

Household Determinants of Tree Planting on Farms in Rural Rwanda

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Abstract In Rwanda, trees on farms are widely recognized for increasing and diversifying farm productivity while releasing pressure on existing forests. However, the motivation of rural households to plant trees on farms is often unclear. This study evaluates rural households demographic and socio-economic characteristics, as well as their attitudes, that influence the presence of trees on farms. Data used in this study were collected from a survey of 480 households across three altitude regions of Rwanda. Binary logistic regression analysis using PASW Statistics was applied to determine relevant predictor variables for the presence of trees on farms. The results show regional variation in explaining the presence of trees on farms. When data from the three regions were analysed together, significant predictor variables comprise the gender of head of the household, the number of salaried members of the households, the amount of farm fuelwood, the number of meals per day, the geographical location of the households and the selling of tree products. The presence of different tree species on farms was driven by economic factors, of which availability of food, firewood, and poles, and total income were most common. The results of the study imply that policy measures that target food security and income diversification in rural areas may, at the same time, enhance tree planting. Moreover, it is concluded that rural development and extension in agriculture should be site specific, to account for bio-physical conditions and specific rural household motivations to plant trees on farms.

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Introduction

In many developing countries, forests are declining in area and the associated biodiversity and regulating functions are lost. To a large extent, this results from population increase, leading to high demand for agricultural land. In Africa, the net annual loss of forests exceeded 4 million hectares between 2000 and 2005 (FAO 2007). Cleveland (2008) reported both direct and indirect causes of deforestation. Agricultural expansion by subsistence farmers has been identified as a major factor in many studies on deforestation (e.g. Colchester and Lohmann 1993; Brown and Pearce 1994; Barraclough and Ghimire 1995; Palo and Mery 1996; Sponsel et al. 1996; Dubois 1997).

In Rwanda, where 90% of the population depends on agriculture for their livelihoods, the annual deforestation rate between 2000 and 2005 reached an alarming rate of almost 7%, which is very high even compared to the high average annual deforestation rate of 3.9% reported for Africa (FAO 2005). The main effect of deforestation is environmental degradation associated with such problems as soil erosion, soil fertility decline, climate change, biodiversity depletion and poverty. Environmental degradation is particularly acute when living conditions of poor households relying on natural resources as a basis for farming, building poles and energy production are concerned.

The development of sustainable agricultural technologies has been taken up to address the problems referred to above. Agroforestry using multipurpose trees in different regions of Rwanda have been evaluated before (e.g. Newmann and Pietrowicz 1986; Yamoah et al. 1989; Balasubramanian and Sekayange 1992; Roose et al. 1993; Niang et al. 1995; Burleigh and Yamoah 1997) and have shown to be promising for smallholder farmers.

On farms, different tree species may be present in form of scattered trees, along erosion control ditches, along contours, on farm boundaries, or established as rotational woodlots or blocks (Balasubramanian and Egli 1986; den Biggelaar 1996; den Biggelaar and Gold 1996). Such trees are managed in combination with crops in agroforestry systems and serve a number of ecological and economic functions that are partly similar to those of trees in forests, although different in extent (Kleinn 2000). However, the presence of trees on a limited amount of agricultural land may seriously interfere with crop production due to competition for scarce resources. Despite existence of trees in the agricultural landscape, and the competition interference with the crop, the motivation of farmers to plant trees on relatively small sized farms of less than 1 ha for 80% of farmlands (NISR 2010), is largely unknown.

Farm level studies can provide insights into the socio-economic factors and attitudes leading farmers to plant trees on farms. Issues concerning the adoption of agroforestry practices have been discussed in many studies (e.g. Godoy 1992; Adesina 1994; Alavalapati et al. 1995; Ayuk 1997; Franzel et al. 2001). In the Rwanda context, qualitative surveys identified the reasons why farmers planted trees on farms or adopted agroforestry technologies (e.g. von Behaim and Bezzola 1994;

Den Biggelaar 1996; Bigirimana 2002; Uwiragiye 2002; Tuyisenge 2003; NISR 2010). Many of these studies were conducted in different parts of the country using structured interviews or focus-group discussions. Research on adoption of agroforestry generally focused on social, biophysical and wealth parameters, leading to the ranking of constraints and benefits by rural households as well as priority areas for research (e.g. Djimde et al. 1988; Mukuralinda et al. 1999).

The development of agroforestry in Rwanda is among the guiding principles of the forest policy (MINIFOM 2010). The Rwanda government promotes farm forestry in order to curb depletion of forest resources, declining soil fertility and environmental degradation, and to contribute to solving the rural energy crisis, dealing with land scarcity, and preventing soil erosion. Achieving these goals requires attention to farmers' attitudes and decision making about planting of trees. Farmers' choices to grow trees depend on many social, cultural, economic and technical factors, and for interventions aimed at stimulating agroforestry practices to be successful, these factors must be understood. In addition, local situations are important to consider when examining why smallholder farmers grow trees in association with crops.

There is little information available on farmers' decisions about tree planting on farms and the perceptions and attitudes which influence their decision-making. To this end, we investigated the reasons why and when farmers are planting trees on their farms. Here, trees on farms refer to trees on farmlands other than those found in woodlots. The study focused on the low, medium and high altitude regions of Rwanda in order to account for regional differences in attitudes and motivations towards tree planting. The specific objectives of the study were: (1) to identify factors that lead farmers to plant trees in agricultural lands across the low, medium and high altitude regions of Rwanda, (2) to determine factors that may increase agricultural household motivations for tree planting on farms, and (3) to determine the most important aspects that households consider when deciding to plant different tree species on their farms. We presumed that an understanding of the process by which farmers make tree planting decisions may broaden the general farmers perception, and may lead to an increase in the number of trees grown on farms and the benefits the farmers may take from this. The findings of the research are believed to be useful to policy makers, researchers, development professionals and extension agents in developing and disseminating agroforestry technologies and practices that aim to meet the needs and demands of smallholder farmers.

Methods

Study Sites and Selection of Sample Households

Rwanda comprises three altitude regions characterized by elevations and rainfall (Gotanègre et al. 1974). The low altitude region (LAR) has altitude less than 1,500 m and rainfall less 1,000 mm. The medium altitude region (MAR) has an average altitude of 1,700 m with a maximum of 1,900 m, with rainfall between 1,000 and 1,250 mm. The high altitude region (HAR) covers the areas between 1,900 and 2,500 m, where annual rainfall ranges between 1,250 mm and more than 2,000 mm.

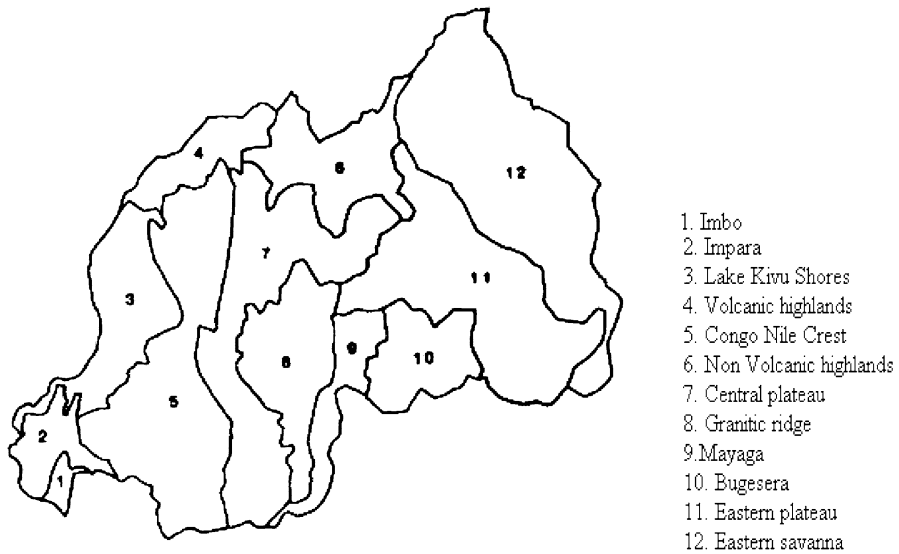


Fig. 1 Agro-ecological zones of Rwanda

Data for this study were gathered in these three regions, which were subdivided by Delepiere (1982) into 12 agro-ecological zones (Fig. 1), defined by altitudes, rainfall and soil characteristics (Table 1). Since the altitude regions cover large and disconnected areas, considerable heterogeneity exists in farmers' characteristics. The regions were further stratified in agroecological zones. Trees on farms along with agricultural crops are influenced by agro-ecological conditions, and the agroecological zoning invokes similarities with farming systems (Olson 1994). In order to capture the households' characteristics, a further stratification of the agroecological zones was made based on administrative units.¹ The administrative structure of Rwanda is organised into Districts, Sectors and Cells. The first two units were randomly selected from each agroecological zone. A single Cell within an administrative sector was chosen as the sampling unit. Since each cell is sparsely occupied by farming households that have different socioeconomic status, subgroups could not be formed. Therefore a different sampling scheme was adopted to select a random sample households for the survey.

