Food vs. Wood: Dynamic Choices for Kenyan Smallholders

M. Alexandra Peralta and Scott M. Swinton*

Michigan State University
Department of Agricultural, Food and Resource Economics

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2009 AAEA & ACCI Joint Annual Meeting, Milwaukee, WI, July 26-28, 2009.

* Alexandra Peralta (peralta3@msu.edu) is an M.S. student and Scott M. Swinton (swintons@msu.edu) is Professor in the Department of Agricultural, Food and Resource Economics, Michigan State University, 202 Agricultural Hall, East Lansing, MI 48824-1039.

The authors are grateful for material and financial support from the Pro-Poor Rewards for Environmental Services in Africa (PRESA) at the International Agrofrestry Center (ICRAF), the Challenge Program for Water and Food (CPWF) at the International Center for Tropical Agriculture (CIAT) and the Department of Agricultural, Food and Resource Economics at Michigan State University. We thank Brent Swallow and Nancy Johnson for scientific support, Fredah Maina, Wilson Nindo, Joyce Kasyoki and Katherine Kimengu, for logistic support of the field work and the farmers of Kaplelartet for their hospitality and collaboration.

Abstract: Food vs. Wood: Dynamic Choices for Kenyan Smallholders

Smallholder farmers in 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 occupy land that could produce annual food crops. Eucalyptus is one fast-growing tree species that is grown globally, including in East Africa. This study uses a polyperiod linear programming whole-farm model to explore the opportunity cost of planting eucalyptus trees versus crops in the Nyando watershed of western Kenya. The model indicates that over a ten-year time horizon, a profit maximizing representative farmer would allocate 30 percent of a 4-acre farm to producing eucalyptus poles, a typical level reported in farmer individual interviews. Depending on the price of poles, land planted to eucalyptus ranged from 8 to 80 percent. Firewood was less remunerative and did not enter the solution unless poles were excluded. The results are consistent with observed behavior, suggesting that smallholder farmers in western Kenya are responsive to relative prices between timber tree products and crops, and that they grow eucalyptus for its high profitability in the medium term. Timber production is not likely to replace food crops given the high cost of meeting household subsistence requirements from marketed grains.

JEL classification code: O13, Q12

Keywords: agroforestry, eucalyptus, food security, Kenya, linear programming, smallholder agriculture, whole farm model

Food vs. Wood: Dynamic Choices for Kenyan Smallholders

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 for *Eucalyptus tereticornis* were found to reach Rs. 1,340,000 per hectare in plantations of 6-8 year old trees, and are almost three times greater than returns for *Dalbergia sisso* plantations with trees of the same age (Jalota and Sangha, 2000). In Sudan, comparisons on profitability of *Eucalyptus*, *Acacia* and bananas found that the net present value (NPV) of investments was higher for Eucalyptus compared with the other two choices (Sharawi, 2006).

When choosing to plant trees, farmers give up land for growing crops that provide both food and cash. Although the studies mentioned above have explored the profitability of *Eucalyptus* in the tropics, the opportunity cost of growing eucalyptus instead of food crops needs to be explored.

Western Kenya is one area where the planting of fast growing trees such as eucalyptus 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).

Therefore, farmers face a stark trade-off in deciding whether to allocate scarce land and working capital to plant eucalyptus for timber sales or annual crops for food. This paper explores the choices between crops and trees, given the land, labor, and capital constraints typical of a smallholder farmer in the Nyando watershed of western Kenya.

