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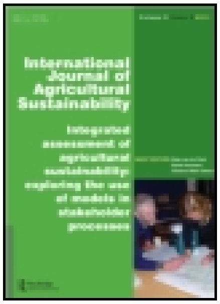

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Sustainable agricultural intensification: the role of cardamom agroforestry in the East Usambaras, Tanzania

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The East Usambaras in Tanzania are a tropical biodiversity hotspot where current agricultural management practices pose threats to forest conservation and development objectives. Promoting sustainable agricultural intensification (SAI) would improve long-term productivity and reduce pressure on forest reserves. The study objective was to identify household-level characteristics that influence adoption of improved management practices, specifically soil replenishment practices, in order to identify opportunities and constraints to scaling up SAI to landscape level. First, three common farming systems and a fourth agroforestry (AF) model were developed to estimate the relative profitability of incorporating fallow, manure, and non-timber forest product activities. Next, household surveys were conducted and a logistic regression analysis was used to measure the influence of socioeconomic characteristics, physical and financial assets, tenure security, and plot-specific attributes on adoption of soil replenishment practices that were specified in the model. Findings showed that the AF model was financially competitive but raises opportunity costs to labour when compared to common systems. Marital status, household size, remittances, credit access, and tenure security significantly influenced adoption of fallow and applying organic inputs. Significant plot-specific attributes included perceived fertility and distance from the homestead. Policies to scale up SAI should consider these factors and emphasize improving markets for AF species and extension services.

Keywords: sustainable agriculture; intensification; agroforestry; soil fertility; adoption; cardamom; Tanzania

1. Introduction

Low agricultural productivity in sub-Saharan Africa threatens food security, compromises health and nutrition, and undermines poverty alleviation efforts (Diao *et al*. 2010, Pretty *et al*. 2011). Key constraints to increasing productivity include socioeconomic and biophysical factors (Pender *et al*. 2006). Investments in soil fertility are essential to increase agricultural productivity and improve rural livelihoods (Place *et al*. 2003, Wollni *et al*. 2010, Dethier and Effenberger 2012).

Agricultural practices influence levels of food production and, more broadly, the state of the global environment (Tilman *et al*. 2002). Population pressures have reduced land availability and led to a breakdown of natural fallow systems that were used to replenish soil fertility (Ajayi *et al*. 2007). The removal of subsidies has increased fertilizer costs, making them largely unaffordable, and opportunities to extensify are limited (Reardon *et al*. 1999, Dethier

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and Effenberger 2012). As farmers turn to cultivation of marginal lands, including steep mountain slopes, increased soil erosion, and reduced water availability negatively affect long-term agricultural productivity (Maertens *et al*. 2006). Unsustainable intensification has been identified as a prominent driver of land-use change and biodiversity loss in tropical regions (Sala *et al*. 2000, Wright 2005).

Sustainable agricultural intensification (SAI) relies on natural, social, and human capital assets and the use of available technologies and inputs to minimize or eliminate harm to the environment (Pretty 2008). The goals of SAI include improving agricultural productivity, household (HH) food security, and rural livelihoods while simultaneously mitigating environmental degradation (Lee *et al*. 2006). SAI increases output and reduces negative environmental impacts while contributing to natural capital and the flow of environmental services (Pretty 2008, Conway and Waage 2010, Godfray *et al*. 2010). Labour and capital inputs affect the long-term sustainability of intensification processes. Labour-led intensification, or capital-deficient intensification, refers to the emphasis on labour to improve short-term agricultural productivity by cropping more densely, weeding, and harvesting more frequently (Clay *et al*. 1998, Reardon *et al*. 2001). Capital-led intensification relies on the substantial use of non-labour variable inputs or practices that enhance soil fertility (Reardon *et al*. 2001). Management practices to improve soil fertility include agroforestry (AF) (Nair *et al*. 2008), fallowing, and adding organic matter (Reardon and Vosti 1995, Clay *et al*. 1998). Although indigenous AF practices are widespread in Africa (Franzel and Scherr 2002), abandonment is high (Pattanayak and Sills 2001, Pattanayak *et al*. 2003) and adoption of practices to improve soil productivity is generally low (Pretty *et al*. 2003, Tenge *et al*. 2011, Ajayi *et al*. 2007).

The East Usambaras, located in northeast Tanzania, are a tropical biodiversity hotspot where current management practices are unsustainable and contribute to forest and biodiversity losses. Few farmers invest in soil replenishment practices, despite growing population pressures and land scarcity concerns. Developing sustainable strategies to balance use and conservation of fragile natural resources in mountainous areas is a challenge (Schreinemachers *et al*. 2013). Promoting and enhancing farmer adoption of improved management practices could both improve long-term agricultural productivity and reduce pressure on forest reserves. The study objective was to identify household-level characteristics that influence adoption of improved management practices, specifically soil replenishment practices, in order to identify opportunities and constraints to scaling up SAI to landscape level. A cross-sectional design and mixed methods approach was used. Focus groups were used to classify three common farming systems and a fourth AF model was developed to estimate the relative profitability of incorporating practices to improve soil fertility, specifically fallow and organic inputs. Additionally, non-timber forest product (NTFP) activities were included in the model to smooth income flows during low periods of crop production. Next, household surveys were used to evaluate the roles of socioeconomic characteristics, physical and financial assets, tenure risk, and plot-specific characteristics on adoption of the soil fertility improvement practices specified in the model. Logistic regression analyses were used to identify household factors that would potentially create opportunities or challenges to scaling up SAI to landscape level. The remainder of the paper is organized into four sections. The first section describes the study area, farming system, and household data collection. Next, descriptive data, profitability, and logistic model results are presented and discussed in terms of their implications for creating opportunities and challenges to adopt soil improvement practices. The paper is concluded with policy recommendations for how to promote and scale up SAI in the East Usambaras and other areas of high conservation importance.

2. Methodology

2.1 *Study area*

The East Usambara Mountains lie within the Eastern Arc Mountains, a chain of 13 mountain blocks and coastal forests in Tanzania and Kenya that support approximately 3300 km^2 of montane forests (Burgess *et al*. 2007) (Figure 1). The Eastern Arcs are classified as a biodiversity hotspot by Conservation International (Burgess *et al*. 1998, Mittermeier 1999, Mittermeier *et al*. 2004). They support the highest ratio of endemic flora and fauna per 100 km^2 of all biodiversity hotspots in the world: 35% of the plants (e.g. 40 tree species) and more than 25% of animal species (e.g. 80 vertebrate species) are endemic (Burgess *et al*. 2007). At least 70% of the Eastern Arc's natural forest habitat has been lost, increasing the risk of extinction for many species (Newmark 1998, 2002, Burgess *et al*. 2007).

