MODELING AGROFORESTRY ADOPTION AND HOUSEHOLD DECISION MAKING IN MALAWI

P.H. THANGATA *, P.E. HILDEBRAND**, C.H. GLADWIN***

*College of Natural Resources and Environment, Interdisciplinary Ecology Program ,
University of Florida,103 Black Hall, Gainesville,FL 32611-6455, USA
**International Programs-IFAS and Department of Food and Resource Economics,
University of Florida, 2126 McCarty C Hall, Gainesville FL 32611-0410, USA
*Department of Food and Resource Economics, University of Florida, G155 McCarty A Hall, Gainesville, FL 32611-0410, USA

Abstract

Low resource farmers make decisions about adopting new technologies as part of the overall strategy for ensuring subsistence and cash income for their food security needs. This paper reports on a study conducted in Malawi, southern Africa, to evaluate the potential for small-scale farmers to adopt improved fallows. Simulations of two representative households, a male and a female headed, were carried out using dynamic ethnographic linear programming in a ten-year model. Results show that the adoption pattern for improved fallows differs between male and female-headed households. Adoption of improved fallows is more likely to happen in male-headed households because they have more labor. However, female-headed households with adolescent male children that contribute to the family labor force may also adopt the technology. Additionally, female-headed households with insufficient labor may hire labor for other cropping activities, which enables them to plant improved fallows. Furthermore, simulations show that when households are able to sell seed from the fallows, both male and female households stop taking farm credit; they still grow tobacco, the cash crop, and produce most of their maize without chemical fertilizers. It is concluded that, in Malawi, improved fallows will only be adopted if they have multiple benefits and in households with enough labor.

Keywords:Ethnographic linear programming, Improved fallow, Agroforestry, Modeling.

1. Introduction

Soil fertility depletion is considered a major constraint for smallholder farmers in nutrient–poor tropical soils, especially in sub-Saharan Africa (SSA). High population pressure has led to land shortages and continuous arable cultivation without fallowing, leading to high nutrient losses in Malawi where agriculture is the mainstay of the economy. About 85% of the population in Malawi is rural and is dependent on agriculture. Long duration natural fallows that were traditionally used to overcome soil fertility depletion (Nye and Greenland, 1960) are no longer possible due to increasing population pressures on the land. The decline in soil fertility has led to reduced soil productivity and hence more food insecure households. However, agroforestry has the potential to improve soil fertility through the maintenance or increase of soil organic matter and biological N_2 fixing from nitrogen fixing tree species (Young, 1997). Apart from the decline in soil fertility, institutional constraints such as structural adjustment programs (SAPs) required by the World Bank and other donors have also had an impact on food security in Malawi and other developing countries.

Fertilizer prices have risen sharply in Malawi since the removal of fertilizer subsidies in 1994 and 1995 (Zeller et al., 1998). Farmers are able to purchase very little fertilizer, if any at all. Most affected are women, who account for over 70% of the food production group

(Quisumbing et al., 1995) and who grow most of the subsistence food crops. The major production goal for most small-scale farming households is to secure sufficient food supplies for their families. They pursue diverse food procurement strategies in order to first suffice home needs, and then sell any surpluses. The different strategies pursued have significant implications for the types of technologies farmers are able to adopt. For example, the introduction of a new technology, such as agroforestry, may require more labor than is available.

Studies have indicated a number of reasons for greater sustainability and productivity of agroforestry systems in comparison with other cropping systems. Agroforestry systems tend to optimize ecological and economic concerns to obtain higher, more diversified, and more sustainable total production than is possible with a single land use (Ffolliott et al., 1995). Agroforestry provides diversified outputs for smallholder farmers in the form of fuelwood, poles and in some cases can provide a more diverse farm income by reducing risks of food insecurity. When agroforestry is used for conservation, soil is protected from erosion and improves its productive potential. The roots of agroforestry trees along rivers can filter contaminated groundwater. If used as a windbreak, agricultural crops and grazing animals are protected from detrimental effects of wind.

