maize, banana, Irish potato and olericulture. It is clear that fertilizer rather than manure application is more preferred for annuals than perennials. Fertilizer and manure application are nonetheless positively correlated suggesting their application complementarities. Manure application is however negatively correlated to farm size probably indicating its insufficiency for whole farm application.

Unlike a positive correlation between fertilizer application and farm tree basal area (m^2), manure application was negatively correlated to tree basal area. This is perhaps suggestive of a wider fertilizer application on farm parcels which benefits trees, unlike manure application which is limited. Coffee also receives high fertilizer inputs perhaps due to credit facilities from cooperatives and government subsidies under the ‘economic stimulus programme’. The program more recently provided smallholders subsidized fertilizers and seeds to compensate for total crop loss experienced during droughts.

In spite of seemingly sizeable fertilizer and manure application reported by farmers, soil analysis showed that organic C, total N, and P are the most deficient nutrients in smallholder coffee farms. Interestingly, the main types of fertilizers consumed by farmers in the surveyed area and indeed in Kenya are compound fertilizers that provide both Nitrogen and Phosphate. Macro-nutrient deficiency has severe productivity implications to farmers and is likely to be exacerbated by nutrients exports through coffee and increased horticulture farming activities. Bases such as, Ca, Mg, were satisfactory for Meru but very low in Embu and highly variable in Kirinyaga. Principal component analysis identified the significance of B prevalence under PC1 score. B is often an ignored micronutrient in coffee systems despite its important contribution in ensuring quality coffee yields. Boron was very low (< 0.5 ppm at 75% percentile) in Kirinyaga, followed by Embu and Meru. B assessment in coffee systems of Ghana showed effects of its low levels on coffee plant growth since it is associated with plant cell division, lignification and other produce quality. B is related to the amount of Ca (Ca/B ratio) and is prevalent in low PH soils of less than 6.5. Its supplementation would therefore be preferred through fertilizer application other than soil acidification.

Soil fertility management by farm categories showed a slight nutrient decline in the ‘decreasing’ farmer category compared to the ‘increasing’ and ‘constant’ categories. This is perhaps due to reduced nutrient inputs with less return from coffee; less fertilizer is received from farmer cooperative society market arrangements since this is provided against coffee cherry deliveries. Nutrient application has been linked to household wealth status by Nkonya et al., 2005 who observed that land use systems for wealthier farmers in Uganda showed higher N and P balances than systems with poorer farmers.

Soil nutrient mining cannot therefore be generalized (Cobo et al., 2010). There is however a need to use reliable indicators of soil nutrient mining and associated land degradation. Studies on soil nutrient inflow and outflows have showed that negative nutrient balances, do not necessarily imply an immediate decline in crop production as soils with high nutrient stocks can still support continued cultivation for several years (Palm et al., 1997; de Jager et al., 1998). Hence, the dynamics of soil fertility decline (i.e. nutrient mining) or recovery (i.e. nutrient accumulation) is better estimated as a rate of change (proportion) of the total soil nutrient stocks.

6.5 CONCLUSIONS

Through NIR diagnostic tools, soil sample analysis was performed in a relatively rapid and accurate manner enabling nutrient prevalence assessments in smallholder coffee farms of Mount Kenya to be determined. Constructed partial least square calibration models for principal component scores on spectra, showed a high coefficient of determination (r^2 = 0.87) confirming that infrared techniques adequately accounted for variations in the analyzed samples with only about 13% loss of information. Predictions for P, Zn, and Na were nonetheless sub-optimal, probably due to errors in principal components extraction and accuracy of the wet chemistry soil sample tests. Developed nutrient indicators scores provided a rapid way of investigating correlations with assembled household socio-economic factors.

Results showed that smallholder coffee farms are deficient in organic C, N and P in spite of seemingly improved NP-compound fertilizer applications offered through market instruments in the coffee subsector. Manure application was confirmed to be insufficient and is negatively correlated to farm size but positively correlated to basal fertilizer application, indicating possible complementarities. Measurement of application per household was difficult due to different sources of manure, timing and measure of application. Labour constraints appeared to impede manure utilization. Other than an acute deficiency of organic C and total N, sample analysis showed wide variability of B prevalence across the survey sites, with Kirinyaga showing the lowest levels in the three sites studied. Even though largely ignored, B is one of the most important soil micronutrients in coffee systems with prevalence determined by Ca/B ratio. Embu coffee farms were found to be most deficient in bases followed by Kirinyaga and Meru.

Results are sufficiently robust to suggest that nutrient prevalence in small coffee farms are associated with application costs of organic manure and fertilizer; yields of coffee and food-crops; tree basal area and farm size. It is clear that dis-incentives in the coffee subsector which tends to reduce coffee yield productivity will have negative effects on fertilizer and manure inputs on smallholder coffee farms.

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CHAPTER 7

7.0 CONCLUSIONS

This study has illustrated a number of factors associated with smallholder decision making and transitions within coffee agroforestry systems of Mount Kenya. A better understanding of farmers' position with respect to their resources and livelihood strategies in managing coffee farms under conditions of reduced enterprise profitability is underscored. These factors were more closely measured by adopting a farming systems typology that used coffee production to mirror the productivity and concomitant management behaviour of smallholder coffee farms. The approach was followed in order to aid the design and implementation of policy concepts that are of interest to heterogeneous farmers who are often assumed to be a homogeneous group.

Results from this study imply that policy instruments to substantially increase the value of maize and banana produced by coffee farmers will have significant enterprise shifts among farmers with smaller land sizes and already declining or stagnated coffee production. However measures such as improved dairy production and returns seem to cushion farmers intending to expand or maintain coffee production. The typology of coffee farms used to assess smallholder productivity behavior proposed here may be generalized consistently across coffee landscapes studied, to contribute to better targeting of innovations. Generally, land size, coffee production (number of bushes, cherry yields/ha), livestock units, agro forestry trees, banana, maize value, nutrients (manure and fertilizer) and labour costs influence farm productivity, and are ideally used to distinguish between farm types.