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, capital, labor and to subsistence food consumption requirements. The relation between relative prices of the outputs and the ratio of the marginal products of the inputs 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, maize and beans which are annual crops, and perennial trees for timber using available labor, land and variable capital. Therefore, the production functions are described as follows:

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

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

Where:

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

Q_{2t}: trees plated 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, period t
K_{t2}: working capital for trees, 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. Land dedicated to trees in period *t* depends, in turn, on land previously dedicated to trees in period *t-1*. In each time period the household can decide whether to devote more land to tree planting after harvesting the annual crops. Capital is required for planting and buying seedlings. 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 a profit function that is concave and twice differentiable:

$$\pi_t = \sum_{t=0}^{n} \{P_{1t}Q_{1t}(.) + P_{2t}Q_{2t}(.) - w_t(L_{1t} + L_{2t}) - r_t(K_{1t} + K_{2t})\} \tag{3}$$

P_{1t} and P_{2t} are farm gate prices of the annual crop (Q_{1t}) and timber (Q_{2t}) products, w_t is the market wage for agricultural labor activities and r_t is the opportunity cost of working capital. Therefore, the household revenues are determined by the prices and quantities produced of grains and timber. 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:

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

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

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

The amount of land and family labor 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 and perennial trees is fixed and restricted by land area dedicated to trees in the previous period. There is a fixed amount of working capital for the period that is required for variable inputs, including staring activities (6). Therefore, the inter-temporal constrained optimization problem becomes:

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

Where λ_{1t}, λ_{2t} and λ_{3t} are the Lagrange multipliers for labor, land and variable capital, and each of them determines the shadow prices of these resources (Hazell and Norton, 2000).

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

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

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

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

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

$$P_{1t}\frac{\partial Q_{1t}}{\partial K_{1t}} = r_t + \lambda_{3t} \quad \textit{and} \quad P_{2t}\frac{\partial Q_{2t}}{\partial K_{2t}} = r_t + \lambda_{3t}$$

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 resources will be allocated to annual crops and trees production until the marginal value products of these inputs are equal to their shadow prices. From the FOC, we can interpret the different trade offs for the farm activities, in equations (8), (9) and (10). The allocation of inputs available at 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 capital, land and labor 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 prices on the output mix and associated land allocation.

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 short-term products like eucalyptus poles (harvestable after 4 years) compare with more valuable but delayed products like 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 (4-6) over a ten year time horizon. 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 only beans are feasible. In the first year, crops and eucalyptus are planted. In the subsequent years, annual crops are planted and harvested. In the fourth and eight years, poles for construction can be harvested, while in the tenth year industrial firewood 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 also includes activities and constraints to carry over cash from one period to other. 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 discount rate of 10%, which is assumed to be the opportunity cost of capital. It corresponds to the interest rate from the Central Bank of Kenya for one year bonds in 2008.

The empirical model provides an initial endowment of working capital for starting farming activities. After that, working capital needs must be met from cash carried over from the previous year. Similarly, land that has been planted with *Eucalyptus* in year one remains under this activity in the next period, thereby diminishing the land area available for planting crops. It is also assumed that annual maize and bean crops are harvested 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 (at a higher cost to cover transportation costs and marketing margins). Crop production not consumed is sold at the farm gate each year; no surplus is left in storage.

Trees, on the other hand, are planted on year one and can be harvested for poles after four years, and again after eight years, due to the coppicing ability of the trees, with no associated replanting cost. Timber for industrial firewood 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.

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 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. The study farms are located close to the Equator, between S 0º 21' and S 0º 21' 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 secure. 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* on the farm boundaries, and vegetables and fruit trees such as avocado and papaya in small farm gardens.

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 the 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 90 kg bags of maize and beans, produce and sweet potatoes in tins, which are bags of two kg. The timber products are poles for construction and firewood for industrial use by a tea processor. Poles are bought by middle man 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 deducts transportation costs.

Production activities

The technology for producing maize and beans during the first season (S1) includes the use of a tractor for the first tillage and the use of oxen and plough for the second tillage. For planting beans 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 in S2. Activities for growing, buying, selling and consuming maize and beans 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. Trees are planted in year one, poles are harvested in years four and eight, while firewood is harvested in year 10.

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 and beans as well for *Eucalyptus grandis* trees. 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 and beans correspond to consumption levels 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 and beans, individual poles, and cubic meters of industrial firewood (after deduction of transportation cost). Prices are in Kenyan shillings (Ksh) of 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), 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 middle-man wants the timber, the bargaining abilities from both the middle-man and the farmer, and the best alternative source for the middle man to buy the timber he needs. Three prices for poles are reported in Table 3. The price for industrial firewood was held constant since the main buyer in the area is a tea factory, which pays a fixed price.

