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Agroforestry as a climate change mitigation practice in smallholder farming: evidence from Kenya

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Abstract

The promotion of agroforestry as a mitigation practice requires an understanding of the economic benefits and its acceptability to farmers. This work examines the agroecological and socio-economic factors that condition profitability and acceptance of agroforestry by smallholder farmers in Western Kenya. We differentiate the use of trees according to the permanence of carbon sequestration, introducing a distinction between practices with "high mitigation benefits" (timber) and practices with "low mitigation benefits" (fuelwood). This study goes beyond the analysis of incentives to plant trees to identify incentives to plant trees that lead to high mitigation outcomes. We show that environmental factors shaping the production system largely drive the choice for planting trees with high mitigation benefits. Most trees in the area are used for fuelwood, and the charcoal economy outweighs economic factors influencing planting of trees with high mitigation benefits. Larger households tend to produce more fuelwood, while high mitigation uses are positively related to the education level of the household head, and to the belief that trees play a positive role for the environment. Where trees contribute significantly to incomes, the norm is that they are owned by men. We conclude that although agroforestry is not perceived to be more profitable than traditional agricultural practices, it plays an important economic and environmental role by supporting subsistence through provision of fuelwood and could relieve pressure upon common forest resources. In areas with high tree cover, it also represents a way of storing capital to deal with risks and cope with uncertainty.

Keywords Fuelwood · Charcoal · Profitability · Acceptability · Gender · Labour

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1 Introduction

The benefits of agroforestry to soil fertility are particularly valuable where poor soils are associated with low and declining crop yields, food deficits, and dependence on food aid (Verchot et al. 2007; Okalebo et al. 2006). Tree-based land uses sequester carbon dioxide from the atmosphere into the carbon (C) stored in plant and soil biomass, with the most significant increases in C storage achieved by moving from low biomass systems (grasslands, agricultural fallows, permanent shrublands) to tree-based systems (Roshetko et al. 2007). Agroforestry practices can emit less non-CO_2 gases than other land uses if managed properly (Rosenstock et al. 2014), and therefore, agroforestry can contribute to climate change mitigation, especially in smallholder systems (Verchot et al. 2007; Montagnini and Nair 2012).

The socioeconomics of agroforestry systems have received little attention in research (Mbow et al. 2014). However, "it is the production from agroforestry systems that makes it an attractive land use for farmers, not its environmental benignancy" (Hosier 1989 p. 1835), and "for agroforestry to successfully spread, it must be economically profitable to the smallholders who are practicing it" (ibid. p. 1827). Agroforestry systems provide food, fuelwood, bioenergy (for cooking, heating drinking water, bathing, or washing clothes), medicine, livestock feed, timber, and construction materials. Trees are also viewed as "stored capital" or "money in the bank," and sold as timber when the need arises (Rice 2008). Agroforestry provides a means for diversifying incomes, and systems that produce a variety of wood and non-wood products are preferred because they meet household needs and help reduce risks (Roshetko et al. 2007).

Examining agroforestry options for their mitigation benefits requires understanding how farmers perceive and value the various benefits they receive from a particular practice. The promotion of agroforestry as a mitigation practice therefore requires an understanding of the economic benefits for farmers, namely its financial value. However, previous studies have shown that adoption of a practice is also determined by its acceptability to farmers (Franzel et al. 2001), which depends on the compatibility of the practice with farmers' sociocultural values, and its suitability to accepted gender roles (Franzel et al. 2001; Swinkels and Franzel 1997). Acceptability of a practice also depends on its feasibility from the farmers' point of view (Franzel et al. 2001; Swinkels and Franzel 1997)—for instance, the opportunity costs of switching household labor to agroforestry from an alternative activity should not be high.

Recent studies have looked at sociopsychological factors, such as perceptions and attitudes, to explain adoption behavior in relation agroforestry practices. Ajayi (2007) show that technical characteristics are important, but not the only factors affecting adoption of improved technologies by farmers in Zambia, and challenges to widespread uptake of improved fallow technologies include land constraints, property rights, availability of seeds, and the knowledge-intensive nature of the technology. Zubair and Garforth (2006) found that willingness to grow trees by farmers in Pakistan was a function of their attitudes towards the benefits and challenges of growing trees, their perception of the opinions of salient referents, and a number of other factors that encourage and discourage farm-level tree planting. Tree planting was perceived as increasing income, providing wood for fuel and furniture, controlling erosion and pollution, and providing shade for humans and animals. Sood and Mitchell (2004) found that in the Western Himalayas, farmers' perceptions of the restrictions on tree felling on their own land and their attitudes towards agroforestry were the most important sociopsychological factors influencing the decision to grow trees. Meijer et al. (2015) developed an analytical framework that emphasizes the role of knowledge, attitudes, and perceptions in the decision-making process of adoption.

This work examined the agroecological and socioeconomic factors that condition profitability and acceptability of agroforestry by smallholder farmers. We differentiated the use of trees according to the permanence of C sequestration, introducing a distinction between practices with "high mitigation (HM) benefits" and practices with "low mitigation (LM) benefits." These categories were distinguished using the following approach: all uses of trees which implied that trees were allowed to grow for extended periods and therefore sequester C in the longer term (e.g., production of timber, fodder, fruits/nuts, medicinal products) were considered to deliver HM benefits. On the other hand, uses of trees implying early harvest of products and leading to C losses—including production of fuelwood, charcoal, and livestock feed (the latter due to the large biomass harvest)—were categorized as LM. As such, this study goes beyond the identification of incentives to plant trees, as many earlier studies have, to the exploration of the factors and incentives for planting trees that lead to HM outcomes in particular.