Research in southern Africa has shown that some farmers are adopting improved fallows, a system where short duration trees or herbaceous species are planted in rotation with cultivated crops to achieve soil fertility replenishment benefits of natural fallows (Sanchez, 1995). Sesbania [*Sesbania sesban* (L) Merr.], and tephrosia (*Tephrosia vogelii* are fast-growing, leguminous, nitrogen-fixing trees and woody shrubs respectively; and in an improved fallow system have been reported to provide nutrient inputs and increase yields of subsequent crops and produce fuelwood (Sanchez, 1995). These fallows not only have the potential to replenish soil fertility and thereby increase crop yields, but can also control soil erosion (Kwesiga, et. al., 1999). However, to increase acceptability and promote wider adoption of improved fallows by resource-poor farmers, it is important to identify and analyze factors that affect the technology’s adoptability for farm households with differing characteristics such as household composition and gender of the household head.

The conventional criterion in technology evaluation is yield per hectare. This implies that land is the most limiting resource on the farm and therefore land productivity is the most important evaluation criterion. This is not always the case. Nor is the same constraint necessarily the most limiting for different crops (Hildebrand and Poey, 1985). Other limiting constraints, such as labor or cash, have been known to affect overall farm production. Most studies on agroforestry have focused on single crops from researcher-managed trials. Such types of research disregard other food or cash crops that are in the farming system. Farmers’ decision making about the choice and management of agroforestry practices has been shown to be an integral part of the overall strategy for ensuring subsistence, cash income, and savings in many farming systems. Scherr (1992) has argued that agroforestry development efforts fail due to a mismatch between the interventions promoted and farmer incentives to practice them.

Gender also plays a role in the adoption of technologies. Differences in the household's access to financial and commodity markets significantly influence the hectarage of crops and farm income (Zeller et al., 1998). Relatively, women get lower crop yields than men, due to differences in the intensity of input use such as inorganic fertilizers, labor, credit, and extension education However, given the same resources, Adesina and Djato (1997) found no differences in the efficiency of men and women in African agriculture and concluded that women are equally good farm managers as men. When women have control over resources, they tend to use them differently than men, often spending more on their children, with different results for the welfare of the household (Frankenberger and Coyle, 1992). Their choice of cropping activities is therefore different from that of the males. A deeper understanding of household decision-making will help policy makers and technology developers target individuals in the most effective way.

This paper reports on a study carried out to evaluate the potential for small-scale farmers to adopt improved fallows of sesbania and tephrosia, which have recently been introduced by ICRAF in Malawi. Linear programming (LP) is used to assess whether it is feasible and economically viable for smallholder farmers to adopt improved fallows. The next section of the paper gives an outline of the study methodology. Section three establishes the model framework. Section four is the modeling approach while section five covers the results. Finally the paper ends with conclusions and discussion in section six.

2. Methodology

2.1. The study Area

The research was conducted at two extension planning areas, Chulu and Kasungu–Chipala, in Kasungu, central Malawi. The main land use system for Kasungu is maize cropping with tobacco as the cash crop. Although people in this area used to own livestock, most have been sold as a coping strategy or to pay for agricultural loans in bad years. The climate is tropical and predominant soils are oxisols, ultisols and alfisols (USDA taxonomy) (Young and Brown, 1962). The rainfall pattern is unimodal with the wet season running from November/December to March/April with erratic rains, ranging from 500 to 1200 mm per year, and a prolonged dry season.

2.2. Data collection

Data collection occurred between September and December 1999 and again between June and August 2001. Primary data collected in 1999 involved household surveys, sondeos (Hildebrand, 1981) and informal interviews to produce data for linear programming models. First, meetings were held with extension workers. Group meetings followed with farmers from the two areas. Later, using structured and semi-structured questionnaires, detailed formal interviews were conducted with ten (10) randomly sampled households. In line with FSRE philosophy, different households were selected so that they could eventually serve as representations of different recommendation domains (Hildebrand and Russell, 1996). For consistency, the first author conducted all the interviews. Linear programming (LP) models were developed for each of the ten households interviewed. Only two representative households are reported in this paper. Agronomic data such as yields from the first year after fallows were obtained with the help of Malawi Agroforestry Extension Project (MAFE). Secondary data were gathered from ICRAF, MAFE and the Kasungu Agricultural Development Division. In 2001, the ten households interviewed in 1999 were re-visited to test the models' prediction ability, and to validate and check areas where the models needed improvements. Discussions were held with farmers to see whether the models' preliminary output results adequately depicted what they produce and how they produce it. Another 31 farmers were interviewed to ascertain the labor data and to check how well the models selected from the households interviewed in 1999 represent the community by comparing the household compositions, labor availability and food requirements.