Results and discussion

The PLP model generated an annualized net income of KSh63,600, about US$980[1]. The GDP per capita for Kenya at PPP for 2007 was US$1550 (World Bank). Labor was constraining only in Year 1, when harvesting crops coincides with weeding tree seedlings. Land was binding for all periods and seasons, except for the season 1 of Year 1. Its shadow price was Ksh2,046 per acre in Year 1, very close to the reported annual rental rate in the area of Ksh2,000. The subsistence consumption constraint was also binding, with a value equal to the farm gate selling price of maize and beans.

The PLP model allocation of land between trees and annual food crops was sensitive to the price of timber. Sensitivity analysis to changes in pole prices was conducted using the range of farm gate prices for poles reported in Tabel 3 by farmers interviewed. The paper presents three eucalyptus pole price scenarios, *ceteris paribus*. The price scenarios are

[1] The exchange rate during July, 2008, was US$1.00 = Ksh65.

displayed on tables 4, 5 and 6 show that at a price of 80 Ksh per pole, the representative farmer allocates only 0.34 acres of land to eucalyptus trees, while if the price is Ksh150, the farmer allocates 3.45 acres of land. At the intermediate price of Ksh115 per pole, the representative farmer allocates 1.17 acres of land to tree planting, which is very close to the amount of land that a typical farmer allocates for eucalyptus wood lots.

Farmers will not plant trees for industrial firewood production at the current farm gate price of Ksh1,000 per cubic meter, even when poles were prices at only 80 Ksh 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.

In order to test whether the speed of returns would affect the land allocation between trees and food crops, in one scenario, only *Eucalyptus* planting for firewood production was considered. As shown in Table 7, the farmer will dedicate 0.34 acres of land to eucalyptus for firewood in this case. Compared with the results when eucalyptus for pole production is included, this result suggests that the time horizon does not matter as much as the high profitability of planting trees for poles.

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 at a 10% annual discount rate, particularly given the coppicing capacity of the trees. Coppicing is limited, since after two or three rotations tree yields will drop, but that is beyond the ten-year time horizon modeled. The model 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. 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 and bean staples.

Conclusion

The literature on eucalyptus timber farming systems focuses on a cost benefit analysis, which does not incorporate limited farmer capital, labor and land resources. Moreover, that literature is quite scanty for Africa. This whole-far, dynamic analysis adds to the literature by incorporating these resource constraints and evaluating the effects of alternative price 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. Trees seem to be an choice preferred by better educated farmers; evidence suggests that farmers with secondary education levels in Uganda tend to diversify their livelihoods and invest in medium and long term investments, such as planting trees (Bamwerinde et al., 2006).

Trees also act as a saving strategy. 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 alternative. In the case of eucalyptus, it offers returns over a variety of time horizons. Like livestock, a traditional savings medium in many developing countries, trees build capital (Chambers and Leach, 1989). Savings in the form of trees serve as a source of liquidity when the household falls short of capital for planting annual crops, for paying school fees, health bills and 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. They rarely plant other tree species, which fail to provide comparably timber products as much or as rapidly as eucalyptus.

Future research should explore the long-term environmental impacts of eucalyptus planting compared to other tree species. 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 under in most years[2]. However, other private environmental costs of eucalyptus deserve attention, such as allelopathy toward crops and depletion of soil nutrients. Likewise, environmental externalities (both positive and negative) deserve attention, including 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.

[2] 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.

Table 1. Labor Schedule of activities per Acre, for planting annual crops (beans and maize) and *Eucalyptus*, upper Awach, western Kenya, 2008.

