FOOD VS. WOOD: DYNAMIC CHOICES FOR KENYAN SMALLHOLDERS

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ABSTRACT

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Smallholder farmers in many areas of the semiarid tropics are planting exotic tree species that provide alternative income sources, fuel, and building materials. While providing other benefits, these trees often occupy land that could produce annual food crops. This study uses a polyperiod, linear programming model to explore the opportunity cost of planting *Eucalyptus grandis* and *Grevillea robusta* trees compared to crops in the Nyando watershed of western Kenya. Results of the ten year period wealth maximization model suggest that a representative farmer's decisions on farm resource allocation are sensitive to changes in the relative prices of short rotation tree products and annual crops. The model also suggests that there are economic tradeoffs between planting trees and crops, as well as between planting different tree species. Timber production is not likely to replace food crops for two main reasons: (1) the high cost of meeting household subsistence requirements from marketed grains, (2) household cash flow needs met by annual crops. Farmers plant eucalyptus for commercial purposes because they can obtain timber products within four years; however if the prices of these short rotation products go down, farmers will prefer to grow timber from high yield grevillea.

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Introduction

Smallholder farmers in many areas of the semiarid tropics are planting exotic tree species that provide alternative income sources, as well as fuel and building materials. According to Rudel (2009),

> "Between 1980 and 2000 the extent of forest plantations increased seven fold in developing countries, smallholders in Africa created woodlots behind their houses, corporations have planted extensive tree farms in South America, villages in mainland Southeast Asia have planted trees in nearby uplands and state agencies have planted trees on degraded lands in South Asia."

Exotic tree species such as *Eucalyptus spp* grow fast, so planting them can reward farmers with a rapid income flow from their investment. Eucalyptus rates of return for Northern Ethiopia were found to be above 20% (Jagger and Pender, 2003). In India the net returns from *Eucalyptus tereticornis* were found to reach Rs. 1,340,000 per hectare in plantations of 6-8 year old trees, almost three times greater than returns for *Dalbergia sisso* plantations with trees of the same age (Jalota and Sangha, 2000). In Sudan, comparisons of profitability of *Eucalyptus*, *Acacia* and

bananas found that the net present value (NPV) of investments was higher for eucalyptus compared to the other two choices (Sharawi, 2006). In Tanzania, financial and economic evaluations determined that eucalyptus could be grown profitably in woodlots, with a financial internal rate of return (IRR) that ranges between 14% and 23.5%, above the real interest rate of 7% , and an economic IRR between 25% and 38%, way above the shadow interest rate of 9% (Kihiyo, 1996).

Profitability is an important driver of farmers' decision on planting trees, but it is not the only one. Farmers in Thailand ranked the most important factors that determine their decisions on whether or not to plant eucalyptus, in the following order: the size of landholdings, the price of eucalyptus wood, the prices of alternative crops, and ease of planting and maintenance (Amatayakul and Azar, 2008). Among smallholder farmers on the Amazon frontier, Amacher, Merry and Bowmar (2009) found that timber selling decisions mainly depended on access to credit, off-farm income, forest area, timber price and formal settlement. Shively (1999), found that tree-planting decisions among farmers in the Philippines depend on farm characteristics, prices of timber products and the risk of price changes.

Farmers confront constraints to planting trees for timber and other purposes. When planting trees, they also deal with tradeoffs between planting trees and crops, and between different species of trees (e.g., exotic vs. indigenous). When choosing to plant trees, farmers give up land for growing crops that provide both food and cash. An example of this tradeoff between trees and crops was found in the Philippines, where higher prices for maize and rice were negatively correlated with mango tree planting, and prices of mangoes where positively correlated with

mango tree planting. Higher price risk for maize and rice were associated with a higher probability of planting trees (Shively, 1999).

However, exotic tree species plantings have displaced indigenous tree species in Kenya (Kehlenbeck et al, 2011). Exotic tree species such as *Eucalyptus grandis* (from now on referred to as eucalyptus) and *Grevillea robusta* (from now on referred to as grevillea) have been introduced by government extension agencies, non-governmental organizations (NGO) and the private sector (tea factories and energy industry are among the main buyers of timber from exotic trees) (Nindo, 2008). Eucalyptus grows fast, and products from this tree species, such as poles, can be harvested as fast as after four years. Grevillea also grows fast, and timber from this tree can be harvested and sold after 10 years. These trees have economic appeal for farmers, due to short rotation periods for selling its products, and that there is a demand for eucalyptus and grevillea timber, particularly for eucalyptus (Nindo, 2008; Cheboiyo and Langat, 2006). Farmers also perceive that the exotic tree species require less labor and are easy to manage (Shively, 1999; Nindo, 2008).

The planting of eucalyptus and grevillea tree species has been controversial, since it has been argued that these tree species are detrimental to the environment, through their water use and other properties such as the allelopathy of eucalyptus trees. Some eucalyptus growers claim that they cannot grow food crops in land where they have planted eucalyptus before, because the soil conditions have deteriorated (Amatayakul and Azar, 2008).

It has been suggested that deciduous indigenous trees such as the East African species *Melia volkensii* and *Croton Megalocarpus* use less water, particularly during the dry season, because these trees shed their leaves (Calder, Hall, and Prasanna, 2002; Broadhead, Ong and Black, 2003). These species are suitable for intercropping and offer alternatives not only in terms of timber, but also non timber products. Farmers recognize that native trees provide more products than eucalyptus, and that the timber they provide is of better quality (Nindo, 2008), but not enough information is available on the profitability and environmental effects of native tree species to recommend production systems based on *Melia volkensii* and *Croton megalocarpus* over *Eucalyptus* or *Grevillea robusta*.

Farmers face a stark trade-off in deciding whether to allocate scarce land, labor and working capital to plant eucalyptus for timber sales or annual crops for food. The previous studies have made use of different methods to determine the trade-offs that farmers face, however these studies have usually considered one tree species versus one alternative crop. Bartemeu and Gimenez (2006), developed a simple linear programming model at the plot level to determine if farmers in the Philipines will choose to grow a monocrop (maize) or an intercrop system of maize with a timber tree like (*Gmelina arborea*). Lilieholm and Reeves (1991), developed a model of the decision between hypothetical crops and agroforestry systems, and incorporated a risk component. Amatayakul and Azar (2008) studied the determinants of the decision to plant eucalyptus or cassava in Thailand. And Muchuri, Pukkala and Miina (2002), used simulation to determine the optimal management practice for maize and *Grevillea robusta* to be grown by farmers in Kenya, according to the profitability of the system.

Previous studies on the profitability of eucalyptus and grevillea suggest that short term returns to eucalyptus investments may be a reason that it is preferred by farmers. The studies do not go further in analyzing whether discount rates influence decisions on planting eucalyptus versus annual food crops. If farmers have high discount rates, is possible that they might not be willing to plant trees, or it could be the case that smallholder farmers do not have high discount rates. Therefore there is a need to test if high discount rates are influencing farmers' decisions on planting eucalyptus, and if so, to what extent.

This paper also aims to contribute through elaborating a model that incorporates different choices of crops and trees, and that considers the tradeoffs not only between trees and crops, but also between different tree species within a deterministic polyperiod linear programming model. This model considers the seasons of the year when crops are planted, since different crops are grown in each season, and farmers rely on the bimodal rainfall patterns of western Kenya for planting their crops. The model also takes into account the different rotations for obtaining tree products, within a period of 10 years.

Western Kenya is one area where the planting of fast growing trees such as eucalyptus and grevillea, has spread rapidly over the past 20 years (Cheboiwo and Langat, 2008). According to farmers, land is scarce in the area, as farms have become small due to subdivision through land inheritance practices. Farmers lack access to formal credit markets, so working capital from farming activities comes from sales of crops, trees, land and livestock (Nindo, 2008).

This paper explores the choices between crops and trees, using the main crops and trees identified by farmers on the study region, given the land, labor, and capital constraints typical of

a smallholder farmer in the Nyando watershed of western Kenya. The paper is organized as follows: it presents the theoretical framework, describes the methodology, data and setting of the study, reports results, and offers conclusions.

Theoretical framework: Multi-period profit maximization

A representative farmer is assumed to maximize accumulated wealth over a multi-period time horizon as a function of the production of timber and crops, subject to the availability of land, labor, working capital and to subsistence food consumption requirements. The relation between relative prices of the outputs and the ratio of the marginal products of constrained fixed resources determines the optimal decisions on planting trees or crops. Following the structure developed by Labarta, White and Swinton (2008), the household is assumed to produce two types of goods, annual food crops, and perennial trees using available labor, land and variable capital. The production functions can be described as follows:

$$Q_{1t} = f\{L_{1t}, T_{1t}(T_{2t-1}), K_{1t}\} \quad (1)$$

$$Q_{2t} = f\{L_{2t}, T_{2t}(T_{2t}), K_{2t}\} \quad (2)$$

Where:

Q_{1t}: annual crops planted in period t

Q_{2t}: trees planted in period t

L_{1t} : family labor for annual crops in period t

L_{2t}: family labor for trees in period t

T_{1t}: land allocated to annual crops in period t

T_{2t}: land allocated to trees in period t

T_{2t-1}: land allocated to trees in period t-1

K_{t1}: working capital for annual crops production, period t

K_{t2}: working capital for trees production, period t

A key feature of the model is the persistent effect of perennial investments. Hence, in a given period, *t*, the production of annual crops is feasible only on land not dedicated to trees. In period 1 the representative farmer makes the decision on how much land to allocate to tree production, which has an effect on the amount of land available for annual crops production in subsequent periods. Annual crops serve two purposes; first comply with household consumption requirements and second to provide cash in the short term. Trees provide resources in the longer-term through the production of timber products, which are harvested when ready. Regeneration of trees after timber harvest requires negligible capital, because eucalyptus trees coppice.

The rural household is assumed to maximize the net present value of accumulated net income over n periods:

$$\pi_t = \sum_{t=1}^{n} \beta^t \left\{ P_{1t} Q_{1t}(.) + P_{2t} Q_{2t}(.) - w_t (L_{1t} + L_{2t}) - (K_{1t} + K_{2t}) \right\} \qquad (3)$$

Where the present value factor $\beta = \frac{1}{1+r}$, P_{1t} and P_{2t} are farm gate prices of the annual crop (Q_{1t}) and timber (Q_{2t}) products, w_t is the return to family labor, and r is the annual discount rate. Therefore, the household revenues are determined by the prices and quantities of the grain and timber produced, the production costs are determined by the cost of labor and the amount of

working capital available each period. An initial endowment of working capital is available, after which working capital in each period depends on the cash flows from activities on previous periods. The representative farmer can decide whether to use working capital for farming or for consumption activities. Therefore the key constraints state that:

$$\left(L_{1t} + L_{2t}\right) \leq \overline{L_t} \tag{4}$$

$$\left(T_{1t} + T_{2t}\right) \leq \overline{T_t} \tag{5}$$

$$\left(K_{1t} + K_{2t}\right) \leq \overline{K_t} \tag{6}$$

The amount of family labor and land are restricted to a fixed amount each time period, as shown by (4) and (5). As already mentioned, land currently available for new plantings of annual crops is fixed and restricted by land area dedicated to trees. Therefore, the Lagrangean function for the constrained optimization problem becomes:

$$\Lambda = \pi_t + \lambda_{1t}(\overline{L_t} - L_{1t} - L_{2t}) + \lambda_{2t}(\overline{T_t} - T_{1t} - T_{2t}) + \lambda_{3t}(\overline{K_t} - K_{1t} - K_{2t}) \tag{7}$$

Where λ_{1t} and λ_{2t} are the Lagrange multipliers for labor and land, and each of them determines the shadow prices of these resources (Hazell and Norton, 1986).