3. Model framework

3.1. Model development and specification

The LP models used in this study are ethnographic in nature (Kaya et. al., 2000). Ethnographic linear programming (ELP) is an adaptation of linear programming that has been developed at the University of Florida by Hildebrand and associates. ELPs are a means of quantifying ethnographic data, mostly qualitative, and are both descriptive and analytic. Ethnographic linear programming (ELP) models have an advantage of helping researchers understand the complexity and diversity of smallholder farming systems. ELP simulates the farmers' strategies by handling different technological alternatives representing different degrees of crop intensity, labor and /or land saving techniques available, taking into account their respective costs, constraints and advantages.

Model size reflects the detailed specification of the relationships of different activities being represented. The model was implemented in Microsoft Excel spreadsheet. Microsoft Visual Basic was used to make calling and solving different households easy and flexible. The premium add-in solver (Frontline Systems, 2000) for Excel was used to handle the large number of variables. The objective function in the ELP is represented by the general format:

$$\begin{aligned} &\text{maximize} \quad && z = cx \\ &\text{subject to} \quad && Ax \leq b \\ & && x \geq 0 \end{aligned}$$

where z is the farm end year cash, c is the row vector of enterprise end year cash, x is a column vector of enterprise levels (all x's are equal to or greater than zero). A is a matrix of technical coefficients and b is a column vector of farm resource endowments, right hand side (RHS).

3.2. Objective function

The objective function is to maximize farm discretionary cash income (z) after necessary cash expenses are met subject to assurance of food security in the household under constraints such as land, labor and cash for necessary expenses (b). A constraint in the RHS of consumption units reflects the need for the households to first satisfy household food requirements before considering marketing any surplus. Minimum food requirements for the household are specified for each crop.

3.3. Assumptions of the model with respect to production activities

The model makes certain assumptions about smallholder production, based on details elicited from the farmers interviewed. For example, crops in Kasungu are assumed to be monocrops. Crops grown in Kasungu include maize, the staple food; tobacco, the cash crop; sweet potatoes, cassava, and groundnuts. Improved fallows of sesbania and tephrosia were considered as alternative cropping activities that can be planted every year and thus are also represented by columns in the matrix. Maize is either produced fertilized or non-fertilized, or following a two-year improved fallow of sesbania or tephrosia. Since the improved fallow trees can be planted every year, maize can come after the fallow plots every year after the second year. Tobacco, the main cash crop, is never planted after the fallow trees, because both sesbania and tephrosia are hosts to root knot nematode, and tobacco is susceptible to nematode attack. Due to storage and marketing problems, the model limits the production of sweet potatoes and cassava to 0.25 and 0.33 hectares respectively.

3.4. Cash and credit assumptions

The model also makes certain assumptions about the limits to farmers' use of cash and agricultural input credit. For example, in 2000/2001, the interest rate for loans was 55%, and only households that planted tobacco had access to agricultural credit. They also had limited cash available to them; hence the model assumes the total amount of cash inputs available is enough for one hectare of purchased fertilizer, seed, nursery chemicals, and transportation to the auction floors in the case of tobacco. The model assumes farmers, especially FHHs, split the fertilizer meant for tobacco and apply a portion of it on their maize crop. In cases where labor is hired, food is oftentimes provided, and this requirement also has to be met.

A borrowing activity is included such that, when needed, a household can borrow inputs and repay with interest at the end of the season. The model also allows for cash to be transferred from one year to the next to be used for purchasing agricultural inputs after satisfying household requirements. This activity allows the models to take only the required amount of credit depending on the farm's shortfall.

3.5. Labor assumptions

Similarly, the model makes assumptions about farmers' use of labor, again based on farmer reports. It is assumed that households, especially female headed households, hire labor from outside the region and pay them a lump sum payment at the end of the season after tobacco sales. The model separates labor inputs by gender and by month; and labor supply in any calendar month is the total amount of labor available from the contribution of all household members and hired labor. Because women are responsible for childcare, the number of infants (under 5 years old) reduces the female labor contribution in a household. For school-going adolescents, food consumption and labor contributed vary according to whether they stay at home or school during term time.