Forty households were randomly selected in each cell (Table 1). In this sampling, the number of sample cells equalled the number of agroecological zones, and the total number of households arising from three to five corresponding agroecological zones, was considered to be representative of a particular altitude region. In fact, agricultural and agroforestry practices within each altitude region are relatively uniform in terms of households' needs, interests, opportunities and constraints as was reported in many survey studies (e.g. Djimde et al. 1988; Niang and Styger

¹ The Republic of Rwanda comprises four Provinces and the City of Kigali, divided into 30 districts, which are subdivided into 416 sectors, which are further subdivided into 2,148 cells. The cell is the smallest politico-administrative unit of the country and hence closest to the people.

Table 1 Characteristics of the different agroecological zones and corresponding number of interview households

Agroecological zones by altitudinal regions	Altitude (m)	Rainfall (mm)	Soil groups (FAO 2006)	Number of sample households
Low altitudinal region				200
Bugesera	1,300–1,500	700–900	Nitrosols and ferralsols	40
Eastern Plateau	1,400–1,800	900–1,000	Ferralsols	40
Eastern Savanna	1,250–1,600	800–900	Nitrosols and ferralsols	40
Imbo	970–1,400	1,050–1,600	Vertisols	40
Mayaga	1,350–1,500	1,000–1,200	Nitrosols	40
Medium altitudinal region				160
Central Plateau	1,500–1,900	1,100–1,300	Humic Nitrosols and humic Ferralsols	40
Granitic Ridge	1,400–1,700	1,050–1,200	Leptosols	40
Impala	1,400–1,900	1,300–2,000	Lixisols	40
Lake Kivu Shores	1,460–1,900	1,150–1,300	Nitrosols	40
High altitudinal region				120
Congo Nile Crest	1,900–2,500	1,300–2,000	Humic ferralsols	40
Non-volcanic highlands	1,900–2,500	1,100–1,300	Ferralsols	40
Volcanic Highlands	1,600–2,500	1,300–1,600	Andosols	40

1990; Mukuralinda et al. 1999; Zaongo et al. 2003). Therefore, the results of the household survey were combined and extrapolated to apply to each altitude region in order to understand the motivations of households to plant trees on farms over the entire study area.

From this sampling, the number of sample households surveyed was 200, 160 and 120 in the LAR, MAR and HAR respectively. In total, 480 rural households were interviewed. Data collection was done on a per household basis using a structured questionnaire. The household heads or their wives were chosen as respondents based on the presumption that they had satisfactory information regarding their farms. The choice of the wives in the absence of their husbands was supported by the fact that tree species choices, their management and uses appear not differentiated by gender (e.g. Bonnard and Scherr 1994). Moreover, adoption of agroforestry technologies appears gender neutral (e.g. Gladwin et al. 2002; Phiri et al. 2004). Since agriculture decisions in farming households are often jointly taken, information on management of trees on farms and their benefits are difficult to differentiate between the wives and their husbands. If the head of the household or his wife was not present, the household was rejected for interviewing and the next household was visited.

Survey Instrument

A uniform pre-tested structured questionnaire was used to derive information on demography, livelihood activities, socio-economic status, tree species growing on

the farms and their uses, agricultural crop production, and household fuel consumption. The questionnaire also included the sources of the fuelwood collected, the distance travelled to gather fuelwood, and the amount of fuelwood purchased or collected from each source.

Fuelwood and vegetable materials are the main sources of energy for cooking in Rwanda (REMA 2009). Hence, the survey included questions about the use of these materials, their sources, frequency of use per week, and on farmers' strategies when the fuel in use was short in supply. Since it was not possible to know the precise amount of fuelwood collected or purchased by households, interviewees were asked to specify the number of bundles of firewood and bags of charcoal they used per week or per month. Then, where bundles of firewood and bags of charcoal were available, these were weighted using a spring scale. The average weight (in kg) was used to estimate the amount of fuelwood being used in the households for which bundles of firewood were unavailable by the time of the survey and for which the number of bundles or bags of charcoal being used were recorded. The average weight of a bundle of wood splits and of a bag of charcoal was 12.5 and 35 kg respectively.

In rural areas of Rwanda, modern energy sources such as electricity, gas and kerosene are hardly used. Respondents were asked for other sources of energy used in cooking meals when fuelwood was not available. The household interviews also provided information on level of education, source of income, income and expenditure, the number of meals per day, the types of stoves in use, farms sizes, crop types, tree species on farms and their uses, income from the selling of tree products and tree species collected for fuelwood.

Statistical Analysis

In this study, the dependent variable is a categorical dichotomy (i.e. presence/absence of trees on farms) and the independent variables include a mix of categorical and continuous variables. Logistic regression is a preferred statistical technique for analysing models of dichotomous dependent variables (Hosmer and Lemeshow 1989; Menard 1995). Discriminant analysis can also be used to predict a discrete outcome, but it is used to predict group membership for only two groups. When the independent variables are categorical, a mix of continuous and categorical, logistic regression is preferred because it results into fewer classification errors compared to discriminant analysis (Montgomery et al. 1987; Lei and Koehly 2003; Rausch and Kelly 2009). Moreover, logistic regression has similarity to linear regression and is related through an appropriate link function (Dobson 1990). Just like ordinary regression, logistic regression has also straightforward statistical tests and the ability to incorporate non-linear effects and a wide variety of diagnostics (Hair et al. 1998).

Logistic regression tools models have been widely used for statistical analysis of proportions or rates in educational, social and behavioural sciences (e.g. Catts et al. 2001; Flowers and Robinson 2002; Glaser et al. 2002), in biological and medical sciences (e.g. Udris et al. 2001; Phillips et al. 2003; Sahiner et al. 2004) as well as in management sciences (e.g. Jo et al. 1997; Avlonitis et al. 2000). These models have

recently been applied to decisions of household energy consumption choice (e.g. Macht et al. 2007; Couture et al. 2009; Ekholm et al. 2010). Damte and Koch (2011) used logistic regression methods for evaluating the choice of fuelwood sources in rural Ethiopia, while Neupane et al. (2002) demonstrated its application for understanding the determinants of the adoption of agroforestry in Nepal.

In a binary logistic regression model, the dependent variable is of binary nature and this applies in the case of the presence or absence of trees on farms. This dependent variable is 0 in the case of the absence of trees on farms, and 1 if trees are present. Categorical variables were incorporated into the regression models by recording them using an indicator coding (Field 2005). This means that if there were c categories for a variable, then the variable was taken as having c vectors, with the first category denoted $(1, 0, \dots, 0)$, the next category $(0, 1, \dots, 0)$, ..., and the final category $(0, 0, \dots, 0, 1)$.

Logistic regression procedures have been used for each altitude region and for all regions combined, in order to identify which variables predict whether a farmer is likely to plant trees or not. In each case, the model assumed that farmers faced socio-demographic and economic factors that influence their choices to plant trees. Let Y_i represent a dichotomous variable that equals 1 if the farmer planted trees on farms and 0 if no tree was established. Given several predictor variables, the probability of Y_i occurring is given by the following equation (Dobson 1990):

$$P(Y_i) = \frac{1}{1 + e^{-(b_0 + b_1X_1 + b_2X_2 + \dots + b_nX_n + \varepsilon_i)}}$$

in which $P(Y_i)$ is the probability of Y occurring, e is the base of natural logarithms, b_0 is the intercept, b_n is the regression coefficient of the corresponding variable X_n and ε is the residual term.