From the first order conditions for a maximum (FOC) we have that:

$$P_{1t}\beta^t \frac{\partial Q_{1t}}{\partial L_{1t}} = w_t + \lambda_{1t} \quad \textit{and} \quad P_{2t}\beta^t \frac{\partial Q_{2t}}{\partial L_{2t}} = w_t + \lambda_{1t}$$

Therefore, $$-\frac{P_{1t}}{P_{2t}} = \frac{\frac{\partial Q_{2t}}{\partial L_{2t}}}{\frac{\partial Q_{1t}}{\partial L_{1t}}} \quad (8)$$

$$P_{1t}\beta^t \frac{\partial Q_{1t}}{\partial T_{1t}} = \lambda_{2t} \quad and \quad P_{2t}\beta^t \frac{\partial Q_{2t}}{\partial T_{2t}} = \lambda_{2t}$$

Therefore, $$-\frac{P_{1t}}{P_{2t}} = \frac{\frac{\partial Q_{2t}}{\partial T_{2t}}}{\frac{\partial Q_{1t}}{\partial T_{1t}}} \quad (9)$$

$$P_{1t}\beta^t \frac{\partial Q_{1t}}{\partial K_{1t}} = r + \lambda_{3t} \quad and \quad P_{2t}\beta^t \frac{\partial Q_{2t}}{\partial K_{2t}} = r + \lambda_{3t}$$

Therefore, $$-\frac{P_{1t}}{P_{2t}} = \frac{\frac{\partial Q_{2t}}{\partial K_{2t}}}{\frac{\partial Q_{1t}}{\partial K_{1t}}} \quad (10)$$

Labor, land and capital will be allocated to annual crops and trees production until the annual marginal value products of these inputs are equal to the shadow prices for available land and family labor, and the price of other inputs. From the FOC, we can interpret the different tradeoffs for the farm activities, in equations (8), (9) and (10). The optimal allocation of resources available to the household depends on the relative prices of annual crops and timber. A decrease in the relative price of annual crops relative to timber due to an increase in the price of timber (P_{2t}), *ceteris paribus*, would cause an increase in the production of trees relative to annual crops. This means that the farmer would shift land, labor and working capital toward the production of trees until the new product price ratio equaled the (now reduced) marginal rate of product substitution between annual crops and trees.

Objectives for empirical analysis

While the role of relative prices in output supply is evident from theory, the degree of supply response is an empirical question. In a linear programming model, a solution basis may remain stable over a range of relative prices. Hence, one objective for empirical analysis is to assess the effects of variable product prices on the output mix and associated land allocation. Changes in productivity also have effects on relative prices, through changes in the marginal products of capital, land and labor.

A second objective for empirical analysis is to investigate the effect of tree product harvest timing on optimal product mix. Given that time discounting reduces the net present value of delayed returns, how do lower-priced, shorter-term products like eucalyptus poles (harvestable after 4 years) compare with more valuable but delayed products like industrial firewood (harvestable after 10 years). These two objectives regarding price and time horizon responses by farmers will be tested using polyperiod linear programming, which allows for incorporating the different economic life cycles of trees and crops, farm resource constraints and cumulative cash flow effects on working capital availability.

Polyperiod linear programming model

A polyperiod linear programming (PLP) model is developed to maximize Equation (3) subject to the constraints in Equations (4-5) over a ten-year time horizon. Based on conditions in the Nyando watershed of western Kenya, each year is divided between the early, long season (S1), when maize and beans can be grown together, and the later, short season (S2), when beans and sweet potato are grown. In the first year, annual crops and timber trees can be planted. In the subsequent years, annual crops can be planted. In the fourth and eight years, poles for construction from eucalyptus can be harvested, while in the tenth year industrial firewood from either eucalyptus or grevillea can be harvested. Each year includes activities related to planting, managing and harvesting crops and managing trees with the corresponding resource requirements and constraints. Each year the model also includes activities and constraints to carry over cash from one period to other. It also includes constraints that prevent land that is allocated to planting trees in the first period from being used for growing crops in later periods,

The tableau is formed of 10 periods containing, in the first period, 22 activities in the column, and 22 constraints in the rows, from which 3 are transfer rows. For the subsequent periods, there are 22 activities in the columns, from which 4 are transfer columns, and 25 constraints in the rows from which 4 are transfer rows. Years 4 and 8 include one extra activity for sales of tree products, and an extra row in the constraints, for incorporating tree yields for the different tree products, not included in the other years. In year 10, two extra activities for sales and two extra rows for incorporating yields are incorporated in order to take into consideration that sales of poles from eucalyptus take place in years 4 and 8, and sales of timber for firewood for eucalyptus and grevillea, both take place in year 10. Savage value of eucalyptus for pole production is not

included in year 10. The model contains in total of 223 activities and 250 constraints. A complete list of the activities and constraints included in the model is provided in Appendix 1.

Figure 1 shows the structure the PLP tableau for the first year, showing how transfer row constraints link land use and cash flow from one season to the next within a year. Similar constraints carry over from one year to the next, implying that land that has been allocated to tree planting is not available in subsequent periods for growing crops. Figure 2 conveys the structure of a simplified tableau for the ten periods of the model, where the shadowed cells represent transfer rows and transfer columns from year 1 to years 4, 8 and 10, representing tree planting activities that take place in season 1 of year 1, and tree product sales which take place in subsequent years. Eucalyptus poles are sold in years 4 and 8, whereas eucalyptus and grevillea firewood are sold in year 10. The software that was used to develop and run the empirical PLP model is Risk Solver Platform for Microsoft Excel 2010, version 11.0.

The objective function maximizes the discounted value of the net income from the different farm activities for the ten-year time horizon at an annual real discount rate of 10%, which is assumed to be the opportunity cost of capital (Gittinger, 1982). This baseline discount rate will be varied to incorporate different inter-temporal preferences that might affect the decisions of whether to plant trees or not, made by farmers.

The discount factor enters in the model, multiplying the values of each of the prices for the subsequent years after year 1, a cell on the tableau spreadsheet contains the discount rate, and for each year a cell containing the formula for the discount factor, $\beta = \left(\frac{1}{1+r}\right)^t$, where r is the

discount rate and t the time period, is included to multiply all the prices of the given period t, for a fix r, linking the formula with the one that contains the discount rate.

The empirical model provides an exogenous initial endowment of working capital for starting farming activities of 20,000 Kenyan shillings (US$307 at US$1=Ksh65 in 2008) in season one of year one. After that, working capital needs must be met from cash carried over from the previous year. Similarly, land that has been planted with eucalyptus or grevillea in year one remains under this activity in the next period, thereby diminishing the land area available for planting crops. It is assumed that annual maize, bean and sweet potato can be planted and harvested in each cropping season. Food crops can be sold or used to meet seasonal food subsistence constraints, which can also be met by purchasing food from the market. Crop production not consumed is sold at the farm gate each year; no surplus is left in storage.

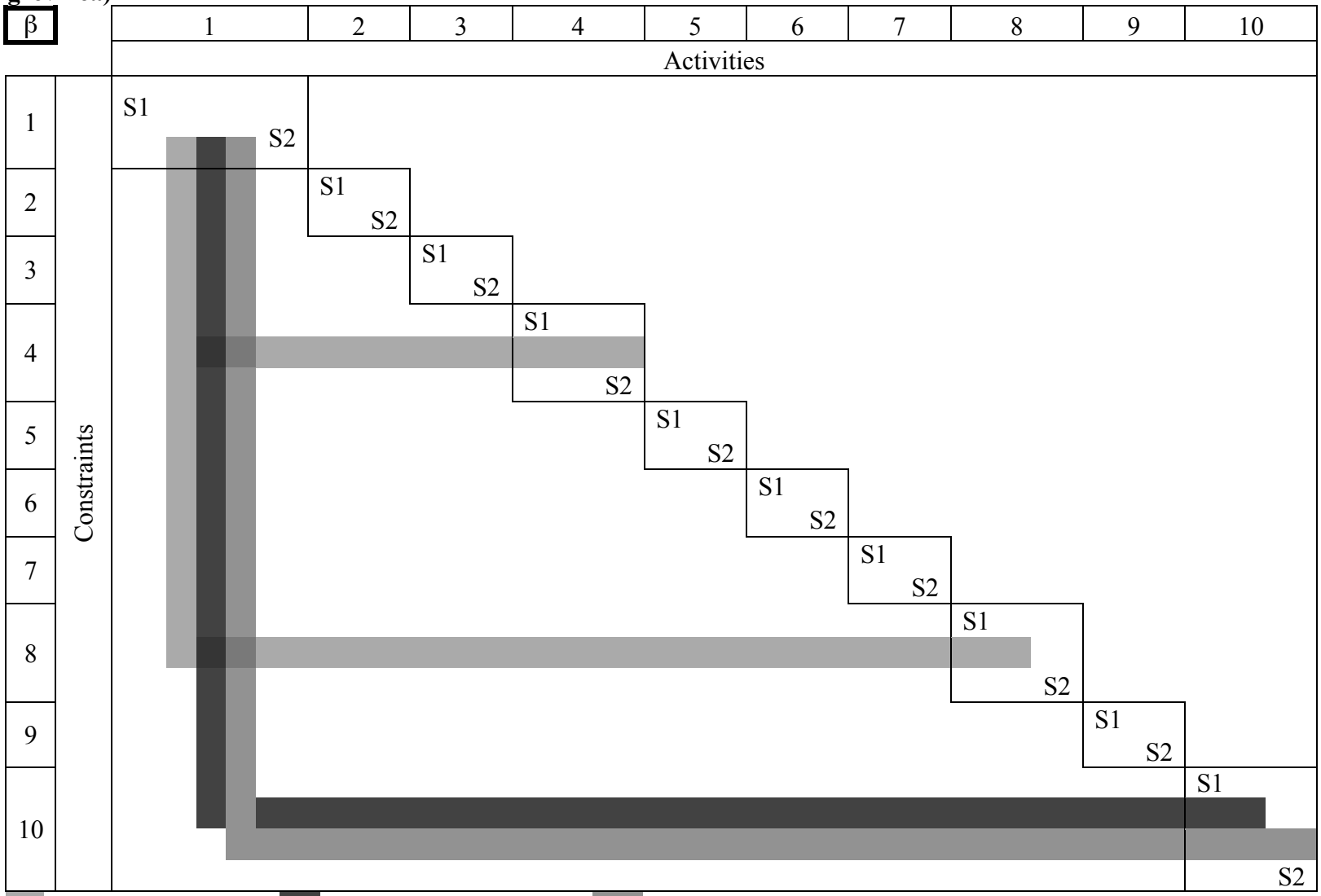
Trees can be planted only in year 1. Eucalyptus can be harvested for poles after four years, and again after eight years. Due to the coppicing ability of the trees, there is no replanting cost after the first harvest. Timber for industrial firewood from eucalyptus and grevillea can be harvested after ten years (National Academy of Sciences, 1980). Timber products are sold at the farm gate to buyers who harvest and transport the wood. Consequently, the labor and working capital required for tree harvesting are negligible.

Figure 1. Sketch of Year 1 of the tableau.

	Season 1						Season 2						
	Grow crops	HH crops cons	Sell crops at farm gate	Buy crops at market	Grow trees	Transfer cash	Grow crops	HH crops cons	Sell crops at farm gate	Buy crops at market	Land constraint for trees	Transfer cash	RHS
Return	-	0	+	-	-	0	-	0	+	-	0	0	
Land					1								<= c
Labor planting													<= c
Labor weeding													<= c
Labor harvesting													<= c
Yields for crops													<= c
Household crops consumption													>= c
Transfer cash	+	0	-	+	-	1							<= 0
Land					1								<= c
Land constraint for trees					1						-1		<= c
Labor planting													<= c
Labor weeding													<= c
Labor harvesting													<= c
Yields for crops													<= c
Household crops consumption													>= c
Transfer cash						-1	+	0	-	+	0	1	<= 0

Note: “HH crops cons”, refers to household crops consumption. “RHS”, refers to the right hand side, and “c” represents a constant value for the constraint at the RHS. Positive and negative coefficients are indicated by the signs “+” and “-”.

Figure 2. Sketch of the 10 period tableau, showing production periods for poles (eucalyptus) and firewood(eucalyptus and grevillea)



Note: S1 and S2 refer to Season 1 and Season 2 correspondingly. β is the discount factor.

Data and setting

Information on the costs and farm-gate prices of annual crops as well as on production costs and prices of trees was collected by the author through interviews and focus group meetings held in the Nyando watershed of western Kenya in July 2008. The farms where the individual interviews took place are located in Kaplelartet district in the upper catchment of the Awach, a tributary of the Nyando River.

A total of four focus groups were conducted with different groups of farmers in Kaplelartet: (1) farmers who grow eucalyptus and other trees, (2) farmers who grow grevillea and other trees, (3) women, and (4) farmers who do not plant trees. We identified focus group participants in meetings with the village chief and village members, collecting a list with information of the trees and crops grown, the amount of land owned, age and number of household members for each of the farmers with the village chief and a group of village elders. From this list we formed groups of farmers to participate in the focus groups. The questionnaire used on the focus groups is included in Appendix 2, and a summary of the main focus group conclusions is included in Appendix 3.

In depth individual interviews were conducted with three farmers identified from the focus groups; we selected these farmers based on a screening questionnaire circulated among farmers while the focus groups were taking place. We chose farmers typical of the study zone. The

farmers chosen have been planting trees for more than 6 years. They reported that they have grown eucalyptus in woodlots of 0.3 acres to 1 acre, and grevillea was grown in hedgerows. These farmers had farms of less than 10 acres of land. The individual interview questionnaire is provided in Appendix 4. The main findings from the focus groups and individual interviews are use throughout this text.