4. Modeling approach

To model gender differences in household composition, we simulate two representative households, a male-headed household (MHH) and a female headed household (FHH). The MHH is assumed to be composed of one adult male, one adult female and three adolescent children, two boys and one girl. The FHH is assumed to have one adult female and three adolescent girls. Both households have 3.5 hectares (ha) at their disposal for all their cropping activities. The households have the option to take credit in the form of farm inputs. Only the FHH hires labor; while the MHH does not because it is assumed to have enough labor.

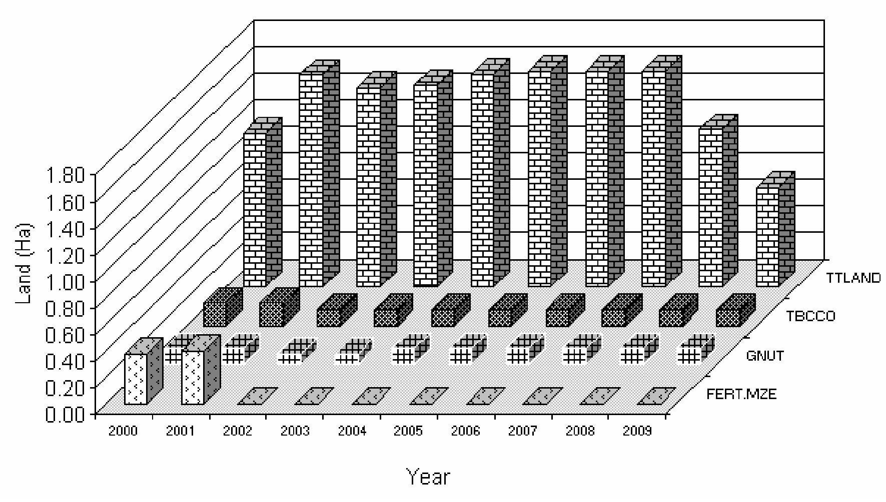
At the initial stage of diffusion of improved fallow technologies, ICRAF and other NGOs were buying sesbania and tephrosia seeds to give to other farmers. Sales of tree seeds amounts to a windfall profit for early adopters and a monetary incentive to adopt improved fallow technologies for late adopters. This was a temporary benefit, which has almost stopped. To evaluate whether this additional income from improved-fallow seeds enhances adoption, and to test under what conditions farmers adopt improved fallow technologies, we test two scenarios. In scenario 1, farmers do not sell sesbania or tephrosia seeds; in scenario 2, there is a market for the seeds. In both scenarios, simulations are run with all crops and both fallow species, and solved for the optimal resource allocation, to see if farmers adopt improved fallow technologies. The only difference between scenarios 1 and 2 is that scenario 2 allows the households to engage in selling sesbania and tephrosia seed both to their neighbors and to ICRAF personnel.

5. Results and discussion

5.1. Scenario 1. Simulations without seed selling activity.

Without the option of selling improved fallow seeds, the results of running scenario 1 of the LP simulations show FHHs plant maize and tobacco but do not plant more improved fallow plots than MHHs. In the first two years, the MHHs plant 0.38 ha and 0.39 ha respectively of fertilized maize (Figure 1a). In the third year both kinds of households reduce their tobacco loan amounts; this is reflected in the drop in tobacco hectarage from 0.17 to 0.12 for the MHHs and from 0.19 to 0.15 for the FHHs (Figures 1a and 1b).