Smallholder annual crop diversification or intensification practices will most likely result in lower agroforestry tree species richness and probably landscape domination by some popular (usually exotic) species. This trend appears to be accelerated by reduction of the perennial cash crop, namely coffee. Farmer are accumulating more exotics such as *Grevillea robusta, Eucalyptus sp. Macadamia sp.* and *Mangifera* *indica* on coffee farm plots, thereby displacing usual native species such as *Croton macrostychyus* and *Vitex keniensis*. *Cordia africana* however shows high abundance within coffee systems, perhaps due to its excellent compatibility qualities with coffee and crop polycultures. Tree abundance and basal area distribution show small-tree diversity and high relative densities suggesting rapid tree compositional turnover. This implies changing patterns and structures of tree populations on coffee farms. Small tree-size diversity, unevenly distributed among farms, has implications if farm tree populations are to be considered for germplasm provisioning (possible low viability). Further, botanical families are skewed, showing patterns of distribution that perhaps have been ignored during priority setting of species domestication.

Biophysical assessments of the prevalence of farm nutrients showed that smallholder coffee farms are primarily deficient in organic C, N and P, in spite of improved NP-compound fertilizer applications. Manure application is implied to be largely insufficient and negatively correlated to farm size, but positively correlated to basal fertilizer application, suggestive of complementarities. Measurement of manure application per household was noted to be cumbersome due to the many different sources and timing of application. Assembled data suggests that labour demands impede manure utilization.

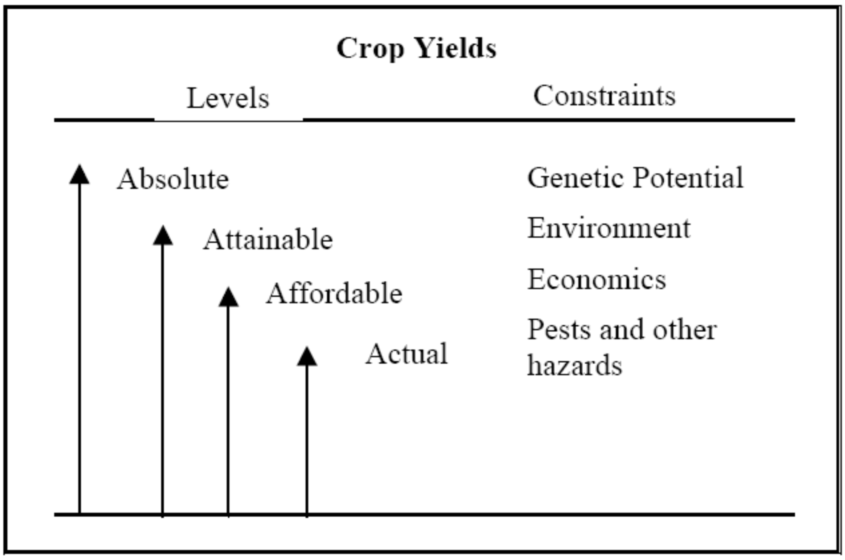
Other than an acute deficiency of organic C and total N, sample analysis showed a wide variability of B prevalence across the survey sites, with Kirinyaga showing the lowest levels of the three sites studied. Even though generally ignored, B is one of the most important soil micro nutrients in coffee systems, with prevalence determined by the Ca/B ratio. It’s more prevalent in acidic soils. Embu coffee farms are most deficient in bases followed by Kirinyaga and Meru. Results are sufficiently robust to suggest that nutrient prevalence in small coffee systems may be associated with a combination of use of organic manures and fertilizers, yields of coffee and food-crops, tree basal area, farm size, and costs of fertilizers.

Annex 1 Productivity

Theoretically, productivity can be characterized as absolute, attainable, affordable or actual (Cook and Veseth, 1991). These are explained as:

1. The *absolute yield* (maximum yields ever recorded) - is the yield possible with no limiting factors except the genetic potential of the crop.
2. The *attainable yield* is the highest yield possible in any given soil in any given year, i.e. yield is limited by factors that cannot be altered within the given year. These include factors such as water availability, growing-degree days, depth of top-soil and total radiation.
3. The *affordable yield* is limited by factors that cannot be ameliorated because management solutions are not affordable to the crop producer (value of potential yield gain is less than its cost) or to the larger society (ecological costs are too high).
4. The *actual yield* is the yield harvested in any given field and is limited by factors that were not ameliorated because they were unforeseen or effective solutions were not known or not implemented.

The four A’s of crop productivity (Source: adopted from Cook and Veseth, 1991).



Annex 2 Inventoried tree species, abundance and status (exotic or indigenous)