A typical farmer of the study area owns between 3 and 10 acres of land. He grows maize, beans and sweet potatoes on the main plots, mainly for household consumption. He also grows perennial crops in small plots, such as sugar cane, tea or coffee, mostly for sale. Horticultural crops and fruit trees are grown in a farm garden. This farmer plants eucalyptus trees in woodlots and grevillea rubusta in hedgerows, and has been planting trees for 6 years or more. He also has planted a few *Cypressus lusitania* trees on his farm.

The study farms are located close to the Equator, between latitudes S 0º 21' and S 0º 23' and longitudes E 35º 02' and E 35º 03'. The altitude is between 1,600 and 1,700 meters above sea level (see Figure 3, for study site location). The area is characterized by a bimodal rainfall pattern, with long rains between March and June and short rains between September and November. Mean annual rainfall is 1800 mm. Land tenure is secure; farmers have a legal title over their land (Nindo, 2008). Soils are fertile loams. All households interviewed where headed by men, and the household heads had partially or fully completed secondary education. The main crops grown in the area are maize, beans, sweet potatoes, sugar cane and tea. Farmers plant *Eucalyptus grandis* in small woodlots, *Grevillea robusta* in hedgerows on farm boundaries, and vegetables and fruit trees such as avocado and papaya in small farm gardens.

Figure 3. Location of the study site: Kaplelartet village, Western Kenya.

Source: Google Earth, 2012.

The road infrastructure linking farmers to markets is very poor. The rough dirt road to the Kisii-Kisumu road gets very muddy during the rainy season, making it difficult to get products to market. Transportation costs are high, due to the high prices of fuel, and farmers prefer donkeys for taking produce to local markets. No farmers reported having access to the formal credit market. Even if they were able to obtain the collateral required by financial institutions for a loan, farmers face distance and transportation barriers that impede access to credit (Nindo, 2008).

In general, farmers sell their products at farm gate. They sell maize, beans and sweet potatoes in 90 kg bags, and sell produce in two kg tins. The timber products are poles for construction and firewood for industrial use by a tea processor. Poles are bought by a middleman who comes to the farm, negotiates the price with the farmer, and undertakes harvest and transportation of the poles. Industrial firewood is bought by the local tea factory, which harvests and transports the wood, paying a price per cubic meter and deducting transportation costs.

Production activities

The technology for producing maize and beans during the first season (S1) of the PLP model includes the use of a tractor for the first tillage and the use of oxen and plough for the second tillage. For planting beans and sweet potatoes in the second season (S2), oxen and plough are used. One bag of diammonium phosphate (DAP) fertilizer per acre is applied for growing maize intercropped with beans in S1, while no fertilizer is applied for beans and sweet potatoes in S2. Activities for growing, buying, selling and consuming maize, beans and sweet potatoes are included in the model, since these staple crops are also cash crops for the household. Costs and prices as well as technical requirements are assumed to remain constant across the ten years. Hence the 10% discount rate reflects a real rate of discount.

The production of trees requires manual labor for planting and weeding and working capital to purchase seedlings. Eucalyptus is planted in woodlots for producing poles or industrial firewood, the costs and resource requirements for these activities are identical. Grevillea is planted for

industrial firewood production. Trees are planted in year one, poles are harvested in years four and eight, while industrial firewood is harvested in year 10. For purposes of this model, grevillea is used as a competing tree to eucalyptus, planted in woodlots, instead of in hedgerows as it has been observed in the field.

Constraints

Constrained resources for the representative farm in the PLP model include total land area, labor hours available per activity, cash balances, subsistence consumption of maize and beans, and land area previously committed to trees, which is carried over between the years modeled. The farm has four acres of homogeneous land, available for cultivation of maize, beans and sweet potatoes as well for *Eucalyptus grandis* and *Grevillea robusta* trees. A maximum area of 0.5 acres was imposed for sweet potatoes. From individual farmer interviews we learned that planting material for sweet potatoes is usually given for free by neighbors to farmers to grow this crop. Therefore the area of sweet potatoes to be grown depends on the availability of planting material, which is assumed to be enough for planting 0.5 acres of land with sweet potatoes. Even if this crop is attractive, due to its high yield, there exist barriers in western Kenya for its commercialization (Low, 1995). At the study site, sweet potato is mainly grown by women who share tubers for growing this crop (Nindo, 2008)

Labor availability and requirements per activity and per season are shown in Table 1. The labor endowment corresponds to two adults working 8 hours per day, from Monday to Friday during the different periods of the year when farming activities are undertaken. The household

consumption constraints for maize (5.33 bags of 90 Kg), beans (1.10 bags of 90Kg) and sweet potatoes (16 bags of 90Kg) correspond to the amounts produced for consumption during the year, as reported by farmers in the individual interviews.

Cost, prices and yields

The information on costs, prices and yields per acre for trees and annual crops is reported in tables 2 and 3. The prices provided by farmers, refer to farm gate prices for 90 kg bags of maize, beans and sweet potatoes, and for individual poles. The prices per cubic meter of industrial firewood were provided by the local tea factory and by farmers (after deduction of transportation cost). Prices are in Kenyan shillings (Ksh) of 2008(US$1=Ksh65 in 2008); real prices assumed not to vary over the ten years modeled. The variable costs modeled do not include the cost of capital goods or their depreciation. Both costs and yields have been transformed to units per acre, using the information from the interviews conducted. Data on yields for *Eucalyptus grandis* trees of four, eight and ten years old are from Uganda (FAO, 1979) the yields correspond to yields of the trees when grown in plantations. Yields for 10 year old *Grevillea robusta* trees are from Rwanda (Kalingare, 1996). First we introduce *Grevillea robusta* with low yields in the model.

Then in the sensitivity analysis, yields for grevillea are increased with respect to the baseline scenario. The information on medium yields, used in the baseline scenario, corresponds to yields of grevillea grown in plantations. High yields for grevillea, used in alternative scenarios correspond to grevillea planted in hedgerows of at least 10 trees.

For the two tree species considered, yield data was taken from sites where the agro-ecological characteristics are similar to western Kenya. Information on coppicing of eucalyptus trees is from the National Academy of Sciences (1980). Given these data and eucalyptus pole dimensions from the local markets at Katito, Sondu and Kapsorok, it was possible to calculate yields of poles and industrial firewood per tree and per acre of trees.

Table 1. Labor schedule of activities per acre, for planting annual crops (beans, maize and sweet potatoes), *Eucalyptus grandis* and *Grevillea robusta*, upper Awach, western Kenya, 2008.

Labor schedule	Constraint (hours)	Maize and beans Season 1 (hours)	Beans Season 2 (hours)	Sweet Potatoes Season 2 (hours)	Planting Eucalyptus (hours)	Planting Grevillea (hours)
Labor (January-March) planting-crops S1	1200	53				
Labor (April-May) weeding crops S1, planting trees, includes digging holes and time for buying and transportation of seedlings	800	165			160	225
Labor (June) harvest crops S1- 1st weeding trees	400	109			77	71
Labor (December) 1st and 2nd tillage S1	400	87				
Labor (July-August) 1st and 2nd tillage - 2nd weeding trees and seedling replacement	800		71	16	72	72
Labor (September) planting crops S2	400		53	48		
Labor (October) weeding crops S2	400		53	120		
Labor (November - December) harvest crops S2	400		71	120		

*The information on labor hours for Eucalyptus and Grevillea planting corresponds only to the amount of labor allocated for this activity in period 1.

Source: Focus Groups and individual interviews with farmers and individual interviews, Upper Awach, July 2008.

Table 2. Costs, prices and yields per acre for annual crops (maize, beans and sweet potatoes), lower Awach catchment, western Kenya, 2008

Crop	Unit	Farm gate price KSH	Buying Market price KSH	Yield	Variable Cost KSH
Maize and beans season 1 with fertilizer*	Maize bag 90 Kg	1,800	2,400	15.95	7,096
	Beans bag 90 kg	3,200	4,000	1.59	
Beans season 2 without fertilizer	Beans bag 90 kg	2,250	4,000	3.34	1,315
Sweet potato season 2 without fertilizer	Sweet potato bag 90 Kg	600	750	80	3,000

Note: the prices and cost per acre correspond to Kenyan shillings (KSH) for 2008. US$1=Ksh65 in 2008

Source: Focus Groups and individual with farmers and individual interviews, Upper Awach, July 2008.

*Maize and beans are planted together during season 1.

Table 3. Costs, prices and yields per acre, *Eucalyptus grandis* and *Grevillea robusta*, lower Awach catchment, western Kenya, 2008

Tree product	Unit	Farm gate price KSH	Yield	Coppicing yield	Variable Cost KSH
Eucalyptus poles	10cm x 6.5m	80	1,089	1,416	4,481
	10cm x 6.5m	140	1,089	1,416	4,481
	10cm x 6.5m	150	1,089	1,416	4,481
Eucalyptus firewood*	m^3	1000	128	-	4,481
Grevillea firewood medium yield**	m^3	1000	186	-	6,063
Grevillea firewood high yield**	m^3	1000	421*	-	6,063

Note: Prices and cost are in Kenyan shillings (KSH) for 2008. US$1=Ksh65 in 2008. Buyers incur harvest costs .

Source: Focus Groups and individual with farmers and individual interviews, Upper Awach, July 2008.

*Source: National Academy of Sciences, 1980. **Source: Kalinganire, 1996.

Farmers interviewed reported that prices for eucalyptus poles at the farm gate can vary widely, depending on how badly the middleman wants the timber, the bargaining abilities of both the middleman and the farmer, and the best alternative timber source for the middleman. Prices in the market also vary a lot depending of the width and length of poles. Here we assume eucalyptus poles are 10cm diameter and 6.5m long, but pole size is the other major source of price variation. Three prices for poles are reported in Table 3, the lowest price of Ksh80 and the highest price of Ksh150 were reported by farmers, and an intermediate hypothetical price of Ksh140 (in the sensitivity analysis was found that farmers will grow 0.34 acres of land for eucalyptus poles at prices per pole between Ksh80 and Ksh139, 1.17 acres at prices per pole between Ksh140 and Ksh145, and 3.15 acres at prices per pole between Ksh146 and Ksh150). The price for industrial firewood was held constant since the main buyer in the area is a tea factory, which pays a fixed price.

Discount Rates

Two discount rates are tested to determine whether different inter-temporal preferences by farmers change their decisions on planting trees or crops. The base model uses a 10% annual discount rate (Gittinger, 1982). The alternative scenario uses a 50% discount rate corresponding to the rural informal credit markets in Kenya (Fafchamps, 1998).

Model Scenarios

For the analysis, the model was run with different scenarios. The first scenario incorporates growing intercropped maize and beans (using fertilizer and tractor), in the first season, beans and sweet potatoes (without using fertilizer, and plough instead of tractor), in the second season. Land for growing sweet potatoes is constrained to 0.5 acres of land, and the costs of growing sweet potatoes do not include the cost of planting materials. The farmer plants eucalyptus and grevillea on the first season of Year 1. The baseline scenario uses a 10% discount rate.

The second scenario is identical to the first one, except that grevillea has a higher yield. The third scenario considers the same activities as in the previous two scenarios (including high grevillea yield), except that land for planting sweet potatoes is not constrained to a maximum of 0.5 acres. Also, rather than getting the tubers for planting free from neighbors, they are bought at market. Hence, the cost of sweet potatoes now incorporates the cost of purchasing planting materials. In addition, the yields of timber from grevillea remain high. In both scenarios the discount rate use is still 10%.

Finally, a fourth scenario is considered, with the same characteristics of the third scenario, but with a discount rate of 50%.

For all the three scenarios mentioned above, sensitivity analysis was conducted varying the prices of eucalyptus poles.

Results and discussion

The PLP model incorporates activities for production consumption and sale of maize, beans and sweet potatoes, as well as for production and sale of poles and firewood from eucalyptus and firewood from grevillea. At an intermediate price per poles of Ksh140, the first scenario for this model generated an annualized net income of KSh776,600, about US$1,990 (US$1.00 = Ksh65). The GDP per capita for Kenya at purchase parity prices (PPP) for 2007 was US$1550 (World Bank).

Labor was constraining in the first season of Year 1, when harvesting crops coincides with weeding tree seedlings. Labor is also binding for weeding and harvesting crops in the second season for all 10 years of the model. Land was binding for all periods and seasons, except for season 1 of Year 1 and Year 5. Labor was binding for weeding crops and growing trees in these years, because the available labor is insufficient to work all the land. The shadow price of land was Ksh3,465 per acre in Year 1, higher than land rent, which was reported to be Ksh2,000. The subsistence consumption constraints are also binding, with shadow prices equal to the farm-gate buying price of maize, beans and sweet potatoes. This result is probably because the home consumption constraints are met by farm production, and not buying at the market. All crops are produced above the required quantities to comply with household home consumption constraints requirements. The constraint for land for sweet potatoes was also binding.