Settlement of the Usambara Mountains dates back to 100 CE (Schmidt 1989). Activities from the 1960s to the present, such as commercial logging, estate farming, the expansion of smallholder agriculture, and conservation initiatives, have influenced the landscape (Conte 2004, Rantala and Vihemäki 2011). Semi-subsistence farming is the main livelihood for most people in the highlands. Favourable agro-ecological conditions support diverse food and cash crop production, including high-value horticultural products such as spices. Many farmers also manage livestock and dairy cows to sell milk to a local cooperative.

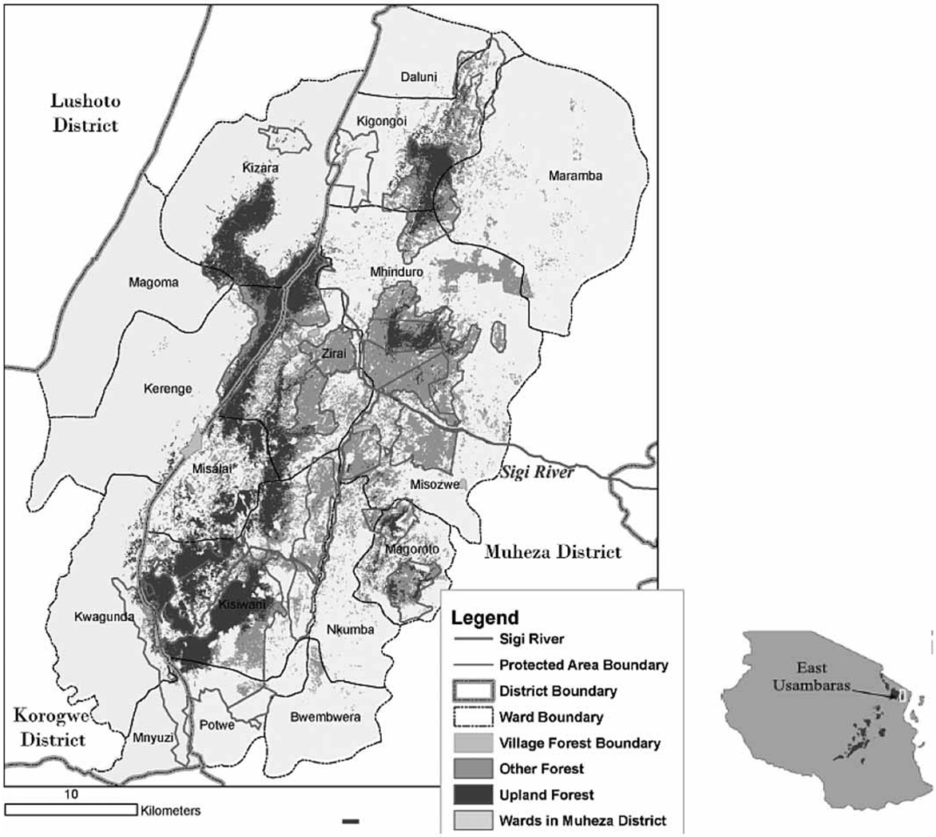

Figure 1. Land cover data classified from SPOT January 17, 2000 satellite image (Map in UTMWGS84 produced by Jaclyn Hall).

Conservation attention increased in the early 1980s (Rodgers and Homewood 1982). The East Usambara Conservation and Development project began in 1987 and linked conservation of biodiversity with economic development (Conte 2004). Despite promotion of soil and water conservation, tree planting, and the use of organic manure (Engh 2011), adoption has been low (EUCAMP 2002, Reyes *et al.* 2010). Productivity is threatened by poor soils, heavy rainfall, and generally poor and unsustainable farming methods (Reyes *et al.* 2006, ANR New Management Plan 2009). Conservation regulations limit traditional shifting cultivation practices (Reyes *et al.* 2010) and population growth pressure and land scarcity threaten the remaining natural forests (Reyes *et al.* 2005). Losses of productive land and inefficient farm management motivate clearance and cultivation on marginal lands, including steep slopes (Reyes *et al.* 2005).

2.1.1 *Cardamom AF*

Cardamom is a perennial shrub commonly grown in highland AF systems. Cardamom (*Elettaria cardamomum*) was first introduced in the 1890s by German settlers (Reyes 2008) and later promoted by the Tanzanian government in the 1980s as part of its export diversification strategy. In the East Usambaras, the number of households estimated to cultivate cardamom range from 60% to 90% (Sah 1996, Reyes 2008; Bullock's fieldwork). Cardamom sales comprise approximately 30% of household income and more than half of the total cash crop income (Reyes *et al.* 2006). Cardamom cultivation in the East Usambaras has been identified as one of the primary threats to natural forests outside of protected reserves (Stocking and Perkin 1991, Newmark 2002, CEPF 2005, Reyes 2008). However, cardamom production, relative to other crop systems, conserves more trees on farms (Woodcock 1995). Other tropical commodities grown in AF systems, such as cocoa and coffee, have garnered attention for their role in maintaining trees on private farms. Maintaining trees on farms outside reserves reduces pressures on natural forests (Huang *et al.* 2002) and provides diverse products and services that can contribute to wider landscape approaches to reconcile agriculture and conservation land uses (Sayer *et al.* 2013)

However, in the East Usambaras, labour-led intensification practices undermine the potential of Cardamom AF as a long-term, sustainable farming system. Approximately, 50% of the tall canopy trees are removed and the entire understory is cleared (Reyes 2008). Initially, species and structural diversity in the agroforest canopy is high (Hall *et al.* 2010), but labour-intensive management steadily reduces shade tree density and diversity (Perfecto *et al.* 1996, Rappole *et al.* 2003). Cardamom is densely intercropped with cash and subsistence crops, including several varieties of banana and cocoyams (*Xanthosoma* sp.). Continuous cropping, which has become more commonplace in Africa (Kassie *et al.* 2012), accelerates fertility declines that lead to poor cardamom production after seven years (Stocking and Perkin 1991). At this point, farmers often convert Cardamom AF to second-stage farming systems that support annual sun grown crops (Stocking and Perkin 1991, Reyes 2008), such as sugarcane (*Saccharum officinarum*), maize (*Zea mays*), and cassava (*Manihot esculenta*) (Reyes 2008). Natural fallowing, or withdrawal of land from cultivation to permit natural vegetation to grow, is rare (Reyes 2008). Under the current intensification regimes, land is barren and unproductive after 17 years (Stocking and Perkin 1991) further exacerbating problems associated with productivity and land availability. Deliberate management of Cardamom AF that incorporates practices to improve soil fertility could be a feasible strategy to sustain productivity outside reserves and support broader landscape scale conservation objectives.

2.2 *Data collection*

Data were collected during field visits made in 2008–2010. Villages were purposively selected. Kwezitu, Zirai, IBC Msasa, and Kizerui were selected for high cardamom production based on district reports. Mixed methods, including household questionnaires, interviews and focus group discussions (FGD) were used to gather information about farming systems and household characteristics that influence the adoption of management practices that improve soil fertility.

