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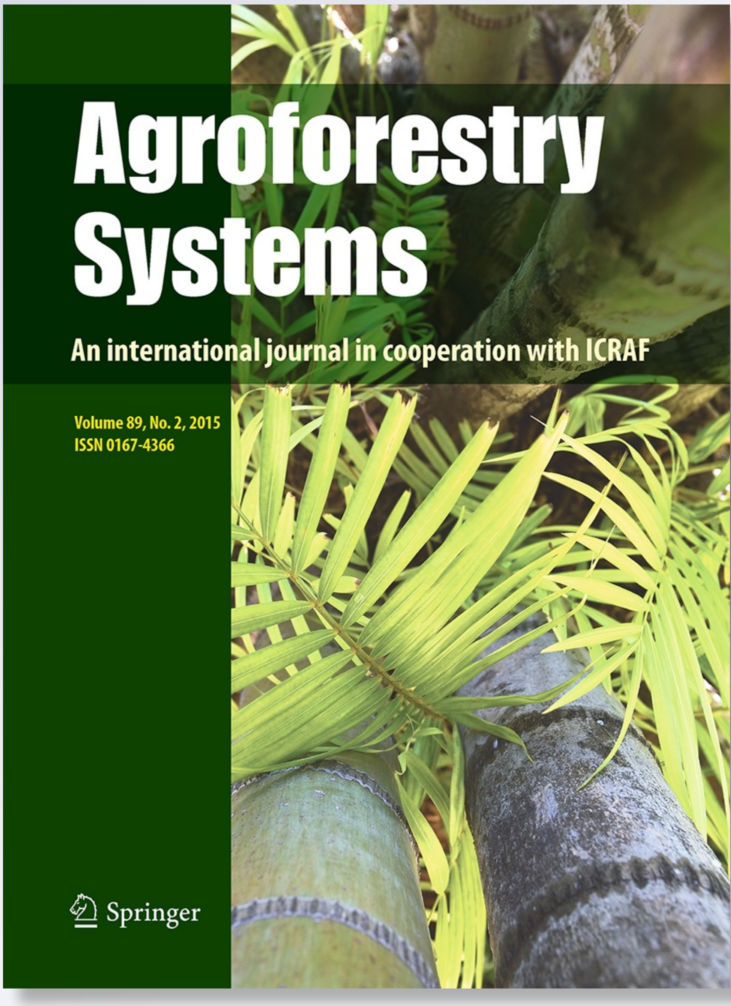


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# Agroforestry in Liberia: household practices, perceptions and livelihood benefits

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**Abstract** In Liberia emphases have been placed on reducing deforestation and increasing food security through the transition of smallholder farmers from shifting cultivation to permanent agricultural systems, including tree cropping and agroforestry systems. A structured survey instrument was administered to 80 households in Bong and Lofa counties, Liberia to assess the socio-cultural feasibility of increasing tree cropping and agroforestry practices among smallholder farmers. The survey investigated household use, perceptions and impediments towards tree cropping and agroforestry and livelihood impacts of these practices, including income diversification and food security. Income was the driving motivation for tree cropping, and insecure land tenure was the most significant impediment. Tree cropping households tended to be male-headed, and differed in age distribution. Households that practiced tree cropping had improved income diversification, and those which used agroforestry practices experienced enhanced food security. Respondent perceptions regarding competition between tree crops and herbaceous crops often prevented incorporation of agroforestry practices. Nearly all households practiced shifting cultivation, independent of whether or not they cultivated trees. This suggests that a transition away from shifting cultivation to agroforestry systems will require greater efforts to address socio-political factors, including cultural perceptions and traditions, land tenure, gender, and household demographics.

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## Introduction

Tropical rainforests are globally valued for their rich biodiversity, economic assets and their ability to store large amounts of carbon, thus mitigating global climate change (Myers et al. 2000; FAO 2005; Gibbs et al. 2007). They are intimately connected to the livelihoods and culture of forest-dwelling communities, who often depend on them for subsistence agriculture, hunting, timber, non-timber forest products, and cultural and religious purposes (Wunder 2001; Sheil et al. 2006). Despite these benefits, large-scale logging, intensified agriculture, development, and mining have driven widespread deforestation and degradation of tropical rainforests worldwide (Malhi and Grace 2000; Achard et al. 2002; Geist and Lambin, 2002; FAO 2005). International attention has been increasingly focused on conservation of tropical rain forests through sustainable forest management, designation of protected areas, and reduced deforestation. One such effort is the transition of farmers away from traditional systems of shifting cultivation and towards more permanent agroforestry systems, which are thought to reduce deforestation (Sanchez et al. 2001) and improve smallholder livelihoods (Mai 1999; Garrity 2004; Rahman et al. 2012). Here we report a study to assess whether agroforestry may act as alternative livelihood to shifting cultivation in Liberia, West Africa, where tropical rainforest conservation and poverty reduction have become national priorities.

Liberia is an ideal setting to study the interactions between forest use, smallholder agriculture, and rural livelihoods in the context of shift towards tropical rainforest conservation. After 14 years of civil conflicts, and a much longer history of social divisions, insecure land tenure, and foreign-dominated markets, Liberia suffers from extreme poverty and infrastructure devastation (Mayson and Sawyer 1979; Alden Wily 2007; Broudic 2008). Ranked as the 14th lowest country globally in terms of human development by the United Nations Development Programme (UNDP 2013), Liberia's people are highly subject to poverty with 83.8 % living on less than $1.25 per day (UNDP 2013). According to a report by the national government's Ministry of Agriculture (MOA 2010), nearly fifty percent of Liberia's population is either food insecure or highly vulnerable to food insecurity. As the Government of Liberia (GoL) seeks to rebuild Liberia's economy and reduce poverty, they have placed significant emphases on the potential of Liberia's forests to aid in national recovery (IMF 2011). Home to the largest remaining tract (42 %) of West Guinean tropical rainforest, Liberia's forests host endangered and vulnerable species, including chimpanzees, pigmy hippos, and forest elephants (FDA 2006; World Bank 2010), and are valued for their rich biodiversity, ecosystem services, economic assets, and carbon storage potential (World Bank 2010; IMF 2011). Liberia's forests are also the predominant source of livelihoods for rural people, who depend on them for agriculture, hunting, charcoal production, and forest products (FDA 2006; World Bank 2010; IMF 2011).

Liberia's forests are viewed as valuable assets for rebuilding the national economy and supporting local livelihoods. The conservation and sustainable management of Liberia's forests have therefore become top priorities of the GoL (World Bank 2010). According to an assessment by the United Nations Food and Agriculture Program (FAO 2005) Liberia has lost 22 % of its tropical rainforests between 1980 and 2005, largely due to the illegal timber trade during the civil wars. Logging, mining, development, commercial agriculture, charcoal production and shifting cultivation are the current major drivers of deforestation in Liberia (R-PP 2012). Though there is contention over the amount of primary forest loss in Liberia (Fairhead and Leach 1997), and though current deforestation rates are fairly low (<1 % annually) (FAO 2005, R-PIN 2008), there is concern that deforestation will increase due to escalating population pressure, development, and expanding markets for agricultural commodities (World Bank 2012). To help conserve Liberia's forests, the GoL, through assistance with the Forest Carbon Partnership Fund (FCPC) and the World Bank, has commenced preparation for engagement in REDD+ (Reducing Emissions from Deforestation and Degradation), a mechanism to encourage forest conservation through compensation of carbon credits (R-PP 2012). In preparation for REDD+, the GoL has outlined strategies for reducing deforestation in its Readiness Preparation Proposal (R-PP 2012).

The R-PP identifies shifting cultivation as one the major drivers of deforestation in Liberia (R-PP 2012). Shifting cultivation, or "slash and burn farming", is the practice of clearing and burning forest to prepare agricultural land, cultivating crops for one or more years, and then leaving the land fallow for several years before returning to repeat the process (Raintree and Warner 1986). Shifting cultivation is a longstanding practice in Liberia, and is currently the predominant source of food and income generation for 40 % of Liberia's population (MOA 2007). Despite its prevalent use, shifting cultivation is often viewed as a major cause of deforestation, a threat to biodiversity, and a source of carbon emissions (Brady 1996; UNDP 2006; MOA 2007). Shifting cultivation is considered less than ideal for rural livelihoods in Liberia, as it is thought to lead to reduced crop productivity and have high labor requirements (R-PP 2012).