The PLP model allocation of land between trees and annual food crops was sensitive to the price of poles. Sensitivity analysis to changes in pole prices was conducted using the range of farm gate prices for poles reported in Table 3 by farmers interviewed. The paper presents three

eucalyptus pole price scenarios, *ceteris paribus*. Land distribution patterns under this scenario, for different prices per pole are displayed in the three first columns of Table 4, this table displays all three scenarios of the model, the first five rows describe the main features of each scenario, the net present value (NPV) and the land allocation for each scenario. At the price of Ksh80 per pole, the representative farmer allocates only 0.34 acres of land to eucalyptus trees, while if the price is Ksh150, the farmer allocates 3.15 acres of land to planting eucalyptus for poles. Through the sensitivity analysis, it was found that between prices Ksh137 and Ksh145, 1.17 acres of land will be allocated to plant eucalyptus for pole production (see Table 4). Hence, an intermediate price of Ksh140 was chosen to capture the changes of the representative farmer's decisions. The land allocated by the representative farmer to eucalyptus trees is very close to the amount of land allocated by the typical farmers interviewed, at prices of Ksh80 and Ksh140, farmers who attended the focus groups reported eucalyptus woodlots of 0.3 acres of land and 1.0 acres of land, however no farmers reported a woodlot of 3.5 acres. Detailed results of these price scenarios are displayed on Appendix 5, Tables 5, 6 and 7, using a 10% discount rate.

Farmers will not plant eucalyptus or grevillea trees for industrial firewood production at the current farm gate price of Ksh1,000 per cubic meter, even when the price of poles is as low as 80Ksh per pole. Pole production is very profitable in the model, given the coppicing capacity of *Eucalyptus grandis*, which increases tree yields by 30% for the second harvest. Moreover, poles are obtained every four years instead of the ten year delay for industrial firewood. This high profitability in a shorter time period drives the choice of poles over firewood. During the focus groups, several farmers reported having some trees more than four years old that they were

letting grow in order to obtain a higher price in the future. However, there is no evidence from the field that these trees constituted an entire woodlot.

The representative farmer's response to an increase of yields of timber from grevillea was tested, at different prices per eucalyptus pole. Land distribution patterns can be seen in the columns that correspond to scenario 2 in Table 4. At low prices per eucalyptus pole (Ksh80), the typical farmer will grow 0.34 acres of grevillea, instead of eucalyptus for poles. However at prices of Ksh140 and Ksh150, the land allocated to eucalyptus for poles is still 1.17 and 3.15 acres (see Table 4). In this scenario we still observe a behavior that is similar to what is observe in reality for low and intermediate prices, however it is not the case for the high price of Ksh150. Detailed results are shown in Appendix 6, Tables 8, 9, and 10, using the same three different prices for eucalyptus poles.

Allocation of land to tree planting is also sensitive to the profitability of annual crops. In this third set of scenarios, there is no restriction on the amount of land for growing sweet potato. This crop offers high net return to farmers, even if they have to incur in the cost of the planting materials. In addition, in this scenario grevillea yields are still high and the discount rate used is still 10%. Land distribution patterns are displayed in Table 4, for the columns corresponding to scenario 3. At a price of Ksh80, 0.67 acres of land are allocated to grevillea planting for firewood, whereas no land was allocated for planting eucalyptus for poles production, now land allocated to grow sweet potatoes on the second season is of 3.33 acres, and no beans are grown, but rather purchased on the market for home consumption (See Table 4). Detailed results for this scenario,

Table 4. Land allocation under the different model scenarios.

			Scenarios											
	Activity	**Unit**	**1. Baseline**			**2. Sweet potato land restricted**			**3. No sweet potatoes; land restriction**			**4. Baseline with 50% discount rate**		
Scenario treats	Grevillea yield		medium	medium	medium	high	high	high	high	high	high	high	high	high
	Land sweet potatoes restricted		yes	yes	yes	yes	yes	yes	no	no	no	no	no	no
	Prices per pole	Ksh	80	140	150	80	140	150	80	140	150	80	140	150
	Prices per m3 firewood	Ksh	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	Discount rate	%	10	10	10	10	10	10	10	10	10	50	50	50
Solutions	NPV (thousands)	Ksh	743	776	805	770	776	805	157	1,581	1,592	652	659	661
	Grow Euc poles	Acres	0.34	1.17	3.15	0.00	1.17	3.15	0.00	0.67	0.67	0.34	0.34	0.34
	Grow euc Firewood	Acres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Acres	0.00	0.00	0.00	0.34	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00
	Grow maize and beans S1	Acres	3.66	2.83	0.85	3.66	2.83	0.85	3.33	3.33	3.33	3.66	3.66	3.66
	Grow beans without fertilizer S2	Acres	3.16	2.33	0.35	3.16	2.33	0.35	0.00	0.00	0.00	0.00	0.00	0.00
	Grow sweet potato without fertilizer S2	Acres	0.50	0.50	0.50	0.50	0.50	0.50	3.33	3.33	3.33	3.33	3.33	3.33

considering different prices per eucalyptus pole are shown in Appendix 7, Tables 11 and 12.

With poles at Ksh140 and Ksh150 each, 0.67 acres of land are allocated for planting eucalyptus for pole production, in comparison with 1.17 acres and 3.15 acres respectively, when sweet potato was restricted to only 0.5 acres (see Table 4). No land is allocated to planting trees for firewood production, and again 3.33 acres of land are grown with sweet potatoes and beans are not grown on the second season of each year (see Table 4).

According to the results of two scenarios 2 and 3, there is a tradeoff between trees and crops, which becomes apparent when the relative prices of eucalyptus poles and crops, such as sweet potatoes, are changed. The results suggest that there is also a tradeoff between planting different tree species, but this one is less important than the tree-crop tradeoff, since trees do not provide with staples required for home consumption. The results are consistent with the wealth maximizing behavior of this model, where changes in relative prices change the allocation of farm resources between different activities, to maximize net returns to household resources.

Finally, the 4th scenario of high yielding grevillea, eucalyptus for poles and timber, and unconstrained planting of sweet potatoes, was used to test how inter-temporal preferences affect the representative farmer's decision on how to allocate resources, using a discount rate of 50%. For all three prices (Ksh80, Ksh140 and Ksh150 per pole), the representative farmer will plant 0.34 acres in eucalyptus trees for poles, would not plant trees for timber production, and will grow annual crops on the remaining available land. The results are presented in Appendix 8, Table13, and land allocation is shown in the last three columns of Table 4 (scenario 4 columns).

In general, the results imply that farmers are planting *Eucalyptus grandis* not just because they prefer short-term investments over long term ones. Planting trees for short-cycle pole production is simply more profitable than long-cycle firewood even at a 10% annual discount rate, particularly given the coppicing capacity of the trees. After two or three harvests, coppiced eucalyptus yields will drop, but that is beyond the ten-year time horizon modeled. When grevillea is high yielding and farmers face a choice of a profitable annual crop, decisions over eucalyptus production change. For example, eucalyptus is not part of the optimal solution at low prices per pole, when there is a higher timber yield from *Grevillea robusta* and an alternative highly profitable annual crop such as sweet potatoes. The exclusion of a savage value for poles that are still growing in year 10 and could be harvested in year 12, does not affect the results of the model in terms of land allocation to activities.

Comparing the results from the model scenarios with the results observed in reality, the baseline model is the one that yields results closest to what is observed in the field. Farmers who participated in focus groups reported that they have eucalyptus woodlots of 0.3, 0.5 and 1.0 acres. Farmers participating in the individual interviews grew maize and beans on 0.9, 2.0 and 2.5 acres of land on the first season, beans in 1.5 and 2.0 acres of land of beans on the second season and 0.3 and 0.5 acres of sweet potatoes on the second season, similar to the land dedicated to these crops as predicted by scenario 1 (see appendices 5 and 6).

The PLP model has limitations, since it assumes that farmers will grow trees in a woodlot and harvest all the trees, when tree products are ready. The model is deterministic, which does

incorporate uncertainty in key variables that affect farmers' decisions, such as prices for both tree products and crops. It also does not include the costs of removing tree stumps in order to allocate land to other uses, as these future costs do not seem to have entered farmer decisions. Information on production costs, labor time and prices for native high value timber tree species such as *Marcamia lutea, Melia volkensii* and *Prunus africana*, is scant, and does not allow modeling how a representative farmer decision would change if other timber tree species were included in the model. However, the model does provide understanding on the tradeoffs faced by farmers when making decisions on whether to grow crops or plant trees for commercial purposes.

The model also suggests that under no observed price scenario will timber production entirely replace food crops, perhaps due to the significant marketing margin between the farm gate costs of home-grown and purchased maize bean staples, which makes it cheaper to comply with household consumption constraints by growing crops instead of buying at market. Moreover, farmers are not likely to plant all their land in trees because of the length of time that they have to wait to sell tree products. In the model, the representative farmer consistently grows annual crops above home consumption requirements, suggesting that despite the high profitability of eucalyptus for pole production, a representative farmer will still grow annual crops.

Discussion and conclusion

The literature on eucalyptus agroforestry systems does not incorporate limited farmer capital, labor and land resources, and mainly focuses in alternatives between single tree species and a staple/cash crop. Moreover, that literature is quite scanty for Africa. This whole-farm, dynamic analysis adds to the literature by incorporating different alternative tree species and crops, farm resource constraints, and evaluating the effects of alternative price and yields scenarios for a representative farm from the Nyando watershed in western Kenya.

Eucalyptus grandis planting in small woodlots provides a livelihood supplement to farmers that can offer high net returns in the medium term, as does allocation of land for planting *Grevillea robusta* (Sherr, 1995). Trees seem to be the choice preferred by educated farmers. Evidence from Uganda suggests that farmers with secondary education tend to diversify their livelihoods and invest in medium and long term investments, such as trees (Bamwerinde et al., 2006).

Trees also act as a saving mechanism. Due to the lack of access to financial services and the high interest rates in the informal credit markets in Kenya (Fafchamps, 1998), planting trees constitutes a savings mechanism, and a mean to provide other assets for children through inheritance (Sherr, 1995). Eucalyptus offers returns over a variety of time horizons, whereas grevillea offers a long term investment opportunity. Like livestock, a traditional savings medium in many developing countries, trees build capital (Chambers and Leach, 1989). Savings in the

form of trees can be liquidated when the household falls short of capital for planting annual crops, for paying school fees and health bills or for other investments (Nindo, 2008).

Farmers in the Nyando watershed appear to prefer *Eucalyptus grandis* over other tree species, because it grows fast and it coppices. When they grow *Grevillea robusta,* they usually do so in hedgerows. They rarely plant other tree species. Most of the indigenous and fruit tree species are planted in farm gardens, with no commercial or saving motivation. These other tree species fail to provide timber products as abundantly or as rapidly as eucalyptus.

The PLP model results using a high yield for grevillea suggest that at low prices of eucalyptus poles, the typical farmer will choose a higher yield timber tree alternative, such as grevillea. The model also suggests that when high yield crops can be grown and sold, farmers will prefer to grow crops rather than plant eucalyptus for pole production.

The relative prices of eucalyptus products with respect to other timber and crop products have an important role on farmers' decisions. More research is required on how farmers make decisions when facing uncertainty, since the variability of prices for poles from eucalyptus trees is high. Clearly, relative prices matter. So how farmers determine their expectations on the future prices of tree products is likely to affect decisions on how much land to allocate to trees. As indicated by the results, their decisions seem to coincide with an intermediate level of the price of poles of Ksh140, instead of the extreme prices reported. Shively (1999) points out that farmers may exhibit delayed decisions in response to changes in relative prices, so past prices may explain

current planting decisions. Given the effect of relative prices on the profitability of an alternative crop or tree, how price expectations are developed could be further explored.

Further development of the PLP model could also take into consideration woodlots with trees of different ages, which would allow introducing more tree species and harvesting tree products on a yearly basis. Another useful model extension would be to compare performance and profitability of eucalyptus and grevillea with native East African species, such as *Melia Volkensii*, *Croton megalocarpus* or *Prunus africana*. This would require more information on production costs, labor and other input requirements to grow these native trees, information on prices and marketing.

Future research should also explore the long-term environmental impacts of eucalyptus planting Information on the ecological effects of planting *Eucalyptus grandis* is ambiguous. Although eucalyptus has been found to deplete soil water in semi-arid settings (Kuya, 2006; ICRAF, 2003; Scott, 1997), precipitation in the highlands of western Kenya appears to be sufficient to avoid this problem in most years[1]. However, other private environmental costs of eucalyptus deserve attention, such as allelopathy toward crops and the depletion of soil nutrients. Environmental externalities also deserve attention, including the effects of eucalyptus on carbon sequestration and on water flows to downstream users (e.g., flood prevention and irrigation availability). These environmental factors may alter the balance of net benefits for eucalyptus as compared with crops or native tree species.

