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Food vs. Wood: Dynamic Choices for Kenyan Smallholders

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Abstract

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.

Keywords: linear programming, farm forestry, Kenya

1. 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 (Rudel, 2009). Exotic tree species such as *Eucalyptus spp* grow fast, so planting them can reward farmers with a rapid income flow from their investment, Eucalyptus has been found as a profitable alternative to farmers in several studies in developing countries (Jagger, Pender, & Gebremedhin, 2005; Jalota & Sangha, 2000; Kihiyo, 1996; Sharawi, 2006), however information on profitability of agroforestry systems for developing countries is still scarce (Hoch, Pokorny, & Jong, 2012). Further information is required to inform scientists, policy makers and stakeholders interested in the promotion of agroforestry systems with native tree species for soil and water conservation, for carbon sequestration schemes, and biodiversity conservation.

Profitability is an important driver of farmers' decision on planting trees, but it is not the only one. Decisions on planting trees also depend on other factors such as size of landholdings, labor availability, the price of eucalyptus wood, the prices of alternative crops, ease of planting and maintenance, access to credit, off-farm income, forested area, formal settlement, farm characteristics, and risk of price changes (Amacher, Merry, & Bowman, 2009; Amatayakul & Azar, 2008; Shively, 1999).

Farmers confront constraints to planting trees for timber and other purposes. When planting trees, they also deal with tradeoffs between planting trees and crops (e.g. land and labor allocation), and between different tree species (e.g., exotic vs. indigenous). When choosing to plant trees, farmers give up land for growing crops that provide both food and cash(Dhakal, Cockfield, & Maraseni, 2012). 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 in the last decades (Jose, 2011; Kehlenbeck, Kindt, Sinclair, Simons, & Jamnadass, 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). Eucalyptus grows fast, and products from these 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 (Cheboiyo & Langat, 2006). Farmers also perceive that the exotic tree species require less labor and are easy to manage (Shively, 1999).

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 & 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 (Broadhead, Ong, & Black, 2003; Calder, Hall, & Prasanna, 1993). 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, 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.

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. Previous studies have made use linear programming methods to determine the trade-offs that farmers face, however these studies have usually considered one tree species versus one alternative crop (Amatayakul & Azar, 2008; Bertomeu, Bertomeu, & Giménez, 2006; Lilieholm & Reeves, 1991; Muchiri, Pukkala, & Miina, 2002).

This paper aims to develop 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. It also goes further in analyzing whether discount rates influence decisions on planting eucalyptus versus annual food crops. 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.

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. It aims to provide information on the profitability of exotic tree species and shade light on the trade offs smallholder farmers face, not only in terms of resources allocation, but also in their choice of tree rotation.

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:

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

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

Where the subscript 1 refers to annual crops, and the subscript 2 refers to trees, Q refers to the quantity planted, L to the labor requirements, T to the amount of land, and K to working capital required for production, the subscript t refers to the time period considered.

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:

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

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:

$$(L_{1t} + L_{2t}) \le \overline{L_t} \tag{4}$$

$$(T_{1t} + T_{2t}) \le \overline{T_t} \tag{5}$$

$$(K_{1t} + K_{2t}) \le \overline{K_t} \tag{6}$$

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 lagrangian 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 & Norton, 1986).

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

$$-\frac{P_{1t}}{P_{2t}} = \frac{\frac{\partial Q_{2t}}{\partial L_{2t}}}{\frac{\partial Q_{1t}}{\partial L_{1t}}} = \frac{\frac{\partial Q_{2t}}{\partial T_{2t}}}{\frac{\partial Q_{1t}}{\partial T_{1t}}} = \frac{\frac{\partial Q_{2t}}{\partial K_{2t}}}{\frac{\partial Q_{1t}}{\partial K_{1t}}} \tag{8}$$

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 optimality condition in equation (8), we can interpret the different tradeoffs for the farm activities. 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.

1.1 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.

1.2 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 the conditions of 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 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.

The empirical model provides an exogenous initial endowment of working capital for starting farming activities of Ksh20,000, US$307 (US$1=Ksh65) 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.