Family	Species	Abundance	Status
Proteaceae	Grevillea robusta	14925	exotic
Myrtaceae	Eucalyptus sp.	2879	exotic
Proteaceae	Macadamia sp.	2445	exotic
Anacardiaceae	Mangifera indica	1402	exotic
Boraginaceae	Cordia africana	1086	indigenous
Caricaceae	Carica papaya	1059	exotic
Lauraceae	Persea americana	969	exotic
Celastraceae	Catha edulis	921	indigenous
Cupressaceae	Cupressus lusitanica	920	exotic
Euphorbiaceae	Bridelia micrantha	722	indigenous
Euphorbiaceae	Croton macrostachyus	691	indigenous
Burseraceae	Commiphora eminii	633	indigenous
Fabaceae	Calliandra calothyrsus	613	exotic
Fabaceae	Acacia mearnsii	611	exotic
Guttiferae	Harugana madagascariensis	438	indigenous
Rosaceae	Eriobotrya japonica	422	exotic
Myrtaceae	Psidium guajava	400	exotic
Verbenaceae	Vitex keniensis	307	indigenous
Fabaceae	Millettia dura	301	indigenous
Bignoniaceae	Markhamia lutea	290	indigenous
Euphorbiaceae	Ricinus communis	261	indigenous
Rosaceae	Prunus africana	200	indigenous
Euphorbiaceae	Croton megalocarpus	199	indigenous
unidentified	unknown	180	indigenous
Combretaceae	Combretum molle	166	indigenous
Solanaceae	Cyphomandra betacea	157	exotic
Boraginaceae	Ehretia cymosa	114	indigenous
Malvaceae	Azanza garckeana	112	indigenous
Bignoniaceae	Jacaranda mimesifolia	106	exotic
Fabaceae	Erythrina abyssinica	99	indigenous
Moraceae	Morus alba	94	exotic
Rutaceae	Citrus sinensis	94	exotic
Fabaceae	Leucaena leucocephala	89	exotic
Fabaceae	Cassia siamea	86	indigenous
Melianthaceae	Bersama abyssinica	86	indigenous
Bignoniaceae	Spathodea companulata	84	indigenous
Combretaceae	Terminalia brownii	75	indigenous
Rutaceae	Fagaropsis angolensis	74	indigenous
Bambusoideae	Bambusa vulgaris	73	exotic
Meliaceae	Trichilia emetica	71	indigenous
Moraceae	Ficus sur	70	indigenous
Apocynaceae	Rauvolfia caffra	69	indigenous
Pinaceae	Pinus sp.	65	exotic

Family	Species	Abundance	Status
Moraceae	Ficus thonningii	64	indigenous
Oleaceae	Fraxinus pennsiivanica	64	exotic
Rubiaceae	Vangueria madagascariensis	64	indigenous
Fabaceae	Senna spectabilis	63	exotic
Ulmaceae	Trema orientalis	63	exotic
Euphorbiaceae	Sapium ellepticum	62	indigenous
Combretaceae	Terminalia mantaly	54	indigenous
Fabaceae	Leucaena trichandra	54	exotic
Moraceae	Milicia excelsa	51	indigenous
Myrtaceae	Callistemon citrinus	51	exotic
Fabaceae	Acacia sp.	49	indigenous
Euphorbiaceae	Margaritaria discoidea	48	indigenous
Poaceae	Arundinaria alpina	46	exotic
Ebenaceae	Euclea divinorum	38	indigenous
Rutaceae	Casimiroa edulis	36	exotic
Tiliaceae	Grewia similis	36	indigenous
Fabaceae	Albizia gummifera	35	indigenous
Annonaceae	Annona cherimola	34	exotic
Fabaceae	Acacia abyssinica	32	indigenous
Labiatae	Plectranthus barbatus	31	indigenous
Flacourtiaceae	Dovyalis abyssinica	27	indigenous
Fabaceae	Erythrina melanacantha	24	indigenous
Fabaceae	Piliostigma thonningii	24	indigenous
Casuarinaceae	Casuarina equisetifolia	22	exotic
Boraginaceae	Cordia monoica	21	indigenous
Moraceae	Ficus sp.	21	indigenous
Rutaceae	Teclea nobilis	21	indigenous
Meliaceae	Melia volkensii	20	indigenous
Myrtaceae	Syzingium guineense	20	indigenous
Ulmaceae	Celtis gomphophylla	20	indigenous
Apocynaceae	Nerium oleander	19	exotic
Euphorbiaceae	Jatropha curcas	19	exotic
Fabaceae	Senna siguana	19	indigenous
Rosaceae	Malus domestica	19	exotic
Myrtaceae	Eucalyptus globulus	17	exotic
Araliaceae	Cussonia holstii	16	indigenous
Fabaceae	Senna didymobotrya	15	indigenous
unidentified	muburaura	15	exotic
Asteraceae	Solanecio manii	14	indigenous
Cecropiaceae	Myrianthus holstii	14	indigenous
Combretaceae	Combretum zeyheri	14	indigenous
Annonaceae	Monanthotaxis schweinfurthii	13	indigenous
Papilionoideae	Lonchocarpus bussei	13	indigenous
Bignoniaceae	Kigelia africana	12	indigenous
Sapindaceae	Blighia unijugata	12	indigenous