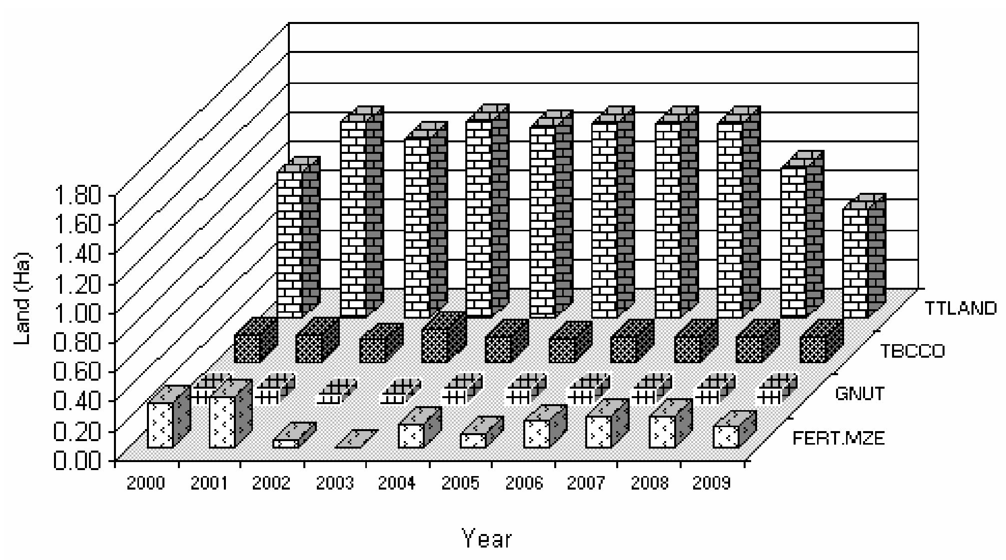
Figure 1a: Crop diversification and total land used by MHHs in scenario 1.



TTLAND=Total land, TBCCO= Tobacco, GNUT =Groundnut, FERTMZE= Fertilized maize.

A comparison of Figures 1a and 1b shows that FHHs plant more land in tobacco than MHHs, probably due to that fact that they need to meet household cash needs, pay for labor costs, and repay the tobacco loan. Hired labor results in the need for more maize in the FHHs, hence they take a loan to obtain fertilizer that is split between the tobacco and maize. The substantial reduction in the tobacco loan amounts for MHH in the third year is probably due to the fact that the MHH does not need to pay for hired labor costs, and therefore produces only enough tobacco to cover cash needs and repay the loan. The FHHs grow a substantial amount of groundnuts (0.12 ha) in all the years except for years 3 and 4 (0.08 ha each). Both kinds of households grow cassava and sweet potatoes for home consumption only.

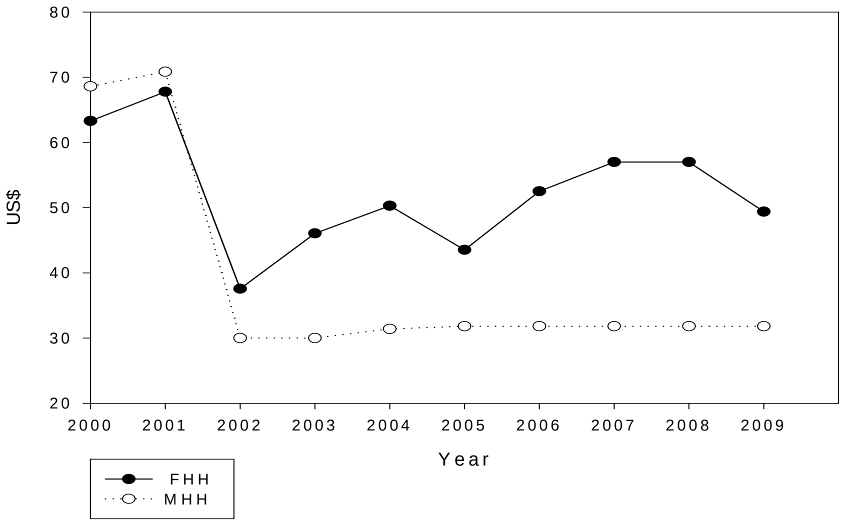
Figure 1b: Crop diversification and total land use by FHH before seed selling activity.



The decrease in tobacco land for the MHHs from 0.17 to 0.12 ha in the third year and later maintained throughout the 10-year period (Figure 1a) results in more fallow land. This can be due to the realization of the benefits from fallows to maize. To plant fallows, labor is hired by the FHHs to take care of other cropping activities like tobacco. The continued need for fertilized maize in the FHHs results in less fallows.