We first analyzed factors that determine the HM and LM potential uses of trees on-farm. Our goal was to understand whether and to what extent HM and LM uses were determined by household characteristics, environmental factors, and farmers' perceptions regarding economic and environmental benefits of having trees on their farms. We subsequently investigated how HM and LM uses contributed to household incomes and livelihoods, looking at the financial returns from the two types of uses of trees. Thirdly, we analyzed factors influencing the amount of labor allocated to agroforestry efforts, asking whether and to what extent decisions to allocate labor to agroforestry were influenced by household characteristics, environmental factors, and farmers' perceptions regarding the overall benefits of growing trees. We computed returns to labor and compared labor productivity of agroforestry to that of traditional farming practices in the region. In the analysis of labor allocation and productivity, we did not differentiate between HM and LM uses of trees because farmers were only able to estimate the time spent on managing trees but not the amount of time spent on HM versus LM uses. Finally, we investigated more in depth the sociocultural aspects of acceptability of agroforestry, assessing a number of non-material factors affecting adoption, namely a set of perceptions regarding benefits and challenges from growing tees, and a number of cultural beliefs regarding gender roles, and their relationship with environmental factors.

Our data were collected through a survey on agroforestry practices carried out from November 2013 to April 2014 on 200 farms in the Lower Nyando Basin in Western Kenya, together with a detailed household survey collected in 2012 in the same site (Rufino et al. 2013a). This study was part of the Standard Assessment of Mitigation Potential and Livelihoods in Smallholder Systems (SAMPLES) project, an approach developed by the CGIAR Climate Change, Agriculture, and Food Security Program (CCAFS), which aimed to improve the quantification of baseline GHG emissions to support climate change mitigation (Rosenstock et al. 2013).

2 Data and methods

2.1 Study site and sampling

The Lower Nyando Basin in Western Kenya is in a sub-humid zone, with a bimodal rainy season (March to July and August to November). Farming systems are characterized as mixed rainfed crop-livestock (Kristjanson et al. 2012). The research site is a grid of 10 × 10 km purposively selected by CCAFS to conduct action research on climate-smart agriculture (Förch et al. 2014) (Electronic Supplementary Material, ESM, Fig. 1).

Data on agroforestry were collected from a random sample of 200 farms distributed across 20 villages randomly selected by the SAMPLES team to collect data on GHG emissions and located in two sub-counties: Kericho West (Kericho County, Rift Valley region) (60%) and Nyakach (Kisumu County, Nyanza region) (40%). The random selection of farms involved first participatory mapping exercises (Dorward et al. 2007), which consisted in preparing for each village detailed maps using key informants (a total of 29 elders and community leaders), who helped mapping a total of 789 households, identifying in each village presence and distribution of trees with different uses. Subsequently, 200 farms were selected randomly to collect specific data on agroforestry. One person was interviewed in each farm—the head of the household or an adult member with good knowledge of the farm.

The village-level data show differences in agricultural practices in the landscape—lowlands versus midslopes versus highland areas—which reflect the dynamics of the expansion of agriculture over the last 30 years. In this study, we refer to these areas as production systems. In the highlands, 73% and 56% of households grow trees for fruits and construction materials, respectively, while only 28% grow trees for fuelwood. The midslopes have the largest proportion of farms with trees used for fuelwood (80%), a fair proportion with trees for construction (49%), and a smaller proportion with fruit trees (17%). In the lowlands, trees for construction dominate (59% of households), but we also found trees for fuelwood (24%) and for fruits (22%).

2.2 Data

In the selected farms and for each tree species, we collected uses; number; approximate age; ownership; decision-making (regarding harvesting and selling); use of labor; and other inputs; outputs: quantity collected; consumed; sold; donated; used as animal feed, etc.; frequency of collection; training received. Data at household level included household head gender; age; education; land size; sources of income; household composition; on-farm and off-farm family labor; factors affecting the decision to plant/grow trees, perceptions of challenges and benefits, common beliefs with regard to trees, and gender norms pertaining to trees (division of labor, ownership of resources).

2.3 Approach and methods

We hypothesized that the economic benefits from agroforestry depend on factors related to the environment and the type of production system and to household and farm characteristics. The adoption of agroforestry depends on sociocultural acceptability: practices are adopted when they are in line with gender relations and labor norms.

When possible, we distinguish between practices that have a high potential for sequestering C (HM) and practices that have a low potential for sequestering C (LM). A better understanding of the different drivers behind HM and LM practices in agroforestry can contribute to strategies that lead to smallholders playing a greater role in lowering GHG emissions and improving their livelihoods with more trees on-farm. We first examine the factors that explain the choice of HM and LM practices. We then investigate labor allocation to agroforestry. Finally, we compare returns to labor with that of other farming practices. Our analysis excluded fruit trees, for which reliable data on production and prices could not be collected.