Family	Species	Abundance	Status
Cupressaceae	Juniperus procera	11	indigenous
Meliaceae	Azadirachta indica	11	exotic
Meliaceae	Melia azedarach	11	exotic
Rosaceae	Prunus domestica	11	exotic
Rubiaceae	Hymenodictyon parvifolium	11	indigenous
Loganiaceae	Anthocleista grandiflora	10	exotic
Rutaceae	Citrus limon	10	exotic
Caesalpiniaceae	Acrocarpus fraxinifolius	9	exotic
Rubiaceae	Vangueria infausta	9	indigenous
Sapindoideae	Cardiospermum halicacabum	9	exotic
Capparidaceae	Capparis tomentosa	8	indigenous
Myrtaceae	Syzingium cuminii	8	exotic
Rutaceae	Citrus sp.	8	exotic
Punicaceae	Punica granatum	7	exotic
Fabaceae	Newtonia buchananii	6	indigenous
Flacourtiaceae	Flacourtia indica	6	indigenous
Oleaceae	Olea africana	6	indigenous
Ulmaceae	Celtis africana	6	indigenous
Asteraceae	Vernonia auriculifera	5	indigenous
Malvaceae	Thespesia sp	5	indigenous
Moraceae	Artocarpus heterophyllus	5	exotic
Verbenaceae	Premna maxima	5	indigenous
Araliaceae	Polyscias fulva	4	indigenous
Euphorbiaceae	Euphorbia tirucali	4	indigenous
Fabaceae	Sesbania sesban	4	indigenous
Fabaceae	Tamarindus indica	4	indigenous
Rubiaceae	Mitragyna microdonta	4	indigenous
Sapindaceae	Pappea capensis	4	indigenous
Araliaceae	Polyscias kikuyuensis	3	indigenous
Arecaceae	Raphia faranifera	3	indigenous
Canellaceae	Warburgia ugandensis	3	indigenous
Combretaceae	Combretum collinum	3	indigenous
Combretaceae	Combretum fragrans	3	indigenous
Fabaceae	Securidaca longipedunculata	3	indigenous
Flacourtiaceae	Oncoba spinosa	3	indigenous
Loganiaceae	Strychnos innocua	3	indigenous
Pinaceae	Pinus patula	3	exotic
unidentified	mumangu	3	exotic
Anacardiaceae	Lannea sp.	2	indigenous
Anacardiaceae	Rhus natalensis	2	indigenous
Anacardiaceae	Rhus vulgaris	2	indigenous
Apocynaceae	Carissa spinarum	2	indigenous
Apocynaceae	Tabernaemontana stapfiana	2	indigenous
Asteraceae	Crassocephalum montuosum	2	exotic
Combretaceae	Terminalia pruniodes	2	indigenous

Family	Species	Abundance	Status
Euphorbiaceae	Synadenium compactum	2	indigenous
Fabaceae	Caesalpinia volkensii	2	indigenous
Moraceae	Ficus sycomorus	2	indigenous
Myrsinaceae	Myrsine melanophloeos	2	indigenous
Proteaceae	Faurea saligna	2	indigenous
Rhamnaceae	Maesopsis eminii	2	indigenous
Rubiaceae	Rothmannia urcelliformis	2	indigenous
Rubiaceae	Vangueria volkensii	2	indigenous
Rutaceae	Fagara chalybea	2	indigenous
Solanaceae	Withania somnifera	2	exotic
unidentified	mucau	2	indigenous
unidentified	mutiso	2	indigenous
unidentified	mwitatho	2	indigenous
Anacardiaceae	Heeria reticulata	1	indigenous
Anacardiaceae	Ozoroa insignis	1	indigenous
Anacardiaceae	Schinus molle	1	exotic
Annonaceae	Annona muricata	1	exotic
Apocynaceae	Acokanthera schimperi	1	indigenous
Apocynaceae	Carissa edulis	1	indigenous
Asclepiadaceae	Mondia sp.	1	indigenous
Asteraceae	Solanacio angulatus	1	indigenous
Asteraceae	Vernonia lasiopus	1	indigenous
Capparidaceae	Capparis sepiaria	1	indigenous
Chrysobalanaceae	Parinari curatellifolia	1	indigenous
Dracaenaceae	Dracaena steudneri	1	indigenous
Euphorbiaceae	Antidesma venosum	1	exotic
Labiatae	Rosmarinus officinalis	1	exotic
Meliaceae	Lovoa swynertonii	1	indigenous
Moraceae	Ficus benjamina	1	exotic
Moringaceae	Moringa oleifera	1	exotic
Moringaceae	Moringa stenopetala	1	exotic
Podocarpaceae	Podocarpus sp	1	indigenous
Rubiaceae	Fagara chalybea	1	indigenous
Rubiaceae	Mitragyna rubrostipulata	1	indigenous
Rubiaceae	Rothmannia longiflora	1	indigenous
Rubiaceae	Vangueria apiculata	1	indigenous
Sapotaceae	Pouteria adolf-friedericii	1	indigenous
Sterculiaceae	Dombeya torrida	1	indigenous
unidentified	mubathi	1	indigenous
unidentified	mubiricio	1	exotic
unidentified	mucee	1	indigenous
unidentified	mucharia	1	exotic
unidentified	mucuca	1	exotic
unidentified	mufa	1	indigenous
unidentified	mugunaciu	1	exotic

Family	**Species**	**Abundance**	**Status**
unidentified	muja	1	indigenous
unidentified	mujua	1	exotic
unidentified	mukumwa	1	exotic
unidentified	mukuthuku	1	exotic
unidentified	munabiu	1	exotic
unidentified	munanga	1	exotic
unidentified	munee	1	exotic
unidentified	muthengo	1	indigenous
unidentified	muthithia	1	indigenous
unidentified	Muvatia	1	indigenous
unidentified	muviriti	1	indigenous
unidentified	Velvetia velviana	1	exotic

Annex 3 Multiple linear regression on some measured farm variables against coffee farm types and AEZ