To help meet REDD+ goals of reduced deforestation and degradation, the R-PP (2012) and other government documents propose a transformation from shifting cultivation systems towards semi-permanent and permanent agricultural systems, including smallholder tree cropping and agroforestry systems (MOA 2008; World Bank 2010). The replacement of shifting cultivation with alternative agroforestry systems has been shown to reduce deforestation and degradation, increase productivity, and help raise farmers out of poverty in other developing countries, including Bangladesh and Vietnam (Mai 1999; Rahman et al. 2012). In Liberia, a transition away from shifting cultivation will also free up more land for Protected Areas (PAs), for rainforest conservation and carbon storage (World Bank 2010, R-PP 2012). The GoL has required setting aside 30 % of Liberia's forests in PAs in their National Forestry Reform Law (NFRL 2006), where shifting cultivation would be prohibited (World Bank 2010). Regrowth of forests in PAs would also be used for government income generation through REDD+ financing. While this may lead to improved rainforest conservation, the removal of local people from PAs into surrounding lands would reduce their access to forests for shifting cultivation and hunting, threatening their ability to produce food and harvest forest products and potentially deepening the cycle of rural poverty (World Bank 2010).

Permanent agricultural systems, such as tree cropping systems, are one proposed alternative to compensate for these lost livelihoods, with the potential to cause less tropical deforestation than shifting cultivation (MOA 2008; World Bank 2010; R-PP 2012). In Liberia, the cultivation of tree crops already occurs at large-commercial, medium and smallholder scales. The large-scale agricultural production of rubber and other export crops contributes 77 % of Liberia's gross domestic product (CIA 2014). Commercial rubber plantations are cultivated in monoculture, which is shown to impair soil fertility, decrease biodiversity, and increase vulnerability to pest and disease outbreaks (Andow 1982; UNDP 2006). While commercial plantations may counteract these affects with fertilizers, herbicides and pesticides, smallholder farmers have limited affordable access to such inputs (Weise and Wilcox 2007). For these reasons, cash crop monocultures may leave smallholders vulnerable to crop failures and reduced yields. Furthermore, the reliance on a single cash crop can also increase household vulnerability to shocks, such as droughts, floods, and market fluctuations.

Agroforestry, the integration of one or more tree crops into an agricultural ecosystem with herbaceous crops (ICRAF 2005), has the potential to offer greater ecological and social benefits to smallholders than monoculture tree cropping (Lal 1991; Altieri 1995, 1999; Montagnini and Nair 2004), and can potentially reduce deforestation from shifting cultivation by increasing land use efficiency (Sanchez et al. 2001; Schroth et al. 2004). Agroforestry systems can also reduce land degradation (Cooper et al. 1996), while providing ecosystem services such as increased carbon storage, enhanced nutrient cycling, reduced erosion, and improvements in soil quality (Lal 1991; Altieri 1995; Montagnini and Nair 2004; Penot 2004). Agroforestry systems can help improve food security through enhanced crop yields and the provision of a wider variety of food and fuel products (Oduol and Aluma 1990; Lal 1991; Altieri 1995; Sanchez et al. 1997; Cardoso et al. 2001; Nath et al. 2005; Jamnadass et al. 2013). The provision of tree products can allow households to diversify their incomes, offering protection against fluctuations in the market prices of any particular good (Feintrenie et al. 2010). The self-regulating nature of many agroforestry systems can also reduce the need for inputs, and decrease maintenance and labor requirements, which tend to be high in monoculture plantations (Altieri 1999; Feintrenie et al. 2010). Agroforestry systems may also support livestock through the provision of fodder in the form of fallen leaves, branches, and weeds (Tajuddin 1986).

In Liberia, a transition from shifting cultivation to agroforestry systems may help meet the dual priorities of forest conservation and poverty reduction. In recognition of these potential benefits, not-for-profit ACDI–VOCA (2011) has employed extension programs to increase agroforestry and sustainable forest management practices in Liberia, including the Livelihood Improvement for Farming Enterprises (LIFE) and People, Rules and Organizations Supporting the Protection of Ecosystem Resources (PROSPER). The widespread adoption of agroforestry practices, however, remains hindered by cultural and socio-political factors, including the insecure state of land tenure, lack of affordable access to inputs for smallholder farmers, undeveloped transportation infrastructure, and under-developed markets (MOA 2007; World Bank 2010). Furthermore, there is a paucity of data regarding the cultural and socio-political feasibility of tree cropping as related to household livelihoods and perceptions (Weise and Wilcox 2007). This is at least partially due to the 14 years of Liberian civil wars (1989–2003), when research in-country would have been challenging and dangerous. The result is that in-country agroforestry programs seem to lack a strong basis in site-specific data about local practices and perceptions, which are critical to designing effective agroforestry programs as they can provide insights about the motivations for, and impediments against, adoption of these systems (Scherr 1991; Belsky 1993). In addition, cultural beliefs and traditions can impede the transition from shifting cultivation towards agroforestry systems (Rahman et al. 2012). Without knowledge of these socio-cultural dynamics in Liberia, it is difficult to predict whether a move away from shifting cultivation towards more permanent agricultural systems is possible.

Our objective in this study was to assess whether agroforestry may be a feasible alternative to shifting cultivation, from a socio-cultural perspective. We hoped to better inform decision makers on the current state of smallholder agroforestry practices in Liberia, and how the adoption of these practices is influenced by cultural and socio-political factors, including household perceptions, gender, land tenure and demographics. We sought to answer these questions: (1) Do agroforestry systems provide more social benefits than shifting cultivation and monoculture systems, including enhanced food security and income diversification? (2) How is the adoption, or lack thereof, of tree cropping and/or agroforestry practices influenced by cultural and socio-political dynamics, including household perceptions, gender, demographics, and land tenure? (3) Do households that engage in tree cropping and/or agroforestry still practice shifting cultivation? We hypothesized that: (1) Households engaging in agroforestry would experience greater livelihood and food security benefits; (2) Socio-political factors might be impediments to adoption of agroforestry systems; and (3) Households engaging in agroforestry systems would be less likely to engage in shifting cultivation. Our study was administered in Bong and Lofa counties, where tree cropping is widely used, where agroforestry extension services are less prevalent than in other parts of the country, and where data on household perceptions related to agroforestry is sparse.

## Methods

### Study site

Liberia is located in the tropical rainforest belt of West Africa. Bong, Lofa and Nimba counties make up the "cocoa belt" of Liberia where tree crop production is highest (Weise and Wilcox 2007). The study site was primarily limited to Bong and Southern Lofa counties, as heavy rains and unpaved roads made Nimba County and northern Lofa County largely inaccessible. This region receives between 2,000–3,000 mm of rain annually, with the rainy season extending between June and October and the dry season from November to February (MOA 2007). Bong County is slightly more developed than Lofa County, which is covered by denser regions of rainforest (MOA 2007). Inclusion of both counties was meant to provide some variability in terms of the villages' level of development and proximity to dense tropical rainforest. Unpaved roads and poor transportation infrastructure limited our range to accessible villages, often located along major roads. Our study site extended northward to the village of Zorzor (N07°45.325′ W009°23.761′) in Lofa County, with the western limit in Palala (N07°05.00.121′ W009°17.277′) and the southeastern limit in Gboquelema (N06°50.396′ W009°50.616′).

We developed the survey instrument with consultation from the Social Research Institute and received approval from the Institutional Review Board at the University of Michigan. Consultations were conducted in-country with the international not-for-profit organization ACDI-VOCA (LIFE and PROSPER programs) for information about current agroforestry programs. The survey was refined after consultation with Liberian agriculture students at Cuttington University, in Gbarnga, Liberia, to assure it was culturally appropriate and translatable. Students were trained to help enumerate and translate the survey. The instrument was pilot-tested in a village near Cuttington Campus, in Gbarnga. Small modifications were made based on our experience with respondents during pilot-testing, including minor changes to wording and language and simplification of questions that were too complex or time-consuming for respondents.