The equation form of the logistic transformation of the probability of farmer's decision to plant trees, $P(Y_i = 1)$ can be represented as:

$$\text{Log} \left[\frac{P(Y_i = 1)}{1 - P_i(Y_i = 1)} \right] = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \dots + \beta_nX_n$$

or

$$\text{Log} \left[\frac{P(Y_i = 1)}{1 - P_i(Y_i = 1)} \right] = \beta_0 + \sum_{i=1}^n \beta_iX_i$$

where P_i is the probability that a household owns trees on their farm, $(1 - P_i)$ is the probability that a household has no trees on his farm, $(P_i/(1 - P_i))$ denotes the odds of planting trees on farms, β_0 is a constant, β_i represent the coefficients associated with the predictor variables denoted X_i . The coefficients represent the effects of the predictor variables on the odds of planting trees on farms. The transformation from odds to probability is a monotonic transformation (Sweet and Grace-Martin 2003; Johnson and Bruce 2008), meaning that the odds increase as the probability increases or vice versa. A positive coefficient of a predictor variable means that an increase in this variable is associated with an increase in the odds of planting trees

on farms. Inversely, a negative coefficient means that an increase in the predictor variable implies a decrease in the odds of planting trees on farms.

The parameters β_i of the variables influencing the presence of trees on farms, were estimated using a maximum likelihood estimator. Forward inclusion was used to select the predictor variables one by one and to include them in the model if they were statistically significant. In this way, the variables were included in the model one by one in an iterative process. At each stage in the process, after a new variable was added, a test was made to check if other variables could be deleted without notably increasing the residual sum of squares. This procedure was completed when the inclusion of additional variables did not make significant improvement to the fit of the model.

To determine the fit of the models, the goodness of fit test, which is the Chi-square difference between the baseline model (i.e. with the constant only) and the final model (containing one or more predictor variables), was performed. Model coefficients were tested for their significance for inclusion or elimination by carrying out a Wald test and by determining the Hosmer–Lemeshow statistics (Hosmer and Lemeshow 1989), Cox and Snell R^2 (Cox and Snell 1989) and Nagelkerke R^2 (Nagelkerke 1991). The Hosmer–Lemeshow statistics indicated a good fit if the significance value was greater than 0.05. The two R^2 -statistics are based on the log likelihood of the model compared to the log likelihood of a baseline model.

The model variables were tested for multicollinearity using collinearity statistics viz. tolerance value and Variance Inflation Factor (VIF). A tolerance value less than 0.1 indicated a serious collinearity problem (Menard 1995) and a VIF greater than 10 was also a cause of concern of collinearity (Myers 1990). The Statistical Package program SPSS/PASW Statistics was used for the analysis.

Conceptualization of Variables Included in the Models

In Rwanda, the average area of farmland by household is 0.76 ha, and about 80% of farmlands are less than 1 ha (NISR 2010). Therefore, many farms are small and production of trees, crops and livestock has to take place on a small area. The establishment of trees as a sole crop requires households to allocate part of their farmlands to trees, which further reduces the size of the farms; because of competition between trees and crops, woodlot owners are not expected to adopt production systems that integrate trees and crops on very small farms, since they can acquire fuelwood from the woodlot.

One of the factors that limit farmers to plant trees, is the size of the farm (Niang and Styger 1990; Mukuralinda et al. 1999). In response to scarcity of wood and non-wood products, farmers may plant trees in their agricultural lands in a way that minimizes competition on crops, and possibly has positive effects on crop productivity as well e.g. through soil improvement. Both small and large farm owners are expected to own trees on farms, but possibly in different configuration. The small farm size is partly due to family heritage, where land is becoming smaller in successive generations. The common mode of land ownership is by inheritance for about 82% of households (NISR 2010). Typically, older heads of households

have large farms as compared to young farmers, and the age of household head is strongly related to farm size. It is likely that older households are able to plant more trees on their farms than younger household heads.

The level of education of the household head has a positive effect on the planting of trees on farms (Haglund et al. 2011; Muhammad et al. 2011). Educated people have more income opportunities and can afford to use more land to plant trees. Thus, it was hypothesized that the level of education was positively correlated with tree planting practices, and this aspect was included in the equation as an independent variable.

The social context of Rwanda in a post-genocide situation implies that some households are headed by females. A national survey in 2008 found that female heads of households represented 27% of the total agricultural households (NISR 2010). Even under normal circumstances, women were found to contribute 40–80% of agricultural farm labour, even though men were present in the households (Randolph and Sanders 1992). Thus, women are expected to have a decision making role for the family in crop production as well as in on-farm tree planting.

In Rwanda, the common source of income for the majority of rural households is crop and livestock farming. Additional income results from off-farm activities predominantly done by the heads of households. Off-farm employment may generate more income than farm labour; hence the heads of households involved in off-farm employment are less likely to take the decision to plant trees on farms. It is anticipated that the employment of the heads of households in off-farm activities is negatively associated with the presence of trees on farms. In addition, households in which family members are involved in off-farm employment that generates more total income, may be less motivated to use household labour in planting trees. Thacher et al. (1997) reported that households allocated family labour to off-farm employment for purposes of increased income.

Higher income households are expected to plant less trees as compared to lower income households because the former can afford to purchase wood products from local markets. Similarly, expense categories of households are expected to follow the same trend, meaning that the probability to plant trees on farms is higher for low expense households compared to higher ones. Agroforestry may enhance food production and farmers' economic conditions through positive contribution to household income (Neupane and Thapa 2001). Potential selling of tree products (including fuelwood) may have a positive effect on farmers' decision to plant trees on their farms.

Farmers make decisions on tree planting on farms based on household and farm characteristics (Bannister and Nair 2003). Adult members in the households (aged ≥ 16 years) influence this decision partly because they are involved in farming activities. The number of adult household members is expected to be positively associated with the availability of trees on farms. In contrast, the larger the household size, the greater its energy needs for cooking meals, and the more emphasis on secure energy supply. As a result, a link between the production of sufficient food and fuelwood is expected, and this may be achieved by planting trees.

Some studies have emphasised scarcity of fuelwood as one of the key factors to motivate farmers in planting trees (Deweese 1992; Dixit and Dixit 2010). Other studies reported that fuelwood from agroforestry is a secondary product from multipurpose trees (e.g. den Biggelaar 1996; Jama et al. 2008). As long as fuelwood could be collected from forests without paying for it, farmers had little incentive to plant fuelwood producing trees (FAO 1985). Due to scarcity of fuelwood, rural households increase frequency of collection from nearby forests. However, as fuelwood collection distance increases, the frequency of collection from the same sites declines with households refocusing their attention to nearby sites (Fisher et al. 2005). Thus, estimations of the amount of fuelwood collected per month, the monthly frequency of collection, the amount of fuelwood used per week and the distance travelled to nearest source of fuelwood were included in the model in order to test whether scarcity of fuelwood stimulated rural households to establish trees on their farmlands.

With improved economic wellbeing, households become less dependent on forests for their energy supply (Sikei et al. 2008). These households do not collect but may purchase fuelwood or use other sources of energy such as electricity or gas for cooking. It is assumed that an increased expenditure on firewood decreases the chance of planting trees on farms and a rise in the number of times households purchase fuelwood decreases the likelihood of planting trees. Similarly, the larger the amount of fuelwood purchased, the lower the chance that the households will plant trees on their farms.

Many studies (Adhikari 1996; Cooke 1998; Fisher 2004) identified an inverse relationship between fuelwood collection frequency and the distance travelled to collection site. Increased distance to fuelwood collection sites requires more energy and become a burden to collecting household members. In response to this problem, households may prefer to manage their own fuelwood source. It is anticipated that an increase in distance to sources of fuelwood increases the probability that households choose to establish short distance sources of fuelwood such as trees growing on their own farmland.

In Rwanda, about 99% of the rural population uses firewood and charcoal for cooking meals (NISR 2006). Fuelwood use has remained high even when households are encouraged to use alternative technologies to improve efficiency of cooking, thereby reducing the impact of fuelwood consumption on deforestation. It is hypothesized that the number of meals per day, leading to frequent use of fuelwood for cooking meals, is correlated with the planting of more trees on farms. When improved stoves are used, the need to plant trees is less because improved stoves use wood efficiently and the households can afford to buy small quantities of wood. Therefore, ownership of an improved stove is expected to be negatively associated with the presence of trees on farms.

The amount of forest area per capita in Rwanda is very small (0.03 ha per capita) and the FAO standard of 1 ha per capita to simultaneously meet the ecological balance and wood demands is unattainable (MINIFOM 2010). The remaining forests are unevenly distributed geographically and by ownership (CGIS-NUR and MINIRENA 2008; ISAR and MINIRENA 2008). As a result, the demand for wood is higher in areas with little forest cover compared to those area with higher forest cover. A decreasing

tree cover may motivate farmers to increase their local source of wood products and therefore the respondents' opinion of the change in tree cover was included in the model in order to test whether the change in availability of forest resources had significant effect on on-farm tree planting. In general, the geographical location and associated agro-ecological factors are expected to have significant impact, linked to favourable environmental conditions for successful planting of trees.