[1] Meine Van Noordwijk ICRAF soil ecologist, personal communication by email, April 15, 2009; Frank Place, ICRAF agricultural economist, personal communication by email, April 16, 2009; Simone Radersma, University of Wageningen soil scientist, personal communication by email, March 25, 2009.

Finally, the model results also suggest that promotion of diverse agroforestry systems in East Africa should consider how relative prices between trees and crops, as well as between different tree species affects farmer decisions on planting different tree species. In Kenya, The Agriculture (Farm Forestry) Rules, introduced in 2009[2], called for maintaining a compulsory farm tree cover of 10% of any agricultural land holding, with the purpose of water, soil and biodiversity conservation, protection of water riverbanks, shorelines, riparian areas and wetlands, providing wood, charcoal and alternative fuel sources, fruits and fodder, and carbon sequestration services. To accomplish these objectives by growing diversified tree species will require an understanding of private farmers' incentives when choosing among different alternatives.

[2] http://www.kenyalaw.org/klr/index.php?id=528

APPENDIX 1

Description of activities included in the Tableau

Year 1:

Activities season 1:

1.0. Grow maize and beans with fertilizer and tractor (Ksh/acre).

1.1. Household consumption of maize (90 Kg bag).

1.2. Household consumption of beans (90 Kg bag).

1.3. Sell maize at farm gate (Ksh/90 Kg bag).

1.4. Sell beans at farm gate (Ksh/90 Kg bag).

1.5. Buy maize at market (Ksh/90 Kg bag).

1.6. Buy beans at market (Ksh/90 Kg bag).

1.7. Grow eucalyptus for poles production (Ksh/acre).

1.8. Grow eucalyptus for industrial firewood production (Ksh/acre).

1.9. Grow grevillea for industrial firewood production (Ksh/acre).

1.10. Transfer column for cash from season 1 to season 2.

Activities season 2:

2.1. Grow beans without fertilizer and with oxen and plough (Ksh/acre).

2.2. Grow sweet potatoes without fertilizer and with oxen and plough (Ksh/acre).

2.3. Household consumption of beans (90 Kg bag).

2.4. Household consumption of sweet potatoes (90 Kg bag).

2.5. Sell beans at farm gate (Ksh/90 Kg bag).

2.6. Buy beans at market (Ksh/90 Kg bag).

2.7. Sell sweet potatoes at farm gate (Ksh/90 Kg bag).

2.8. Buy sweet potatoes at market (Ksh/90 Kg bag).

2.9. Maintenance trees for poles eucalyptus (hours)

2.10. Maintenance trees for firewood eucalyptus (hours)

2.11. Maintenance trees for firewood grevillea (hours)

2.12. Transfer column for cash from season 2 current period to season 1 next period.

Constraints season 1:

1.1. Land (acres)

1.2. Labor for planting and tillage (hours).

1.3. Labor for weeding and planting trees (hours).

1.4. Labor for harvesting and weeding trees (hours).

1.5. Maize yields per acre (bag 90 kg).

1.6. Bean yield (Bag 90 kg/ Acre).

1.7. Household consumption constraint for maize (bag 90 kg).

1.8. Household consumption constraints for beans (bag 90 kg).

1.9. Transfer row for cash from season 1 to season 2.

Constraints season 2:

2.1. Land (acres).

2.2. Transfer row land planted on eucalyptus for poles from season 1 to season 2.

2.3. Transfer row land planted on eucalyptus for industrial firewood from season 1 to season 2.

2.4. Transfer row land planted on grevillea for industrial firewood from season 1 to season 2.

2.5. Labor for tillage of crops, weeding trees and seedling replacement (hours).

2.6. Labor planting crops (hours).

2.7. Labor for weeding crops (hours).

2.8. Labor for harvesting of crops (hours).

2.9. Bean yield (bag 90 kg/ acre).

2.10. Household consumption constraint beans (bag 90 kg).

2.11. Sweet Potato yield per acre (bag 90 kg/ acre).

2.12. Consumption constraint sweet potatoes (bag 90 kg).

2.13. Transfer row for cash from season 2 current period to season 1 next period.

Years 2 to 10:

Activities season 1:

1.0. Grow maize and beans with fertilizer and tractor (Ksh/acre).

1.1. Household consumption of maize (90 Kg bag).

1.2. Household consumption of beans (90 Kg bag).

1.3. Sell maize at farm gate (Ksh/90 Kg bag).

1.4. Sell beans at farm gate (Ksh/90 Kg bag).

1.5. Buy maize at market (Ksh/90 Kg bag).

1.6. Buy beans at market (Ksh/90 Kg bag).

1.7. Transfer column land for eucalyptus for poles production.

1.8. Transfer column land for eucalyptus for industrial firewood production.

1.9. Transfer column land for grevillea for industrial production.

1.10. Transfer column for cash from season 1 to season 2.

Activities season 2:

2.1. Grow beans without fertilizer and with oxen and plough (Ksh/acre).

2.2. Grow sweet potatoes without fertilizer and with oxen and plough (Ksh/acre).

2.3. Household consumption of beans (90 Kg bag).

2.4. Household consumption of sweet potatoes (90 Kg bag).

2.5. Sell beans at farm gate (Ksh/90 Kg bag).

2.6. Buy beans at market (Ksh/90 Kg bag).

2.7. Sell sweet potatoes at farm gate (Ksh/90 Kg bag).

2.8. Buy sweet potatoes at market (Ksh/90 Kg bag).

2.9. Maintenance trees for poles eucalyptus (hours)

2.10. Maintenance trees for firewood eucalyptus (hours)

2.11. Maintenance trees for firewood grevillea (hours)

2.12. Sell poles from eucalyptus (Ksh/pole). This activity only takes place in periods 4 and 8.

2.13. Sell industrial firewood from eucalyptus (Ksh/m^3). This activity only takes place in period 10.

2.14. Sell industrial firewood from grevillea (Ksh/m^3). This activity only takes place in period 10.

2.15. Transfer column for cash from season 2 current period to season 1 next period.

Constraints season 1:

1.1. Land (acres)

1.2. Transfer row land for eucalyptus for poles production.

1.3. Transfer row land for eucalyptus for industrial firewood production.

1.4. Transfer row land for grevillea for industrial production.

1.5. Labor for planting and tillage (hours).

1.6. Labor for weeding and planting trees (hours).

1.7. Labor for harvesting and weeding trees (hours).

1.8. Maize yields per acre (bag 90 kg).

1.9. Bean yield (bag 90 kg/ Acre).

1.10. Household consumption constraint for maize (bag 90 kg).

1.11. Household consumption constraints for beans (bag 90 kg).

1.12. Transfer row for cash from season 1 to season 2.

Constraints season 2:

2.1. Land (acres).

2.2. Transfer row land planted on eucalyptus for poles from season 1 to season 2.

2.3. Transfer row land planted on eucalyptus for industrial firewood from season 1 to season 2.

2.4. Transfer row land planted on grevillea for industrial firewood from season 1 to season 2.

2.5. Labor for tillage of crops, weeding trees and seedling replacement (hours).

2.6. Labor planting crops (hours).

2.7. Labor for weeding crops (hours).

2.8. Labor for harvesting of crops (hours).

2.9. Beans yields (bag 90 kg/ acre).

2.10. Household consumption constraint beans (bag 90 kg).

2.11. Sweet Potatoes yields per acre (bag 90 kg/ acre).

2.12. Consumption constraint sweet potatoes (bag 90 kg).

2.13. Yield of eucalyptus for poles (poles/acre). This constraint only appears in periods 4 and

2.14. Yield of eucalyptus for industrial firewood (m^3/acre). This constraint only appears in period 10.

2.15. Yield of grevillea for industrial firewood (m^3/acre). This constraint only appears in period 10.

2.16. Transfer row for cash from season 2 current period to season 1 next period.

APPENDIX 2.

Focus group questionnaire.

FOCUS GROUPS NYANDO WATERSHED, KENYA

Project: Trees and water availability: choices among evergreen and deciduous species for Nyando watershed, western Kenya.

VERBAL CONSENT SCRIPT

I am Alexandra Peralta, from Michigan State University, department of Agricultural, Food and Resource Economics. I am MSc student working on my thesis. I am conducting a research study on Trees and water availability: choices among evergreen and deciduous species for Nyando watershed, western Kenya. This research will help me to understand what are the economic and environmental implications of eucalyptus plantations and native trees agroforestry systems, in the context of the Nyando watershed, and what would be the policy alternatives more suitable to promote systems that are less likely to caused environmentally negative externalities and at the same time are profitable to farmers.

Today you will be participating in a focus group, which should take approximately 3 hours. Your participation is voluntary. If you do not wish to participate, you may stop at any time. Responses will be completely anonymous; your name will not appear anywhere in the final write up. The

focus group will be taped, I will take the tapes with me to Michigan State University and they will be stored at my office in Cook Hall 208 East Lansing, MI 48824. I will keep the tapes for 15 months, and they will be destroyed after the final manuscript of my thesis is done. There are minimal risks associated with this focus group. Taking part in this activity is your agreement to participate.

If you would like a copy of this letter for your records, please let me know and I will give you a copy now. If you have any questions regarding the research, contact Scott Swinton, Department of Agricultural, Food and Resource Economics, Michigan State University, East Lansing, MI 48824-1039, tel: (517) 353-7218. If you have any questions regarding your rights as a research subject, please contact the Human Research Protection Program at Michigan State University, 202 Olds Hall, East Lansing, MI 48824. Thank you again for your help.

Focus groups questionnaire guide

Topic 1: Production Systems and market barriers

1.1. What crops do you grow? Why do you grow these crops?

1.2. From these crops which ones do you use more for food/self consumption and which ones do you use more for sale?

1.3. Do you grow any woody plants? Which ones? Do you grow them by themselves or in crop? Which crops do you grow in your farm with this tree?

Now let's talk about the different tree species

1.4. What are the different products that you obtain from the different tree species you grow? [e.g. charcoal, firewood, fodder, ash, poles, other]?

1.5. Which of these tree products do you use for your household consumption?

1.6. Do you sell these products? If so, is it easy to take them to the market? Which products are more valuable in the market? [referring eucalyptus/other tree products and other crops produce at the farm, ask about the prices perceived by the farmer]

1.7. If you weren't obtaining the given products from the trees/crops, how would you obtain these products? [Buy in the market? Is it less costly to buy at market or produce directly?]

1.8. When in the year do you work on your trees? At these times do you also have to work in other crops? Off farm labor? [e.g. work on other crops, off-farm job, etc.]

Topic 2: Perceptions on the advantages and disadvantages of the production systems.

2.1. In your opinion what are the advantages and disadvantages of growing eucalyptus/grevillea/ /crops with respect to other different trees or crops? [Labor requirements, profitability, timber and non timber products, lack of knowledge, other problems faced when planting, during growing stage, other]

2.2 If you were to grow eucalyptus/grevillea/crops what would you need to do? For the people who do other trees, what do they do that is different? For boundary planting [Access to land, capital, land prices, interests rates for credit and availability, and crop costs and returns, knowledge of the system, access to market]

Optional topic: access to capital: how do you obtained and what are the interests paid for each lender [bank, middle man] are there other sources of capital such as resources from family members that have migrate for working, or sources from off farm labor?

2.3. When during the production process is labor needed for the production of eucalyptus/grevillea/other and why? Do you need hired labor? [for planting, maintenance, just for the first years? Until when?]

Topic 3: Perceived environmental effects of tree plantations

3.1. Do you think there is an effect on your crops of being nearby trees plantations? [More specific to water, soil moisture, allowing growth of other crops, water availability] [ask for how long have these plantations been on the area].

3.2. Have you observed or experienced changes in soil moisture? [if yes, is this affecting other crops? Stream flows?] How well does the soil retain water after rain?

Topic 4: Property rights issues

4.1. Do you own your land? [if communal land, ask next question]

4.2. Is it communal land? What are you allowed to get from the communal forest?

APPENDIX 3.

Focus groups summary.

This summary was elaborated using comments and fragments of Wilson Nindo's (Nindo, 2008) transcriptions and translation of the focus groups. A total of four sessions were conducted in Kaplelartet, Western Kenya, between July 14th and July 17th of 2008, a total of 23 farmers attended these sessions (see table 5).

Table 5. Focus group sessions held in Kaplelartet, 2008.

Date	Session	Attendance
7/14/08	Grow mostly eucalyptus	8
7/15/08	Grow mostly grevillea	6
7/16/08	Women	6
7/17/08	Do not grow trees	5
	Total	23

Topic 1: Production Systems and market barriers

1.9.What crops do you grow? Why do you grow these crops?

Maize, beans, sweet potatoes, sugar cane, bananas, kale, cassava, avocado, tomatoes, onion, millet. Some farmers grow coffee and tea in small plots and napier grass for fodder. These crops are grown for household consumption and for sale.