The study was focused at the sub-regional scale, rather at the level of a single village. To capture potential heterogeneity among communities at a sub-regional scale, we chose to sample only 2–4 households per community in a larger number of communities, across a broader geographical range. The final survey instrument was administered to households in 30 communities that were randomly selected along four major roads in the study region, stretching north, south, east and southwest from Gbarnga, as well as

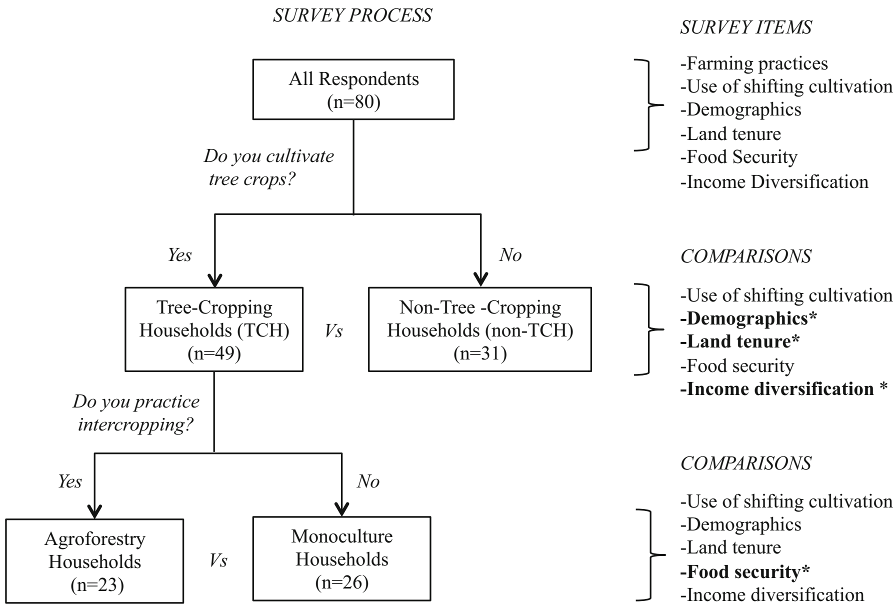


**Fig. 1** The survey process involved designating households into hierarchical groups (TCH and non-TCH, Agroforestry and Monoculture) based on their responses to questions about farming practices. Comparisons were made between groups, of the survey items listed at right. *n* sample size, in number of households; * Denotes a significant difference at $p < 0.05$

along some feeder roads that were accessible. Communities were randomly and systematically selected along these roads, by picking a random number from a table ("n") and stopping at every "nth" community we came upon while driving. Upon entering each community, the Chief was first consulted for permission to enter and survey the community. Once permission was granted, we randomly selected 2–4 households depending on the size of the community. Households were randomly and systematically selected by picking a random number "n" and sampling every "nth" household we came upon while walking in a randomly selected direction. Respondents were selected based on their visible presence in the household during surveying and their involvement in upland agriculture. We primarily surveyed household heads, though other household members would often assist with the survey, especially if the respondent was elderly or did not speak Liberian-English. Student assistants enumerated the survey orally, in primarily Liberian-English or Kpelle, the predominant local language in this sub-region. A total of 80 households were surveyed overall (60 in Bong County, 20 in Lofa County).

## Survey design

The survey instrument was designed to investigate the cultural, socio-economic and demographic differences between households in relation to their use of tree cropping and/or agroforestry practices (Fig. 1; Table 1). To facilitate these comparisons, all respondents were asked a preliminary set of questions and designated into two groups based on their agricultural practices: "tree cropping households" (TCH) and "non-tree cropping households" (non-TCH), or households that did not engage in tree cropping (Table 1). These groupings were made during survey administration, to enable the enumerator to choose the set of specific questions that followed (Fig. 1). For example, the question "what kinds of tree crops do you cultivate?" would only be asked of those who had been assigned to the TCH grouping (Fig. 1). Within the TCH group, further groupings were made based on whether the household cultivated trees using agroforestry practices (the "Agroforestry group") or in monoculture (the "Monoculture group") (Table 1; Fig. 1). These distinctions were made based on responses to a set of open questions about

**Table 1** Definitions of terms used in this study including the groups that households were divided into based on farming practices

| Terms | Definitions |
|---|---|
| Tree crops | Trees cultivated for fruit or cash crop products; may also refer to the products received from cultivated trees |
| Cash crops | Tree crops that produce commodity products, including rubber, cocoa, and coffee |
| Food crops | Herbaceous crops cultivated by the household for consumption*. Includes rice, bitterball, cassava, banana** and vegetables |
| Forest products | Products harvested from trees in nearby forests that are not cultivated by the households; includes timber and fuelwood |
| Agroforestry | The integration (or intercropping) of tree crops with other species of tree crops, or with herbaceous food crops, together in space (spatial) or time (temporal) |
| Monoculture | The cultivation of only one trees species, separate from other species, on a single plot of land |
| **Group labels** | **Definitions** |
| Non-TCH | *Non-Tree Cropping Households* households that do not cultivate any tree crops and only engage in shifting cultivation*** |
| TCH | *Tree Cropping Households* households that cultivate trees for food and/or cash crops* |
| Agroforestry | Of TCH, those which cultivate trees using agroforestry practices |
| Monoculture | Of TCH, those which cultivate trees in monoculture |

Group-wise comparisons of survey results were made between tree cropping and non-tree cropping households (TCH and non-TCH groups) and between Agroforestry and Monoculture groups within the TCH group

* Though food crops or fruit from trees may be sold, they are not considered cash crops in this study; the term 'cash crops' is used here only in reference to commodity tree crops sold for export. ** Bananas and plantains are considered food crops rather than tree crops in this study due to their herbaceous stems. *** Shifting cultivation is not included as a tree cropping or agroforestry practice in this study, nor is the harvesting of products from wild trees in forests (e.g. wild palm)

intercropping (e.g., "do you plant food crops under or between any of these trees?", and "do you plant the different trees together or separately?").

In this study, we define "tree crops" to include both trees species that produce commodity products (rubber, cocoa, coffee), as well as those which provide food products (mango, kola nut, coconut, palm) (Table 1). There was some discrepancy in the meaning of "tree crops" that occurred during translation (both language and cultural), as many of the households only considered "trees" or "tree crops" to be those which produced commodity products, and did not consider fruit trees as "trees". To elucidate whether the household produced fruit trees as well as commodity tree crops, however, we asked more detailed, specific questions about the types of trees cultivated. In addition, there was some difficulty in distinguishing between wild and cultivated palm, as several of the households harvested products from abandoned or naturally growing palm trees in nearby forests.

The survey included both ecological and social topics. Ecological topics included the type of agriculture practiced (shifting cultivation, tree cropping, and/or agroforestry), with descriptions of the practice (e.g. length of fallow, cultivation time, type of vegetation cleared, types of crops planted), and use of agroforestry practices (whether tree crops were cultivated in monoculture or intercropped). The survey followed a structured format, consisting primarily of closed questions, though open questions were used to help determine whether the household used agroforestry practices. Households reported two main types of agroforestry practices, here differentiated as "spatial" and "temporal" agroforestry. Spatial agroforestry is used here to refer to the physical intercropping of different tree crops, or annual crops with tree crops, together on the same land at the same time. Temporal agroforestry refers to the intercropping or rotating of crops with tree crops at different times (Kronick 1984; Nair 1985), and is used here to refer to the practice of cultivating food crops between immature tree crops before they are productive (e.g. rice between young rubber trees). In this study, we do not include shifting cultivation under the designation of "agroforestry", though it may be considered as such due to its incorporation of natural tree regrowth on fallow land for soil regeneration (Raintree and Warner 1986). It better served our purposes to consider shifting cultivation separately, as nearly all households engaged in this practice.

Social topics covered in the survey instrument included household perceptions, demographics, land tenure, gender, food security and income diversification, and were assessed through a combination of closed questions and activities (Fig. 1). Household demographics were measured with questions about gender of the household head, household size (number of members), age distribution (number of members in three age groupings: youth = 0–20 years, middle aged = 20–50 years, elderly > 50 years), and farm labor availability (the number of members in each age category that assists on the farm). Respondents were questioned about land tenure, with ownership defined here as either ownership with a legal deed (statutory tenure) or customary ownership, which respondents referred to as "family land". Designations were not made between the two forms of tenure, due to the sensitive nature of tenure issues, the difficulty of confirming legal tenure, and the lack of a formal land tenure registry in Liberia (MOA 2007). Lack of ownership was defined by either renting, squatting or borrowing.