Finally, rural households in Rwanda are affected by a shortage of fuelwood throughout the country. Fuelwood collection in public forests is illegal, and households are barred from collecting fuelwood from these forests. Thus, it is hypothesized that fuelwood demands drive many households to grow trees on farms. In addition, households that use alternative fuels are expected to have fewer trees on their farms.

Model

Given the hypothesized factors of households' determinants of planting trees on farms, models were developed for each altitude region and for the entire study area. Except the variables gender of the head of the households, the selling of tree products on markets and the distance to the source of fuelwood that are binary as well as the variable number of meals per day that is continuous, the remaining variables are dummies transformed from categorical continuous variables. For each altitude region and for the entire study area, the model was as follow:

$$\begin{aligned} \text{Log} \left[\frac{P(Y_i = 1)}{1 - P_i(Y_i = 1)} \right] = & \beta_0 + \beta_1 \text{AGE} + \beta_2 \text{HSEX} + \beta_3 \text{ADUL} + \beta_4 \text{CHIL} \\ & + \beta_5 \text{HSIZE} + \beta_6 \text{MAGRIC} + \beta_7 \text{MFEMPLOY} \\ & + \beta_8 \text{MIEMPLOY} + \beta_9 \text{MBUS} + \beta_{10} \text{MTOT} \\ & + \beta_{11} \text{HEMPLOY} + \beta_{12} \text{EDUC} + \beta_{13} \text{SINCOME} \\ & + \beta_{14} \text{INCOME} + \beta_{15} \text{EXPENSE} + \beta_{16} \text{MEAL} \\ & + \beta_{17} \text{STOVE} + \beta_{18} \text{FARM} + \beta_{19} \text{WLOT} + \beta_{20} \text{RFIRE} \\ & + \beta_{21} \text{TPROD} + \beta_{22} \text{TINCOME} + \beta_{23} \text{SFUEL} \\ & + \beta_{24} \text{FPURCH} + \beta_{25} \text{FCOLLECT} + \beta_{26} \text{EXPFIRE} \\ & + \beta_{27} \text{DIST} + \beta_{28} \text{FBUNDLE} + \beta_{29} \text{ALTENERG} \\ & + \beta_{30} \text{SEASON} + \beta_{31} \text{TCOVER} + \beta_{32} \text{STRAT} \\ & + \beta_{33} \text{REGION} \end{aligned}$$

where

AGE	Age of the head of the households, from value 1 = 16–20 years to value 10 = >60 years
HSEX	Gender of the household head, HSEX = 1 if female, and 0 otherwise
ADUL	Number of adult household members, defined as individuals aged 16 years and above, from value 1 = 1–2 persons to value 4 = >6 persons

CHIL	Number of children in household, defined as individuals aged below 16 years, from value 1 = 0 to value 7 = >10 children
HSIZE	Total number of household members, from value 1 = 1–3 members to value 5 = >12 members
MAGRIC	Number of household members involved in agriculture, from value 1 = none to value 5 = >6 persons
MFEMPLOY	Number of salaried members of the household, from value 1 = none to value 5 = >6 persons
MIEMPLOY	Number of household members involved in informal employment, from value 1 = none to value 5 = >6 persons
MBUS	Number of household members involved in small business, from value 1 = none to value 5 = >6 persons
MTOT	Total number of household members employed, from value 1 = none to value 5 = >6 persons
HEMPLOY	Employment of head of household, HEMPLOY = 1 if employed and 0 otherwise
EDUC	Education level of the head of household, on a scale of 1 = no school to 7 = some university
SINCOME	Main source of income, coded for 7 categories of activities
INCOME	Estimated monthly income during the past 12 months, from value 1 = <5,000 Rwf to value 10 = >70,000 Rwf
EXPENSE	Estimated monthly expenses during the past 12 months, from value 1 = <5,000 Rwf to value 10 = >70,000 Rwf
MEAL	Number of meals per day, ranges from 1 to 3 times per day
STOVE	Type of stove used for cooking meals, STOVE = 1 if improved, and 0 otherwise
FARM	Farm sizes in ha, with values ranging from 1 = landless to 5 = >2 ha
WLOT	Ownership of a woodlot, WLOT = 1 if the household owns a woodlot and 0 otherwise
RFIRE	Amount of farm fuelwood, from 1 = very small to 6 = very high
TPROD	Selling of tree products. If the household sells tree products, TPROD = 1 and 0 otherwise
TINCOME	Estimated annual income from selling of tree products during the past 3 years, from value 1 = no income to value 12 = >100,000 Rwf
SFUEL	Sources of fuelwood, dummy coded for eight sources of fuelwood
FPURCH	Frequency of purchasing fuelwood per month, on a scale of 1 = no purchase to 7 = >17 times
FCOLLECT	Frequency of collecting fuelwood per month, on a scale of 1 = no collection to 8 = >21 times
EXPFIRE	Monthly expenditure on firewood estimated for the past 12 months, from value 1 = no expenses to value 12 = >10,000 Rwf
DIST	

	Distance to the source of firewood and charcoal, from value 1 = <1 km to value 5 = >10 km
FBUNDLE	Number of firewood head load bundles used per week, on a scale of 1 = <5 bundles to 5 = >16 bundles
ALTERNERG	Other sources of energy used for cooking, evaluated for five categories
SEASON	Season of the year in which much fuelwood is used, coded for five categories
TCOVER	Change in tree cover during the past 5 years as being less, same or high
STRAT	Coping strategies to lack of fuelwood for cooking, dummy coded for 11 categories
REGION	Geographical location of the households in the LAR, MAR and HAR. REGION = 1 for location in LAR, MAR or HAR, and 0 otherwise

Results

Characteristics of the Variables Tested in the Models

This section provides background for interpreting the variables that were used to describe farmers motivation to plant trees on farms. The variables tested in the models were grouped into three categories: (1) demography and socio-economic conditions; (2) land use; (3) fuelwood production and use.

Demography and Socio-Economic Conditions

For the entire study area, 44% of respondents were male and 56% female. The highest proportion of the interviewees (i.e. 15%) were over 60 years old, followed by respondents between 41 and 45 years of age (11%). Each individual household had 4–6 members in about 48% of the cases. Only 3% of household members were not involved in agriculture and more than 85% were not employed nor involved in commercial business. Overall, 1–2 household members were employed in various sectors for the majority (62%) of the cases.

The most important occupations of the household heads were agriculture (77%), formal employment (7%), informal employment (4%), handcraft (2%), and livestock grazing (0.2%). There were 9% of householders who were not engaged in any productive activity because they were old or disabled.

The respondents indicated various level of formal education: 27% did not attend formal education, hence they were unable to read and write; 53% were at the primary level education; 16% at secondary education; and 5% at university level. Therefore, for the entire study area, the rate of literacy of the respondents was about 73%.

Agriculture was the most important source of income for 80% of the households. Crop and livestock farming were the primary activity for 94 and 5% of households. They were listed as secondary by 5% (when livestock was the primary activity) and 55% (when crop growing was the primary activity) of the respondents. Most households combined agriculture with other activities such as farming of small and large livestock, poultry, and employment in formal and informal sectors.

Agriculture was the most important source of income for 80% of the households. Of these, 25% diversified their income sources through the selling of tree products. Only 9% of households sold avocado, mango, papaw, guava and citrus fruit. The annual income generated from the selling of tree products was less than 10,000 Rwandan Francs (FRW) or approximately US\$ 17 (based on 1 US\$ \cong 590 RWF, July 2010). Frequency analysis indicated that 72% of respondents had an annual income of approximately US\$ 200 (or US\$ 0.6 per day), with the highest percentage of households in this category being found in MAR (81%), followed by LAR (70%) and HAR (63%). For the majority of households (83%), the annual expenses were roughly equal to annual income, and savings were seldom made.

Land Use

Households with farms less than 0.6 ha made up 44% of the total number of households. Farms of 0.6–1 ha amounted to 30% of the total, farms of 1–2 ha amounted to 14% and households with lands > 2 ha accounted for 4%. In LAR, 39% of the respondents had farms of 0.6–1 ha. Farm holdings of this size were reported by 30 and 19% of respondents in the highlands and midlands, respectively. For the whole study area, more than 70% of respondents reported farm sizes of less than 1 ha and 8% of cultivating farmers didn't own any land but depended on rented or borrowed lands.