1.10. From these crops which ones do you use more for food/self consumption and which ones do you use more for sale?

Maize, beans, sweet potatoes, cassava, kales and millet are grown mainly for consumption, whereas the other crops mentioned by farmers in 1.1. are grown mainly for sale.

1.11. Do you grow any woody plants? Which ones? Do you grow them by themselves or in crop? Which crops do you grow in your farm with this tree?

Eucalyptus grandis in woodlots, *Grevillea robusta* in hedgerows, some farmers also plant *Cypress lusitanica* in hedgerows, but not as much as grevillea. It is not a common practice to grow crops with these trees. Some farmers grew maize when they planted their eucalyptus woodlots, but only during the year they planted the trees, since they have notice that maize does not do well when planted with eucalyptus.

Farmers mentioned trees such as *Sesbania sesban*, *Casuarina* and *Calliandra* tree species, which have been promoted by international organizations for intercropping with crops, they have knowledge of these trees but do not necessarily plant them on their farms. Farmers also mentioned fruit trees such as avocado and mango that they plant around the homestead.

1.12. What are the different products that you obtain from the different tree species you grow? [e.g. charcoal, firewood, fodder, ash, poles, other]?

Eucalyptus is used to provide timber for building and furniture, posts, poles, firewood and seeds. Leaves and bark are medicinal. The tree is rarely used for charcoal because it produces other more valuable products like posts and posts so farmers rely on it more for “money”. Grevillea

provides seeds, poles, timber and firewood while avocado is planted purposely for fruits but the older trees are cut for firewood or charcoal. Otherwise, charcoal is mostly made from wattle tree and various indigenous trees. Cypress is used for poles and posts for fencing and roofing.

1.13. Which of these tree products do you use for your household consumption?

Mainly non-timber products such as leaves and bark, timber are used for household consumption only when need it for house repairs or for building fences.

1.14. Do you sell these products? If so, is it easy to take them to the market? Which products are more valuable in the market? [referring eucalyptus/grevillea/other trees products and other crops produce at the farm, ask about the prices perceived by the farmer]

Posts, poles, firewood, timber, fruits and charcoal are usually sold while seeds and other medicinal products are not.

It is not easy to take tree products to the market, the road is not good and the transportation costs are high. However, donkeys are used to transport firewood and crop produce to the market.

Given these difficulties, farmers usually do not take products to the market; they rely on the middlemen who buy the products, mainly timber, poles and posts from the farm. Farmers mentioned that the middlemen are established in the business, they are known in the market and they know better where to sell the products, they also know where and when to sell. Farmers lack contacts and market knowledge, which makes it difficult for them to access the market by themselves.

Farmers could sell firewood to Mamul tea factory, within Kericho district but the problem is that timber products require heavy transport and this is expensive for farmers. The other hindrance is that the factory prefers to contract only a few people to supply firewood to the factory for a specified period. This blocks some farmers from selling directly to the factory, which offers better pay.

The most valuable products in the market are the ones that come from eucalyptus, mainly timber, posts and poles. Avocado is considered the second most valuable product; particularly for people who have several trees that produce fruits, while grevillea timber products were in third place.

Several people in the area grows avocado trees and it takes from 3 to 5 years to get fruits from avocado depending on variety but it takes 3 years to get products from eucalyptus mainly starting with poles. Grevillea leads in firewood usage and timber for furniture production. It produces a lot of firewood as compared to avocado and eucalyptus. Farmers also consider grevillea good for improving soil fertility.

Prices of timber products depend on the length and the thickness of the poles and posts and the size of timber.

The main reasons why farmers sell 10 year eucalyptus trees are to buy land, pay school fees, pay dowry (buy cow as bride price), meet health expenses, buy a cow, build a house (they said they can sell a tree and buy building materials like iron sheets). Another reason is that mature eucalyptus trees are the best for timber, posts and firewood and there preferred by the tea factory that pays well for timber from these trees.

From the tree products charcoal and firewood are the only ones that farmers take to the market. Farmers largely produce charcoal for usage at the household from indigenous trees and not eucalyptus. Women are the ones who normally take small quantities of firewood and charcoal on donkeys to the market.

Crop products such as maize, beans, sweet potatoes, and avocado are easier to take to the market because they are less bulky as compared to timber products. All tea leaves picked from the farms are taken to tea buying centers location closer to the farms from where they are weighed and collected by a factory truck. The factory picks up sugar cane at the farms. For tea and sugarcane, farmers' production is recorded and then payment made by check.

The most valuable products from eucalyptus are poles, posts and firewood while for grevillea it is timber and firewood.

When women were asked about the timber prices, and the sizes of pole and posts, they tried to estimate prices and sizes, after a while they said the men are the ones in charge of selling the timber and even the firewood that goes to the factory, therefore they could not estimate the prices of the timber products. Women also said that they have little control of the money that comes to the household from the selling of timber products or firewood that goes to the factory, this money is managed by the men.

When the timber products are sold, there are times when women are not even told by men about the amount of money that was obtained, and women do not even question men about this. Some men may say how much they have sold while some just pocket the money and keep quiet.

Regarding crops, farmers who do not grow trees mentioned that maize is easier to sell; most people come to buy at the farm, but it is also easy to sell at the market because there is high demand for it. Sweet potatoes are taken to the market by farmers, and for this purpose they use donkeys, they are helpful because the road is not good; there are no public transport vehicles on these roads. The potatoes are usually sold downstream, because it is easier to go down than up using the donkey on the road, for a vehicle the road is bad. Farmers said that they do not have problems selling sweet potatoes in the market or taking them there on donkeys.

Farmers consider that there is always market for maize and you can sell it anytime on farm or at the market. It is also an important component of farmers' diet.

Sweet potato is easy to plant, and planting materials can be found for free from other farmers, fertilizer is not needed for its production and there is a market ready for selling it. Maize can be stored for a long time after harvesting; farmers can store and sell when the price is higher. Sweet potatoes cannot be stored for long after harvesting but harvesting can be delayed for a few weeks.

Beans are a quick crop, farmers can plant it from 2 to 3 times in a year and it helps at times of food scarcity. Sweet potatoes as oppose to maize and beans, they can be planted in a small plot, and people get good money. Farmers buy seeds for beans and maize locally from neighbors or from the market.

1.15. If you weren't obtaining the given products from the trees/crops, how would you obtain these products? [Buy in the market? Is it less costly to buy at market or produce directly?]

Farmers buy eucalyptus and cypress posts and poles for building and fencing from neighbors. Other products they get from outside the area include cedar posts for fencing. Cedar is a very valuable tree in eastern Africa; it is water and termite resistant. They also buy from outside markets timber for roofing and furniture (mainly for cypress).

Farmers also buy *Terminalia brownii* posts for building and fencing, this is an indigenous tree from the lower catchment, it produces hardwood and is termite resistant. They use terminalia posts mainly for construction. They buy it from the nearby markets of Tabaita and Kapsomboch.

Farmers also get tree seedlings and seeds from outside, they can get seeds from neighbors, but they also buy in the market. For example Mamul tea factory has a tree nursery from which farmer buy seedlings.

Between producing the timber products or buying at the market, farmers consider it is easier to produce at their farms. The reason are the high transportation costs for timber, which requires hiring a vehicle when need it in quantities that cannot be moved by donkey, bicycle or walking.

It is not easy to take firewood to the market, firewood or timber products are bulky and heavy, one is not sure to sell all of it and transportation is not easy. If you have to transport these products back, it is double cost on transport otherwise the products might have to be stored or left in some insecure place around the market if the farmer cannot pay extra for a watchman. The middleman and market brokers that are well established in the market take advantage of such farmers stranded with unsold products to pay less that the market rate.

Women get firewood from the nearby shrub lands, they normally have to ask for permission from owners of these lands to extract the shrubs.

Women consider that firewood from terminalia is good, but if they do not have this tree, what they do is to buy firewood from people who have it or arrange to get it from them upon request.

When talking about the fruits from the trees, women said that when they do not have them, they can ask from neighbors or buy from them, other fruits such as guavas grow in the shrub area and they can get them from there for free.

1.16. When in the year do you work on your trees? At these times do you also have to work in other crops? Off farm labor? [e.g. work on other crops, off-farm job, etc.]

Farmers work on their trees in April and August, just before the rains.

The majority of farmers work their tree plots in the evening after finishing other activities (e.g. working on other crops, off farm labor) or only for certain days of the week.

The first year is the more intensive one on work, is the time of taking care of the trees, the establishment period. The young trees require, weeding, protection (fencing) and more attention.

In the seasons for tree planting, there is also a lot of work on other crops. Some farmers prefer to let the trees wait as they do the weeding of the crops during these times. Other farmers take weeding of the crops and tree planting simultaneously by doing crop weeding in the morning then work in planting the trees in the afternoon.

When comparing the labor needs of eucalyptus and other trees with crops, women said that trees need less labor, you only do the planting and weeding and then leave them grow, while crops require more labor and attention.

Farmer who do not grow crops mentioned that times of severe shortage or food scarcity are April – May, during this times they prefer to work on their crop fields, but they need to go and get money/food, some produce charcoal for selling. During these months, farmers have already sold stored grain from previous harvests, to obtain capital for the planting season, for buying seeds and fertilizer. At the same time they do not have stored grains at the household. Most people have to go off farm and get money from off farm labor. The man is the one who normally goes to get off farm labor, earn money to buy food, while the woman stays at home and take care of the household crops, undertakes weeding and other farming activities. This situation takes place mainly in the middle and lower catchment, which is a dry area.

Topic 2: Perceptions on the advantages and disadvantages of the production systems.

2.1. In your opinion what are the advantages and disadvantages of growing eucalyptus/grevillea/other with respect to other different trees or crops? [Labor requirements, profitability, timber and non-timber products, lack of knowledge, other problems faced when planting, during growing stage, other]

Eucalyptus advantages:

- "Money maker"
- Good for roofing poles, firewood, charcoal, fencing posts and building local bridges
- Attracts rain (farmer belief about trees)
- Good as wind break

- Coppicing, it re-grows easily after cut
- Requires less labor compared with other trees and crops, “is easier”. For example, maize and sugar cane require a lot of labor in land preparation, weeding and harvesting as compared to eucalyptus

Eucalyptus disadvantages:

- Takes longer to harvest than crops, therefore you have to wait for “making the money”
- Takes a lot of water
- Affects soil fertility
- Difficult to remove to plant something else, labor intensive removal
- Affects other crops if planted close by
- Dangerous in the homestead because its branches brakes during the winds
- Farmers notice that eucalyptus affects the crops gradually, when planted adjacent to the trees.
- Eucalyptus attracts weaver birds that eat the crops (e.g maize)

Grevillea advantages:

- Improves soil fertility
- It can be planted with crops

- Very good for firewood
- Good for timber for furniture

Grevillea disadvantages:

- Requires a lot of labor, at the early stages is also eaten by livestock, especially goats

Grevillea advantages in comparison with Eucalyptus:

- Provides seeds
- Improves soil fertility (from roots and leaves)
- Controls soil erosion. Eucalyptus also helps to prevent soil erosion. Farmers consider that both trees are more or less the same.
- Grevillea's timber is used more for furniture [this might be driven by farmers' preferences and market demand].
- Reduces soil acidity when planted intercropped with cypress
- Windbreak better than eucalyptus, because grevillea does not grow as tall as eucalyptus; it is closer to the house roof providing a better windbreak for the house.
- Contrary to eucalyptus that grows tall, shades the crops, and drains the soils, while grevillea doesn't have these negative effects when planted around the crops.
- They prefer grevillea at homestead. Farmers considered that eucalyptus is dangerous at the homestead, because the branches break and fall dangerously.

- Attracts rain, good for shade, purifies air

Grevillea disadvantages when asked in comparison with Eucalyptus:

- Eucalyptus better for seeds than grevillea
- Since eucalyptus is planted in woodlots it is better in preventing soil erosion compared with grevillea
- Grevillea does not provide good posts, poles and is not preferred for charcoal production or fencing poles.
- For timber farmers must wait for 10 years while for getting timber from eucalyptus they only wait for 5 years.
- Eucalyptus roots drain the soil and roots go further (more spread).
- Farmers think eucalyptus is better in attracting rain than grevillea.

2.2 If you were to grow eucalyptus/grevillea/other what would you need to do?

It is optional to till the whole plot. A farmer can always dig the holes for planting the seedlings without tilling the whole plot. Most people just make the holes to reduce on the labor cost for land preparation (tillage).

Chemical fertilizer is not used for tree planting, a few farmers may be applying manure when planting but most of them do not.

Farmers rely on rainfall to grow trees. They plant just before the rainy season since there are not irrigation systems in the area.