2. 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. From this list we formed groups of farmers to participate in the focus groups.

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 zones, 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 main findings from the focus groups and individual interviews are use throughout this text.

The study farms are located close to the Equator, between coordinates S 0º 21' and S 0º 23' and the E 35º 02' and E 35º 03'. The altitude is between 1,600 and 1,700 meters above sea level. 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 secured; farmers have a legal title over their land. 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 in small woodlots, grevillea in hedgerows on farm boundaries, and vegetables and fruit trees such as avocado and papaya in small farm gardens.

In general, farmers sell their products at farm gate. Transportation costs are high due to the high prices of fuel, and farmers prefer donkeys for taking produce to local markets and the road infrastructure linking farmers to markets is very poor. Farmers 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.

2.1 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.

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.

2.2 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 and grevillea 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, 1998). At the study site, sweet potato is mainly grown by women who share tubers for growing this crop.

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.

2.3 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. Because wood yield data from Kenya are unavailable, we use data from two neighboring countries. Data on yields for eucalyptus 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 trees are from Rwanda (Kalinganire, 1996). First we introduce grevillea 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.

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.

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) tillage (1st and 2nd) S1	400	87				
Labor (July-August) tillage S2 (1st and 2nd) - 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 correspond only to the amount of labor allocated for this activity on 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 bean season 1 with fertilizer*	Maize 90 kg bag	1,800	2,400	15.95	7,096
	Bean 90 kg bag	3,200	4,000	1.59	
Bean season 2 without fertilizer	Bean 90 kg bag	2,250	4,000	3.34	1,315
Sweet potato season 2 without fertilizer	Sweet potato 90 kg bag	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 x6.5 m	80	1,089	1,416	4,481
	10cm x6.5 m	140	1,089	1,416	4,481
	10cm x6.5 m	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

2.4 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, 2000).

2.5 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 before, sensitivity analysis was conducted varying the prices of eucalyptus poles.

3. Results

The PLP model incorporates activities for production consumption and selling of maize, beans and sweet potatoes, as well as for production 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 is binding for weeding crops and growing trees on these years, and with 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 value 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.

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, 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 was tested, at different prices per eucalyptus poles. 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.

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).

Table 4. Land allocation under the different model scenarios

			Scenarios											
	Activity	Unit	1. Baseline			2. Sweet potato land restricted			3. No sweet potatoes land restricted			4. 50% discount rate		
Scenario Traits	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
	NPV (1000s)	Ksh	743	776	805	770	776	805	157	1,581	1,592	652	659	661
Solutions	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 for 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 no 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 no 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

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

Source: Author’s calculation using Focus Groups and individual with farmers and individual interviews, Upper Awach, July 2008.

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 for 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 the 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 price, 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 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 and an alternative highly profitable annual crop such as sweet potatoes. The exclusion of savage value for poles in year 10, for poles that still growing 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 closed 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.

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 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 poles production, a representative farmer will still grow annual crops.

4. Discussion and conclusion

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 & Lesch, 1997), precipitation in the highlands of western Kenya appears to be sufficient to avoid this problem in most years (Note 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.

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 different tree species affects farmer decisions on planting different tree species. In Kenya, The Agriculture (Farm Forestry) Rules, introduced in 2009 (Note 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 required an understanding of private farmers' incentives when choosing among different alternatives.

Finally, understanding the constraint decision making process of allocation of land and labor to tree planting, and the high profitability of short term rotation fast growing trees such as eucalyptus, provides information for those interested in implementing carbon offsets schemes. Smallholder farmers' participation on these schemes is a challenge due to the long term period they have to wait to obtain returns from their investments (Jose, 2011; Susaeta, Lal, Alavalapati, Mercer, & Carter, 2012). It also informs agroforestry schemes for biodiversity conservation, since it implies that native trees that might be part of the habitat of endemic species, and insect population are not the first choice for farmers (Jose, 2011). Due to the importance of native tree species for preserving biodiversity, there is a need for more information to promote these trees, but there are limitations to the analysis due to lack of information of rates of growth, costs and prices of native species.

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Notes

Note 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.

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