2.3.1 Use of trees

To examine the factors that explain the choice of using trees for HM and LM practices, we run i ordered logit models that take this form:

$$N\_Uses_{iz} = \alpha + \beta\ ProdSys_z + \gamma\ NTreeSpecies_z + \delta\ NHIncomes_z + \theta\ NCrops_z + \pi\ HSize_z + \rho\ HHEdu_z + \tau\ HHGender_z + \varphi\ Beliefs_z + \mu\ TimberOffFarm + \Omega\ FuelwoodOffFarm + \varepsilon$$

where i = HM indicates the number of uses of trees contributing to C sequestration (HM); and i = LM the number of uses of trees that have an LM impact in farm z.[1] ProdSys is a categorical variable that indicates the type of production system (lowlands, midslopes, highlands); NTreeSpecies indicates the number of tree species on-farm; NHIncomes is an indicator of wealth that captures the number of sources of income available to the household;[2] NCrops indicates the number of crops grown; HSize is the number of household members; HHEdu and HHGender number of years of formal education and gender of the household head; Beliefs includes two 5-scale Likert variables that capture farmers' agreement with specific statements regarding trees profitability and environmental benefits, hence depicting farmers' beliefs on benefits obtained from trees;[3] TimberOffFarm and FuelwoodOffFarm are dummy variables indicating respectively whether timber and fuelwood (firewood and/or charcoal) were harvested off farm.

We tested the hypotheses that: (1) Production system influences the number of uses (HM versus LM), with farms located in more fertile areas (highlands) more likely to plant tree species that are used for construction (HM); 2) tree species diversity favors HM uses because farms that grow more species also grow more trees which can be used for both HM and LM practices; (3) households that can rely on a larger number of income sources tend to be better off[4] are able to dedicate part of their resources (land, labor) to agroforestry practices that yield long-term economic returns, and are less likely to make myopic decisions that favor the short-term but neglect long-term outcomes (Yesuf and Bluffstone 2018); (4) the larger the varieties of crops grown on the farm, the higher the chances that the farm will be food secure, and the higher the probability of growing trees with HM uses, which represent a form of long-term investment (Jerneck and Olsson 2014): (5) larger households have more of both HM and LM trees, to satisfy both the need for diversification of incomes (wood for construction and charcoal) and for fuelwood; (6) beliefs matter: farmers who express an interest in both income and environmental benefits of trees (namely providing shade, attracting rainfall, functioning as wind breaks, and controlling soil erosion) prefer growing HM trees; and (7) collection of

[1] Each dependent variable is a numeric variable equal to the sum of the number of high or low mitigation practices from each species of tree at farm level.
[2] Possible sources of income included work in other farms, salaried employment, self-employment, gifts/remittances, environmental services, government projects, formal credit, informal credit, rent of machines/animals, rent of land, and sale of farm products.
[3] The farmers were asked how much they agreed with the following statements: "Trees are profitable" and "trees are good for the environment." Answers ranged from "strongly disagree" to "strongly agree."
[4] Reardon et al. (2007) show that in poor areas, households typically operate both farm and non-farm activities, and although they may not do either very efficiently, they are able to manage risk, compensate for a poor asset base, and survive. At household level, increasing household income is typically associated with higher rates of pluriactivity. Rufino et al. (2013b) show that more diverse income sources results in both more income and more food security in East Africa.

timber off-farm should reduce the need to keep trees with HM uses, while collection of fuelwood off-farm should reduce the need to keep trees with LM uses.

2.3.2 Valuing high and low mitigation tree products

To investigate the factors influencing the value of the products from the i types of practices in farm z, we regress the value of products for HM ($Value\_Products\_HM_z$) and LM uses ($Value\_Products\_LM_z$) on a number of independent variables:

$$Value\_Products_{iz} = \alpha + \beta\ ProdSys_z + \gamma\ NTrees_z + \delta\ N\_Uses_{iz} + \theta\ AFLabor_{(f,m,h)z} + \pi\ HHEdu_z + \varepsilon$$

where NTrees represents the number of trees grown; N _ Uses indicates the number of HM and LM uses in each farm; and AFLabor is a vector of indicators for the time (number of hours per year) spent on agroforestry by household members (female, male) and hired laborers. Given that the exact time when products were collected over the previous year could not be specified by the farmers, a zero discount rate was used in the assessment of their value.

We hypothesized that the labor invested in agroforestry is positively related to the value of production; the number of trees grown and the number of HM and LM uses increase the monetary value of the products of each type; highlands produce more valuable products; and finally, more educated household heads produce higher value products.[5]

2.3.3 Allocation of labor

To investigate the determinants of labor allocation to agroforestry, the following model was estimated:

$$AFLabor_z = \alpha + \beta\ ProdSys_z + \gamma\ NCrops_z + \delta\ NTrees_z + \theta\ OtherFarmWork_z + \pi\ HSize_z + \rho\ HLaborCost_z + \tau\ Beliefs_z + \varepsilon$$

where $AFLabor_z$ indicates the total labor spent on agroforestry (household and hired work), over the 12 months prior to the survey in farm z. OtherFarmWork is a dummy indicating whether cash is earned through work in other farms (around 70% of farmers admitted to have done work in other farms in the previous year). HLaborCost is the hourly cost of household labor, estimated by asking to the farmer how much (s)he would have paid if (s)he had to hire someone to do the task.[6]

We hypothesized that: Household size is positively related to the amount of work dedicated to trees; the number of crops grown and off-farm work are negatively related to labor spent on trees; the (opportunity) cost of household labor reduces time spent on trees[7]; and finally,

[5] Fruits represented around 10% of all products obtained from trees. For this reason, the economic value of high-potential mitigation uses might be underestimated.

[6] The cost of hired labor is not included in the regression due to the small number of observations.

[7] Our focus was primarily on the opportunity cost of household labor invested in agroforestry activities, which is a fundamental aspect of acceptability of a practice, as it affects its perceived feasibility. The opportunity cost of household labor was defined as the value of resources lost or forgone in order to develop HM and LM products, and that could have spent elsewhere (Reed 2007).

farmers who have positive beliefs regarding benefits from growing trees allocate more labor to agroforestry.