Due to the sensitive nature regarding income, as well as the lack of higher education and formal accounting of farm income by most households, an activity was developed to measure income diversification. Four sets of pictures were printed on a sheet, which represented categories of products the household could sell for income: forest products (charcoal and timber), tree crops (rubber, cocoa, coffee, and tree fruits), food crops (rice, corn, cucumbers, bitterball, etc.) and livestock (chickens, goats, pigs, and sheep) (Table 1). Each respondent was provided 10 pieces of corn to represent the household's total farm income during the rainy season, and asked to divide the corn accordingly between the categories to provide a sense of the different relative proportions of income received by the household from the different product groups. The activity was repeated for both wet and dry seasons, to assess seasonal differences.

Food security was measured through three simplified metrics: (1) the average number of meals consumed per day by adults and children in households; (2) the kinds of livestock owned by the household; and (3) Two questions adopted from the United States Department of Agriculture (USDA 2000). These two USDA questions were as follows (Appendix):

Q1: How often do you have enough food to satisfy you?

(a) always enough food, and always the kinds of food I want, (b) always enough food, but not always the kinds of food I want, (c) sometimes not enough food, (d) often not enough food.

Q2: How often do you cut portions because there is not enough food?

(a) never (b) rarely (c) sometimes (d) often

For both questions, responses (a) and (b) were designated as food secure, and questions (c) and (d) were food insecure. It became apparent during the study that most respondents did not understand USDA Q2, due to confusion during translation from English to Liberian-English or Kpelle. For this reason, results from the second question were discarded. The measures of food security were constrained to these few metrics due to the time restrictions of the study, and are not intended to be exhaustive.

## Survey statistics

Descriptive statistics were used to summarize the different types of agricultural practices employed, and household perceptions regarding these practices. Statistical tests were used to compare differences in demographics, tenure, food security, and income diversification between TCH and non-TCH groups and between Agroforestry and Monoculture groups, within the TCH group (hereon referred to as "group-wise differences") (Fig. 1).

Numerical responses were compared using the Wilcoxon Rank Sum test (otherwise known as the Mann–Whitney U test), which is the non-parametric substitute to the independent samples t-test. Similar to the independent samples t-test, the Wilcoxon Rank Sum test tests the null hypothesis that two different populations have the same values, through calculation of a test statistic (W), to determine significance ($p < 0.05$). Wilcoxon Rank Sum tests may be applied to non-normal distributions however, and were used in place of the independent samples t-test due to the skewed distribution of the data.

Wilcoxon Rank Sum tests were used to compare age distributions (the number of household members in each category: youth, middle aged, elderly) between TCH and non-TCH households, and between Agroforestry and Monoculture households, within the TCH group. The Wilcoxon test was also used to assess differences in labor, or the number of household members in each age category that helped on the farm, between groups. Group-wise differences in length of fallow (years) for shifting cultivation were also assessed using the Wilcoxon Rank Sum test.

Chi-squared tests of independence and Fisher's Exact tests were used to compare categorical responses between TCH and non-TCH, and between Agroforestry and Monoculture households, within the TCH group. Chi-squared tests are used to assess independence between two categorical variables (e.g., gender and land tenure), through the use of contingency tables to calculate a test statistic ($\chi^2$). The test statistic is compared to the critical value from the chi-squared distribution, to determine whether there is a significant relationship between categorical variables at $p < 0.05$ (e.g., whether gender and land tenure are related). Specifically, chi-squared tests were used to assess differences in gender of the household head, the sale of charcoal, and responses to USDA Q1, between groups (TCH vs non-TCH; Agroforestry vs Monoculture).

Fisher's Exact tests also use contingency tables to determine associations between categorical data, but may be used when sample sizes are too small to apply a chi-squared test (when the count in any one cell of the contingency table is below 5). Fisher's Exact tests produce an odds ratio, instead of test statistic, with a corresponding p value to determine significance ($p < 0.05$). Fisher's Exact tests were used to assess differences in land tenure, the number of meals consumed daily by adults in the household (1, 2, and 3), the type of vegetation cleared for shifting cultivation (primary forest, transitional forest, and other), types of livestock owned (goats, pigs, chickens), and whether or not the household sold wood, between groups.

To assess whether tree-cropping had an effect on income diversification, we compared the proportions of seasonal income earned from each of four product groups (tree crops, food crops, forest products, and livestock) between TCH and non-TCH. For example, we hypothesized that TCH would earn a higher proportion of income from tree crops, than non-TCH. For households reporting farm income ($n = 74$), each respondent estimated the proportion of household farm income from the 4 product groups, for the rainy and dry seasons separately, using the activity described above. To account for the repeated measures nature of this data (i.e. the income proportions from the four product groups sum to 100 % for each household), we used a linear mixed-effects models (lme), a regression model that includes both fixed effects and random intercepts (effects). The random intercepts account for the effect of the different households. We fitted four instances of the lme model, one for each of the four product groups (Eq. 1):

$$y_{ij} = \beta_0 + \beta_1 \times \text{Season}_i + \beta_2 \times \text{Group}_j + \beta_3 \times \text{Season}_i \times \text{Group}_j + \mu_{0j} + \epsilon_{ij} \tag{1}$$

For each model instance, the dependent variable ($y_{ij}$) is the proportion of income earned from the product group in question, for a given household ($j$) in season ($i$). The predictors are household group (TCH, non-TCH), season (rainy, dry), and group × season interaction. The fixed intercept ($ß_0$) and the random intercept effect ($\mu_{0j}$) together yield the unique random intercept (effect) for each household. The lme modeling process finds the best fit for the regression coefficients $ß_1$ through $ß_4$ across all households with farm income ($n = 74$). The model then tests each fixed effect for significance using a t-test. The models were assessed in R, using the REML program coding.

To assure the model was an appropriate fit, these assumptions were tested for each of the four model instances: (1) that the random intercept variances are normally distributed, and (2) the fitted residuals are normally distributed. For the first assumption, we plotted the fitted values against predicted vales in a scatterplot and inspected visually to assure there were no strong deviations or patterns. For the second assumption, we tested normality of the residuals for each model by plotting histograms of the fitted residuals. Visual inspection of these plots revealed no serious issues with kurtosis or skewness for 3 of the 4 models. The instance of the lme model for the 'forest crops' group exhibited obvious skewness and was therefore not included in the analysis.

## Results

### Tree cropping

Across the 80 total households surveyed, 49 households cultivated tree crops (TCH) and 31 did not engage in tree cropping (non-TCH). Of TCH, 31 % cultivated only tree cash crops, 29 % only fruit or nut trees, and 41 % cultivated both kinds of tree crops (Table 2). TCH respondents listed income as the dominant motivation for cultivating tree crops (77 % of TCH), followed by provision of fruit (11 %), and additional benefits (12 %) including: long term production, land protection, wind blocking, wood for charcoal production, and tree products as gifts. The majority of TCH respondents reported learning to cultivate trees from their relatives (42 %) or from watching others (38 %). Other TCH respondents (20 %) reported learning tree cropping practices from school, Firestone Rubber Company, NGOs or other organizations. Similarly, 75 % of rubber tree cropping households reported learning tree cropping practices from friends, relatives, and watching others.

## Agroforestry

Among TCH, 47 % reported using agroforestry practices (the "Agroforestrygroup"); 20 % of TCH reported using only spatial agroforestry, 20 % use only temporal agroforestry, and 7 % use both spatial and temporal agroforestry practices (Table 2). Fifty-three percent of TCH cultivated tree crops in monoculture (the "Monoculture group") (Table 2). Spatial intercropping was more common amongst fruit trees than with cash crop trees and included the intercropping of different fruit trees (e.g. orange and kola nut), and the intercropping of food crops between fruit trees (e.g. rice or corn under palm) (Table 2). Tree cash crops were occasionally spatially intercropped (e.g. cocoa and coffee, cocoa and palm, coffee and kola nut), but were planted in spatially separate areas the majority of the time (Table 2). Rubber was the most popular tree cash crop overall (32 % of all households). Mature rubber plantations were always monoculture, though temporal intercropping of rice between young rubber trees was common (46 % of rubber tree owners) (Table 2).