Since their only source of income is from tobacco, both FHH and MHH households grow tobacco each year. Without the option of selling improved fallow seeds and no other source of cash, FHHs have to grow tobacco and take tobacco loans with an interest rate of 55%. As shown in Figure 2, starting in year 3 FHHs take out more tobacco loans than MHHs. Since tobacco requires more male labor, FHHs must hire labor that has to be fed, and paid at the end of the season. Therefore it seems reasonable for FHHs to continue taking tobacco loans to grow tobacco and maize. There is no labor left for agroforestry, which will have its first benefit in the third year.

Figure 2: Changes in the amount of credit (US$) for MHHs and FHHs over a 10-year period without a seed selling activity.



Although FHHs hire labor to help in their farm operations, unlike their male counterparts, they put less land to improved fallows (Table1).

Table 1: A comparison of land for maize production from fallows (ha)

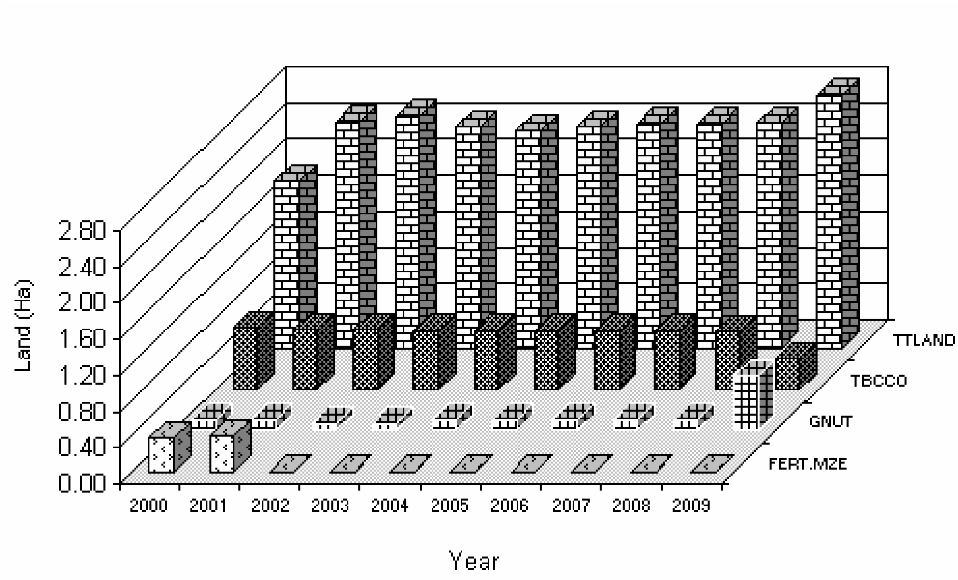
	Male headed household (MHH)			Female headed household (FHH)		
Year	No seed selling	Seed Selling	% Change	No seed selling	Seed Selling	% Change
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	0.42	0.60	31	0.29	0.34	17
2003	0.42	0.65	36	0.39	0.36	-7
2004	0.42	0.53	21	0.20	0.36	82
2005	0.43	0.49	11	0.29	0.38	32
2006	0.43	0.49	12	0.20	0.38	91
2007	0.43	0.50	13	0.20	0.42	109
2008	0.43	0.57	24	0.20	0.42	109
2009	0.43	0.57	24	0.27	0.42	52

The need for cash for home use dictates that they grow tobacco, which requires a loan, and the hired labor increases the maize needed. Fertilized maize yields more than fallow maize; hence they grew more fertilized maize in addition to fallow maize (Figure 1b). In contrast, MHHs plant more fallows, so they produce all their maize following fallows.