All households managed their farms predominantly for the production of food crops. Across the three altitudinal regions, respondents grew a range of agricultural crops belonging to different product categories (Table 2). There were few cases of regional differences in growing specific crops associated with local climatic and soil conditions.

For the whole study area, 73% of the surveyed households had scattered, boundary or contour planted trees on their farms. The percentage of respondents who established trees in LAR, MAR and HAR were 77, 76 and 63%, respectively. Woodlots were reported to be available on 42% of farms, with the highest proportion of respondents being recorded in the HAR (62%), followed by the MAR (47%) and least in LAR (27%). Of the 42% woodlots owners recorded in the whole study area, 32% also kept scattered trees on their farms (Fig. 2).

Fuelwood Production and Use

Of the 480 respondents, 220 (46%) collected fuelwood from their own agricultural land. Thus, more than 50% of households obtained their supplies from outside their own farmlands. Within the LAR, MAR, and HAR, respondents who collected fuelwood from trees on farms represented 43, 41 and 58%, respectively.

Table 2 Percentages of households growing food crops in the three altitudinal regions

Crop	Percentage of households			Mean
	LAR	MAR	HAR	
Cereals				
Sorghum	37	21.9	50.8	35.4
Maize	59	26.9	54.2	47.1
Wheat			31.7	7.9
Rice	13	3.8		6.7
Roots and tubers				
Cassava	65.5	55		45.6
Sweet potatoes	32.5	70.6	8.3	39.2
Irish potatoes	9	10	85.8	28.5
Taro	2.5	21.3	1.7	8.5
Pulses				
Bean	90	91.9	66.7	84.4
Peas	0.5	0.6	20	5.4
Oil plants				
Soybean	4.5	20.6		8.8
Groundnut	12.5	3.1		6.3
Vegetables				
Spinach	0.5	8.8	11.7	6
Tomatoes	1.5	5		2.3
Onions	0.5	2.5		1
Carrots		0.2	0.4	0.6
Eggplants	0.5	0.6		0.4
Stimulants				
Coffee	4.5	6		2.1
Tea			6.4	2.1
Fruit				
Banana	24	35.6		21.9
Natural insecticide				
Pyrethrum			0.8	0.2

When respondents were asked “How do you rate the amount of fuelwood obtained from your own agricultural fields”, many respondents rated the amount of fuelwood from farms as being small. In the HAR, MAR and LAR, the majority of respondents rated the amount of on-farm fuelwood as high, moderate and small, respectively (Fig. 3). All altitude regions combined, about 69% of the respondents collected fuelwood, 14% used purchased fuelwood and 17% utilized both collected and purchased fuelwood.

In order to get a better insight into the source of fuelwood, respondents were asked to indicate where they usually collect or buy fuelwood. The first three major sources of fuelwood were identified as: (1) farms; (2) forests; and (3) markets (Table 3). In general, respondents gathered fuelwood from their farms but

Fig. 2 Distribution of respondents according to the availability of woodlots and trees on farms

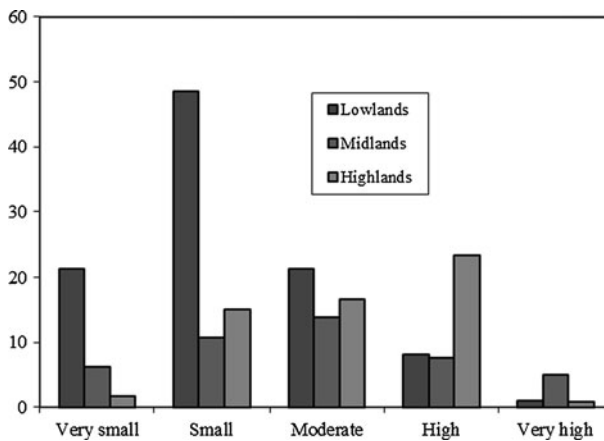
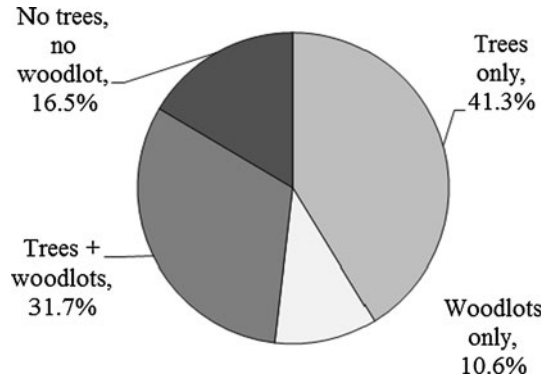


Fig. 3 Percentages of respondents rating the amount of fuelwood from farms on a scale of very small to very high in the three altitude regions

Table 3 Percentage distribution of respondents according to fuelwood sources in the low, medium and high altitude regions and in the whole study area

Sources of fuelwood	Percentages of households			All regions
	Lowlands	Midlands	Highlands	
Farms	23.8	31.8	41.2	30.9
Forests ^a	28.1	42.4	3.5	26.0
Farms and markets	5.4	3.0	4.4	4.4
Farms and forests	2.2	3.8	16.7	6.5
Bushes	17.8			7.7
Markets	15.7	7.6	19.3	14.2
Forests and markets	7.0	11.4	14.9	10.4
Total	100	100	100	100

^a By forests, we mean public forest plantations, natural forests, savanna woodlands, other wooded lands and private woodlots in which households collect firewood as a source of energy for cooking meals

diversified sources of fuelwood in order to meet their fuelwood needs by collecting firewood from public and private forests, bushes and by purchasing firewood from markets or from neighbours.

About one quarter of the households collected fuelwood 10–13 times per month, and 33% of households purchased fuelwood less than two times per month; 28% of households purchased fuelwood two to five times in a month. The high monthly frequency of fuelwood collection prompted many households to collect fuelwood at least once every 2 days.

The frequency of collecting fuelwood was not significantly related to the distance travelled to the source of this material. With long distance to fuelwood sources, the number of household collectors tended to decrease. Table 4 presents the percentage distribution of respondents according to monthly frequency of fuelwood collection and the distance to nearest sources of fuelwood. Only for distances less than 1 km, the number of households collectors is higher compared to longer distances.

Expenditures on firewood and charcoal were made by only a few households in the study area. Thus, approximately 67% of households did not purchase any firewood and 97% did not purchase charcoal, indicating that rural households predominantly resort on collected fuelwood. The percentage of households that purchased firewood (33%) was higher compared to that using purchased charcoal (3%). The average monthly expenditure on firewood ranged between US\$ 2 and US\$ 9 per month while expenditure on charcoal was between US\$ 5 and US\$ 8.5 per month.

Out of the 480 rural households surveyed, 93% of the respondents relied on firewood for cooking meals, 1% used crop residues and 0.4% used charcoal only. Both firewood and charcoal were used by 6% of the total number of sample households. Wood burning stoves were used by 76% of respondents and only 20% used traditional stoves, implying that firewood was used efficiently by many households. The majority (i.e. 79%) of respondents reported that meals were taken twice a day (lunch and dinner).

Fuelwood consumption in households appeared to be the same across the LAR, MAR and HAR. Ninety six per cent of households consumed approximately 100 kg of firewood per week, corresponding to a daily fuelwood consumption of 2.3 kg per

Table 4 Percentage distribution of sample households according to monthly fuelwood collection frequency and distance to nearest source of fuelwood

Monthly frequency of fuelwood collection	Distance to the nearest source of fuelwood		
	<1 km (<i>n</i> = 285)	1–5 km (<i>n</i> = 109)	5.1–10 km (<i>n</i> = 10)
<2 times	49 (17.2%)	9 (8.3%)	0
2–5 times	41 (14.4%)	8 (7.3%)	0
6–9 times	40 (14.0%)	15 (13.8%)	1 (10%)
10–13 times	31 (10.9%)	17 (15.6%)	0
14–17 times	20 (7.0%)	6 (5.5%)	1 (10%)
18–21 times	68 (23.9%)	32 (29.4%)	0
>21 times	36 (12.6%)	22 (20.2%)	8 (80%)

Table 5 Percentage distribution of households according to coping strategies to unavailability fuelwood in the low, medium and high altitude regions of Rwanda