	Coffee farms typology			**Agro-ecological zones**			
	Constant	**Decreasing**	**Increasing**	**UM1**	**UM2**	**UM3**	
Measured farm plot variables	**Mean (Range)**	**Mean (Range)**	**Mean (Range)**	**Mean (Range)**	**Mean (Range)**	**Mean (Range)**	**P-Value**
Land size (Ha)	1.42*** (0.25-5.5)	0.96 (0.10-3.64)	1.17 (0.30-4.05)	1.18*** (0.10-5.47)	1.17 (0.05-6.88)	1.42 (0.20-4.86)	0.3768
Tree abundance	208.68*** (21-627)	123.55 (17-486)	176.70 (18-594)	170.14*** (17-627)	185.84 (9-701)	273.71** (16-1475)	0.00999
Tree richness	16.32*** (5-35)	12.32 (2-27)	14.19$^{.}$ (2-27)	14.27*** (2-35)	17.59* (2-42)	20.33*** (6-35)	0.00139
No. of indigenous trees	39.29* (2-116)	18.57 (1-111)	33.81 (1-260)	30.79* (1-260)	47.26$^{.}$ (1-260)	70.55*** (2-374)	0.00649
No. of exotic trees	170.18*** (16-577)	105.59 (11-374)	143.19 (14-545)	139.90*** (11-577)	140.10 (9-592)	202.24* (9-1443)	0.09276
Tree basal area (m^2)	2.96*** (0.13-6.49)	2.57 (0.09-15.16)	2.69 (0.17-10.2)	2.73*** (0.09-15.16)	2.83 (0.22-10.74)	3.41 (0.13-9.77)	0.2707
Tree biomass volumes (m^3)	36.72*** (0.98-101)	29.49 (0.52-150.46)	33.57 (1.11-102.4)	33.28*** (0.52-150.46)	34.14 (1.59-184.84)	44.97$^{.}$ (0.83-196.55)	0.1907
No. of coffee plants	525.00*** (180-2000)	542.55 (90-2100)	729.15** (130-3000)	606.34*** (90-3000)	463.93 (35-1800)	575.48 (120-3000)	0.00359
Cherry per coffee plant (kg)	5.10*** (0.5-20)	4.87 (0.29-16.67)	5.19 (0.79-10.1)	5.06*** (0.29-20)	3.94$^{.}$ (0.05-25)	4.16 (0.55-11.43)	0.1857
Coffee yields value per year (Ksh)	66692.59*** 7837.5-356250	57777.27 4275-285000	76944.72** (0-256500)	67829*** (0-356250)	48631$^{.}$ (0-285000)	64715 (3420-228000)	0.0016
Tropical livestock units	4.57*** (0.3-31.62)	4.62 (1.55-8.8)	4.54 (0.16-10.58)	4.57*** (0.16-31.62)	3.36* (0.02-9.52)	4.66 (0.04-14.11)	0.1193
No. of trees per coffee plot	83.91*** (16-150)	74.36 (13-291)	86.07** (17-231)	81.77*** (13-291)	99.28* (9-286)	115.26** (16-266)	0.00144

Annex 4 Rènyi diversity order for the surveyed coffee regions and agro-ecological zones

Coffee areas	alpha (H_0)	alpha (H_1)	*alpha* (H_∞)
All areas	5.24	2.58	0.87
Sub-regions			
Meru	4.88	2.96	1.10
Kirinyaga	4.68	2.18	0.61
Embu	4.62	2.67	1.05
Agro-ecological zones			
Upper-midland (UM1)	4.46	2.54	1.00
Upper-midland (UM2)	4.71	2.75	0.91
Upper-midland (UM3)	4.91	2.53	0.77
Type of coffee farm			
Stagnated	4.82	2.55	0.88
Declining	4.94	2.48	0.78
Increasing	4.88	2.57	0.93
Type of maize system			
Polyculture	4.74	2.38	0.85
Monoculture	4.95	2.47	0.79

Annex 5 Summary of diversity indices (Magurran, 2004)

(I) Shannon-Wiener index (*H*) - The index indicates species heterogeneity (richness and evenness) of a vegetation community. The index accounts for both abundance and evenness of species present. Shannon index is calculated from the equation.

$$H = -\sum_{i=1}^{S} p_i ln p_i$$

The quantity (*pi*) is the proportion of individuals found in the i^{th} species. A higher value of *H* indicates high species diversity in the sample.

(II) Simpson's diversity index-The Simpson index describes the probability that a second individual drawn from a population (vegetation community) will be of the same species as the first. Simpson's reciprocal index considers the number of species present, as well as the abundance of each species. The index is calculated as:

$$D = \sum \left(\frac{n_i(n_i - 1)}{N(N - 1)} \right)$$

where n_i is the number of individuals in i^{th} species, and *N* is the total number of individuals. As *D* increases, diversity decreases. Simpson index is therefore usually expressed as 1 - D or 1/D. It captures the variance of the species abundance distribution. The value will rise as the assemblage becomes more even.

(III) The Evenness index- refers to distribution pattern of the individuals between the species. Shannon's evenness is calculated as:

$$j^{i} = \frac{H}{H_{max}}$$

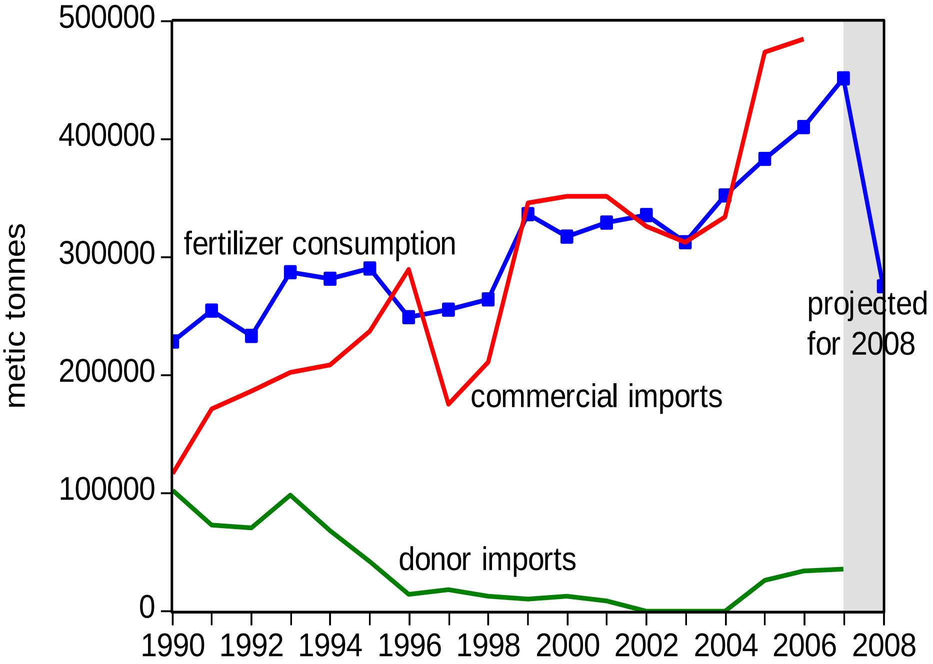
where, *H*-Shannon index. Equitability assumes a value between 0 and 1, with 1 being complete evenness.