5.1. Scenario 2. Simulations with seed selling activity.

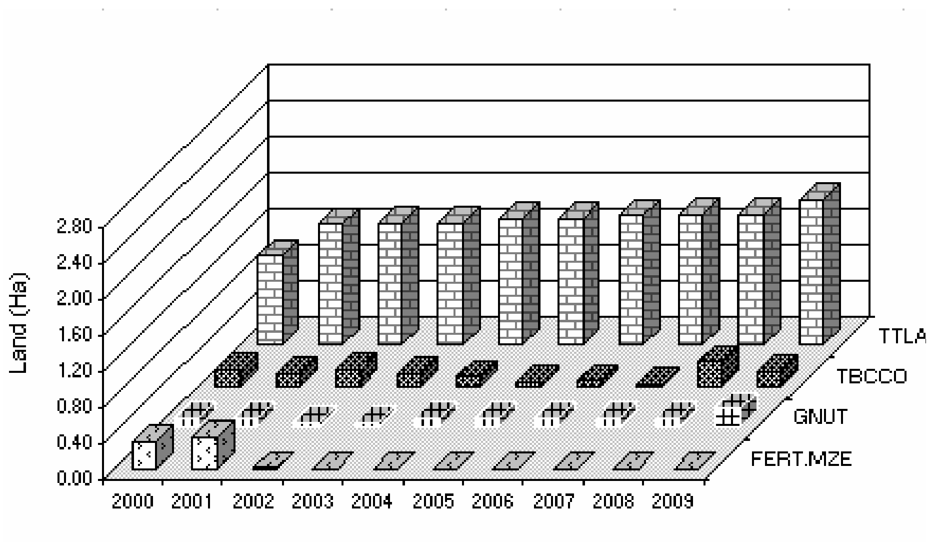
When an improved fallow seed-selling activity was added as an incentive in the model, MHHs do not take a loan after the first year. In this scenario, MHHs increase land for tobacco production to 0.65 ha and maintain groundnut production at 0.12ha, which increases to 0.60ha in the tenth year, 2009 (Figure 3a). Fallow land increases and fertilized maize follows the scenario 1 trend, being removed from the system in the second year the fallows start benefiting the MHHs (Figure 3a).

Figure 3a: Crop diversification and total land use by MHH after seed selling activity.



The increase in groundnut production by MHHs is encouraging. Groundnut does not require much labor and almost no inputs, unlike tobacco. It is now being considered as a replacement for tobacco in the farming system.

Figure 3b: Crop diversification and total land use by FHH after seed selling activity.



Further investigation of the models reveals that, in both cases, MHHs put more land to improved fallows than FHHs. When the seed selling activity is included, FHHs start planting more fallows (Figure 3b). Other crops like groundnut follow the MHHs trend, however at a reduced hectarage. Both households plant very small areas of cassava and sweet potatoes, except in year 10 when both start growing more for home consumption and sale.
The FHHs maintain production of 0.1 ha of groundnut, which increases to 0.2ha in the last year. In this scenario, the FHHs like the MHHs do not take a loan after the first year (Figure 3). Enough cash is generated from selling sesbania and tephrosia seeds, which results in the FHHs' no longer needing to take a loan for tobacco. Land allocated to tobacco is reduced substantially and almost no tobacco is grown in years 6-8 (2005-2007). After the second year they have enough cash to transfer to the next season's maize crop. They plant more fallows every season and all the maize for home consumption from the third year comes from the fallows (Table 1).

Conclusions and discussion

This study shows that land availability is not the primary constraint to crop production in Kasungu. Labor is the limiting resource and our results corroborate those of a study from Nigeria by Abdulkadri and Ajibefun (1998). MHHs with larger land holdings, more productive labor force and with access to credit facilities take inputs credit to grow cash crops and enough maize for home consumption**.** Since the MHHs have enough labor, they are also able to plant more improved fallows, and hence are more likely to adopt than FHHs. The FHHs are thus constrained by the access to labor and not land. We therefore concur with Scherr's (1992) observation that current agroforestry development efforts tend to overemphasize tree planting and high-intensity systems even where these are not congruent with farmer agroforestry incentives.
Studies of adoption from E. Zambia show that FHHs are more likely than MHHs to adopt improved fallows (Gladwin, 1999, Franzel, 1999). Our results suggest qualifying these findings, depending on whether FHHs have sufficient male family labor. Our analysis shows that FHHs without adolescent male children employ male labor for the tobacco growing activities, most of which are done by males. The male children take the role of a male head in these households, and provide labor for work demanded by crops like tobacco. This allows FHHs to spend their time planting improved fallows during the crucial rainy season rather than tobacco, in addition to other women's tasks such as fetching water, firewood collection, cooking and childrearing. It appears that in Malawi, adoption of improved fallows is more likely to happen in MHHs than in FHHs. If adoption does occur in FHHs, it will occur in those FHHs that have adult male children or cash to hire labor. Results also suggest adoption depends on available incentives, such as whether or not farmers can sell sesbania or tephrosia seeds, as in scenario 2, and thus make a windfall profit from adoption.
The results of this study concur with the results of Gladwin et al., (2001), who suggest that researchers should disaggregate households by household composition as well as gender, and recommend targeting new technologies at subgroups of rural women. Small scale farmers are not all alike, and will not respond equally to a technological intervention. This also applies to agroforestry innovations. In order to evaluate the adoptability of agroforestry technologies, it is necessary to determine the availability of labor in the household, which is an important factor in the degree of adoptability of improved fallows.
Finally, we would like to point out some of the limitations of linear programming. In this study we did not consider all the biophysical benefits from improved fallows and other factors like droughts that are unpredictable. However, as an additional benefit of the fallows, we included the sale of seeds that is a short-term benefit. The projects in the area bought the seeds to give to other farmers, but this is not a sustainable market since the seeds have no