## Impediments to tree cropping and agroforestry

TCH were far more likely to have legal or customary tenure over their land than non-TCH (Table 3). Accordingly, 45 % of non-TCH respondents reported that insecure land tenure was the largest impediment to tree cultivation. Other non-TCH respondents reported

**Table 2** Numbers of tree cropping households (TCH) (A) and Agroforestry households (B) that cultivated each type of tree crop

| Group | Tree crops | Cash crops | | | | Fruit trees | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Rubber | Coffee | Cocoa | | Palm | Orange | Kola | Mango |
| A. TCH | 49 | 35 | 26 | 26 | 12 | 34 | 18 | 16 | 15 | 9 |
| B. Agroforestry | 23 | 19 | 12 | 4 | 5 | 10 | 4 | 5 | 3 | 3 |
| C. Among agroforestry group | | | | | | | | | | |
| Spatial agroforestry | | 6 | 0 | 4 | 4 | 9 | 3 | 5 | 3 | 3 |
| | | Combinations | None | Kola nut(1), cocoa(2), rice(1) | Coffee(2), palm(1), rice(1) | | Cocoa (1), rice & corn(1), pineapple (1) | Kola nut(1), w/fruit trees(3), banana (1) | Coffee (1), orange(1), mango(1) | Kola nut(1), cocoa & coffee (1), fruit (2) |
| Temporal agroforestry | | 13 | 12 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| | | Combinations | Rice (10), bitterball(1), cassava (1) | None | Pepper (1) | | Rice (1) | None | None | None |

Also shown are the specific intercropping combinations (C) used among Agroforestry households. In section (C), columns show the number of households in each Agroforestry sub-group at left (spatial vs temporal agroforestry) that cultivated the different tree types listed in column headings, in intercropping combinations with the other cash or food crops listed. "TCH" refers to all tree-cropping households, while "Agroforestry" refers to only those TCH that use agroforestry practices. See text for definitions of spatial and temporal agroforestry practices

**Table 3** Land tenure of survey households is compared between different groups (TCH vs non-TCH, Agroforestry vs Monoculture)

| Group | Land tenure | | |
|---|---|---|---|
| | n | Owns land | Test result |
| Non-tree cropping (non-TCH) | 31 | 0.61 | Fisher's Exact p = 0.00* |
| Tree cropping (TCH) | 49 | 0.94 | |
| Among TCH | | | |
| Agroforestry | 23 | 1 | Fisher's Exact p = 0.23 |
| Monoculture | 26 | 0.88 | |
| All households | 80 | 0.81 | |

Land ownership is represented by the proportions of households in each group that own land (n = number of households), including both customary and statutory ownership (tenure). Comparisons are made using Fisher's Exact tests for independence of categorical variables, considered significant where * $p < 0.05$

**Table 4** Gender of the household head is compared between tree-cropping (TCH) and non-tree-cropping (non-TCH) households

| Group | Gender of household head | | | |
|---|---|---|---|---|
| | n | Male | Female | Test result |
| Non-tree cropping (non-TCH) | 25 | 0.32 | 0.68 | $\chi^2 = 6.96$ p = 0.01* |
| Tree cropping (TCH) | 43 | 0.65 | 0.35 | |
| Among TCH | | | | |
| Agroforestry | 20 | 0.55 | 0.45 | $\chi^2 = 1.68$ |
| Monoculture | 23 | 0.74 | 0.26 | p = 0.19 |
| All households | 68 | 0.53 | 0.47 | |

Within TCH, further comparison is made between households that use agroforestry versus monoculture tree-cropping practices. Gender is described using proportions of the number (n) of households in each group as listed at left. Values of n here are slightly lower than in other analyses because only data from respondents that were the head of household were used. Chi-squared ($\chi^2$) tests are used to assess whether gender of the household head (male, female) differed significantly between groups (TCH vs non-TCH; Agroforestry vs Monoculture), with significance at * $p < 0.05$

a lack of knowledge about tree cropping (23 %), insufficient money (14 %), or other reasons (18 %), including that "burning the land would harm trees", as their primary reason for not cultivating trees.

Gender of the household head also differed between TCH and non-TCH, with TCH more likely to be headed by males (65 %), and non-TCH predominantly female-headed (68 %) (Table 4). We tested whether this difference in tree cropping might be related to gender-based differences in land tenure. This hypothesis was not supported, as male and female household heads reported equal rates of land ownership (Fisher's Exact test, p = 0.74).

Age distribution also differed based on the household's use of tree cropping; as TCH reported having two additional youth per household compared to non-TCH (Table 5). However, when respondents were asked about the number of total household youth that assist with farm labor, there was no difference reported between TCH and non-TCH households (W = 638, p value = 0.23). Within the TCH grouping, there were no significant differences in gender of the household head, land tenure, or age distributions between Agroforestry and Monoculture households (Tables 3, 4, 5).

Among tree cropping households (TCH), the biggest impediment to agroforestry practices was the widespread belief that intercropping would harm crop production. Specifically, Monoculture respondents did not intercrop herbaceous food crops under trees because they believed that: (1) shade from the trees would harm herbaceous crop production (64 %), (2) they would not grow well together (21 %), (3) intercropping would attract pests (8 %), (4) burning the litter and surface soil (a common means of preparation for cultivation of herbaceous crops) would hurt the trees (5 %), and other reasons (2 %). Similarly, the most prevalent reason respondents gave for not intercropping different tree crops together were: that the different tree crops would not grow well together due to competition (71 %), that shading would harm tree crop production (18 %), that there would be insufficient space to intercrop (6 %), and other reasons (5 %).

## Livelihood benefits

Agroforestry households reported being more food secure than Monoculture households, according to the survey food security indices (Tables 6, 7). Households that used agroforestry practices consumed more meals per day than those which used monoculture tree cropping practices (Table 6). Specifically, 22 % of the Agroforestry households consumed 3 meals per adult per day, as compared to 0 % of the Monoculture households (Table 6). Additionally, 70 % of Agroforestry households reported that always had enough

**Table 5** Household age distribution is compared between tree cropping (TCH) and non-tree cropping (non-TCH) households

| Group | Age distribution of household members | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | n | Total (members) | Youth (0–20 years) | Test result | Middle-aged (20–50 years) | Test result | Elderly (>50 years) | Test result |
| Non-tree cropping (non-TCH) | 31 | 9.5 (1.7) | 4.5 (0.4) | W = 543 | 3.7 (0.1) | W = 713 | 1.3 (0.3) | W = 745 |
| Tree cropping (TCH) | 49 | 11.5 (0.9) | 6.2 (0.5) | p = 0.03* | 4.0 (0.1) | p = 0.64 | 1.2 (0.2) | p = 0.89 |
| Among TCH | | | | | | | | |
| Agroforestry | 23 | 11.7 (1.4) | 6.3 (0.8) | W = 312 | 3.8 (0.6) | W = 344 | 1.6 (0.3) | W = 234 |
| Monoculture | 26 | 11.2(1.1) | 6.1 (0.7) | p = 0.80 | 4.2 (0.5) | p = 0.3649 | 1.0 (0.2) | p = 0.18 |
| All households | 80 | 10.7(0.6) | 5.5 (0.4) | | 3.9 (0.1) | | 1.2 (0.1) | |

Within TCH, further comparison is made between households that use agroforestry practices versus those using monoculture tree-cropping practices. Columns list the average number of young (0–20 years), middle-aged (20–50 years) and elderly (>50 years) household members in each group at left (TCH, non-TCH, Agroforestry, Monoculture), with standard error in parentheses. Wilcoxon rank sum tests are used to compare the number of household members in each age category between groups, with significance at * $p < 0.05$

**Table 6** Household meal consumption, measured as meals consumed per adult per day, is compared between tree cropping (TCH) and non-tree cropping households (non-TCH) as an index of food security

| Group | Meals per day (per adult) | | | | Test result |
|---|---|---|---|---|---|
| | n | One | Two | Three | |
| Non-tree cropping (non-TCH) | 31 | 0.52 | 0.45 | 0.03 | Fisher's Exact |
| Tree cropping (TCH) | 49 | 0.55 | 0.35 | 0.10 | p = 0.49 |
| Among TCH | | | | | |
| Agroforestry | 23 | 0.52 | 0.26 | 0.22 | Fisher's Exact |
| Monoculture | 26 | 0.58 | 0.42 | 0 | p = 0.04* |
| All households | 80 | 0.54 | 0.38 | 0.08 | |

Within TCH, further comparison is made between households that use agroforestry versus those that use monoculture practices. *n* number of households in each group at left; other values shown refer to proportions of households in each group that fall in each column). Fisher's exact tests were used to assess differences in meal consumption (number of meals per day: one, two or three) between groups (TCH vs non-TCH; Agroforestry vs Monoculture), with significance at * $p < 0.05$

food, as compared to only 31 % of Monoculture households, in response to USDA Q1 (Table 7).