2.2.1 *Farming systems*

FGD and personal interviews were used to gather farming system data to be analysed via a financial accounting matrix. Three common farming systems were classified into first- and second-stage land uses. The first-stage land use is Cardamom AF and was reported to last a total of 13 years, which differs from Stocking and Perkin's (1991) estimate. Two common second-stage systems that typically follow Cardamom AF were *Grevillea* AF or Spice Perennials. A third alternative second-stage system, Improved AF, was developed to model financial returns when soil improvement practices are included. A total of 16 FGDs were conducted in four villages. FGDs were selected as the optimal method to solicit financial data due to poor record keeping and individual recall. Similarities across reported figures confirmed that results were reliable. A snowball sampling approach was used to select five to seven male and female farmers to participate in each focus group. Men and women were interviewed separately. FGD participants characterized cropping systems into stages and provided labour, tradable inputs, and revenue figures for each crop in each system on a per acre basis, the local commonly used unit of land. Figures were later converted into the standard per hectare basis.

Common land establishment activities in all farming systems include clearing trees and slashing vegetation. Revenues from conversion activities were not accounted for because burning of residues is common during land preparation. Primary and secondary products included fruits, poles, and fodder collected during the productive phase (years 1–13). Cardamom AF is converted into second-stage land uses after 13 years, the most common reported were *Grevillea* AF and Spice Perennials. The alternative model, Improved AF, was developed using both primary and secondary data. All second-stage farming systems were analysed for 13 years to compare financial returns evenly. Second-stage system productivity may extend past the years that were analysed in this study.

Seasonal crop variations and yield changes over the system lifespan were specified by FGD participants. Final figures in the accounting matrix were based on averages. Figures were reported in local currency (TSh) and converted into US$ based on the nominal exchange rate of TSh1355 = US$1 in July 2009. Crop selling price was the annual average for point of sale in the village for the previous year, 2008–2009. Data feedback sessions held in three villages were used to validate the final accounting matrix figures.

Annual tradable inputs costs included tools, seeds, planting materials, and labour. Replacement tool costs were accounted for the system lifespan. Labour costs are based on eight hours of work or one-person day (ps-day). Family and hired labour were valued at the local daily farm wage rate in 2009 of TSh 2000/day (US$1.50/day). Labour activities were disaggregated into land preparation, maintenance tasks (weeding and mulching), planting, and harvesting tasks. Transportation labour was not included because of the high variability of distances travelled between households and farms. Land costs were not accounted due to price variability based on plot-specific attributes.

A 10% discount rate was applied to estimate profits and calculate the Net Present Value (NPV) (see Hoekstra 1985). The NPV totals the discounted annual costs and revenues over the system lifespan of each system. A sensitivity analysis assessed the impact of changed assumptions on NPVs. Changes in price and yield were applied uniformly to all products in each system. Similarly, wage rate changes were applied to all labour activities.

2.2.2 *Household surveys*

Household surveys were used to identify characteristics that influence adoption of soil improvement practices in order to assess the feasibility of scaling up SAI based on practices included in the Improved AF model. Households from three villages and five sub-villages were randomly selected using village registers. The survey was pre-tested and translated into Swahili. Trained enumerators administered the survey to the head of household and spouse, which lasted approximately one hour. The head of household's responses (144) were used since many of the variables were measured at household level and chi square tests of independence indicated that responses did not differ significantly between husband and wife. Many adoption studies have relied on logistic models to analyse dichotomous adoption decisions in which the dependent variable is binary (Mercer 2004). In our case, the dependent variables were adoption of fallow and the use of organic inputs, cattle manure, on farm plots. Respondents were asked for details about each of the plots they owned. They were asked whether they invested in soil improvement practices, specifically fallow and manure. Households were assigned 1 if they reported implementing the practice and 0 otherwise. Two models were specified for each practice based on independent variables categorized into household and plot-specific characteristics. A total of four models were run. Independent variables in the household model included: (1) socioeconomic characteristics, which included measures of human capital; (2) physical and financial capital as wealth indicators; and (3) tenure risk. Four independent variables were included in the plot-specific model. Variables with variance inflation factor >5 were excluded from the model to minimize multi-collinearity effects. The hypothesized influence of independent variables is illustrated in Table 1.

Among socioeconomic indicators, *Single-headed household* status is predicted to negatively influence fallow adoption due to the potential land constraints that may limit the possibility of taking land out of production. Adding organic inputs is relatively more labour intensive, and it is, therefore, hypothesized that adoption is negatively influenced by single-headed household status. *Gender of household head* significantly affects adoption since extension systems are biased towards male farmers (Gladwin *et al*. 1997), thus lowering adoption among female-headed households. *Age* is expected to be significant because younger farmers are more progressive and likely to adopt new practices (Sanni 2008, Mabuza *et al*. 2013). *Years settled* plays a significant role since farm plots that have been in use longer will require soil fertility investments to improve production, thus increasing adoption of both fallow and organic inputs. *Household size* is a proxy for labour availability. We hypothesized that less family labour availability positively influences fallow adoption and negatively influences the use of organic inputs. Tiwari *et al*. (2008) found associations between larger household size and manure investments. Education facilitates learning, which instils a favourable attitude towards the use of improved farm practices (Nkamleu and Manyong 2005). *Education* in this case is a binary measure in which primary school attendance equals one. In a previous study in the area, Reyes *et al*. (2010) found that farmers reported low use of soil improvement methods due to poor extension services. *Farm training* is a measure of either attending training or being visited by an extension agent and is hypothesized to positively influence the adoption of soil fertility practices.

Physical and financial capital indicators were included as proxies of wealth. Households with higher wealth are more likely to adopt new technologies because of their economic position and ability to manage risk (Ajayi *et al*. 2003, Phiri *et al*. 2004). Better off households may also allocate labour to off-farm sector activities, thereby reducing negative intensification effects (Lee *et al*. 2006). *Total plot* refers to the number of plots managed. Managing multiple plots increase crop diversity and enable greater flexibility in making production decisions. Owning more plots is hypothesized to coincide with higher levels of adoption of soil improvement practices. *Total land* size influences a farmer's technology adoption decisions. Farmers with more land

Table 1. Factors affecting SAI adoption practices.