other use, and once all the farmers have fallows, the seeds can no longer be bought.

References

ABDULKADRI AO, AJIBEFUN IA. 1998. Developing alternative farm plans for cropping system decision making. *Agricultural Systems* 56: 431-442.

ADESINA AA, DJATO KK.1997. Relative efficiency of women as farm managers: Profit function analysis in Cote d'Ivoire. *Agricultural Economics* 16: 47-53.

FRANKENBERGER TR, COYLE PE. 1992. Integrating household food security into farming systems research-extension. *J. of Farming System Research-Extension* 4:35-66

FRANZEL S. 1999. Socioeconomic factors affecting the adoption potential of improved fallows in Africa. *Agroforestry Systems* 4: 305-321.

FFOLLIOTT PF, BROOKS, KN, GREGERSEN HANSM, LUNDGREN.1995. *Dryland Forestry: Planning and Management.* John Wiley & Sons, Inc. New York, NY.

FRONTLINE SYSTEMS. 1999. Premium solver for Excel for Windows.

GLADWIN C, THOMSON AN, PETERSON JS, ANDERSON AS. 2001."Addressing food security in Africa via multiple strategies of women farmers."*Food Policy* 26:177-207.

HILDEBRAND PE. 1981. Combining disciplines in rapid appraisal. The *sondeo* approach *Agricultural Administration.* 8:423-432

HILDEBRAND PE, POEY F.1985. *On-farm Agronomic Trials in Farming Systems Research and Extension.* Lynne Rienner Publishers, Inc. Boulder, Colorado.

HILDEBRAND PE, RUSSELL JT.1996. *Adaptability analysis: a method for the Design, analysis and interpretation of on-farm research-extension.* Iowa State University Press, Ames Iowa.

KAYA B, HILDEBRAND PE, NAIR PKR. 2000. Modeling changes in farming Systems with the adoption of improved fallows in southern Mali *Agricultural Systems* 66:51-68.

KWESIGA F, FRANZEL S, PLACE F, PHIRI D, SIMWANZA CP.1999. *Sesbania sesban* improved fallows in Eastern Zambia: their inception, development and farmer enthusiasm. *Agroforestry Systems* 47: 49-66.

NYE PH, GREENLAND DJ. 1960. *The soil under shifting cultivation.* Technical. Communication No.51. Commonwealth Bureau of Soils, Harpenden, UK.

QUISUMBING AR, BROWN LR, FIELDSTEIN HS, HADDAD L, PENA C. 1995. *Women: The Key to Food Security*. IFPRI. Food Policy stat. No. 21.

SANCHEZ PA. 1995. Science in agroforestry. *Agroforestry Systems* 30: 5-55.

SCHERR SJ.1992. Not out of the woods yet: Challenges for economic research on agroforestry. *American Journal of Agricultural Economics* 74: 802-809.

YOUNG A, BROWN P. 1962. *The physical environment of Northern Malawi: with special reference to soils and agriculture.* Bulletin on Northern Malawi. Government printer. Zomba, Malawi.

YOUNG A.1997. *Agroforestry for Soil Conservation*. 2nd edition. CAB International, Oxford, UK.

ZELLER M, DIAGNE A, MATAYA C.1998. Market access by smallholder farmers in Malawi: implication for technology adoption, agricultural productivity and crop income. *Agricultural Economics*.19: 219-229.