Further, evenness can be calculated by dividing the reciprocal form of the Simpson's index by the number of species in the sample. The Simpson's evenness measurement ranges from 0 to 1 and is not sensitive to species richness

$$E_{1/D} = \frac{(1/D)}{S}$$

$E_{1/D}$ is Simpson's evenness; *S*, is the number of species in the sample; 1/D is the reciprocal.

Annex 6 Trend in fertilizer consumption in Kenya (Source: Haggblade and Jayne, (u.d)



Annex 7 Communalities

Soil properties	Initial	Extraction
Al	1.000	.887
B	1.000	.924
C.E.C	1.000	.821
Ca	1.000	.831
Cu	1.000	.701
EC.S.	1.000	.845
Fe	1.000	.762
K	**1.000**	**.514**
Mg	1.000	.800
Mn	1.000	.807
Na	1.000	.925
P	**1.000**	**.644**
pH	1.000	.851
S	**1.000**	**.622**
C	1.000	.925
N	1.000	.897
Zn	**1.000**	**.553**

Extraction Method: Principal Component Analysis.

Annex 8 Soil properties principal component scores (4 components extracted)

Soil properties	Principal Components			
	1	2	3	4
pH	**.900**	.097	-.136	-.109
Al	-.897	.105	.058	.261
C.E.C	**.881**	.092	.121	.150
Ca	**.878**	.216	.107	-.046
Mg	**.876**	.078	-.163	.006
B	**.764**	-.022	.536	-.229
Mn	.659	-.254	.516	-.205
S	-.628	-.447	.015	.167
K	.579	.083	-.174	.377
Zn	.566	.337	.318	.132
P	-.069	**.770**	.082	.199
Cu	.038	**.636**	-.486	-.243
N	-.445	**.620**	.516	.219
C	-.451	**.592**	.567	.222
Fe	.204	**.576**	**-.621**	-.042
Na	.329	-.029	-.248	**.868**
EC.S.	-.455	.449	-.034	-.660

Extraction Method: Principal Component Analysis

Annex 9 Selected principal components (in bold) accounting for 78.5% of data variability

Principal Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	**6.584**	**41.150**	**41.150**	**6.584**	**41.150**	**41.150**	**5.760**	**35.999**	**35.999**
2	**2.605**	**16.282**	**57.431**	**2.605**	**16.282**	**57.431**	**2.721**	**17.003**	**53.002**
3	**2.038**	**12.736**	**70.168**	**2.038**	**12.736**	**70.168**	**2.241**	**14.006**	**67.009**
4	**1.340**	**8.376**	**78.544**	**1.340**	**8.376**	**78.544**	**1.846**	**11.536**	**78.544**
5	.764	4.773	83.317						
6	.702	4.388	87.705						
7	.548	3.422	91.127						
8	.428	2.677	93.803						
9	.257	1.605	95.408						
10	.218	1.360	96.768						
11	.187	1.172	97.940						
12	.106	.663	98.603						
13	.091	.570	99.173						
14	.056	.353	99.525						
15	.046	.289	99.814						
16	.030	.186	100.000						

Extraction Method: Principal Component Analysis

Annex 10 Fertilizer types consumed in Kenya annually (Source: MOA 2009)

Fertilizer Type	Crops	Quantity (tons)	% change per annum
Straight fertilizers			
CAN(26.0.0)	Coffee, maize	36000	12.7
Urea (46.0.0)	Sugar	15000	5.3
ASN (26.0.0)	Coffee, tea	4000	1.4
SA (21.0.0)	Rice, tea	6000	2.1
SSP (0.21.0)	Sugar, barley	3000	2.1
TSP (0.46.0)	Sugar, barley	3000	1.4
NP Compounds			
DAP (18.45.0)	Food crops	76000	26.9
MAP (11.55.0)	Barley wheat	10000	3.5
20.20.0	Maize	24000	8.5
23.23.0	Maize	20000	7.0
NPK's			
20.10.10	Coffee	21000	7.4
17.17.17; 16.16.16	Coffee	2000	0.7
25.5.5+5S; 22.6.12+5S	Tea	43000	15.2
15.15.6	Tobacco	1000	0.4
6.18.20	Tobacco	2000	0.7
Others	Cash crops	10000	3.5

Annex 11 Role of agroforestry in coffee systems: farmer socio-economic survey

Date : …./…./2009

Enumerator: blank_______________ Questionnaire No ☐

Section 1 : General information

Farmer name:	Location:
Age:	GPS:
No. of family members on farm:	AEZ:
Land size:	Altitude:
Category:	

1.1 Is there any member of your family with off-farm employment/business?

1.2 Kind of employment/business:

1.3 Are employed family members able to provide financial support to the family?

☐Yes ☐No

1.4 If **yes** how often

☐Every month
☐After every two months
☐After every four months
☐Half yearly
☐Yearly
☐Other, specify

1.5 Which of these categories would fit the amount of financial support received in every instance funds are received?

☐Less than Ksh500
☐Ksh 500-1000
☐Ksh 1000-1500
☐Ksh 1500-2000
☐Ksh 2000-2500
☐Ksh 2500-3000
☐More than 3000