When the farmers are planting crops among young trees that are establishing, instead of doing the first weeding around each individual tree, they till the entire tree plot after trees are just planted. They then plant the crops and weed trees 2 months after of planting the trees.

Farmers usually do not prune *Eucalyptus grandis* since it is self-pruning. Grevillea and other trees require almost the same process for planting, compared to eucalyptus. The process of eucalyptus production is the same when planted on boundaries as in woodlot.

First of all farmers need to think about where to buy the seedlings (which tree nursery). When making the holes, farmers can estimate how many trees they want to plant, this will let them know how many seedlings they will need to buy.

Before making the holes, farmers first think about how to get the money to buy seedlings, then, they make the holes and think about how much money they need to buy the seedlings. When doing the holes, some farmers mix the soil with manure for planting.

Farmers mainly use wire or pole/post fencing while trees are small to protect the trees from livestock that might eat or damage the trees. Without wire fencing, some farmers put thorns around the base of the tree to protect the trees from livestock. The thorns also prevent the young trees from damage by the chicken.

Men and women work on the trees, during planting and weeding, it is a shared job. When there is need to water the newly planted young tree seedlings, women always carry out this work. In

cases where there is a tree nursery watering is done, otherwise trees are planted just before the rains when watering is not so necessary. Men are usually the ones in charge of digging the holes for trees planting. The decision about where the trees will be planted is done by the man, or in consultation between the man and the woman, but a woman cannot make this decision herself. For the cases of the women that are household heads (widow), they make the decisions as well as arrange do the work on their own, they make the holes, and they negotiate with the person who comes to buy the trees. Looking after the growing young trees is the role women and children. The man does observation and supervision.

For growing crops farmers buy beans and maize seeds from neighbors or from the local market. For maize and beans land preparation requires a lot of work because the soil needs to be made finer for the maize and the beans to do well. These two crops require tillage twice during land preparation. Oxen or bull draft is normally used for this purpose.

During the planting period there is a lot of labor needed, because there is someone guiding the bull, holding the plough, putting the fertilizer and another the seeds. Farmers hire more labor during planting, some use their own oxen, some farmers share labor, for those who cannot pay labor, and they negotiate and work together. After planting they wait for 2 to 3 weeks for the first weeding, they hire labor but not as demanding as during planting. They can do a second weeding after 2 to 3 weeks but that second weeding is optional. Harvesting is done with family labor; unless it is a big plot do they hire some labor. A farmer mentioned that they use fertilizer for maize and beans, and hires labor during planting and tillage.

Optional topic: access to capital: how do you obtain and how much are the interest is paid to each lender [bank, middle man]? Are there other sources of capital such as resources from family members that have migrate for working, or sources from off farm labor?

Capital for starting the enterprise: sale of livestock, maize, off farm employment, sale of big trees, remittances, get a loan from bank (very infrequent), buy seedlings on credit (agreement with person who has nursery)

Middlemen does not provide loans to farmers for tree planting.

In this case for farmers who do not grow trees, for getting the money to grow maize/beans and sweet potatoes farmers they sell some crops from their previous harvest, some make and sell charcoal to get the money for the seeds and the fertilizer, others sell rough stones from their plots, livestock especially goats and terminalia posts.

Farmers harvest crops, sell and use for household consumption part of it, they also store some part of it to sell during planting season and be able to buy inputs.

When asked about loans they said they don't take loans from a financial institution.

Farmers also borrow money from family or friends or share the costs of growing the crop with friends/neighbors/relatives.

2.3. When during the production process is labor needed for the production of eucalyptus/other and why? Do you need hired labor? [for planting, maintenance, just for the first years? Until when?] GROUP QUESTION

Farmers use primarily family labor (not paid) and when needed they hire labor.

Labor is more needed when planting, this stage requires a lot of labor and in most cases they hire labor. Labor is also needed during weeding and when harvesting.

If the products are not sold to the middleman, harvesting requires a lot of labor, because there is also the need to take products to the market, again, here there is need to hire labor. Farmers therefore prefer to negotiate and leave the cost of harvesting to the buyer.

Labor is intensive during making of holes and weeding for tree planting.

Labor needs for grevillea in comparison with eucalyptus is the same for the process of planting and growing the trees. The difference is that mostly people do not plant grevillea in woodlots as they do with eucalyptus.

Topic 3: Perceived environmental effects of tree plantations

3.1. Do you think there is an effect on your crops of being nearby trees plantations? [More specific to water] [then mention, for example eucalyptus] [soil moisture, allowing growth of other crops, water availability] [ask for how long have these plantations been on the area]
GROUP Q

Eucalyptus is planted more than any other tree in the area, mainly in the last 10 years.

The main effects of eucalyptus on crops are apparent when planted in the boundaries of crops, but when planted in a woodlot separated from the crop farm, the effect are not so much felt on the crops. Farmers prefer to separate eucalyptus from crop fields.

In some cases there are conflicts between neighbors when one wants to plant eucalyptus in the boundaries and in the other side the neighbor wants to plant crops. A farmer who wants to plant eucalyptus normally thinks about what would be the reaction of the neighbor. The farmers said that most neighbors complain, but this does not happen with grevillea.

Farmers agree that within at least six meters (three meters radius) around the trees, crops do not do well. Farmers consider that eucalyptus near the crops will gradually diminish crop yields. They also consider that cypress has the same effect as eucalyptus in crop yields but not with grevillea.

Since eucalyptus grows tall, farmers consider that crops particularly maize will suffer with the shade but this is not the case with grevillea.

Groundwater effects: a few of the people with wells in their homesteads said that they were not sure that planting eucalyptus on their farms might have an effect on the amount of water they get from the wells, but they think it could be. In the other hand, they think that planting grevillea won't have effects on the amount of water they obtain from the wells.

A farmer mentioned that people are blaming eucalyptus for water scarcity, but people have also cut down the forest to open more land for crop production.

Farmers also think that trees attract rain and purify the air.

The following were some of the farmers' perceptions about grevillea:

- Improves soil fertility (from roots and leaves).
- Controls soil erosion.
- Reduces soil acidity when planted intercropped with cypress (farmers think cypress causes soil acidity).
- Good for shade and purifies the air.

When asked about environmental effects of trees, farmers disputed on the effects of eucalyptus in soil fertility, as well as on soil acidity effects. Farmers were not very sure about the soil fertility loss caused by eucalyptus, they said that the nearby tea factory the area planted tea in an area that was planted with eucalyptus before, the eucalyptus was there for 10 years, and the tea did well in that soil. Farmers also said that fertilizer was put on the soil, because of these reason, they do not know that the effect of eucalyptus actually was on the soil or just fertilizer. However they consider eucalyptus better for seeds and products such as poles.

Women said that there are some trees that are good when planted with crops, such as casuarina, sesban and grevillea, and there are some such as eucalyptus that is not good with crops. Eucalyptus roots, they said, spread in the farm and interferes with crops, and it also takes a lot of water. They said that no crop would do well with eucalyptus. Because of these reasons farmers normally set a side some corner for eucalyptus or plant on the boundaries of homestead. With boundary planting, the neighbors with crops on their farms will come complaining about the eucalyptus. Grevillea is considered good for everything, for boundaries, or within crop fields. It is friendly with crops. The other tree that is not good with crops is cypress, which has the same effects on crops as eucalyptus.

3.2. Have you observed or experienced changes in soil moisture? [if yes, is this affecting other crops? Streamflows?] How well does the soil retain water after rain? GROUP QUESTION

Stream flow: farmers gave an example of a spring in the area (Tililbei) which they said experienced diminishing levels of water flow over the past 10 years, farmers consider that the main cause is that farmers have planted eucalyptus near the spring. In addition to this, farmers think that another reason for the reduced levels of water flow is deforestation.

There was a discussion about what was causing the reduction in the spring flow, eucalyptus or deforestation, one of the farmers explained that even if there is no research, when he cuts a eucalyptus trees it drains a lot of water from its trunk, therefore, it is obvious it consumes a lot of water.

Soil moisture: farmers gave and example on how soil that has organic matter retains more water than that with less organic matter. They used this example to explain and conclude that soil retains less water when is planted with eucalyptus. Farmers consider that this tree consumes a lot of organic matter, as well as water.

Since farmers of the area discovered charcoal production, terminalia trees have been depleted, now the run off from upstream finds bare soils and this has exacerbated the erosion problems in the area.

<u>Topic 4: property rights issues</u>

4.1. Do you own your land? [if communal land, ask next question] GROUP QUESTION

For planting trees farmers use their own land, but for other crops (e.g maize, sugar cane) they can rent land, this practice is not for trees, given the long term nature of this crop.

Farmers possess titles over their lands. Even the areas under shrubs belong to individuals who have title over that land. Farmers own their land; they also practice renting land for crops, but not for trees.

4.2. Is it communal land? What are you allowed to get from the communal forest?

There are common areas, as schools, churches, cattle dip areas, markets, chief's office, are areas where activities such as tree planting is restricted and nobody is allow just to go there and grow something or harvest something without the direction from the authorities.

Appendix 4.

Individual interviews questionnaire.

Individual Interview Questionnaire
MSU, CPWF, ICRAF, CIAT

Introduction: Consent Script

1. Basic Information

   1.1. Case Study ID: _____

   1.2. Date of the interview: ____/____/____

   1.3. District : _____

   1.4. Village: _____

   1.5. Name of respondent: _____

   1.6. Relation of respondent with household head:_____

   1.7. GPS coordinates of the household

   Latitude _____

   Longitude _____

   Altitude _____

2. House characteristics [A household is defined as the group of people who share food from the same pot].

   2.1. Household head

   2.1.1. Gender (1: female, 0: male) _____

   2.1.2. Age (years) _____

   2.1.3. Education (years) _____

2.1.4. Main economic activity _____

2.2.Household composition

Gender	Total	Under 14 years old	Attending school	Older than 60 years old
Men				
Women				
Total				

3. Are there household members that have any off farm job?

Household member	Regular (all year)	Seasonal	Months	Days	Salary/ day	Different district? (1: yes, 0: no)	If yes, Where?

4. What is the size of your farm?

	Cultivated	Non cultivated	Homestead	Rented	Other	Total
Area (acres)						

5. What is the price for renting land in your area? _____Ksh/Acre
6. Do you have any irrigation systems at your farm? YES (____) NO (____). If yes, which one?

_____

If no, how are you watering your crops/trees?_____

7. Do you plant trees in your farm? YES (____) NO (____). If yes do you plant trees at:

Location at farm	1: yes, 0: no	Tree species	No. of trees
Homestead			
Boundaries			
Woodlot			
Intercropped			
Other			

Note: If less than 50 trees of a given species, don't ask Question 9.

8. For how long have you been planting trees?_____years

9. Now we are going to talk about individual fields or woodlots on your farm. Let's talk about your most common tree species.

Tree species: _____Mark with an X if at: Boundary (___) No._____Woodlot (___) No._____Intercropped (___) No._____

Woodlot (_) No. trees:_____ Spacing between trees: _____Area:____ (Acres) Length: ____(meter/feet) Width: ___ (meter/feet)

Boundary (_) No. trees: _____Spacing between trees: _____Length: _____ (meter/feet)

Intercropped (_) With which crops: _____How long do you plant the crops after planting the trees:_____

Soil type: _____Ownership: Owned (___) Rented (___) Shared (___)

Note: person – day, is number of persons – number of days worked in the activity.

Family Labor the age ranges are defined as: 1: < 14 years old, 2: between 14 and 60 years old, and 3: 60> years old.