There were no significant differences found in food security between TCH and non-TCH (Tables 6, 7). In response to the USDA Q1, half of both groups answered that they sometimes or often did not have enough food (Table 7). Additionally, both TCH and non-TCH consumed the same number of meals per adult per day (Table 6). There were also no differences in whether households owned livestock, the type of livestock owned, or proportion of income derived from livestock, between groups (Fig. 2). Of all households, 26 % owned goats, and 8 % owned pigs. The majority of TCH with livestock (58 %) reported allowing their livestock to graze under trees.

Altogether, households spent 50 % of their total expenditures on food purchases and received 78 % of their income from farm products, with no differences between TCH and non-TCH. TCH and non-TCH differed in terms of income diversification, however. TCH received a 17 % lower proportion of their annual farm income from herbaceous food crops and a 21 % greater proportion from tree crops, as compared to non-TCH (Fig. 2). The lme model further supports these results, showing a significant effect of Group (TCH vs non-TCH) in both the Tree crop and Food Crop model instances, revealing that whether or not a household cultivated tree crops influenced the proportion of household income earned from both tree crops and food crops (Table 8). Season (rainy or dry) had no effect on income proportion in all of the model instances, nor was there any interaction effect between group and season (Table 8). The Intercept (random effect) in each model instance is significant,

**Table 7** Household responses to United States Department of Agriculture (USDA) question 1 ("How often do you have enough food?") are compared between tree cropping (TCH) and non-tree cropping households (non-TCH)

| Group | Food security Q1 (USDA) | | | Test result |
|---|---|---|---|---|
| | n | Always enough | Not enough | |
| Non-tree cropping (non-TCH) | 31 | 0.49 | 0.51 | $\chi^2 = 0.05$ p = 0.82 |
| Tree cropping (TCH) | 49 | 0.52 | 0.48 | |
| Among TCH | | | | |
| Agroforestry | 23 | 0.70 | 0.30 | $\chi^2 = 7.4$ |
| Monoculture | 26 | 0.31 | 0.69 | p = 0.01* |
| All households | 80 | 0.50 | 0.50 | |

Within TCH, further comparison is made between households that use agroforestry versus those that use monoculture tree cropping practices. Households that use agroforestry practices reported having "enough food" more often than those using monoculture tree cropping practices. *n* number of households in each group at left; other numbers refer to proportions of households in each group that fall in each column). Chi-squared ($\chi^2$) tests were used to assess differences in survey responses to the food security question ("always enough" vs "sometimes/often not enough"), between groups as shown (TCH vs non-TCH; Agroforestry vs Monoculture

* Significant differences between values in columns, at $p < 0.05$

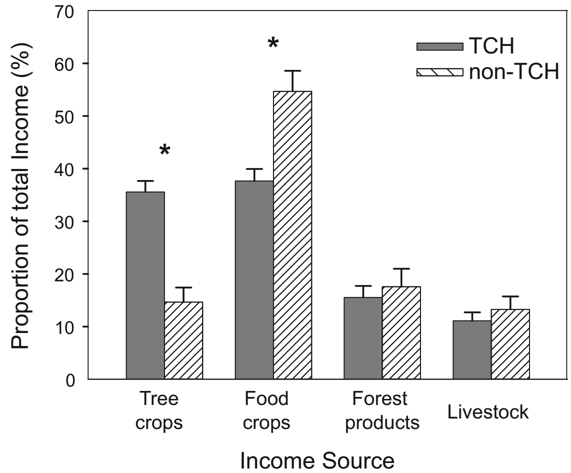


**Fig. 2** Income diversification as compared between tree cropping households (TCH) and non-tree cropping households (non-TCH), represented by the proportions of household income earned from four product groups (tree crops, food crops, forest products, and livestock). * Significant differences between TCH and non-TCH for each product group, at $p < 0.05$

confirming that the household is having a random effect on the outcome.

While conducting the survey, we noticed a source of uncertainty in household measures of "tree crop" versus "forest product" income. We conceived of "tree crop" income as that which comes from the sale of cultivated tree crops, and "forest product" income as is that which arrives from the sale of products harvested from nearby forests. However, due to challenges during translation, some non-TCH households reported income from wild palm products as "tree crop" income, though it should have been under the "forest product" category. This resulted in non-zero measures of "tree crop income" for non-TCH households, as shown in Fig. 2. As a result, differences in tree crop income between TCH and non-TCH households may be slightly greater than reported in our survey results.

In regard to forest products, the results were less clear. More of the TCH sold wood (29 %) than non-TCH (10 %), though this was not quite significant (Table 9). Forty-six percent of all households sold charcoal, independent of whether or not they cultivated trees (Table 9). Both TCH and non-TCH received the same proportion of income from forest products (Fig. 2). This proportion is captured as a group average, however, and the highly skewed nature of the data on forest product income likely affected this result. In addition, it is uncertain which of these forest products came from cultivated tree crops, and which were harvested from nearby forests.

## Shifting cultivation

Shifting cultivation was practiced by 88 % of all respondents, with an average fallow of 6.8 years (Table 10). There was no difference in use of shifting cultivation between TCH and non-TCH or between Agroforestry and Monoculture households (Table 10). The majority (85 %) of survey respondents using shifting cultivation farmed on the land for only 1 year before leaving it to fallow, whereas 15 % planted for 2–4 years consecutively before leaving the land to fallow. The few households that planted consecutively on the same land for more than 1 year tended to

**Table 8** Results of the linear mixed effects (lme) model for income diversification reveal that the household cultivation of tree crops ("Group" (i.e. tree cropping households [TCH] vs non-tree cropping households [non-TCH])) correlates with the proportion of household income earned from both tree crops and food crops

| Dependent variable | Fixed effect | Coefficient (SE) | DF | t value | p value |
|---|---|---|---|---|---|
| Tree crop income | (Intercept) | 17.93 (3.77) | 72 | 4.76 | 0.00 |
| | Season | −6.55 (4.25) | 72 | −1.54 | 0.13 |
| | Group | 21.18 (4.83) | 72 | 4.38 | 0.00* |
| | Season × Group | −0.56 (5.45) | 72 | −0.10 | 0.92 |
| Food crop income | (Intercept) | 51.03 (4.64) | 72 | 10.98 | 0.00 |
| | Season | 7.24 (4.54) | 72 | 1.59 | 0.12 |
| | Group | −16.15 (5.96) | 72 | −2.71 | 0.01* |
| | Season × Group | −1.69 (5.82) | 72 | −0.29 | 0.77 |
| Livestock income | (Intercept) | 11.38 (3.10) | 72 | 3.66 | 0.00 |
| | Season | 3.79 (3.11) | 72 | 1.21 | 0.23 |
| | Group | 0.84 (3.98) | 72 | 0.21 | 0.83 |
| | Season × Group | −6.01 (3.99) | 72 | −1.51 | 0.13 |

The lme model was applied to three product groups for household income (tree crop, food crop, livestock), to assess whether these dependent variables were affected by 3 fixed effects: group (TCH or non-TCH), season (rainy or dry), and group × season. The model intercepts accounts for the random effect of the household. As represented in Eq. 1, the model fits regression coefficients ($ß_1$ … $ß_4$) with standard error (SE) for each fixed effect, then evaluates the significance of each fixed effect using a t-test (t value = test statistic; *DF* = degrees of freedom)

* Significance at $p < 0.05$

**Table 9** Household sale of forest products (wood and charcoal) are compared between tree-cropping (TCH) and non-tree cropping households (non-TCH), and between Agroforestry and Monoculture households within the TCH group

| Group | n | Sale of forest products by household group | | | |
|---|---|---|---|---|---|
| | | Wood | Test result | Charcoal | Test result |
| Non-tree cropping (non-TCH) | 31 | 0.10 | Fisher's Exact | 0.45 | $\chi^2 = 0.02$ |
| Tree cropping (TCH) | 49 | 0.29 | p = 0.05 | 0.47 | p = 0.88 |
| Among TCH | | | | | |
| Agroforestry | 23 | 0.26 | Fisher's Exact | 0.35 | $\chi^2 = 3.61$ |
| Monoculture | 26 | 0.31 | p = 0.76 | 0.58 | p = 0.06 |
| All households | 80 | 0.21 | | 0.46 | |

Sale of forest products is shown as the proportion of total households (n) in each group at left that sell wood or charcoal. Fisher's Exact tests were used to assess differences in the household sale of wood (yes, or no) between groups (TCH vs non-TCH; Agroforestry vs Monoculture). Chi-squared ($\chi^2$) tests were used to assess differences between groups with regard to sale of charcoal (yes, no)

* Significance at $p < 0.05$

engage in conservation farming, which involves tilling weeds into the soil between planting seasons, to act as a green manure. The type of vegetation cleared for agriculture did not differ between TCH and non-TCH households or between Agroforestry and Monoculture households: 57 % of all respondents cleared secondary forest, 39 % cleared primary forests, and 4 % cleared other land types (Table 11).