Coping strategies	Percentages of households			
	Lowlands (<i>n</i> = 103)	Midlands (<i>n</i> = 79)	Highlands (<i>n</i> = 71)	All (<i>n</i> = 253)
No cooking/no meals	24.3	25.3	1.4	18.2
Borrowing firewood from neighbours	2.9	2.5	0.0	2.0
Collection of sources of fuel everywhere	1.9	30.4	8.5	12.6
Cooking less firewood demanding food	25.2	1.3	14.1	14.6
Less firewood demanding and reduced frequency of cooking	1.9	0.0	2.8	1.6
Collecting firewood from existing constructions	0.0	0.0	2.8	0.8
Permanent use of another fuel	0.0	2.5	7.0	2.8
Purchase of fuelwood (firewood, charcoal)	0.0	1.3	1.4	0.8
Reducing the frequency of cooking meals	1.0	11.4	11.3	7.1
Reducing the number of meals per day	36.9	17.7	23.9	27.3
Stop less important activities using the fuel in shortage	0.0	0.0	8.5	2.4
Use of energy saving stoves	0.0	0.0	1.4	0.4
Temporal use of another fuel	2.9	7.6	15.5	7.9
Temporal use of another fuel & reduced frequency of cooking	2.9	0.0	1.4	1.6
Total	100	100	100	100

capita.² In the MAR, many households consume more than 100 kg compared to the remaining two altitude regions. More fuelwood than normal was used during the long wet season as reported by 61, 86 and 71% of respondents in LAR, MAR and HAR, respectively. In a few occasions, households consumed less than 20 kg of charcoal per week, or approximately 3 kg per day.

When firewood was short in supply, many respondents (about 90%) had no alternatives, but a few indicated that they supplemented fuelwood with crop residues (7%), grasses (1%), a mix of grasses and crop residues (1%), and cow-dung (0.4%) particularly in the LAR where livestock farming is common and cow-dung is readily available. Table 5 indicates coping strategies when the energy sources for cooking meals were unavailable. These strategies varied widely among households across the altitude regions. However, a reduction of the number of meals per day, followed by “no cooking” appeared to be the common strategies to many rural households.

To the question on changes in tree cover during the past 10 years, there was no much difference in the proportions of households that reported an increase in tree cover (44%) and a decline in tree cover (46%) for the whole study area. On regional basis, there were notable differences in the proportions of respondents (Fig. 4).

² Authors' estimation based on 7 days per week and average household size of 6 members.

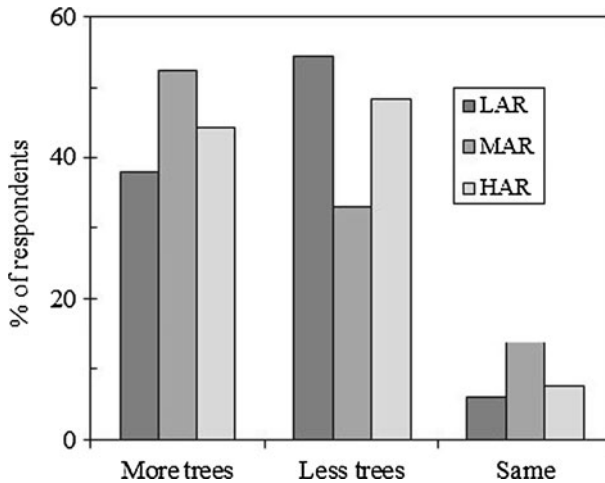


Fig. 4 Rate of forest cover change during the last 10 years by the respondents in the low, medium and high altitude regions of Rwanda

Farmers' Motivations for Planting Trees on Farms

Of the 350 households who owned trees on farms, 1–4 tree species were growing on their farms and generally used for more than one purpose. This number of species is lower compared to the farm species diversity recorded in other studies because in our study, tree species in and around the home compounds were not recorded. In fact, the study focused only on tree species on farms that are more productive areas of wood products and services while increasing crop yields. In general, households were motivated to plant trees on farms for economic benefits which can be grouped into 11 product categories. The proportions of households utilising different tree species for different products categories were small, indicating large variations in species preferences and management objectives (Table 6).

Fruit tree species including *Persea americana* (avocado), *Citrus* spp., *Carica papaya* (papaw), *Mangifera indica* (mango) and *Psidium guava* (guava) were found to be among the most planted tree species on farms. These were used mainly as sources of food and income from the selling of fruit. The study found that the majority (56%) of households planted *Grevillea robusta* mainly to produce timber (22%), firewood (17%) and both timber and firewood (7%). Because the trees are not felled before they attain a size that can produce timber, firewood from *G. robusta* is collected mostly during pruning and pollarding used by farmers to manage competition for light with crops. The remainder of firewood is obtained from branches and non-merchantable stems after final felling. Although *Grevillea* trees were present on farms, they were seldom used for firewood. People were primarily motivated to plant them for timber and management of the trees in agroforestry systems provide firewood only as additional benefit. Other tree species planted on farms that targeted timber production included *Ficus* spp., *Markhamia*

Table 6 Percentage distribution of households according to planted tree species and their purposes

Tree species	Tree product categories ^a										Total	
	Fi	Ti	Po	Ti&Fi	Fi&Po	Ti&Po	Fo	Ic	Fo&Ic	Fd		Other ^b
<i>Persea americana</i>	16.9	0.3					40.0	3.7	24.0		0.6	68.6
<i>Grevillea robusta</i>	6.0	21.7	2.9	7.1	2.3	0.9					4.3	56.0
<i>Ficus</i> sp.	6.9	5.4		0.3						2.3	6.9	20.9
<i>Eucalyptus</i> sp.	1.7	1.7	5.7	2.9	1.4	0.3					0.3	19.1
<i>Carica papaya</i>	3.4	8.0	0.9	1.4	0.3	0.6	14.9	0.3	2.6		0.3	17.7
<i>Markhamia</i> sp.	14.6										0.3	14.9
<i>Vernonia amygdalina</i>											0.3	14.9
<i>Mangifera indica</i>	11.7				0.3		10.3	2.0	2.6		1.4	14.9
<i>Euphorbia tirucalli</i>												13.4
<i>Psidium guajava</i>	9.1		0.6		0.6		8.0	0.6	2.0			10.6
<i>Senna spectabilis</i>	1.1	7.4	0.9	0.3	0.3	0.3					0.3	10.6
<i>Cedrela serrata</i>												10.3
<i>Citrus lemon</i>							5.4	0.3	3.1			8.9
<i>Calliandra calothyrsus</i>	8.0									0.6		8.6
<i>Cupressus lusitanica</i>	0.3	6.6	0.3	0.6								7.7
<i>Ricinus communis</i>	2.0										4.0	6.0
<i>Erythrina abyssinica</i>	0.9	2.6									2.3	5.7
<i>Leucaena</i> sp.	5.1									0.3		5.4
<i>Jacaranda mimosaeifolia</i>	1.1	1.7	0.9	0.6							0.3	4.6

Fi firewood, Ti timber, Po poles, Ti&Fi timber and firewood, Fi&Po firewood and poles, Ti&Po timber and poles, Fo food, Ic income, Fo&Ic food and income, Fd fodder

^a Percentage of households are only presented for tree species recorded on $\geq 5\%$ of farms in the whole study area

^b Other tree product categories include staking materials for climbing beans or heavy banana bunches, trees for boundary marking, cultural value, erosion control, soil improvement, fence, medicine, ornament or a combination of these benefits with major benefits (e.g. firewood, timber, poles, fodder, etc.)

spp., *Erythrina abyssinica*, *Cedrela serrata*, *Cupressus lusitanica*. The first three species are indigenous and commonly maintained on farms as a source of timber for making woody products.

Next to grevillea trees, the most cited sources of firewood comprised mainly shrub species including *Vernonia amygdalina*, *Euphorbia tirrucalli*, *Senna spectabilis*, and *Calliandra calothyrsus*. Eucalyptus trees were preferred for fuelwood use by many rural households (19%) in the study area. The economic reasons for owning *Eucalyptus* spp. included firewood (7%) and building poles (6%). Other reasons for planting eucalyptus on farms included the production of timber, a combination of timber and firewood as well as a mix of both firewood and building poles. Though eucalyptus were appreciated for multiple values, they were not planted on farms by many rural households, probably because they were aware of the competition effects of eucalyptus on agricultural crops. Beside commonly planted tree species, many other multipurpose tree species were reported by very small proportions of households.