2.3.4 Productivity

Returns to land and to labor are commonly used to assess the financial value of trees (Ramadhani et al. 2002). We estimate returns to labor because trees in the study area are typically planted sparsely or as live fences, and do not occupy large areas. We compute annual labor productivity of a farming practice at farm level by dividing the total annual gross value of production by the amount of labor allocated to the practice.

There is no theoretical basis for knowing a priori how returns to labor influence agroforestry practices; therefore, we estimate this empirically. Data on agroforestry products, labor, and wage rates were collected from the farmers interviewed, and for output prices from key informants (elders and leaders). Data on other farming practices came from the 2012 IMPACTlite survey (Rufino et al. 2013a).[8] The farms included in the two surveys are not the same since only few farms surveyed in 2012 had tree records.

2.3.5 Social acceptability

Decisions regarding planting trees are related to farmers' perceptions regarding benefits and challenges of growing trees. Farmers who state that trees have positive economic or environmental functions (profitable, good for the environment) are more likely to grow trees than farmers who believe that trees cause negative effects (reduce land fertility, shade other crops, host parasites), or report that their decision to grow trees is affected by a number of constraints (price of seedlings, availability of water, availability of labor, lack of skills).

Decisions regarding growing trees may also be related to norms that define gender roles and division of labor, decision-making processes, and ownership of resources within the household. Gender norms can influence decisions regarding the species and number of trees planted. On gender norms and how these affect agroforestry practices, see for instance Kiptot and Franzel (2012).[9]

During the survey, farmers were asked to express their degree of agreement with a set of perceptions regarding the benefits from, and challenges of, growing trees, as well as gender roles and ownership in relation to trees. Their answers were recorded on a 5-point Likert scale ranging from "strongly disagree" to 'strongly agree." We used one-way ANOVA to test whether farmers' perceptions and their gender beliefs differ across production systems.

[8] We obtained a measure of labor productivity per hour for the majority of farming practices for which we had records of production and prices (maize, sugarcane, beans, sorghum, sweet potato, millet, groundnut, and intercropping of these).

[9] According to the authors, "women in Africa remain disadvantaged in the agricultural sector due to cultural, sociological, and economic factors. Such factors include limited access to resources and household decision-making. Such resources that are directly linked to agroforestry include land and tree resources, financial credit, extension service, labor, and appropriate technology. Furthermore, many African societies have taboos that prohibit women from undertaking certain activities, which may limit their participation in developmental interventions such as agroforestry."

3 Results

3.1 Uses of trees

The decision to use trees for early harvesting of products like fuelwood, which would lead to C losses or for late harvesting of products like timber that were likely to sequester C in the longer term, was found to be significantly related to production system (highlands, midslopes, lowlands) and household characteristics (Tables 1 and 2). Farmers located in the midslopes and the highlands reported having more trees with both HM and LM uses. Farmers with a greater diversity of trees more frequently used them for HM benefits. LM uses were positively related to household size, indicating that larger households need more fuelwood. Together with the number of tree species, the type of production system was the strongest determinant of HM practices.

The factors significantly influencing LM practices also included production system and household size. The education level of the household head was positively related to HM uses of trees ($p = 0.10$). The belief that trees are good for the environment was positively related to HM practices. Interestingly, the belief that trees are profitable did not seem to affect either HM or LM uses in our results. Households with more income sources were more likely to keep

Table 1 Ordinary logit model, variables, and parameters that explain the number of high and low mitigation uses of trees

Variables	*Y*=Nuses_HM		*Y*=Nuses_LM	
	Coefficient	s.e.	Coefficient	s.e.
ProdSys = midslopes	1.994***	0.536	1.32**	0.531
ProdSys = highlands	2.308***	0.534	1.195**	0.586
NTreeSpecies	0.164***	0.056	0.06	0.047
Ncrops	0.163	0.107	0.074	0.092
HSize	0.194	0.122	0.382***	0.079
HHEdu	0.254*	0.141	−0.121	0.181
HHGender	0.361	0.38	0.252	0.375
Beliefs_Environment	0.696*	0.368	0.06	0.378
Beliefs_Profit	0.086	0.162	−0.113	0.167
NHIncomes	0.305***	0.105	0.381***	0.091
TimberOffFarm	−0.374	0.305	−0.645*	0.349
FuelwoodOffFarm	0.314	0.287	0.179	0.377
Constant cut1	6.458***	2.037	1.258	1.742
Constant cut2	8.117***	2.094	3.627**	1.772
Constant cut3	9.309***	2.141	5.313***	1.786
Constant cut4	10.45***	2.185	6.41***	1.802
Constant cut5	11.097***	2.215	6.909***	1.817
Constant cut6	11.77***	2.253	7.634***	1.828
Constant cut7	12.813***	2.248	8.521***	1.87
Constant cut8	13.069***	2.257	8.944***	1.845
Constant cut9	13.828***	2.222	9.656***	2.14
Constant cut10	14.555***	2.336		
Observations	193			193
r2_p	0.116			0.107
P	1.84E-07			0
chi2	54.96			75.83

Data source: authors' survey and economic analysis 2013–14, farm-level data

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 2 Ordered logit model, standardized coefficients