Labor schedule (S1=early season; S2=late season)	Constraint (hours)	Maize and beans Season 1 (hours)	Beans Season 2 (hours)	Eucalyptus trees (hours)
Crop planting S1 (Jan-March)	1200	53		
Crop weeding S1 & Tree planting (April-May)	800	165		160
Crop harvesting S1 - Tree 1st weeding (June)	400	109		77
Crop tillage S1 (Dec)	400	87		
Crop tillage S2 Tree 2nd weeding & seedling replacement (July-Aug)	800		71	72
Crop planting S2 (Sep)	400		53	
Crop weeding S2 (Oct)	400		53	
Crop harvest S2 (Nov)	400		71	

*The information on labor hours for Eucalyptus planting correspond only to the amount of labor allocated for this activity on period 1.
Source: Focus Groups with farmers and individual interviews, Upper Awach, July 2008.

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

Crop	Unit	Farm gate price (Ksh/bag)	Yield (bags/ac)	Variable Cost (Ksh)
Maize and beans season 1*	Maize bag 90 Kg	1,800	15.76	
	Beans bag 90 kg	3,200	1.17	7,169
Beans season 2	Beans bag 90 kg	2,250	3.34	1,315

Note: the prices and cost per acre correspond to Kenyan shillings (KSH) for 2008.
*Maize and beans are plated together during season 1

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

Tree product	Unit	Variable Cost of planting (Ksh/ac)	Yield (units/ac)	Coppicing yield (units/ac)	Farm gate prices (Ksh/unit)
					80
Poles	0.1 x7 m	4,481	1,089	1,416	115
					150
Firewood	m3	4,481	139	-	1,000

Note: Prices and cost are in Kenyan shillings (KSH) for 2008. Buyers incur harvest costs.

Table 4. Polyperiod linear programming model results: Low price of poles scenario.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize+beans	Acres	3.41	3.66	3.66	3.66	3.41	3.66	3.66	3.66	3.66	3.66
	Home consumption of maize	90 kg bag	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell maize at farm gate	90 kg bag	48.76	52.60	52.60	52.60	48.76	52.60	52.60	52.60	52.60	52.60
	Sell beans at farm gate	90 kg bag	3.49	3.77	3.77	3.77	3.49	3.77	3.77	3.77	3.77	3.77
	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	Acres	0.34	0.34	0.34	0.34	0.34	0.34	0.34	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
Season 2	Grow beans	Acres	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell beans at farm gate	90 kg bag	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
	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
	Sell poles	No. Poles	0.00	0.00	0.00	375.34	0.00	0.00	0.00	487.94	0.00	0.00
	Sell firewood	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Polyperiod linear programming model results: Medium price of poles scenario.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize+beans	Acres	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
	Home consumption of maize	90 kg bag	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell maize at farm gate	90 kg bag	39.59	39.59	39.59	39.59	39.59	39.59	39.59	39.59	39.59	39.59
	Sell beans at farm gate	90 kg bag	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81
	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	Acres	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
	Grow euc Firewood	Acres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Season 2	Grow beans	Acres	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell beans at farm gate	90 kg bag	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73
	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
	Sell poles	No. Poles	0.00	0.00	0.00	1273.94	0.00	0.00	0.00	1656.12	0.00	0.00
	Sell firewood	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Polyperiod linear programming model results: High price of poles scenario.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize+beans	Acres	0.43	0.43	0.43	0.43	0.32	0.32	0.32	0.32	0.32	0.32
	Home consumption of maize	90 kg bag	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell maize at farm gate	90 kg bag	1.75	1.75	1.75	1.75	0.00	0.00	0.00	0.00	0.00	0.00
	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 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	0.13	0.13	0.13	0.13	0.13	0.13
	Grow Euc poles	Acres	3.57	3.57	3.57	3.57	3.68	3.68	3.68	3.68	3.68	3.68
	Grow euc Firewood	Acres	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Season 2	Grow beans	Acres	0.43	0.43	0.43	0.43	0.32	0.32	0.32	0.32	0.32	0.32
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell beans at farm gate	90 kg bag	0.14	0.14	0.14	0.14	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	0.03	0.03	0.03	0.03	0.03	0.03
	Sell poles	No. Poles	0.00	0.00	0.00	3889.74	0.00	0.00	0.00	5213.46	0.00	0.00
	Sell firewood	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: No poles production scenario.