Factors Affecting the Planting of Trees on Farms in the Low, Medium and High Altitude Regions

Many of the hypothesized variables in “[Conceptualization of Variables Included in the Models](#)”, were removed by the likelihood ratio test (Forward: LR method) because they had no effect on the presence of trees on farms. In MAR model, no explaining factors were found. In the LAR model, the number of adult members in households, the presence of woodlots and the selling of tree products on markets had significant positive effects on the presence of trees on farms (Table 7). As expected, the adult members of households are usually involved in agricultural activities and hence could grow trees on farms. The presence of woodlot on farms doesn't support the hypothesis that woodlot owners were likely not to plant trees on farms, indicating that those households planted also trees in other arrangements and locations in farmlands. The result is not surprising because the Rwanda agricultural survey in 2008 found that many agricultural households (34%) owned both scattered trees and woodlots (NISR 2010).

The selling of tree products had a strong impact on the presence of trees on farms. In fact, the odds of owning trees on farms for households who marketed tree products were 15 times higher than those who did not sell any tree products. The result showed a strong support to our hypothesis that markets of tree product increase households' decision to plant scattered trees on farms.

In the same model, the coefficients of both monthly expenses and amounts of farm fuelwood were statistically significant but showed a negative influence on the presence of trees on farms. An increase in monthly household expenses decreased the probability of planting trees on farms. More precisely, higher monthly expenditure households were less likely to plant trees on their farms. The odds ratio reported in Table 7 as $\text{Exp}(\beta)$ was less than 1, indicating that a change from a lower to a higher monthly expenditure category decreased the odds of planting trees on farms, which is similar to saying that households falling in higher expenditure categories were less likely to plant trees on farms compared to lower monthly

Table 7 Results of maximum likelihood estimates of the determinants of the presence of trees on farms in the low altitude region of Rwanda

Variables	β	SE	Wald	df	95% CI for $\text{Exp}(\beta)$		
					Lower	$\text{Exp}(\beta)$	Upper
Number of adults members in the household	0.97**	0.35	7.46	1	1.31	2.62	5.25
Monthly expenses	-0.45*	0.17	6.71	1	0.46	0.64	0.90
Presence of woodlot	1.35*	0.60	4.99	1	1.18	3.85	12.57
Amount of farm fuelwood	-0.43**	0.14	8.95	1	0.49	0.65	0.86
Selling of tree products	2.68*	1.24	4.62	1	1.27	14.51	166.22
Constant	1.28	0.89	2.07	1		3.61	
Model χ^2	34.28***						
Hosmer and Lemeshow R^2	3.34						
Cox and Snell R^2	0.22						
Nagelkerke R^2	0.33						
Overall accuracy of classification (%)	76.3						

* $p < 0.05$; ** $p < 0.001$; *** $p < 0.0001$

expenditure households. Similarly, an increased use of farm fuelwood decreased the odds of the presence of trees on farms, suggesting that households harvested fuelwood trees on their farm without replanting. As a result, on-farm fuelwood collection led to the depletion of trees on farms.

An inverse significant relationship between the amount of farm fuelwood and the presence of trees on farms was also found for the HAR model (Table 8). The confidence intervals for $\text{Exp}(\beta)$ indicated that the direction of the relationship may be stable in the population as a whole. In the HAR model, the presence of trees on farms was positively associated with the monthly frequency of collecting firewood, the monthly expenditure on firewood, and the season in which much firewood is used (Table 8). Of these variables, the coefficients of monthly frequency of fuelwood collection and monthly expenditure on firewood were the most significant ($p < 0.01$). These results are in disagreement with the earlier assumptions that households who collected fuelwood and those who purchased it tended to plant less trees on their farms. The season in which much firewood was used exhibited the expected relationship with the presence of trees on farms. Many households were likely to plant trees on farms in order to guarantee the supply of firewood during the wet seasons.

In the LAR and HAR models, the values of the χ^2 statistics, the Hosmer–Lemeshow statistic and R^2 -values of both models indicated that the selected variables fit the estimated models well (Tables 7, 8). However, the HAR model was better than the LAR model because the R^2 values were the highest. There was no collinearity among the predictor variables of the LAR and HAR models, indicating that there was no dependency among the predictor variables, resulting in unbiased models.

Table 8 Results of maximum likelihood estimates of the determinants of the presence of trees on farms in high altitude region of Rwanda

Variables	β	SE	Wald	df	95% CI for Exp(β)		
					Lower	Exp(β)	Upper
Amount of farm fuelwood	-0.81***	0.23	12.67	1	0.29	0.45	0.70
Monthly frequency of firewood collection	0.38**	0.14	7.44	1	1.11	1.46	1.91
Monthly expenditure on firewood	0.99**	0.29	11.29	1	1.51	2.68	4.76
Season in which much fuelwood is used	0.56*	0.25	4.88	1	1.07	1.74	2.86
Constant	-0.88	1.22	0.52	1		0.42	
Model χ^2	46.78***						
Hosmer and Lemeshow statistic	8.96						
Cox and Snell R^2	0.4						
Nagelkerke R^2	0.55						
Overall accuracy of classification (%)	76.9						

* $p < 0.05$; ** $p < 0.001$; *** $p < 0.0001$

General Determinants of Households' Choices to Plant Trees on Farms

In order to identify factors influencing the current practices of planting trees on farms in the whole study area, the logistic regression model was developed from the pool of data collected across three regions. Of the cases used to create the model, 233 of the 241 (i.e. 97%) farm tree owners were classified correctly. Fourteen out of 91 (i.e. 15%) who didn't own farm trees were classified correctly. Overall, 73% of the cases were classified correctly.

The Hosmer–Lemeshow statistic indicated a good fit of the data to the estimated model because the significance value was greater than 0.05. Also, the value of the log-likelihood ratio (log LR) of the model was highly significant ($p < 0.001$), indicating that the selected variables had a significant effect on the predictive ability of the model (Table 9). These variables contributed significantly as a group to understanding why farmers owned trees in agricultural fields, although the strengths and signs of their influence were different.

Of the six variables included in the model, the number of household members in informal employment, the number of meals per day, the selling of tree products on market and the location of households had positive and significant influence on the presence of trees on farms. Somewhat surprisingly, the male heads of households and the amount of fuelwood from own farms had significant negative effects on the presence of trees on farms. The negative and significant effect of this variable means that, the odds that households headed men fall in the category of farm tree owners were lower than those of households headed by women. In other words, the households headed by women were more likely to plant trees on farms than the households headed by men.

The significant negative effects of the amount of farm fuelwood implied that fuelwood collections from own farmlands decreased the probability of recording trees on farms. Continued exploitation of trees on farms for fuelwood supply

Table 9 Results of maximum likelihood estimates of the determinants of the presence of trees on farms in the entire study area

Variables	β	SE	Wald	df	95% CI for Exp(β)		
					Lower	Exp(β)	Upper
Male versus female heads of the households	-0.69*	0.31	4.90	1	0.27	0.50	0.92
Number of household members in informal employment	1.00*	0.48	4.35	1	1.06	2.71	6.92
Number of meals per day	0.89**	0.28	10.12	1	1.41	2.44	4.23
Amount of farm fuelwood	-0.22**	0.08	7.47	1	0.69	0.81	0.94
Selling of tree products	1.16**	0.44	7.05	1	1.36	3.20	7.56
Location in LAR versus HAR	0.80*	0.33	5.88	1	1.17	2.22	4.24
Location in MAR versus HAR	1.15**	0.36	10.47	1	1.57	3.16	6.35
Constant	-1.22	0.95	1.65	1		0.30	
Model χ^2		50.05***					
Hosmer and Lemeshow statistic		10.33					
Cox and Snell R^2		0.14					
Nagelkerke R^2		0.19					
Overall accuracy of classification (%)		77.5					

* $p < 0.05$; ** $p < 0.001$; *** $p < 0.0001$

without replanting or coppicing leads to an unsustainable situation in which the tree stock reduces progressively. As result, the more on-farm fuelwood collection increased, the more the probability of the presence of trees on farms inclined towards total depletion of all trees on such farms.

The confidence intervals for the Exp(β) for the variables explaining the presence of trees on farms over the whole study area indicated that the direction of the relationship may be stable in the population of rural households as a whole. The classification of 142 cases used to validate the model showed that 76% of these cases were classified correctly. There was no collinearity among the predictor variables.