Variables	N_Uses_Hmit							N_Uses_Lmit						
	b	*z*	*P* > *z*	bStdX	bStdY	bStdXY	SDofX	*b*	*z*	*P* > *z*	bStdX	bStdY	bStdXY	SDofX
ProdSys = midslopes	1.994	3.717	0.000	0.912	0.869	0.397	0.457	1.320	2.486	0.013	0.604	0.611	0.279	0.457
ProdSys = highlands	2.308	4.317	0.000	1.071	1.006	0.467	0.464	1.195	2.038	0.042	0.555	0.553	0.257	0.464
NTreeSpecies	0.164	2.941	0.003	0.656	0.072	0.286	3.996	0.060	1.283	0.199	0.240	0.028	0.111	3.996
Ncrops	0.163	1.529	0.126	0.321	0.071	0.140	1.966	0.074	0.811	0.417	0.146	0.034	0.068	1.966
Hsize	0.194	1.587	0.112	0.323	0.085	0.141	1.661	0.382	4.838	0.000	0.635	0.177	0.294	1.661
HHEdu	0.254	1.798	0.072	0.239	0.111	0.104	0.939	− 0.121	− 0.669	0.504	− 0.114	− 0.056	− 0.053	0.939
HHGender	0.361	0.949	0.343	0.156	0.157	0.068	0.433	0.252	0.674	0.501	0.109	0.117	0.051	0.433
Beliefs_Environment	0.696	1.891	0.059	0.296	0.303	0.129	0.426	0.060	0.160	0.873	0.026	0.028	0.012	0.426
Beliefs_Profit	0.086	0.531	0.595	0.079	0.038	0.034	0.912	− 0.113	− 0.678	0.498	− 0.103	− 0.053	− 0.048	0.912
HIncomesN	0.305	2.912	0.004	0.402	0.133	0.175	1.320	0.381	4.171	0.000	0.503	0.176	0.233	1.320
TimberOffFarm	− 0.374	− 1.225	0.220	− 0.174	− 0.163	− 0.076	0.466	− 0.645	− 1.849	0.064	− 0.301	− 0.299	− 0.139	0.466
FuelwoodOffFarm	0.314	1.094	0.274	0.154	0.137	0.067	0.491	0.179	0.476	0.634	0.088	0.083	0.041	0.491

b raw coefficient

z *z*-score for test of $b = 0$

$P > z$ *p* value for *z*-test

bStdX *x*-standardized coefficient

bStdY *y*-standardized coefficient

bStdXY fully standardized coefficient

SDofX standard deviation of *X*

trees for both HM and LM uses. Finally, households who relied on collection of timber off-farm had fewer LM trees, but collection of timber off-farm was not significantly related to having HM on-farm trees.

During our survey, very few farmers claimed to use trees for environmental purposes (e.g., to restore degraded land), suggesting that agroforestry for soil fertility improvement is not the main goal (see also Jama et al. 2008; Pisanelli et al. 2008). Franzel (1999) and Backes (2001) found that farmers in Western Kenya find it difficult to fallow land, because there is a small arable land available, and thus, it is now being continuously cropped. Our findings support Kiptot et al.'s (2007) conclusion that for improved fallow technologies to be attractive to farmers, they must provide other economic benefits additional to the soil fertility improvement benefits.

3.2 Economic value

Around 60% of the trees produced multiple products in the surveyed farms. Outputs included products used in construction, i.e., poles, timber, and trunks (37% of the records), fuelwood (35%), charcoal (11%), and fruits (10%). Altogether, these six products represented 93% of total outputs, with the remaining 7% being fodder, leaves, and products for medicinal use.

Most products were collected occasionally, with the exception of fuelwood and charcoal, which represent a source of regular income in the midslopes (ESM Fig. 2). Only 18% of the products were collected regularly, with 82% collected when ready or when there was need (mainly fuelwood, poles, trunks, and timber) (Table 9, ESM).

In the midslopes, income from charcoal and firewood—on average 19,850 ± 47,500 Kenyan shillings (KSh) per household per year (or approximately \$198 ± 475, \$1 = KSh 100) clearly outweighed the net benefits from HM uses of trees (on average KSh 1150 ± 4500, or \$11 ± 45 per household per year). On-farm trees were used to meet household needs, and through the market, community fuelwood needs—including the needs of lowland and highland communities. In this area, local forest resource conservation efforts might benefit from these practices, since exploiting on-farm wood resources can relieve the pressure upon forest resources (Rice 2008). HM products provided farmers in the lowlands and the highlands a relatively larger but infrequent source of finance (on average around KSh 2450 ± 5500 per household per year, or \$24 ± 55, and KSh 2400 ± 7900, or \$24 ± 79, respectively). Hence, it seems that in the lowlands and the highlands, more than in the midslopes, trees were viewed by farmers as 'stored capital," in that they were used as lumber (Rice, 2008), and as a means of generating income and limiting risk (Roshetko et al. 2007).[10]

The results from our regression (Table 3) show that in the midslopes, the value of LM products was higher than those in other production systems, while the value of HM products was lower. The value of LM products is positively related to male and female labor spent on agroforestry. We found a negative relationship between labor allocated by male-headed households and the value obtained from HM products: farmers who earned more with HM products were also those who dedicated less labor to managing trees, perhaps because the products sold were harvested by the buyers, a common practice in the area. The level of education of the household head was not related to the value of HM products, but it was negatively related to the value LM products, suggesting that less educated households will be challenging targets for projects aimed at increasing mitigation uses of agroforestry.

[10] Due to issues of data reliability, fruits as well as minor products like fodder, leaves, thin poles used in construction, and medicinal herbs were excluded from the analysis.