**Table 10** Comparison of shifting cultivation practices between tree-cropping (TCH) and non-tree cropping households (non-TCH), and between Agroforestry and Monoculture households

| Group | Shifting cultivation practices | | | | |
|---|---|---|---|---|---|
| | n | Use shift. cult | Test result | Fallow time (yrs) (SD) | Test result |
| Non-tree cropping (non-TCH) | 31 | 0.81 | Fisher's Exact | 6.5 (2.1) | W = 440.5 |
| Tree cropping (TCH) | 49 | 0.92 | p = 0.73 | 7.0 (2.1) | p = 0.21 |
| Among TCH | | | | | |
| Agroforestry | 23 | 0.96 | Fisher's Exact | 6.9 (2.2) | W = 237.5 |
| Monoculture | 26 | 0.88 | p = 0.66 | 7.1 (2.1) | p = 0.73 |
| All Households | 80 | 0.88 | | 6.8 (2.1) | |

Use of shifting cultivation is represented as the proportion of total households in each group at left (n) that use shifting cultivation, and fallow time is depicted as the mean number of years land is left to fallow (SD = Standard deviation). Fisher's Exact tests were used to assess differences in the use of shifting cultivation (yes, now) between groups (TCH vs non-TCH; Agroforestry vs Monoculture). Wilcoxon rank sum tests were used to compare the length of fallow time between groups (W = Wilcoxon test statistic)

* Significance at $p < 0.05$

**Table 11** The types of vegetation cleared for shifting cultivation are compared between tree cropping (TCH) and non-tree cropping households (non-TCH), and between Agroforestry and Monoculture households within the TCH group

| Group | Type of vegetation cleared | | | | |
|---|---|---|---|---|---|
| | n | Primary forest | Transitional forest | Other vegetation type | Test result |
| Non-tree cropping (non-TCH) | 31 | 0.39 | 0.61 | 0 | Fisher's Exact |
| Tree cropping (TCH) | 49 | 0.39 | 0.55 | 0.06 | p = 0.16 |
| Among TCH | | | | | |
| Agroforestry | 23 | 0.26 | 0.61 | 0.13 | Fisher's Exact |
| Monoculture | 26 | 0.50 | 0.50 | 0 | p = 0.06 |
| All households | 80 | 0.39 | 0.57 | 0.04 | |

Values shown represent the proportions of households (n) in each group at left that clear the vegetation type in the column heading. Fisher's Exact tests were used to assess differences in the type of vegetation cleared (primary, transitional, or other type) between groups (TCH vs non-TCH; Agroforestry vs Monoculture)

* Significance at $p < 0.05$

## Discussion

This study of the socio-cultural feasibility of tree cropping and agroforestry is relevant to REDD+ efforts and rainforest conservation in Liberia, while providing insights into rural livelihoods. The finding of a positive correlation between tree cropping practices and household livelihood measures echoes what has been observed in other studies (Mai 1999; Garrity 2004; Rahman et al. 2012). Also pertinent to forest conservation efforts is our finding that tree cropping and agroforestry practices did not influence the households' decisions to engage in shifting cultivation. As shown, socio-cultural obstacles may impede the transition away from traditional shifting cultivation systems in Liberia.

### Benefits of tree cropping and agroforestry systems

Tree cropping in this sub-region of Liberia can provide diversified sources of income. Tree cropping households received a higher proportion of their income from the sale of tree crops and were less reliant on the sale of herbaceous food crops for income. The reduced reliance on income from herbaceous food crops can free up those crops for household consumption, enhancing food security. It can also make farming incomes less subject to the volatility of markets for herbaceous crops (Feintrenie and Schwarze 2010). These two factors are especially important in Liberia, where import-dominated food markets often cause fluctuating prices for food products (Broudic 2008) and where most rural households rely on subsistence agriculture to meet a large portion of their food needs. In addition, tree cropping households benefited from other non-food products on the trees that they cultivated, including wood and charcoal. Importantly, the provision of fuelwood from tree crops may reduce the need to harvest these products from nearby forests, potentially decreasing deforestation and habitat loss in alignment with the goals of REDD+ and forest conservation (Nath et al. 2005).

There was a positive correlation between agroforestry use and improved food security as hypothesized, though the causes of this relationship could not be determined in this study. It is possible that agroforestry improves food security through diversified sources of income, enhanced crop yields, or additional food products. It is also possible that other factors, such as wealth or knowledge, influence both outcomes. However, it may be noted that the proportions of household income from farm products (tree crops, food crops, livestock) versus other outside income sources (such as wage labor) were similarly distributed in Agroforestry and Monoculture households. This lends credence to the idea that it was not income alone, but results from agroforestry per se, that produced greater food security in Agroforestry households.

## Impediments to tree cropping

Insecure land tenure was the largest impediment to tree cropping in this sub-region. Households that did not engage in tree cropping tended to have neither customary (inherited "family land") nor statutory ("legal") ownership, the two forms of ownership that make up the dual tenure system in Liberia (Alden Wily 2007). Others have noted that, without secure land tenure, Liberian households are hesitant to plant trees; trees make the land more valuable, and increase the risk of others claiming the land as their own (MOA 2007). Households also reported lack of knowledge and insufficient money as barriers to tree cropping. This is supported by other studies which show that tree cropping can pose a financial risk due to its higher initial investment (Cardoso et al. 2001), and longer time for trees to become productive (Rodrigo et al. 2005).

Regarding the finding that female-headed households were less likely to practice tree cropping than male-headed households, it should be noted that this result was based on respondents' answers to the question "are you the head of the household?" This may include some uncertainty because it is unknown whether one spouse might simply claim to be the household head, when the other is absent. However, this result is consistent with other studies both in Liberia (MOA 2007, Weise and Wilcox 2007) and across Sub-Saharan Africa (Kiptot and Franzel 2011), which consistently show that women are often excluded from tree-cropping and agroforestry technologies.

To the extent that these gender-based differences in tree cultivation are accurate, there are several possible reasons for this. Women in Liberia generally have reduced access to land tenure, which as noted above is an important asset for tree cultivation (Unruh 2009). Though there were no gender-based differences in land tenure found in this study, it is possible that insecure land tenure due to gender may be having a hidden or residual effect. Despite the passing of a recent Inheritance Law that grants women rights to customary land (MoFA 2003), there is still resistance among rural men against allowing women full customary ownership (Unruh 2009). Women may not feel secure enough over their land rights to invest in tree-cropping.

There are other possible reasons to explain why female-headed households are less likely to cultivate trees, such as gender-based differences in labor roles (MOA 2007). A report by the Sustainable Tree Crops Program (Weise and Wilcox 2007) found that men are primarily responsible for tree cropping, and women for tending subsistence crops, in Liberia. Women in Liberia are also subject to marginalization and exclusion, which may limit their access to the knowledge, materials or markets necessary for tree crop cultivation (MOA 2007; Kiptot and Franzel 2011). Furthermore, Kiptot and Franzel (2011) found that, while women do the majority of agricultural work in Africa, they are often ignored by policy makers and extension officers, who tend to target men. These gender inequalities in access to technologies can contribute to decreased agricultural production and the deepening of societal poverty (Kiptot and Franzel 2011).

Curiously, tree cropping households in this sub-region had two additional youth per household, on average. It is possible that the supplementary income or food from tree crops enables the household to support more members, such as youth from other households (Dewees and Saxena 1997). Additional income provided by tree crops may also reduce the need for outside sources of income, potentially decreasing out-migration of household youth to conduct wage labor.