Discussion

A wide range of tree products are collected by rural households. These products underscore the economic roles of trees in rural livelihoods and the preference for planting various multipurpose tree species. The results of this study indicated that households were commonly motivated to plant trees on farms to meet their needs in food and firewood as well as in income from the selling of tree products. Of the planted trees, fruit trees are worth mentioning because they are sources of food and income to farmers. Economic factors, therefore, were the strongest motivators of planting trees as has been documented elsewhere (e.g. Entage and Suh 2004). Many studies (e.g. Clay and Lewis 1990; Drechsel et al. 1996; Mateete et al. 1997; Roose and Ndayizigiye 1997) indicated that soil erosion and low soil fertility were the

major impediments to increasing agricultural production. The importance of farm trees in conserving the natural resource base and biodiversity is increasingly recognized (e.g. Acharya 2006; Garrity and Stapleton 2011). Unfortunately, rural households seem to be unaware of all the importance of trees on farms. As reported by Salam et al. (2000), the household decision to grow trees on farm is influenced more by economic than environmental factors. More widespread knowledge of the economic and environmental importance of trees on farms could have a positive impact on the households' decision to grow trees on farms.

The importance of the factors that influenced the planting of trees on farms were determined by considering statistically significant variables for each altitude region, and for all regions combined. In the MAR model, none of the variables studied explained why farmers planted trees in agricultural landscape. The lack of significant predictor variables is likely to provide avenue for future research aimed at a better understanding of the determinants of households' choice to plant trees on farms. The planting of trees on farms by more than 75% of midland households could partly be ascribed to the impact of agriculture and forestry development projects that promoted and disseminated widely agroforestry technologies in the region since the early 1970s.

The households in LAR and HAR have different socio-economic status and are located in different biophysical conditions. For this matter, different sets of variables predicted the planting of trees on farms. The model for the entire study area showed few common variables with one or two regional models. Our results indicated that the amount of farm fuelwood, the selling of tree products and the number of meals per day were the most common predictor variables. These variables had different coefficients, indicating varying effects on the presence of trees on farms across regions.

These findings were partly consistent with theoretical considerations. The amount of farm fuelwood was the most common important and negative factor influencing the presence of trees on farms in both LAR and HAR. The direction of the relationship between the presence of trees on farms and the amount of farm fuelwood remained negative when the pooled data across the three regions were analysed for their effects on the presence of trees at country level. This common effect implied that rural households did not extend the planting of trees on farms or were not replanting, and that effectively the on-farm tree resource was depleted. In addition, many tree species found on farms were not primarily used for fuelwood production. Hence fuelwood collection is not the major driving factor to tree planting. For example, across the three altitudinal regions, the majority of trees on farms were fruit trees for households' consumption and for income. This result seems to agree with those of Degrande et al. (2006) who found that smaller farms had higher fruit tree densities, a relationship that was particularly strong in communities with good market access. The rural households are therefore not primarily motivated to plant trees on farms for fuelwood but have incentives for the production of tree products generating extra income. As argued by Arnold and Persson (2003), firewood is collected as secondary products from trees on farms. Moreover, the use of trees on farms for fuelwood supply without replanting or coppicing result in decline or complete disappearance of trees on farms. The

exploitation of trees on farms affects farm productivity through removals of nitrogen as fuelwood (Gama-Rodrigues 2011). The consumption of farm fuelwood without replanting can cause an adverse impact on the nutrient status of the farms. Consequently, agricultural productivity decline and the ecological status of the farms is not enhanced.

In Rwanda, as in many countries of Africa, it was customary for trees to be established by men, with women responsible for food production (e.g. Den Biggelaar 1996; Mekonnen 1999). The households headed by women appear to plant more trees on farms than households headed by men. This results seem to oppose many studies focusing on gender roles in tree planting and agroforestry adoption (e.g. Mukadasi et al. 2007; Buyinza and Ntakimanye 2008; Deressa et al. 2009; Kideghesho and Msuya 2010). Since fruit trees were predominant in agricultural lands, women had gained an important role in on-farm tree planting, indicating a change in attitude toward this cultural taboo and toward ownership rights over land and planted trees on this land. Women heads of households are also common social units in all provinces of the country (NISR 2010). As a result of heading their own households, women have assumed new roles. A historical process of women undertaking roles and responsibilities of men in the absence of the latter has been reported for a number of societies (e.g. Allan 1965; Cliffe 1975).

Location dummy variables also had significant impact, reflecting the role of the agroecological context in explaining the planting of trees on farms. Compared to the high altitude region, many households in the low and medium altitude regions appeared to belong to the category of farm tree owners. In the high altitude region, more than 50% of agricultural households own farms smaller than the national average of 0.76 ha (NISR 2010). The small size of landholdings could be the reason for planting less or no trees on farms as it is has been found in many farm and socio-economic studies (ex. Zubair and Garforth 2006; Schuren and Snelder 2008; Sood and Mitchell 2009). The availability of forest affect also the planting of trees on farms (Vikram 2006; Rao and Reddy 2007). The proximity of rural households to forests can have influence on the decision to plant trees on farms.

Conclusion

The household-level survey results lead us to conclude that rural households in Rwanda are mainly motivated to plant trees on farms for economic benefits, not for environmental purposes. It appears that making trees planting on farms more economic is a necessary condition for increasing agroforestry cover. Rural households would be able to earn more income and to produce wood and food for their own use, contributing to their improved livelihoods. Expansion of tree planting on farms should be recognized as a way of achieving food and an extra household income by policy makers and extension services. To maximize the benefits from trees on farms, extension workers should motivate households to plant more trees on farms and raise awareness on multiple benefits of trees on farms, including their effects on the natural resource base and the environment. Special extension programmes should target female-headed households to enhance their

technical knowledge in planting and managing multipurpose trees on their farms for increased benefits and environmental protection.

This study indicates that different sets of socio-economic factors and attitudes in fuelwood production and use are associated with the household choice to plant trees on farms. The determinants of tree planting are region-specific, and cannot be easily generalized for all agricultural households at national scale. The current Rwandan forest policy promotes farm forestry. In the process of promoting tree planting and agroforestry practices, extension staff and development professionals should take into account of regional biophysical conditions and the household characteristics. This helps to match tree species with regional conditions and to meet the interests of the households in tree products. The issue of income and food from trees is also important. As long as farm trees produce products for selling, a policy formulated to improve commercialisation of farm tree products is bound to successfully influence the household decision to plant more trees on farms. Overexploitation of trees on farms urgently require strategies for replacement planting and management in terms of fuelwood sustainability for instance using alternative sources of energy or expanding plantation of multipurpose trees. Another important factors that influence households' farm tree planting decisions is the availability labour. The promotion of agroforestry technologies requiring less labour inputs in tree propagation, establishment and maintenance are likely to be adopted by many farming households.

In general, the results of the study bring up many factors that policies aiming at promoting farm tree planting and agroforestry should target or focus on. For instance, policy measures that enhance food security and income diversification in the households would, at the same time, enhance tree planting on farms. The results are also relevant to forestry (agroforestry) policy because they feature which category of tree species are important for rural households and for which purposes, for example to meet the needs in nutrition (fruit), or to address scarcity of fuelwood.

Encouraging tree planting on farms in order to meet the household needs is appropriate for all the categories of agricultural households in rural areas. Under the conditions of low income and small farm size, the households need to produce all products they need on a small area, thus enhancing competition between food crop and tree crop production. Notably in this case, the household tree management capacities need to be enhanced through awareness raising and provision of technical information. If farm size is large or income improves, the households may meet their tree products needs by planting more trees or produce some extra crop for the local markets. Income derived from the selling of crops then can be used to buy wood products, including fuelwood. Extension programmes should consider these issues related to farm size by focusing not only on subsistence and household uses but also on options for market-oriented activities because surpluses are apt to be marketed in many rural areas.

For effective dissemination of agroforestry technologies and their adoption by beneficiary smallholder farmers, development facilitators and extension services must be aware of the factors that contribute to tree planting on farms in the context of agricultural intensification. Their interventions might be more effective if implemented with actions supporting food security and commercialisation of tree products. While the positive effects of trees on farms on crop yields and environment are poorly

understood by farmers, awareness raising and education programmes may result in positive attitudes for tree planting on farms. Building farmers' knowledge, especially for women, about trees on farms and their effects on crops and environment—through training and better access to technical information and tree seeds or seedlings—would increase tree cover in agriculture landscape. Given the interests of farmers in economic benefits from trees, it should be possible to build on them in order to diversify and intensify the production of crops, trees and livestock on sustainable basis and to alleviate poverty in rural areas. In these respects, interventions by government and donor-funded projects should be site (region) specific, to account for biophysical conditions and boundary socio-economic realities that motivate farmers to plant different tree species on their farms.

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