Variable	Description	Level of measurement	A priori sign Fallow	 Organic inputs
(1) *Socioeconomic characteristics*				
Single HH	Single = 1	Binary	−	−
Household gender	Male = 1	Binary	−	−
Age	Years	Continuous	+	+
Years settled	Years	Continuous	+	+
Household size	# of members in HH	Continuous	−	+
Education	1 = Primary education	Binary	+	+
Farm training	Training = 1	Binary	+	+
(2) *Physical and financial assets*				
Total plot	No. plots	Continuous	+	+
Total land	Acres	Continuous	+	+
Livestock	Livestock = 1	Binary	+	+
Cattle	Ownership = 1	Binary	+	+
Sufficient land	Sufficient = 1	Binary	+	±
Off-farm income	Off-farm = 1	Binary	+	−
Remittances	Remittances = 1	Binary	+	−
Loan access	Access = 1	Binary	+	+
Loan receipt	Received = 1	Binary	+	+
Loan for farm activities	Used for farm = 1	Binary	±	±
(3) *Tenure security*				
Land taken for conservation	Land taken = 1	Binary	−	−
(4) *Plot characteristics*[a]				
Distance	Minutes	Continuous	+	+
Plot age	Average years per plot	Continuous	+	+
Perceived fertility	Low = 1; average = 2; high = 3	Ordinal	−	−
Acres	Average # of acres per plot	Ordinal	+	−

[a] For continuous variables the variable was calculated as an average of total plots to generate one score.

under cultivation are better able to practice fallow, while smaller farmers must intensify and invest in maintaining productivity to meet household needs (Clay *et al.* 1998). Households with overall larger land sizes are hypothesized to adopt both fallow and the use of organic inputs. Livestock ownership is positively related to household incomes and wealthier households are more likely to use manure than poorer ones (Mekuria and Waddington 2002). Households who own *Livestock*, a proxy for wealth, are hypothesized to fallow due to greater ability to manage risk due to income diversification. Cattle ownership in particular is predicted to positively influence organic input additions based on availability and access to manure. *Sufficient land* is a perception-based measure that assesses whether a household perceives that their land is sufficient to meet household needs. If land is perceived to be sufficient, we anticipate this will favourably influence the adoption of soil replenishment practices since land may be taken out of production in the case of fallow; the effect on organic input application is more ambiguous.

Household access to alternative sources of employment can both positively and negatively affect the adoption of sustainable practices. Cash sources such as off-farm income may lead to neglect of labour-intensive forms of soil conservation activities (Ellis 2000). *Off-farm income* is predicted to positively influence fallow, but has negative effects on labour-intensive organic input adoption. Remittances play a significant role in overall household income (Mabuza *et al.* 2013) and it is hypothesized that *Remittances* will have adoption effects similar to off-farm income. Limited access to finance and investment opportunities is often seen as a key driver of degradation due to expansion of production into more fragile areas (Saint-Macary *et al.* 2013). Access to credit significantly influences adoption of soil improvement practices (Paudel and Thapa 2004, Tiwari *et al.* 2008, Kassie *et al.*, 2012). Three aspects of loans were analysed: *Access to loan*, which refers specifically to formal micro-credit institutions, *Receipt of loan*, from both formal and informal sources, and *Loan for farm activities*, in which case the loan was used to hire labour for farm-related tasks. We assumed that access and receipt of credit will exert a positive influence on adoption while use of the loan to hire labour for farm activities is more ambiguous.

Tenure security was considered to be important since each of the sampled villages' population was affected by the establishment of the protected areas of Derema Corridor and Nilo Forest Reserve. More than 1000 farmers lost farmland due to the creation of Derema and financial compensation based on crop assessments was paid (Rantala and Vihemäki 2011). However, many farmers were unsatisfied with the compensation process or the amounts paid. *Land taken for conservation* is a measure of land insecurity and was predicted to negatively influence adoption for two reasons. First, farmers who reported having land taken would be less willing to invest in long-term soil fertility investments because of their experience and consequently, higher perceived levels of land insecurity. Second, compensation to create the Derema Corridor was based on crop assessments, in which case, farmers could be incentivized to intensify cropping regimes to ensure compensation if their land is taken in the future.

Plot characteristics exhibit great spatial and biophysical variability; however, bio-physical variables are commonly not included in AF adoption studies, even though they often impart a statistically significant effect (Pattanayak *et al.* 2003). Questions concerning plot-specific details for distance (estimated minutes), age, perceived fertility, and acres were collected for each plot the household owned. An average score was created for each indicator and included in the regression model. Greater *Distance* from the household to the plot was assumed to favourably influence fallow. In densely populated areas where fallowing for restoring soil fertility is no longer a management option, soil fertility typically decreases within a farm at increasing distances from the homestead (Titonell *et al.* 2012). We hypothesized that increased labour associated with organic inputs will negatively influence practices in farms located farther from the household.

Plot age is significant because plots that have been cultivated longer necessitate investments in soil replenishment practices and, thus, positively influence adoption of fallow and organic inputs. Perceived fertility levels influence management practices (Franzel 1999, Reyes *et al.* 2010, Titonell *et al.* 2012). Higher *Perceived fertility* will negatively influence adoption since the farmers would not see the need to adopt soil improvement measures. Higher average plot size, represented by *Acres*, is hypothesized to positively influence fallow, but negatively influence organic inputs since spreading manure over large areas is labour intensive.

3. Results and discussion

3.1 *Farming system descriptions*

Farm-level analysis was used to assess the profitability of adopting SAI investments to prolong Cardamom AF productivity. Focus groups and later, household surveys, confirmed that Cardamom AF is the first-stage land-use system. The system is managed for 13 years and subsequently converted into second-stage systems *Grevillea* AF or Spice Perennials. Table 2 details the products that were valued in the accounting matrix for each farming system.

Table 2. Common cropping systems and financially valued products.

Cropping system	Stage	Products valued in accounting matrix
Cardamom AF	1	Cardamom, bananas, cocoyams, avocados, jack fruits, building poles, timber, fuelwood, fodder, ropes
Grevillea AF	2	*Grevillea robusta* timber, beans, maize, cassava, bananas, fodder
Spice Perennials	2	Cloves, cinnamon, cassava, maize, beans
Improved AF	2	Cardamom, bananas, cocoyams, avocados, jack fruits, building poles, fuelwood, fodder, ropes, Allanblackia nuts, butterfly farming

3.1.1 *First-stage conversion: Cardamom AF*

Cardamom cultivation is the first stage of forest conversion when the tall canopy tree cover is reduced by 40–60% (Reyes 2008; Bullock's observation). The entire understory is cleared and cardamom and other cash and subsistence crops, banana varieties, and cocoyams (*Xanthosoma* sp.) are planted under the remaining trees. Shade tree species include endemic species *Allanblackia stuhlmannii, Cephalosphera usambarensis, Ficus* species, *Milicia excelsa,* and fruit trees such as avocados (*Persea americana*) and jack fruit (*Artocarpus heterophyllus)*. Exotic species such as *Maesopsis eminii* have also been documented (Hall *et al*. 2010).