Table 3 Regression results on the annual value of high mitigation and low mitigation tree products

Variables	*Y1* = Value_Products_HM			*Y2* = Value_Products_LM		
	Coefficient	Beta	s.e.	Coefficient	Beta	s.e.
ProdSys = midslopes	− 2797.115*	− 0.106	1598.21	28859.549***	0.288	7404.31
ProdSys = highlands	286.26	0.011	1804.27	2664.86	0.027	5831.57
Ntrees	3.451**	0.211	1.58	9.02	0.146	6.888
Nuses_HM	2483.28*	0.403	1282.74	− 805.441	− 0.035	1934.30
Nuses_LM	− 655.52	− 0.084	589.21	− 1218.86	− 0.041	2909.89
AF_Labor_F	− 80.609	− 0.055	110.424	1112.014*	0.201	667.488
AF_Labor_M	− 76.233**	− 0.154	37.685	271.096***	0.144	102.401
AF_Labor_Hired	− 10.314	− 0.028	31.589	19.208	0.014	107.521
HHEdu	1241.04	0.088	1029.72	− 8746.681***	− 0.164	2956.68
Constant	− 581.75		2065.05	16304.402***		5428.25
Observations	162			162		
R-squared	0.227			0.258		
r2	0.227			0.258		
r2_a	0.182			0.214		
F	3.26			3.569		
rmse	11,376			42,234		

Data source: authors' survey and economic analysis 2013–2014, farm-level data

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust s.e

3.3 Allocation of labor

Farmers from the midslopes employed significantly more labor on agroforestry than farmers from the lowlands (but not significantly more than farmers in the highlands) (ESM Table 5). There was no difference between production systems with regard to male labor dedicated to agroforestry. However, in the lowlands, we saw significantly less female labor allocated to agroforestry in absolute terms, and in the midslopes, there was significantly more female labor than in the highlands. Hired labor was used less in the lowlands than in the other two systems. The cost of labor, both hired and from the household, was not significantly different across production systems (ESM Table 5).

In line with the results from the ANOVA, our regression results (Table 4) show that labor allocated to agroforestry was positively related to the midslope system, where LM products were also more valuable (Table 3). Labor allocated to agroforestry increased significantly with the number of crops grown, whereas it decreased with off-farm employment. The amount of work invested in agroforestry efforts decreased significantly as the opportunity cost of household labor rose. Contrary to our expectations, however, household size and the total number of trees on-farm was not significantly related to the amount of time dedicated to agroforestry practices. Interestingly, perceived benefits had no significant influence—in particular, farmers with positive perceptions of the benefits from growing trees (either economic or environmental) were not more likely to allocate more labor to agroforestry.

3.4 Comparing returns to agroforestry with other practices

We compared the gross value of agroforestry production with the returns to other farm agricultural practices. Of the 944 cropping fields surveyed in 2012 (Rufino et al. 2013a), around 12% had gross returns above KSh 30,000 year (around \$300). Less than 5% of farmers

Table 4 Regression results on labor (in hours per year) allocated to agroforestry in 2013–2014

Variables	Y = AF_Labor		
	Coefficient	Beta	s.e.
ProdSys = midslopes	25.324**	0.302	10.645
ProdSys = highlands	8.012	0.089	7.187
Ncrops	4.411**	0.185	1.911
OtherFarmWork	− 16.826*	− 0.182	9.25
Ntrees	0.011	0.158	0.008
Hsize	1.737	0.075	1.389
HLaborCost	− 0.091***	− 0.215	0.025
Beliefs_Profit	− 4.947	− 0.109	3.598
Beliefs_Environment	2.123	0.021	6.92
Constant	16.512		31.362
Observations	122		
R-squared	0.238		
r2	0.238		
r2_a	0.177		
F	5.846		
rmse	36.98		

Data source: authors' survey and economic analysis 2013–2014, farm-level data

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust s.e

obtained 30,000 KSh or more as annual gross returns from non-food tree products.[11] Hence, in the study area, about 90% of the population does not get $1 a day from either agroforestry or other farming practices.

Consistent with these results, our data show that most farmers (73%) disagreed with the statement that trees are profitable (18.5% agreed that they are profitable, 8.5% were neutral). Interestingly, farmers who earn more than KSh 30,000 year from the sale of tree products collected regularly did not perceive trees as more profitable than other farmers. Although farmers who earned a regular income from trees were likely to agree that trees are profitable, agroforestry was generally not perceived to be a profitable practice.

To compare the profitability of agroforestry with that of other farming practices, we computed a measure of labor productivity at farm level that did not include the cost of work. The labor productivity of agroforestry (period 2013–2014) was much higher than that of other farming practices (year 2012) (Table 5), because less labor is used in agroforestry, which compensated for the lower revenues from tree products in comparison to products obtained from other farming practices.

3.5 Social acceptability

Farmers in the lowlands were the least convinced about the profitability of trees. Views on the environmental benefits of agroforestry were similar across systems. Farmers in the lowlands stated more strongly that prices of seedlings and availability of skilled labor were important factors affecting their decision to grow trees. Lowland farmers were also significantly more likely to believe that trees make land infertile than farmers in the midslopes (Table 6 ESM).

[11] A measure of net revenues including costs of inputs would show larger net revenues from agroforestry, because little inputs are required (seeds, fertilizers, etc.).