Section 2: Farmer crop and animal farming

2.1 Which are your current **crop enterprises (do farm walk)**:

Types of crops & variety	Method of production	Size of enterprise in m^2	Total Yields	Quantity for home use/year	Quantity sold	Has the enterprise size changed in the past 5 years?	How much change?
		1st Rains 2nd Rains All year	1st Rains 2nd Rains All year			Increased ☐ Decreased☐ No change☐	Increased by Decreased by
		1st Rains 2nd Rains All year	1st Rains 2nd Rains All year			Increased ☐ Decreased☐ No change☐	Increased by Decreased by
		1st Rains 2nd Rains All year	1st Rains 2nd Rains All year			Increased ☐ Decreased☐ No change☐	Increased by Decreased by
		1st Rains 2nd Rains All year	1st Rains 2nd Rains All year			Increased ☐ Decreased☐ No change☐	Increased by Decreased by
		1st Rains 2nd Rains All year	1st Rains 2nd Rains All year			Increased ☐ Decreased☐ No change☐	Increased by Decreased by

Method of production: MC-mixed cropping; M=monoculture; IC= intercropping

2.2 Identify **inputs** and **costs** for crops enterprises on farm:

Types of crops & variety	Kinds of inputs /Costs areas Labour, fertilizer, pesticides	Cost per unit if MC estimate cost of input per unit area	How often	Amount spent/production period

* For mixed crops (MC) estimate quantity of shared inputs per unit area; For family labour estimate number of family members for each activity

2.3 What is considered when selecting types of crops to grow on your farm?

☐ Land size
☐ Market price
☐ Labor requirements

☐ Amount of money required to produce
☐ Time to produce harvest
☐ Other, specify:

2.4 Record farmer **livestock** enterprise sizes:

Types of livestock enterprise (incl. poultry)	Method of production	Types of breeds	No. of livestock	Enterprise product (e.g. milk, meat, sale, hire)	Amt of product consumed	Amt of product sold	Price	Who owns the livestock

2.5 Record **inputs** and **costs** for livestock production

Livestock enterprise	Types Costs areas Labour, feeds, vet services, other	Cost per unit	How often	Amount spent/per month

2.6 What is most important when selecting the type of animals to keep on your farm?

- ☐ Cost of buying animal
- ☐ Available space on farm
- ☐ Ease of obtaining feeds
- ☐ Amount of income it can generate
- ☐ Type of product
- ☐ Market price
- ☐ Other, specify

2.7 Which farm produce is transported to the market?

Produce transported to market	How much	How often	Distance to nearest market	Transport mode & costs/ unit

Section 3: Coffee Farming

3.1 Assess and record farmer coffee farming activities:

Size of initial coffee crop: acres/ m^2 / no of bushes/ variety	**Current size of coffee crop in acres/m^2 / no of bushes/Variety**	**If there is change in size of crop reasons for changed size**	**In case of variety change what were the reasons?**
Size: Variety: Spacing: Yields (kg): Year planted: Price/kg:	Size: Variety: Spacing: Yields (kg)/yr: Year planted: Price/kg:		

3.2 What changes in farming are considered in times of:
  (i) low coffee prices?

  (ii) high coffee prices?

3.3 What changes in farming activities occur in your location in reaction to changes in coffee prices?

3.4 On average how long does it take to receive payments after coffee delivery in the last five years

- ☐2 weeks-1month
- ☐2 to 3 months
- ☐4 to 6 months
- ☐Over 6 months

3.5 What is your preferred marketing channel for your coffee produce?

- ☐Through cooperative (your local factory)
- ☐Through private buyers
- ☐Through certification schemes for organic coffee
- ☐Other, specify

Reasons for selecting this channel:

3.6 What are you future plans on coffee farming?

- ☐Expansion
- ☐Reduction
- ☐Varietal change
- ☐Discontinue
- ☐Retain the same size of crop
- ☐Not sure

Please explain selected option:

3.7 What is you preferred alternative if you discontinue coffee production:

3.8 What kind of support have you received from your cooperative for coffee cultivation?

- ☐Fertilizer and pesticides loans
- ☐Financial loans
- ☐Extension service
- ☐Other, specify

3.9 Are you paying back any loans or any other forms of credit received? Y/N

- ☐Yes
- ☐No

3.9.1 If loans desired, how large can you receive?

- ☐Less than Ksh. 20,000
- ☐Ksh 20,000-50,000
- ☐Ksh 50,000-100,000
- ☐Ksh 100,000-150,000
- ☐Ksh.150000-200,000
- ☐Ksh. 200000-300,000
- ☐Ksh. 300000-500000
- ☐More than, Ksh 500,000

3.9.2 How often?

3.9.3 How is your loan repayment schedule?
☐ On time
☐ Written off
☐ Delayed
☐ Completed
☐ Other, specify

Section 4 Tree cultivation:

4.1 Are you considering planting more trees on your farm? ☐ Yes ☐ No

If **No,** please state reasons:

If **yes**, which ones and by how much?

Preferred tree species	**No. to be planted**	**Source of seedlings**

4.2 Assess tree felling, product use, and marketing on farm:

Which trees on your farm are harvested for:	**Amount of produce for home use**	**Amount sold for last one year**	**Price**	**How often?**	**Who are your customers?**
Timber:					
Fruits:					
Fodder:					
Firewood pollards:					
Medicinals:					
Other products:					

4.3 How much firewood is used by your household per week?

4.4 How much firewood is purchased for household use per week?

4.5 What is the price per unit?

4.6 Which of these other places do you obtain tree products?

☐Community hills
☐Forests
☐Neighbor farms
☐Government land
☐Other, specify

4.7 Using bao game gauge value of the different farmer enterprise contrasted to coffee and trees

Type of Enterprise	**Bao score (scale of 5 to 1)**	**Reasons**

*A score of 5 is maximum value while 1 or 0 is low/poor value

Section 5: Soil quality and variability assessment:

5.1 Soil mapping unit (using FAO classification):___________

5.2 Land slope/erosion class__________________

5.3 Comment on your farm fertility: ☐Poor ☐ Low fertility ☐ Average fertility ☐Very fertile

5.4 How do you determine your farm fertility?

Amount and type nutrient applied per year: animal, manure, compost, other				
Type:	Crop	Amount	Cost	Labour

Amount and type of inorganic fertilizer applied per year				
Type:	Crop	Amount	Cost	Labour

Annex 12 Farm tree inventory

Farmer name:	**Location:**

By farm walks, list types and number of trees planted on farms?