Cardamom begins producing after 2.5 years (Reyes 2008; Bullock's observation) and is harvested three times a year (seasonal yield changes were accounted for in the matrix). Two crop rotations produce a total of 11 years. First rotation yields peak in year 6. In year 9, the second rotation of cardamom is planted at a lower density and mixed in with the older plants. Combined production from first and second rotation boosts yields in year 11. Bananas are grown as a permanent crop and harvested throughout the year. Cocoyams are harvested and replanted annually. Secondary products utilized in the household or sold locally include fuel wood, small timber poles, logs, and wild grasses used for fodder. Cardamom AF is usually converted into *Grevillea* AF or Spice Perennials when cardamom yields decline in year 13.

3.1.2 *Second-stage option 1:* Grevillea *AF*

Grevillea AF is a second-stage cropping system that follows Cardamom AF. *Grevillea robusta* is commonly planted to delineate and secure land tenure in the East Usambaras (Woodcock 2002, p. 83) or intercropped with maize, beans, and cassava that are mainly grown to meet household subsistence needs. Establishment requires clearing trees remaining from the previous Cardamom AF stage, which leads to an estimated 10–25% of tree cover compared to a natural forest. *Grevillea* timber is harvested every 7–10 years. Leaves provide fodder for cattle and small branches are used for fuel wood. Beans, maize (*Zea mays sp.*) and cassava (*Manihot esculenta*) are intercropped and planted on a rotational basis. Beans and maize are row planted together every two years. Maize is harvested once a year and time to maturity can take seven months due to highland agro-ecological conditions. Beans are harvested twice annually. Cassava is harvested as needed. This system may be extended beyond 13 years using rotational fallowing, however farmers reported that yield declines over time.

3.1.3 *Second-stage option 2: Spice Perennials*

Alternatively, farmers may establish Spice Perennials following Cardamom AF. Cloves (*Eugenia caryophyllata*) and cinnamon (*Cinnamomum zeylanicum*) are grown together with food crops until the trees shade out the annual crops, between four to seven years. Land preparation includes slow and steady tree clearance since spices perform optimally in full sunlight. Approximately 10% tree cover, compared to natural forest, is retained. Cloves start producing after seven years and production increases annually by approximately 12 kg per tree. Yields are highly variable due to losses that result from poor harvesting practices. Cinnamon is harvested after a minimum of four years and the timber is used as firewood. The remaining stump coppices and four to seven stems are harvested in four-year intervals. As cloves and cinnamon mature, the system tends towards a mono-cropped and permanent plantation.

3.1.4 *Second-stage option 3: Improved AF*

Improved AF is a farming model developed to calculate the relative profitability of adopting practices to replenish soil fertility and extend productivity of first-stage Cardamom AF. Rather than conversion and following the typical labour intensification pathway, fallowing, organic inputs, that is, manure, and income from commercialized NTFPs are included in the model. Most of the data used in the matrix were collected in FGDs. Specific cardamom production estimates when manure was applied were derived from previous experimental studies (Reyes 2008).

Land preparation requirements are low since tree cover from Cardamom AF is maintained and fallow is practised for the first three years. Less intensive management and lower planting densities maintain the system's financial productivity. Organic inputs, that is, cattle manure, are added to the soil prior to planting in lower densities (50% of the conventional first-stage Cardamom AF) in year 4. Two rotations of intercropped cardamom, cocoyams, and bananas are planted every three years after natural fallowing. Management tasks include less intensive weeding and clearing to allow regeneration and seedling development of canopy tree species and understory layers, which may improve forest health and the potential for regeneration of certain forest species (Ashton *et al*. 2001).

Revenues from commercialized NTFPs, *Allanblackia* fruits and butterflies, are included in the model. Local market development for *Allanblackia* fruits that contain oil-producing seeds has raised the value of the seeds as a source of household income. Fruits mature once or twice per year and may yield up to 150 fruits or up to 50 kg of oil per year (Mwaura and Munjuga 2007). Average household income was estimated to be approximately US$100 but household incomes vary widely based on access to productive trees on private and common lands. Sales of butterfly pupae are the second source of NTFP income. The Amani Butterfly Project assists people to farm butterflies and markets them to live butterfly exhibits in the USA and Europe (Morgan-Brown *et al*. 2010). Annual earnings were US$92,000 in 2008 and were distributed among 350 participating households (Morgan-Brown *et al*. 2010). Interview data were used to calculate average income from butterfly sales in the Improved AF model and were estimated to be approximately US$360 per year per household. Farmers source butterflies from natural forests and AF systems. Pupae are bred in a cage constructed of local materials and purchased mesh. Maintenance tasks average one to two hours per day. Improved AF is proposed as a permanent land use that incorporates soil replenishment practices and NTFPs to extend production and support sustainable, capital-led intensification efforts.

3.2 ***Profitability analysis***

The conversion of forest or semi-natural forests to Cardamom AF is profitable, as demonstrated by cash flows (Figure 2). Cash flow declines that result from fertility losses motivate conversion in year 13. *Grevillea* AF cash flows peak and fall sharply as a result of annual harvesting cycles (Figure 3). Over the long term, cash flow decreases as a result of intensive continuous planting

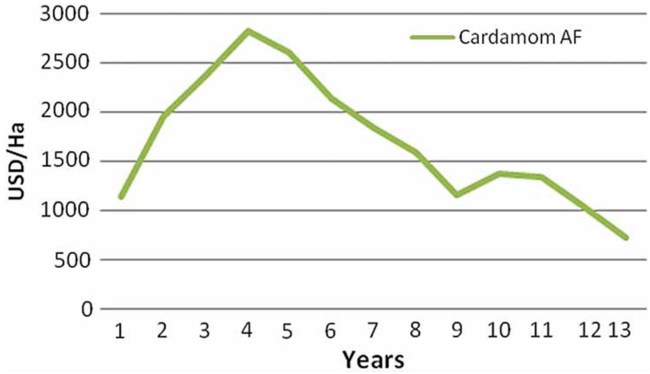

Figure 2. Cardamom AF annual discounted cash flow (US$/ha).

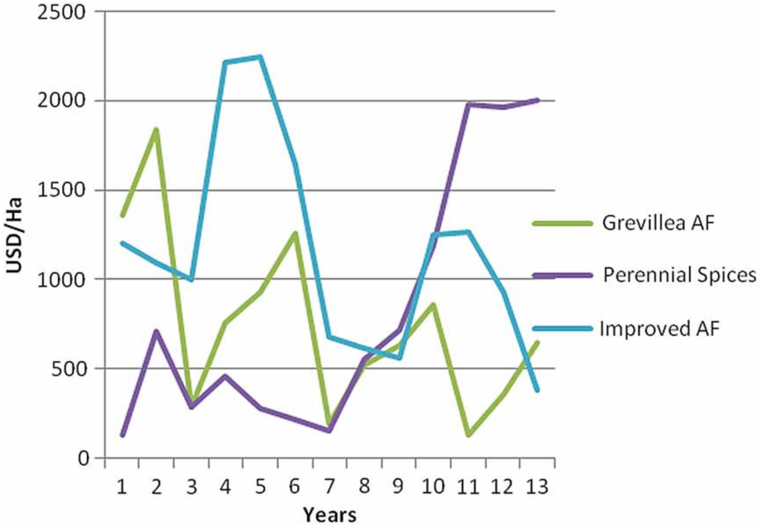

Figure 3. Annual discounted cash flows from second-stage systems (US$/ha).

regimes that reduce soil fertility. Returns are generally lower when compared to cash crop returns from Spice Perennials. Farmers intercrop food crops and perennials to offset income losses as trees mature. Clove production begins in year 7 and generates significant revenues thereafter. Improved AF is competitive until year 6, at which point fallow and lower yields depress revenues. Commercialized NTFPs account for 22% of the total revenue to the system.