Table 5 Annual labor productivity (expressed as gross revenue per hour of work): comparing agroforestry practices across production systems with other farming practices (maize, sugarcane, beans, sorghum, sweet potato, millet, and groundnut and intercropping of these). Agroforestry data include only records for years 2013–2014, IMPACTlite data refers to year 2012

	Agroforestry highlands	Agroforestry lowlands	Agroforestry midslopes	Agroforestry total	Farming practices
Average labor use (hours per year^{-1})	5	6	9	7	264
Revenue from products (KSh per year^{-1})	7093	2843	1622	3752	33,177
Labor productivity (KSh per h^{-1})	1185	807	127	705	172
Max labor productivity (KSh per h^{-1})	30,120	14,250	1985	30,120	5906
Observations	43	47	44	134	544

Data sources: authors' survey and economic analysis 2013–2014, farm-level data, and IMPACTlite data 2012 at field level

Farmers from the midslopes were significantly more likely than highland farmers to assert that labor needs affect their decision to grow trees, which is consistent with our results showing that more labor was needed in the midslopes to manage trees. Farmers in the midslopes, where on-farm tree cover is higher, are also more likely to be concerned about trees shading crops than farmers in the lowlands. In the highlands, farmers have fewer negative perceptions of trees than in the other systems.

Farmers in the highlands, in particular, thought that trees are always owned by men. Farmers in the midslopes were also more likely to believe that trees are only owned by men, and to agree with the contention that trees are "men's work." This is at odds with the fact that in the midslopes, relatively, more female labor was spent on trees.

4 Discussion and conclusions

Our study shows that smallholder farmers managed trees of different species for multiple uses, and in more diverse systems there were more HM uses. Production systems had a big influence on the choice of trees and their uses. Farms located in the midslopes and highlands, characterized by relatively higher rainfall, had more trees and used them both as a source of fuelwood and in a way that contributed to sequestering C. LM uses of trees were positively related to household size, in part, because larger households have higher fuelwood needs. On the other side, HM uses of trees were positively related to the education level of the household head, and to the belief that trees play a positive role for the environment. Finally, wealthier households were able to dedicate more resources (land, work) to agroforestry.

LM products provided a source of regular income to households in the midslopes, where, in particular, charcoal earnings outweighed the returns from HM uses. There, agroforestry practices seemed to play an important role in relieving the pressure upon forest resources (Rice 2008). We also found that more female labor was dedicated to agroforestry in the midslopes, highlighting how women influence the type and use of trees grown (Kiptot and Franzel 2012). Previous studies have documented male control over trees and how this is grounded in cultural norms (David 1997, Chavangi 1987). In line with previous work (Kiptot and Franzel 2012), we found that women's participation was low in enterprises traditionally considered a man's domain, such as timber production, and high in enterprises that have low or no commercial value and high consumption value, such as the collection of fuelwood.

In contrast, HM products, such as timber, provided farmers in the lowlands and highlands relatively more income, but on an on-and-off basis. Hence, it seems that in these systems, more than in the midslopes, trees were viewed by farmers as "stored capital" or "money in the bank." Our results show that farms in the highlands were more diversified in terms of number of crops grown (ESM Tables 2 and 4). If we consider this as an indicator of food security, then drawing on Jerneck and Olsson (2014), our results suggest that relatively food secure farmers in the highlands might act as "opportunity seekers" and adopt HM agroforestry practices; on the other side, due to the "food imperative," people in the lowlands and midslopes act as "risk evaders" and tend to choose LM uses.

Relatively, more farmers get a higher income from traditional farming practices, amounting to around $1 a day, than from growing trees. However, labor productivity for agroforestry seems much higher than labor productivity for other farming practices, most likely due to the smaller amount of work and external inputs used in managing trees. Other evidence suggests that agroforestry products may generate capital beyond subsistence levels, thereby aiding capital accumulation and re-investment at the farm level (Mbow et al. 2014).

Building on our findings, perceptions of agroforestry as a non-remunerative activity could limit agroforestry practices and their mitigation benefits. These perceptions could relate to the relatively longer temporal scale over which rewards are delivered (e.g., waiting 5 to 8 years for fruit or timber products, compared to harvesting two crops per year). Also, agroforestry systems compete with supplies from natural forests where extraction costs are lower than cultivation costs, and the opportunity cost of land for uses other than food production is particularly high for smallholder farmers (Reed 2007), especially in the context of increasing population pressures in Western Kenya. Finally, poor record-keeping on the amount of labor spent and the revenues earned from the periodic sale of tree products could contribute to perceptions of agroforestry as non-remunerative compared to other agricultural practices with regular, seasonal work requirements.

David (1997) shows that in farm households in Western Kenya, off-farm work represents the most important source of income, and tree products are of secondary importance in cash earnings; farmers are likely to give priority to investing in businesses and livestock production, which yield short-term economic returns, as opposed to investing in long-term agroforestry technologies. Our analysis shows that the opportunity cost of household labor is key, and the amount of work dedicated to trees decreases as the perceived opportunity cost of household labor increases.

Agroforestry is increasingly being recognized for its potential to play a key role in global climate change mitigation, while at the same time generating rural development benefits. Yet there are trade-offs to pursuing these twin goals that pose big challenges (Anderson and Zerriffi 2012). There is a clear threat to longer term "mitigative" agroforestry practices from short-term needs for fuelwood and charcoal. This analysis suggests that paying more attention to improved livelihoods through agroforestry initiatives—i.e., the shorter term benefits—will be needed first in order to reap more longer term mitigation benefits.