							Labor (person - day)			
year	Activity	Inputs	Quantity	Unit	Equivalent (kg)	Cost/Unit	Family	Hired Labor	Other	Cost/day
	Fencing						1 2 3			
	Make Holes						1 2 3			
	Buy seedlings						1 2 3			
	Planting						1 2 3			
	1st weeding trees Tillage crops						1 2 3			

	Seedlings replacement						1 2 3			
	2nd weeding trees weeding crops						1 2 3			
	Planting crops Times per year						1 2 3			
	Weeding crops Times per year						1 2 3			
	Pruning *Times per year:*						1 2 3			
	Thinning *Times per year:*						1 2 3			

Notes:

YIELDS									Cost of harvesting								
Year	Harvesting	Yields	Units	Size	Length	Household use	On farm price/unit	Market price/unit	Inputs	Quantity	Units	Equivalent	Cost per unit	Labor for harvesting (person-days)			
														Family	Hired Labor	Other	Cost /day
	Firewood Times per year:													1 2 3			
	Charcoal Times per year:													1 2 3			
	Poles Times per year:													1 2 3			
	Posts Times per year:													1 2 3			
	Timber Times per year:													1 2 3			
	Crops Times per year:													1 2 3			
	Marketing													1 2 3			

Notes:

10. For each of the plots that you have in your farm, please answer the following questions:
Plot No.: __ Soil type: _____Ownership: Owned(_)Rented(_)Shared (_)Area:___(Acres) Length:___(meter/feet)
Width:__(meter/feet)
Spacing between rows: _____(feet) Spacing between plants in row:
_____(feet)
Crops grown in the plot (number of rows per crop): _____ (_____) _____ (_____) _____
(_____)
Are added crops planted in same row or separate rows? _____
Crop rotation: S1: _____S2: _____ S3: _____ (regular rotation they practice in this plot)
Notes: Person-days, is number of persons times days worked.
Days – machinery, number of days times machinery used. Days – animal, is number of days times animals used.
Seasons: S1: Long rains ; S2: Short rains ; S3:

						Labor (person – day)				Machinery (days-machinery)				Animal traction (days–animal)			
Activity	Input	Quantity	Units	Equivalent Kg	Unit cost	Family	Hired	Other	Unit cost	Machinery	Owned	Rented	Cost/day	Animal	Owned	Rented	Cost/day
1st tillage						1											
						2											
						3											
2nd tillage						1											
						2											
						3											
3rd tillage						1											
						2											
						3											
Planting						1											
						2											
						3											

1st weeding						1											
						2											
						3											
2nd weeding						1											
						2											
						3											
Harvesting						1											
						2											
						3											
Harvesting						1											
						2											
						3											

YIELDS

Crop	Yields	Units	Equivalent (kg)	Household use	Farm price	Market price
Crop 1						
Crop 2						
Crop 3						

Notes:

11. Do you have a tree nursery in your farm? YES (___) NO (___). If no, please continue with 11.1.

Seedlings production

Tree species	Average seedlings production per year	Amount for self-consumption	Market price	On farm price

Seedlings production costs

Note: person-days, is number of persons times days worked.

					Labor (person - day)				
Activity	Input	Quantity	Unit cost	Total cost	Family labor	Hire labor	Other	Unit cost	Total cost
Preparing beds					1: 2: 3:				
Planting					1: 2: 3:				
Transplanting					1: 2: 3:				
Marketing					1: 2: 3:				

For family labor: 1: <14, less than 14 years old, 2: 14-60, between 14 and 60 years old and 3: 60> older than 60 years (age ranges)

11.1. If no, do you work in a community/group nursery? YES (___) NO (___). If no, continue to question 12.

If yes, how many days during the year do you dedicate to work in the community/group nursery? _____days

Do you get the seedlings from the community/group tree nursery for free? YES (___) NO (___)

Markets and transportation costs

12. How do you get your products to the market and how much does it cost?

Market	Distance from your farm (Km)	Products that you get to that market	Transportation means used	Cost of transportation to the market

Transportation means codes: donkey [1], hand car [2], bicycle [3], vehicle [4], truck [5]

Labor availability

13. Are there seasons where the wages you pay to the workers you hire vary?

Season	Wages/ per day	Additional benefits (food, other)
Long rains [S1]		
Harvesting [S2]		
Short rains [S3]		

14. What are the different labor trading arrangements that you do with hired workers/ neighbors

Trading arrangements	Season when are commonly done	Terms of payment

Pasture and Livestock.

15. Livestock inventory for adult animals by the last Kenya presidential elections?

Animal	Number	Family labor (person – day)	Times per week
Cow		1: ____2:____3:____	
Bull		1: ____2:____3:____	
Steers		1: ____2:____3:____	
Calves		1: ____2:____3:____	
Goats		1: ____2:____3:____	
Kids		1: ____2:____3:____	
Sheep		1: ____2:____3:____	
Lamb		1: ____2:____3:____	
		1: ____2:____3:____	
		1: ____2:____3:____	
		1: ____2:____3:____	
		1: ____2:____3:____	
		1: ____2:____3:____	

Person – day, is number of persons – number of days worked in the activity.
For family labor: 1: <14, less than 14 years old, 2: 14-60, between 14 and 60 years old and 3: 60> older than 60 years

16. Do you have any land on your farm for livestock grazing? YES (____) NO (____). If yes what is the size of it? _____Acres.

17. Do other farmers graze their animals in your farm? YES (____) NO (____).

Access to credit, other sources of capital

18. Loans that you have acquired for your productive activities

Amount borrowed	Term of the loan	Date received	Date repayable	Payments required (explain)	Comments

19. What are the alternative sources for getting capital for starting a productive activity at your farm, different to a loan?

    _____

Environment

20. Have you experienced changes in yields on any of the crops that you grow in your farm, after planting eucalyptus or any other tree species?

Crop	Tree specie	Mean annual yield before trees	Mean annual yield after trees

21. How do you get water for your farm activities?
    Well (___),
    How deep was the well 20 years ago? _____Now? _____
    By hand (____),
    How deep was the water level 20 years ago? _____ Now? _____

22. What is the depth of the River in a typical year? _____
    What was its depth in a typical year 20 years ago? _____(less, more, same)

23. Have there been springs on or near the farm? YES (___) NO (___). If yes,
    How many 20 years ago? No. _____
    How many now? No. _____
    How much flow 20 years ago? _____(less, more, same)
    How much flow now? _____

Technical assistance

24. Have you receive any technical assistance from one of the following institutions?

ICRAF	YES (____) NO (____).
Kenya Forest Services	YES (____) NO (____).
VI Agroforestry	YES (____) NO (____).
KEFRI	YES (____) NO (____).
KARI	YES (____) NO (____).
NALEP	YES (____) NO (____).
Other	YES (____) NO (____).

Which one(s)?_____

APPENDIX 5.

Linear programming model detailed results Scenario 1

Table 6. Polyperiod linear programming model results: Low price of poles (80Ksh) and 10% discount rate scenario.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans with fertilizer	Ksh	3.41	3.66	3.66	3.66	3.41	3.66	3.66	3.66	3.66	3.66
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize at farm gate	90 kg bag	49.09	52.97	52.97	52.97	49.09	52.97	52.97	52.97	52.97	52.97
	Sell beans at farm gate	90 kg bag	4.34	4.73	4.73	4.73	4.34	4.73	4.73	4.73	4.73	4.73
	Buy maize at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus poles	Ksh	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	Grow eucalyptus Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer	Ksh	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16
	Grow sweet potato without fertilizer	Ksh	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans at farm gate	90 kg bag	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell sweet potatoes at farm gate	90 kg bag	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
	Buy sweet potatoes at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	344.70	0.00	0.00	0.00	448.10	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Polyperiod linear programming model results: Medium price of poles (140Ksh) and 10% discount rate scenario.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans with fertilizer	Ksh	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize at farm gate	90 kg bag	39.81	39.81	39.81	39.81	39.81	39.81	39.81	39.81	39.81	39.81
	Sell beans at farm gate	90 kg bag	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42
	Buy maize at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus poles	Ksh	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
	Grow eucalyptus Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer	Ksh	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
	Grow sweet potato without fertilizer	Ksh	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans at farm gate	90 kg bag	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell sweet potatoes at farm gate	90 kg bag	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
	Buy sweet potatoes at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	1169.94	0.00	0.00	0.00	1520.93	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Polyperiod linear programming model results: High price of poles (150Ksh) and 10% discount rate scenario.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans with fertilizer	Ksh	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize at farm gate	90 kg bag	8.27	8.27	8.27	8.27	8.27	8.27	8.27	8.27	8.27	8.27
	Sell beans at farm gate	90 kg bag	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
	Buy maize at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus poles	Ksh	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
	Grow eucalyptus Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer	Ksh	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	Grow sweet potato without fertilizer	Ksh	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans at farm gate	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell sweet potatoes at farm gate	90 kg bag	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
	Buy sweet potatoes at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	3147.55	0.00	0.00	0.00	4091.81	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 6.

Linear programming model detailed results Scenario 2

Table 9. Polyperiod linear programming model results: Low price of poles (80Ksh) and high yield of Grevillea trees.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans with fertilizer	Ksh	3.43	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize at farm gate	90 kg bag	49.40	52.97	52.97	52.97	52.97	52.97	52.97	52.97	52.97	52.97
	Sell beans at farm gate	90 kg bag	4.38	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73	4.73
	Buy maize at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus poles	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34

Table 9 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer	Ksh	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16
	Grow sweet potato without fertilizer	Ksh	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans at farm gate	90 kg bag	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell sweet potatoes at farm gate	90 kg bag	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
	Buy sweet potatoes at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	145.21

Table 10. Polyperiod linear programming model results: Medium price of poles (140Ksh) and high yield of Grevillea trees.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans with fertilizer	Ksh	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize at farm gate	90 kg bag	39.81	39.81	39.81	39.81	39.81	39.81	39.81	39.81	39.81	39.81
	Sell beans at farm gate	90 kg bag	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42	3.42
	Buy maize at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus poles	Ksh	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
	Grow eucalyptus Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 10 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer	Ksh	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
	Grow sweet potato without fertilizer	Ksh	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans at farm gate	90 kg bag	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95	2.95
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell sweet potatoes at farm gate	90 kg bag	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
	Buy sweet potatoes at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	1170	0.00	0.00	0.00	1520.93	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 11. Polyperiod linear programming model results: High price of poles (150Ksh) and high yield of Grevillea trees.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans with fertilizer	Ksh	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize at farm gate	90 kg bag	8.27	8.27	8.27	8.27	8.27	8.27	8.27	8.27	8.27	8.27
	Sell beans at farm gate	90 kg bag	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
	Buy maize at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus poles	Ksh	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15	3.15
	Grow eucalyptus Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 11 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer	Ksh	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	Grow sweet potato without fertilizer	Ksh	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans at farm gate	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell sweet potatoes at farm gate	90 kg bag	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00	24.00
	Buy sweet potatoes at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	3148	0.00	0.00	0.00	4091.81	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 7.

Linear programming model detailed results Scenario 3.

Table 12. Polyperiod linear programming model results: Low price of poles (80Ksh) and no sweet potato land constraint

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beanswith fertilizer	Ksh	3.22	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize at farm gate	90 kg bag	46.06	47.83	47.83	47.83	47.83	47.83	47.83	47.83	47.83	47.83
	Sell beans at farm gate	90 kg bag	4.04	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22	4.22
	Buy maize at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus poles	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow eucalyptus Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67

Table 12 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow sweet potato without fertilizer	Ksh	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans at farm gate	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans at market	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Sell sweet potatoes at farm gate	90 kg bag	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67
	Buy sweet potatoes at market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	280.87

Table 13. Polyperiod linear programming model results: Medium (140Ksh) and high (150Ksh) price per pole, high yield Grevillea, and no sweet potato land constraint.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans	Ksh	3.19	3.33	3.33	3.33	3.19	3.33	3.33	3.33	3.33	3.33
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize on farm gate	90 kg bag	45.47	47.83	47.83	47.83	45.47	47.83	47.83	47.83	47.83	47.83
	Sell beans on farm gate	90 kg bag	3.98	4.22	4.22	4.22	3.98	4.22	4.22	4.22	4.22	4.22
	Buy maize market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow Euc poles	Ksh	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
	Grow euc Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 13 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer S2	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow sweet potato No fertilizer	Ksh	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans on farm gate	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans market	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Sell sweet potatoes farm gate	90 kg bag	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67
	Buy sweet potatoes market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	666.72	0.00	0.00	0.00	866.74	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 8.

Linear programming model detailed results Scenario 4.

Table 14. Polyperiod linear programming model results: Low (Ksh80), medium (Ksh140) and high (Ksh150) price of poles, high yield Grevillea and no sweet potato land constraint.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize and beans	Ksh	3.41	3.66	3.66	3.66	3.41	3.66	3.66	3.66	3.66	3.66
	Household consumption of maize	90 kg bag	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33	5.33
	Household consumption of beans	90 kg bag	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	Sell maize on farm gate	90 kg bag	49.09	52.97	52.97	52.97	49.09	52.97	52.97	52.97	52.97	52.97
	Sell beans on farm gate	90 kg bag	4.34	4.73	4.73	4.73	4.34	4.73	4.73	4.73	4.73	4.73
	Buy maize market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow Euc poles	Ksh	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	Grow euc Firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow grevillea for firewood	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 14 (cont'd)

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 2	Grow beans without fertilizer S2	Ksh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Grow sweet potato No fertilizer	Ksh	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
	Household consumption of beans	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Household consumption of sweet potatoes	90 kg sack	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
	Sell beans on farm gate	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Buy beans market	90 kg bag	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
	Sell sweet potatoes farm gate	90 kg bag	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67	250.67
	Buy sweet potatoes market	90 kg bag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell timber products poles	No. Poles	0.00	0.00	0.00	344.70	0.00	0.00	0.00	448.10	0.00	0.00
	Sell wood fuel Eucalyptus	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sell wood fuel Grevillea	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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