Tree Species Local Name	Scientific name	Main Use	DBH	Usable Height (timber) L 6”	Height	Age	Tick if on coffee plot	Planting Pattern	Spacing	Form
1.										
2.										
3.										
4.										
5.										
6.										
7.										
8.										
9.										
10.										
11.										
12.										
13.										
14.										
15.										
16.										
17.										
18.										
19.										
20.										
21.										
22.										
23.										
24.										
25.										
26.										
27.										
28.										
29.										
30.										
31.										
32.										
33.										

Key: **Main Use**: 1=timber; 2=firewood; 3=fruits; 4=medicinals; 5=fodder; 6= other; **DBH:** Diameter at Breast Height

Planting pattern: **MP**=mixed planting; **LP**=line planting; **BP**= block planting

Form: 1= poor (defects with disease); 2= average (defects due mgt); 3= Good (partial defects); 4=very good (no defects); 5=excellent (well managed)

Annex 13 Amount of trees felled (tree stump count on farm)

Species	Number of stumps on farm	Site

*Site: EB: external boundary; CL: crop land: WL: Woodlot

Annex 14 List of farmer interviews

Please help select farmer categories from your society/factory membership based on amount of cherry delivered. The categories should show records of farmers with **increasing**, **decreasing** and **constant** cherry deliveries for the last **10 years or so.** Select at least **5 farmers** for each category. Kindly assist in locating identified farmers for interviews.

Society/Factory Name:									
Farmer's name	**Coffee Cherry Produce (Kg delivered) per year**								
Category: Increasing	2000	2001	2002	2003	2004	2005	2006	2007	2008
1.									
2.									
3.									
4.									
5.									
Category: Decreasing/declining	2000	2001	2002	2003	2004	2005	2006	2007	2008
1.									
2.									
3.									
4.									
5.									
Category: Constant	2000	2001	2002	2003	2004	2005	2006	2007	2008
1.									
2.									
3.									
4.									
5.									
Total produce by Society									
Number of members making deliveries									
Number of Women members									

Annex 15 Soil sampling protocol: Normal fields

1. Go to centre of plot
2. Choose the next unused row from the table below
3. Move in the direction indicated
4. Move the % distance to the edge of the field indicated. This fixes the centre of the 5x5 plot
5. Orientate the plot up-down slope unless the field is completely flat, in which case it should be N-S

Field no	Direction	% Distance			Field no	Direction	% Distance	
1	133	90			37	229	80	
2	59	90			38	339	50	
3	135	80			39	125	90	
4	274	90			40	101	90	
5	105	50			41	273	40	
6	300	50			.	81	70	
7	118	80			.	279	70	
8	158	90			.	47	30	
9	77	70			.	307	10	
10	24	50			.	24	40	
11	18	90				48	80	
12	174	70				2	70	
13	357	70				93	80	
14	274	70				54	90	
15	219	90				179	70	
16	183	60				279	90	
17	67	0				199	80	
18	39	90				110	90	
19	272	60				211	50	
20	262	80				197	50	
21	56	60				71	90	
22	275	80				178	50	
23	41	40				110	90	
24	283	80				243	20	
25	107	50				122	70	
26	39	80				28	50	
27	11	80				166	50	
28	233	50				106	40	
29	277	80				61	50	
30	357	70				351	80	
31	290	60				355	60	
32	188	30				60	70	
33	347	50				291	90	
34	179	60				227	80	

Annex 16 Soil sampling protocol: Long thin fields

To be used only for rectangular fields where a 5m x 5m plot cannot fit because the field is too long and narrow

1. Go to centre of plot
2. Choose the next unused row from the table below
3. Move in the direction indicated
4. Move the % distance to the edge of the field indicated in the direction indicated. This fixes the centre of the 5 x 5 plot
5. Orientate the plot up-down slope unless the field is completely flat, in which case it should be N-S

Field no.	left/right	distance		Field no.	left/right	distance
1	Left	50		35	Left	50
2	Right	70		36	Left	50
3	Left	60		37	Left	60
4	Left	0		38	Right	20
5	Left	0		39	Left	20
6	Left	0		40	Right	0
7	Left	10		41	Right	90
8	Right	30		42	Left	10
9	Left	70		43	Left	0
10	Left	40		44	Left	80
11	Right	20		45	Right	30
12	Right	80		46	Left	50
13	Left	20		47	Left	30
14	Left	70		48	Left	90
15	Right	90		49	Right	50
16	Right	10		50	Left	90
17	Right	70		51	Left	60
18	Left	30		52	Left	30
19	Left	30		53	Left	90
20	Right	90		54	Left	10
21	Left	60		55	Left	10
22	Right	90		56	Left	50
23	Right	90		57	Right	0
24	Left	80		58	Right	80
25	Right	90		59	Left	0
26	Left	70		60	Left	70
27	Left	10		61	Right	90
28	Right	80		62	Right	0
29	Right	80		63	Left	50
30	Right	90		64	Left	30
31	Right	60		65	Right	0
32	Right	0		66	Left	90