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References

Ajayi OC (2007) User acceptability of sustainable soil fertility technologies: lessons from farmers' knowledge, attitude and practice in southern Africa. J Sustain Agric 30(3):21–40

Anderson EK, Zerriffi H (2012) Seeing the trees for the carbon: agroforestry for development and carbon mitigation. Clim Chang 115(3–4):741–757

Backes MM (2001) The role of indigenous trees for the conservation of biocultural diversity in traditional agroforestry land use systems: the Bungoma case study: in-situ conservation of indigenous tree species. Agrofor Syst 52(2):119–132

David S (1997) Household economy and traditional agroforestry systems in western Kenya. Agric Hum Values 14(2):169–179

Dorward P, Shepherd D, Galpin M (2007) Participatory farm management methods for analysis, decision making and communication. FAO, Rome

Franzel S (1999) Socioeconomic factors affecting the adoption potential of improved tree fallows in Africa. Agrofor Syst 47(1–3):305–321

Franzel S, Coe R, Cooper P, Place F, Scherr SJ (2001) Assessing the adoption potential of agroforestry practices in sub-Saharan Africa. Agric Syst 69(1):37–62

Förch W, Kristjanson P, Cramer L, Barahona C, Thornton PK (2014) Back to baselines: measuring change and sharing data. Agriculture & Food Security 3(1):13

Hosier RH (1989) The economics of smallholder agroforestry: two case studies. World Dev 17(11):1827–1839

Jama BA, Mutegi JK, Njui AN (2008) Potential of improved fallows to increase household and regional fuelwood supply: evidence from western Kenya. Agrofor Syst 73(2):155–166

Jerneck A, Olsson L (2014) Food first! Theorising assets and actors in agroforestry: risk evaders, opportunity seekers and 'the food imperative' in sub-Saharan Africa. Int J Agric Sustain 12(1):1–22

Kiptot E, Franzel S (2012) Gender and agroforestry in Africa: a review of women's participation. Agrofor Syst 84(1):35–58

Kiptot E, Hebinck P, Franzel S, Richards P (2007) Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. Agric Syst 94(2):509–519

Kristjanson P, Neufeldt H, Gassner A, Mango J, Kyazze FB, Desta S, Sayula G, Thiede B, Förch W, Thornton PK, Coe R (2012) Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa. Food Sec 4(3):381–397

Mbow C, Smith P, Skole D, Duguma L, Bustamante M (2014) Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. Curr Opin Environ Sustain 6:8–14

Meijer SS, Catacutan D, Ajayi OC, Sileshi GW, Nieuwenhuis M (2015) The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. Int J Agric Sustain 13(1):40–54

Montagnini F, Nair PKR (2012) Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agrofor Syst 61:281–295

Okalebo JR, Othieno CO, Woomer PL, Karanja NK, Semoka JRM, Bekunda MA, Mukhwana EJ (2006) Available technologies to replenish soil fertility in East Africa. Nutr Cycl Agroecosyst 76(2–3):153–170

Pisanelli A, Poole J, Franzel S (2008) The adoption of improved tree fallows in western Kenya: farmer practices, knowledge and perception. Forests Trees Livelihoods 18(3):233–252

Ramadhani T, Otsyina R, Franzel S (2002) Improving household incomes and reducing deforestation using rotational woodlots in Tabora district, Tanzania. Agric Ecosyst Environ 89(3):229–239

Reardon T, Berdegué J, Barrett CB, Stamoulis K (2007) Household income diversification into rural nonfarm activities. Transforming the rural nonfarm economy: opportunities and threats in the developing world, 115–140

Reed MS (2007) Participatory technology development for agroforestry extension: an innovation-decision approach. Afr J Agric Res 2(8):334–341

Rice RA (2008) Agricultural intensification within agroforestry: the case of coffee and wood products. Agric Ecosyst Environ 128(4):212–218

Rosenstock TS, Rufino MC, Butterbach-Bahl K, Wollenberg E (2013) Towards a protocol for quantifying the greenhouse gas balance and identifying mitigation options in smallholder farming systems. Environ Res Letters 8(2):021003

Rosenstock TS, Tully KL, Arias-Navarro C, Neufeldt H, Butterbach-Bahl K, Verchot LV (2014) Agroforestry with N2-fixing trees: sustainable development's friend or foe? Curr Opin Agric Sustain 6:15–21

Roshetko JM, Lasco RD, Angeles MSD (2007) Smallholder agroforestry systems for carbon storage. Mitig Adapt Strateg Glob Chang 12(2):219–242

Rufino MC, Quiros C, Boureima M, Desta S, Douxchamps S, Herrero M, Wanyama I (2013a) Developing generic tools for characterizing agricultural systems for climate and global change studies (IMPACTlite phase 2). Report to CCAFS

Rufino MC, Thornton PK, Mutie I, Jones PG, Van Wijk MT, Herrero M (2013b) Transitions in agro-pastoralist systems of East Africa: impacts on food security and poverty. Agric Ecosyst Environ 179:215–230
Sood KK, Mitchell CP (2004) Do socio-psychological factors matter in agroforestry planning? Lessons from smallholder traditional agroforestry systems. Small Scale For Econ Manag Policy 3(2):239–255
Swinkels R, Franzel S (1997) Adoption potential of hedgerow intercropping in maize-based cropping systems in the highlands of western Kenya 2. Economic and farmers' evaluation. Exp Agric 33:211–223
Verchot LV, Van Noordwijk M, Kandji ST, Tomich TP, Ong C, Albrecht A, Mackensen J, Bantilan C, Anupama KV, Palm CA (2007) Climate change: linking adaptation and mitigation through agroforestry. Mitig Adapt Strateg Glob Chang 12:901–918
Yesuf M, Bluffstone R (2018) Consumption discount rates, risk aversion and wealth in low-income countries: evidence from a field experiment in rural Ethiopia. J Afr Econ
Zubair M, Garforth C (2006) Farm level tree planting in Pakistan: the role of farmers' perceptions and attitudes. Agrofor Syst 66(3):217–229