Establishment and production costs for second-stage systems are compared in Table 3 (see Appendix, Table A1 for more details). During establishment, Spice Perennial's labour and total costs are the highest, followed by *Grevillea* AF and Improved AF. Improved AF NPV and revenues for the productive phase (years 1–13) outperform the common farming systems (see Appendix, Table A2 for accounting details). Total discounted and labour costs in *Grevillea* AF and Spice Perennials are comparatively lower. Improved AFs total discounted costs are twice as much as *Grevillea* AF. Over the system lifespan of 13 years, daily returns to labour are lowest for the Improved AF model, which is, in part, a result of high labour costs associated with NTFP activities. In the Spice Perennials system, labour costs associated with farm maintenance decrease over time.

Table 3. NPV and discounted labour, costs, and revenue (US$/ha).[a]

	1	2		
Stage	Cardamom AF	*Grevillea* AF	Spice Perennials	Improved AF
Year 0 (Establishment)				
Total labour	320.9	353.7	*375.4*	126.7
Total costs	809.2	470.6	486.6	230.5
Years 1–13				
NPV	15,659.5	6480.2	7680.1	8542.0
Total discounted revenue	22,075.4	9759.2	10,632.5	15,093.5
Total discounted labour costs	5678.5	2752.6	2646.0	5664.8
Daily returns to labour	3.89	3.55	4.02	2.66
Total discounted costs	6415.9	3279.0	2952.4	6551.5

[a] Stage 1 farming system is included for comparative purposes. Stage 2 systems are compared to each other for the lifespan 0–13.

Italics were used to differentiate Year 0 from years 1–13.

Each system was re-run to assess sensitivity to changes of key factors such as discount rate, price, yield, and wage changes (Table A3). Lowering the discount rate to 5% increased Improved AF's NPV and led to a 66% increase in Perennial Spices NPV, an expected result due to perennial tree production, that is, cloves. The most significant positive change in NPV accrued to *Grevillea* AF and Improved AF when a 25% increase in crop prices was applied, which raised NPV by 38% and 30%.

Farm profitability analysis revealed that Improved AF financial benefits exist; however, high labour costs relative to other second-stage systems could affect farmers' adoption rates *ceteris paribus*. The Improved AF model is profitable based on NPV when compared to other common second-stage systems over a 13-year period. Other studies similarly indicated positive returns associated with adoption technologies (Mekuria and Waddington 2002, Place *et al.* 2003). NTFP activities were included in the model to offset profit losses during the fallow periods. Pattanayak and Sills (2001) found that NTFP collection had an income smoothing response that mitigated agricultural losses. However, NTFP inclusion in the Improved AF model raised labour costs relative to other second-stage systems. Activities associated with butterfly maintenance incurred the highest labour cost (18%), followed by firewood collection (11%). Organic input investments, specifically manuring, were comparatively lower in labour costs (2%). Additionally, lower daily returns to labour raise the opportunity costs of adopting sustainable practices modelled in this scenario. Extending the analysis and measuring long-term returns from continuous cropping schemes that deplete soil fertility, such as *Grevillea* AF, would likely enhance financial incentives for Improved AF, since yields, and consequently income, are sustained permanently.

3.3 *Logistic model results*

Household surveys were used to identify characteristics that influence adoption of improved management practices, specifically soil replenishment practices included in the Improved AF model, which may be a feasible strategy to scale up SAI. Seventy-five percent of respondents manage Cardamom AF plots. Household survey data confirmed that the system is productive for 13 years, at which point, the system is converted. Eighty-one percent of households manage *Grevillea* AF, and 92% planted cloves in the past five years. Sample characteristics are presented in Table 4. Few households practice fallow or add manure. Thirty-five percent of households

Table 4. Sample household characteristics.

	Mean	$N = 144$ (%)
(1) *Socioeconomic characteristics*		
Household gender		Male: 90.3%
Single HH		Single: 11.8%
Age	47.5 ± 15.7	
Years settled	35 ± 16.3	
Household size	5.8 ± 2.5	
Education		90.3%
Farm training		21.5%
(2) *Physical and financial assets*		
Total plot	3.2 ± 1.4	
Total land	7.24 ± 7.02	
Livestock		86.8%
Cattle		16%
Sufficient land		45.1%
Off-farm income		14.6%
Remittances		21.5%
Loan access		13.9%
Loan receipt		13.2%
Loan for farm activities		7.6%
(3) *Tenure security*		
Land taken for conservation		49.3%
(4) *Plot characteristics*[a]		
Perceived distance	35.1 ± 35.8	
Plot age	13.3 ± 1.6	
Fertility		1 = 15.9%; 2 = 58.3%; 3 = 22.9%
Acres	2.6 ± 2.03	

[a] For continuous variables the variable was calculated as an average of total plots to generate one score.

practice fallow on an average of 1.3 plots for 3.2 years. Eighteen percent add manure to their farms, which may be due to low supply since only 16% own cattle. Ten percent of households practice both fallow and organic inputs. Nearly half of the respondents perceive their land as sufficient to meet household needs. Fourteen percent of households have access to formal micro-credit institutions. Eight percent used a loan to hire labour for farm activities. Approximately half of the respondents had land taken to create forest reserves.

Two models were run for each practice to identify characteristics that significantly influence adoption of fallow and manuring practices at $p < 0.05$ (Table 5). A total of seven out of 22 indicators explain adoption of fallow and organic input practices. Logistic results were validated using backward step logistic regression procedures. Socioeconomic indicators that were significant were *Single-headed household* status, which positively influenced fallow practices, and *Household size*, which positively influenced organic input adoption. The significant and positive effect of marital status is different from our hypothesized effect based on land constraint assumptions. Fallowing and adding organic inputs differ in terms of their labour requirements. Labour-related indicators are central to evaluating the viability of promoting sustainable management practices (Lee *et al*. 2006) and constraints have been a major factor limiting a farmer's interest in the adoption of AF technologies (Adesina and Coulibaly 1998, Tripp 2005). Labour constraints may explain the relatively higher odds of practicing fallow among single-headed households. Labour constraints also impact organic input practices. Teklewold *et al*. (2013) and Nkamleu

Table 5. Logistic model regression results.