			Years									
	Activity	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Season 1	Grow maize+beans	Acres	3.41	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
	Home consumption of maize	90 kg bag	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell maize at farm gate	90 kg bag	48.76	52.60	52.60	52.60	52.60	52.60	52.60	52.60	52.60	52.60
	Sell beans at farm gate	90 kg bag	3.49	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77
	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 Firewood	Acres	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Season 2	Grow beans	Acres	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
	Home consumption of beans	90 kg bag	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	Sell beans at farm gate	90 kg bag	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
	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
	Sell firewood	M3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.08

References

Bamwerinde, W., B. Bashaasha, W. Ssembajjwe, and F. Place 2006. “The Puzzle of Idle Land in the Densely Populated Kigezi Highlands of Southwestern Uganda”. *International Journal of Environmental Development* 1(3): 1-13.

Chambers, L. and M. Leach. 1989. “Trees as Savings and Security for the Rural Poor”. World Development”. *World Development* 17(3): 329-342.

Cheboiwo, J. and D. Langat. 2006. “Profitability of *Eucalyptus* Growing in Central and South Rift Valley”. In: *Proceeding of Stakeholders Workshop for Western and North Rift Regional held in Moi University on 17th November, 2006*. Unpublished. Kenya Forest Research Institute KEFRI. Londiani.

Fafchamps, M. 1998. “Ethnicity and Credit in African Manufacturing”. *Journal of Development Economics.* 61: 205–235.

Food and Agriculture Organization of the United Nations, FAO. 1979. *Eucalypts for Planting.* Rome: Food and Agriculture Organization of the United Nations, FAO.

Hazell, P., and Norton, R. 1986. *Mathematical Programming for Economic Analysis in Agriculture*. New York: Macmillan Publishing Company.

International Center for Agroforestry, ICRAF. 2003. "Rising Preference for E*ucalyptus* Poses Dilemma in Eastern Africa". Policy Brief. http://www.relma.org/pdfs/Eucalyptus_policy_brief.pdf

Jalota, R. K., and K. K. Sangha. 2000. "Comparative Ecological-economic Analysis of Growth Performance of Exotic *Eucalyptus tereticornis* and Indigenous *Dalbergia sissoo* in Mono-culture Plantations". *Ecological Economics* 33: 487–495.

Kuyah, S. 2007. Comparative Performance and Water Use of *Eucalyptus grandis*, *Eucalyptus hybrids*, *Grevillea Robusta* and *Cordia Africana*. MS thesis. Jomo Kenyatta University of Agriculture and Technology. Nairobi.

Labarta, R., D. White and S.M. Swinton. 2008. "Does Charcoal Production Slow Agricultural Expansion into the Peruvian Amazon Rainforest?" *World Development*. 36(3): 527-540.

National Academy of Sciences. 1980. *Firewood Crops: Shrub and Tree Species for Energy Production*. Washington: National Academy of Sciences.

Nindo, W. 2008. "Focus Groups Transcriptions, Upper Awach Western Kenya." Unpublished. Kisumu: International Agricultural Research Institute, ICRAF.

Niskanen, A. 1998. “Value of External Environmental Impacts of Reforestation in Thailand”. *Ecological Economics.* 26: 287–297.

Rudel, T.K. 2009. “Tree Farms: Driving Forces and Regional Patterns in the Global Expansion of Forest Plantations.” *Land Use Policy* 26: 545-550.

Scott, D. 1997. Streamflow Responses to Afforestation with *Eucalypfus grundis* and *Pinus putula* and to Felling in the Mokobulaan Experimental Catchments, South Africa. *Journal of Hydrology*. 199 : 360-377

Sharawi, H.A. 2006. Optimal Land-use Allocation in Central Sudan. *Forest Policy and Economics*. 8: 10– 21.