## Impediments to agroforestry practices

Spatial agroforestry was slightly more common among households cultivating fruit or nut trees as opposed to tree cash crops. This is likely due to the traditional, unstructured nature of planting fruit trees, which may be planted around the house, in nearby forests, or on field boundaries (Kiptot and Franzel 2011). Cash crop trees were rarely spatially intercropped though there were some exceptions (e.g. cocoa and coffee, cocoa and kola nut).

Rubber, the most prevalent cash crop, was always cultivated in monoculture due to respondents' beliefs that intercropping would harm crops. Rubber is successfully intercropped in other countries with similar climates, however, such as Nigeria, Indonesia and Sri Lanka (Okafor and Fernandes 1987; Leakey 1998; Penot 2004; Iqbal et al. 2006). Rubber agroforestry may be therefore be feasible in Liberia, but is impeded by the widespread belief that rubber is most productive when in monoculture. The prevalence of this perception likely derives from the historical introduction and spread of rubber-tree cultivation in Liberia. Rubber cultivation was introduced by Firestone Rubber Company in the late 1920s and disseminated to rural Liberians through training programs and extensive wage labor (Mclaughlin 1966). Rural households may be conservatively copying the dominant corporate practice they have seen used around them. Indeed, respondents in our study reported learning about rubber cultivation primarily from watching others.

The tendency to cultivate rubber in monoculture may also be an attempt to maximize income (Feintrenie et al. 2010). Households listed income as their primary motivation for cultivating trees in this sub-region. Lack of knowledge and access to technology are other likely impediments to agroforestry in Bong and Lofa counties, where agroforestry extension programs are less prevalent than in Nimba County.

## Agroforestry as an "Alternative Livelihood"?

Our finding of an average 6.8 year fallow time for shifting cultivation among all households, with no difference between agricultural groupings, is consistent with a report by the International Institute of Tropical Agriculture (IITA) and the Sustainable Tree Crops Program (STCP) (Weise and Wilcox 2007), though less than the 9 year fallow statistic provided by the Liberian Ministry of Agriculture (MOA 2007). Contrary to the idea that permanent tree cropping systems could replace shifting cultivation as a dominant livelihood strategy (MOA 2008; R-PP 2012) nearly all households in this study practiced shifting cultivation, independent of whether or not they used tree cropping or agroforestry practices. This may be due the long-standing cultural tradition of using shifting cultivation in Liberia. Such was the case in Bangladesh (Rahman et al. 2012), where households were reluctant to stop using shifting cultivation because they had used it for generations.

The continued reliance on shifting cultivation is also likely a symptom of poverty, underdevelopment in the smallholder agricultural sector, and inadequate policies (Geist and Lambin 2002). Similarly, poor education, insufficient credit and capital, insecure land tenure, lack of technical knowledge, and underdeveloped markets impede the transition to permanent agriculture systems in Bangladesh (Rahman et al. 2012). These factors are also prevalent in Liberia, where undeveloped domestic agricultural and transportation infrastructure leave smallholder farmers subject to the high costs of transport, import competition, and undeveloped markets, increasing the economic risks associated with tree cropping (Mayson and Sawyer 1979; Broudic 2008).

Shifting cultivation may help households circumvent the risks associated with tree cropping through its impermanent, flexible nature, and short term return on invested labor. It is therefore likely that households will continue to use shifting cultivation until these underlying barriers are addressed. We pose the question: should efforts really be placed on transitioning people completely away from shifting cultivation systems (MOA 2008; R-PP 2012)? The motivation for such a transition is largely guided by the belief that shifting cultivation is a primary driver of deforestation in Liberia (R-PP 2012). Yet a national forest assessment by the World Bank states that there is insufficient data quantifying rates of deforestation from shifting cultivation in Liberia (World Bank 2010). The belief that households are responsible for primary forest loss (UNDP 2006) may also be misguided, as studies show that most of Liberia's forests have been altered at some point by human use (Voorhoeve 1979, find in Fairhead and Leach 1997), and that forest loss from agriculture was more severe 300 years ago (Mayer 1951:25, find in Fairhead and Leach 1997). The claim that local people are to blame for deforestation in Liberia deserves closer inspection and further research. Such claims have been used by non-governmental organizations (NGOs), governments and other actors to legitimize the designation of protected areas, and the forced removal of people from these areas (Fairhead and Leach 1997).

### Can agroforestry be expanded?

Though it may not feasibly *replace* shifting cultivation in the near future, this study reveals compelling evidence that adoption of agroforestry practices *alongside* traditional agriculture can potentially improve rural livelihoods. Our findings suggest several potential routes to increase smallholder agroforestry by expanding on pre-existing practices. For example, though mature rubber was always cultivated in monoculture in our results, a substantial portion of households intercropped rice with young rubber trees. This form of temporal agroforestry enables households to utilize the space between rubber trees for food production during their unproductive stage, in the first 5–7 years (Rodrigo et al. 2005). A relatively simple technology, temporal agroforestry can benefit households through enhanced crop yields, additional food sources, and income diversification (Rodrigo et al. 2000, 2005). Studies also reveal positive effects when rubber is temporally intercropped with banana (Rodrigo et al. 2005), sugar cane (Rodrigo et al. 2000), or both banana and pineapple (Jessy et al. 1997), each of which may be feasible in Liberia.

Temporal agroforestry is already used in Liberia, requires minimal change to pre-existing systems, and has been shown to have little or no negative effects (Rodrigo et al. 2005). Despite these benefits, it was only practiced among half of rubber producers and almost never with fruit trees. Education about this temporal agroforestry would be a simple way to potentially support food security among households during the early stage of rubber-tree cultivation. Livestock can also graze in tree cropping systems, as observed in our study. Studies show that letting sheep graze under rubber trees can help enhance tree production through reduced weed competition and improved soil fertility (Tajuddin 1986), while providing an additional source of food for the household.

### Policy implications

For reasons of cultural feasibility, policies in the near term should endeavor to improve and incorporate agroforestry practices *into* existing systems at the household level, rather than replace them entirely, to better support local livelihoods. Greater efforts are required from the GoL to address land tenure, develop markets and provide education and training on tree cropping and agroforestry practices. Over the longer term the GoL should improve transportation infrastructure and increase the affordability and accessibility of improved agricultural inputs, capital and technologies to smallholder farmers. Future participatory in-country research is needed to elucidate which agroforestry techniques and intercropping combinations will be most effective, with the greatest potential to improve rural livelihoods, in Liberia.

Insecure land tenure was the largest impediment to adoption of permanent tree-cropping practices in this sub-region. The GoL Land Commission has made significant progress towards improving the state of customary land tenure, through its Land Rights Policy of 2013, which recognizes customary land rights as equal to private land rights, for the first time (LRP 2013; SDI 2013). As this policy moves into law, efforts should be placed on ensuring that it continues to protect the rights of customary land owners and women in particular, who are marginalized in Liberia.

Careful policy consideration is needed regarding the designation of Protected Areas and the rights of people currently residing in or around these areas. Forced removal of people from these areas will reduce their access to forest products, land for shifting agriculture and agroforestry, livestock grazing or permanent cropping, and hunting, threatening local livelihoods and food security. Though agroforestry systems have been proposed as alternative livelihoods for people displaced from these areas, our results give reason to believe that a complete transition from shifting cultivation to agroforestry systems may not be feasible without addressing underlying barriers, including rural poverty, traditional practices, household perceptions, and gender dynamics. Protected Areas may also encourage corruption such as bribes to government agents for access to land. As REDD+ and Protected Area conservation strategies move forward, care should be taken that payments do not simply go to governments without benefiting rural populations and their needs for access to land. Emphases should be placed on understanding and incorporating the needs of rural households, who depend so heavily on forests for their livelihoods.

Women were less likely to engage in tree-cropping in this sub-region. With current efforts to improve gender equality in Liberia (MOA 2007), further research should investigate how gender roles and other household demographic factors influence tree cropping practices. Policies that focus on enhancing education, land tenure rights, and access to agricultural inputs, technologies and capital for women can aim to reduce gender disparities. Finally, as current and future agroforestry programs and policies move forward, emphases should be placed on understanding and addressing cultural and social factors, including household dynamics and perceptions about intercropping, which, as our study reveals, impact the adoption of tree cropping and agroforestry practices by households in Liberia.

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