	Fallow				Organic inputs			
Variable	β	SE	Sig.	Odds ratio (e^{β})	β	SE	Sig.	Odds ratio (e^{β})
Single headed	3.448	1.528	0.024*	31.448	−1.136	1.625	0.484	0.321
Age	0.004	0.018	0.829	1.004	−0.005	0.024	0.845	0.995
Gender of HH head	−1.727	1.411	0.221	0.178	−1.453	1.583	0.358	0.234
Years in village	0.029	0.016	0.078	1.029	−0.022	0.022	0.311	0.978
HH size	0.008	0.092	0.928	1.008	0.232	0.120	0.054*	1.262
Education	−0.054	0.755	0.943	0.947	2.774	1.692	0.101	16.017
Training	−0.122	0.592	0.837	0.885	−0.498	0.685	0.467	0.608
Total plots	0.268	0.177	0.129	1.307	0.143	0.205	0.487	1.153
Total land	−0.001	0.041	0.979	0.999	0.089	0.056	0.113	1.093
Livestock	−0.363	0.769	0.636	0.695	0.358	0.972	0.713	1.431
Cattle	0.464	0.599	0.439	1.591	−0.631	0.636	0.321	0.532
Sufficient land	−.505	0.458	0.271	0.604	0.065	0.575	0.911	1.067
Off-farm	0.125	0.610	0.837	1.133	2.173	1.218	0.074	8.789
Remittances	−1.895	0.579	0.001*	0.150	0.170	0.774	0.826	1.185
Loan access	−1.062	0.848	0.210	0.346	−1.901	0.884	0.032*	0.149
Loan receipt	1.836	1.327	0.167	6.274	−0.192	1.181	0.871	0.826
Loan for farm	−0.066	1.509	0.965	0.936	1.876	7.497	0.210	6.527
Land taken for conservation	−0.419	0.446	0.347	0.657	−1.395	0.623	0.025*	0.248
Constant	−3.327	2.009	0.098	0.036	−4.141	2.923	0.157	0.016
Log-likelihood: 147.884					Log-likelihood: 99.621			
Percentage of correct prediction: 76.2%					Percentage of correct prediction: 83.9%			
Hosmer & Lemeshow: 0.294					Hosmer & Lemeshow: 0.564			
Distance (min)	0.000	0.005	0.926	1.00	−0.034	0.013	0.011*	0.967
Years (ave)	0.003	0.017	0.862	1.003	−0.018	0.021	0.388	0.982
Fertility (ave)	1.563	0.381	0.000*	4.771	0.283	0.354	0.424	1.327
Acre (ave)	−0.209	0.113	0.064	0.811	0.015	0.105	0.888	1.015
Constant	−3.308	0.852	0.000	0.037	−0.923	0.828	0.265	0.397
Log-likelihood: 163.391					Log-likelihood: 127.808			
Percentage of correct prediction: 72.2%					Percentage of correct prediction: 81.3%			
Hosmer & Lemeshow: 0.991					Hosmer & Lemeshow: 0.228			

*significant at $p < .05$.

and Manyong (2005) found that family size had a positive effect on the use of manure on farms. A possible explanation is that collecting manure and transporting it to the fields is relatively labour intensive (Kassie *et al*. 2012). Marenya and Barrett (2007) observed a similar result in Kenya. Such findings raise concerns about the feasibility of promoting soil improvement practices that rely on high levels of household labour availability. Other socioeconomic indicators that were hypothesized to influence adoption were insignificant, that is, gender of household head and education. Other studies have similarly found that gender does not play a significant role in AF adoption practices (Pattanayak *et al*. 2003) or related sustainable agriculture practices (Clay *et al.* 1998).

Physical assets, that is, land and livestock, that were hypothesized to influence adoption were found not to be statistically significant in the logistic models. More generally, the impacts of farm size on adoption are inconclusive due to the mixed observations of positive, negative, and insignificant correlations (Knowler and Bradshaw 2007). Although others have found livestock ownership to significantly and positively affect adoption (see Kassie *et al.* 2012), our results suggested that livestock ownership does not affect adoption practices. Labour allocation activities associated with cattle have revealed trade-offs between crops and livestock production that help to explain the low correlation of adoption (Nkonya *et al.* 2005, Mugonola *et al*. 2012). Dairy cattle in the East Usambaras are typically stall fed and labour activities include collecting fodder, a labour-intensive activity that may interfere with manuring practices.

Sources of cash and access to credit influenced adoption of soil improvement practices (see Hazarika and Alwang 2003, Tiwari *et al.* 2008). *Remittances* negatively influenced fallow practices and *Loan access* negatively influenced organic input adoption. These findings suggest that access to cash is not diverting activities towards other off-farm enterprises that could potentially reduce agricultural land pressures. In addition, farmers are not investing income in practices to replenish soil fertility. Low cash investments in soil replenishment practices may also be a consequence of low numbers of households receiving extension services (22%). Other studies have shown that off-farm income negatively affects adoption of sustainable practices (Mbaga-Semgalawe and Folmer 2000, Pattanyak *et al*. 2003). In our study, only 15% of households access off-farm income, which suggests that the opportunity cost of allocating labour towards farm intensification is relatively low since off-farm employment opportunities are few, a trend common in remote rural areas (Ruben *et al*. 2006).

The aspect of tenure security that was measured, *Land taken for conservation*, was significant and negatively influenced the adoption of organic inputs. Respondents who had land taken were assumed to perceive higher levels of tenure insecurity. Fifty percent of sampled households had land taken to create the Derema Corridor or Nilo Forest Reserve. Total average land size and number of plots did not differ significantly between the groups of households who did not have land taken, so intensification is not a result of cultivating smaller farms. Land tenure systems place constraints on long-term investment in land (Msikula 2003) and leads to maximization of short-term investment (Barbier 1990). Kassie *et al.* (2012) also found insecure land access and security negatively impacted adoption of long-term land enhancing investments to improve soil fertility.

At plot level, *Perceived fertility* positively influenced fallow adoption and *Distance* negatively impacted the adoption of organic inputs. Fields categorized according to distance from the homestead, and fields falling in different soil fertility classes as perceived by farmers are managed differently by farmers (Titonell *et al*. 2012). Farmers in the East Usambaras mostly perceive soil fertility to be adequate (Reyes *et al*. 2010). Labour constraints influence agricultural practices and likely explain why farmers practice fallow when soil fertility is perceived to be adequate. Other studies found that farmers' perceptions of low fertility and soil erosion motivated household adoption of soil conservation measures (Mbaga-Semgalawe and Folmer 2000). With respect to plot characteristics, Teklewold *et al.* (2013) found the use of manure to be more likely on plots perceived to have good soil quality. In contrast, Belay and Bewket (2013) found that households evaluated farms treated with manure as having poor fertility. The contrasting findings highlight the importance of conducting site-specific studies to understand complex factors that shape adoption decisions. The effects of distance on adoption of labour-intensive practices have similarly been shown (Brown 2006, Belay and Bewket 2013). The hypothesized effects of other plot-level characteristics, such as age and plot size were not significant in the model.

4. Conclusion

Sustainable agricultural growth is central to many developing countries' goals of improving food security, rural employment, and poverty alleviation (Reardon *et al.* 1999, Lee *et al*. 2006). Efforts to achieve these goals will often require trade-offs among objectives that vary based on distinct agro-ecological and economic conditions (Lee *et al*. 2006). This study contributes to identifying where the potential to enhance synergies between biodiversity conservation and rural development objectives exist and where policy emphasis should be focused to scale up SAI practices.

Focus group data confirmed that labour-led intensification is the most common path of long-term land-use management and occurs primarily in two stages. Following Cardamom AF conversion, *Grevillea* AF typically entails continuous cropping that lowers soil fertility and productivity. The other option is Spice Perennials, which is managed to become a small-scale, mono-cropped and permanent plantation. From a profitability standpoint, the Improved AF model generates competitive returns to farmers, but at a higher labour cost relative to common second-stage farming systems. The household survey revealed that labour constraints hindered the adoption of more labour-intensive investments, that is, spreading organic inputs. Households whose land was taken for the creation of forest reserves were also shown to have lower rates of adoption of soil fertility improvement practices.

Although adoption of soil replenishment investments is low in the East Usambara highlands, efforts to enhance uptake and scale up SAI practices are warranted. Many farmers recognize the benefits of AF, as evidenced by the high number of farmers (75%) who manage Cardamom AF. AF systems contribute diverse products for household consumption and income, including fuel wood, fruits, and *Allanblackia* seeds. AF stabilizes soil on steep slopes and is a more practical land use than cultivating annual species, which require intensive soil tillage and increase soil erosion risks. People typically invest more labour on high-income crops and, since cardamom generates a higher income on smaller plots of land relative to food crops (Hamilton and Bensted-Smith 1989) land-use management practices that are more labour-intensive could be perceived more favourably and enhance adoption uptake. Deliberate management of existing AF systems has the potential to lower extensification to marginal lands. Finally, the management of multiple plots and crops, as is common in the study area, affords farmers greater flexibility to manage labour and risk at different production stages. The multi-seasonal character of AF reduces risk and uncertainty by diversifying smallholders' portfolios (Franzel and Scherr 2002). Further research to investigate the sustainability of Improved AF from a biological and biodiversity perspective is needed (Hall *et al*. 2010). Additionally, the implications of gendered labour divisions in different SAI scenarios would provide more insight into devising feasible strategies to manage farming systems that generate equitable livelihood benefits (see Kiptot and Franzel 2012).

Widespread adoption of AF is strongly influenced by policy and institutional contexts (Ajayi and Place 2012). Farmers must receive satisfactory economic benefits from the resources they invest (Rasul and Thapa 2004), in which case the opportunity costs of allocating scarce household labour towards soil replenishment practices must be addressed. Developing sustainable value chains that support higher agricultural productivity and enable improved environmental, economic, and social outcomes are imperative (see Newton *et al*. 2013). Policy investments to improve production and market value chain development for crops grown in AF systems has, thus far, created financial incentives to retain *Allanblackia*, an indigenous tree species, on farms, for example. Extending such initiatives to include cultivated crops, like high-value cardamom, could stimulate stronger farmer interest and investment in prolonging Cardamom AF production versus labour-led strategies that reduce tree diversity on farms. Secondly, current low employment and availability of off-farm income sources lowers the opportunity cost of labour-led intensification in the highlands. Poor extension has been identified as a key constraint to increasing household production and income in the area (Reyes *et al*. 2005). Social capital formation through the promotion of extension services and technological advice would raise awareness of management practices that improve fertility and subsequently shift the labour-led intensification strategies towards more sustainable and longer term productive land uses.

Farmers' decisions concerning short- and long-term economic choices are influenced by wider institutional and policy environments. Additionally, their decisions concerning farm system management have wider, landscape-scale implications for meeting conservation and rural development objectives. Strengthening institutions to improve financial returns from AF products and working with farmers to develop strategies that are appropriate to specific agro-ecological and socioeconomic conditions will improve efforts to scale up SAI in locations recognized for their conservation importance.

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Appendix

Table A1. Establishment costs (year 0) US$/ha.

	1	2		
Stage	Cardamom AF	*Grevillea* AF	Perennials spices	Improved AF
Total costs	809.2	470.6	486.6	230.5
Labour				
Land preparation	248.0	258.9	248.0	3.6
Maintenance	72.9	94.8	127.7	123.0
Total labour	320.9	353.7	*375.4*	126.7
Tradable inputs				
Tools	50.9	47.4	47.3	103.7
Inputs				
Seedlings	437.4	69.7	63.7	0
Total tradable inputs	488.3	116.8	112.6	103.7

Italics was used to differentiate Labour and Input costs.

Table A2. Financial analysis of the alternative farming systems (over the 13 years lifespan) (US$/ha).[a]

	1	2		
Stage	Cardamom AF	*Grevillea* AF	Perennials	Improved AF
NPV	15,659.5	6480.2	7680.1	8542.0
Total discounted revenue	22,075.4	9759.2	10,632.5	15,093.5
Total discounted costs				
Labour costs				
Land prep	397.7	583.2	288.5	210.0
Maintenance	943.5	1130.8	859.3	1538.8
Harvest	4339.8	1038.9	1496.9	3915.0
Total discounted labour costs	5,678.5	2752.6	2,646.0	5664.8
Tradable inputs				
Tools	237.1	224.8	242.1	301.3
Inputs	–	–	–	116.1
Seedlings	499.0	301.3	64.2	466.8
Total discounted tradable input costs	736.1	526.4	306.3	886.8
Total discounted costs	6,415.9	3279.0	2,952.4	6,551.5

[a] The main purpose of the financial analysis is to compare financial performance of stage 2 systems. Stage 1 was included to present the farming system sequence and calculate stage 2 establishment costs. Stage 2 systems are analysed for a lifespan of 13 years and are discounted from year 0 to 13.

Table A3. Sensitivity analysis results: changes of key factors (%) and associated changes of NPV (%).

System	Cardamom AF (%)	*Grevillea* AF (%)	Perennials (%)	Improved AF (%)
Discount rate				
5%	36.8	34.8	65.8	36.9
15%	−24.5	−22.8	−37.9	−24.3
Price				
+25%	20.9	37.7	34.6	30.1
−25%	−20.9	−37.6	−34.6	−37.6
Yield				
+25%	21.1	34.6	34.6	30.1
−25%	−24.1	−34.6	−34.6	−30.1
Wage rate				
+25%	−30.0	−10.6	−8.6	−16.6
−25%	11.9	10.6	8.6	16.6