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ANALYSIS

Indigenous livelihoods, slash-and-burn agriculture, and carbon stocks in Eastern Panama

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ABSTRACT

Improved crop–fallow systems in the humid tropics can simultaneously sequester atmospheric carbon emissions and contribute to sustainable livelihoods of rural populations. A study with an indigenous community in eastern Panama revealed a considerable biophysical potential for carbon offsets in small-scale slash-and-burn agriculture through longer fallow periods, improved fallow management, secondary forest development, and agricultural intensification. Based on soil and biomass carbon measurements, estimated annual sequestration rates amount to 0.3–3.7 t C ha^{-1} yr^{-1}. Despite such potential, the economic benefits of initiatives aimed at sequestration of carbon in the community are likely to be rather unequally distributed within the community. Heterogeneity in livelihood strategies and uneven asset endowments among households – factors often overlooked in the ongoing carbon and sustainable development debate – are expected to strongly affect household participation. Indeed, only the better-endowed households that have also managed to diversify into more lucrative farm and non-farm activities are likely to be able to participate in and thus benefit from improved crop–fallow systems that capture carbon. Economic, ethical, institutional, and technical concerns need to be taken into account when designing community carbon management and investment plans.

1. Introduction

Secondary forests – a key feature in forest landscapes and slash-and-burn agriculture of small-scale farmers in the tropics – are not only increasing in extent worldwide but also receiving growing attention with respect to their potential ecosystem services and contributions to sustainable livelihoods. Defined as woody vegetation on agricultural land or other lands where previous forest cover has been eliminated (de Jong et al., 2001; Smith et al., 1997), secondary forests covered 165 million ha in 1990 in Latin America alone (de Jong et al., 2001; FAO, 1996). Annual carbon (C) sequestration rates in tropical forest fallow are estimated to account for 25–90% of C losses due to biomass burning in forests (Hughes et al., 1999; Lugo and Brown, 1992; Naughton-Treves, 2004). In addition to global environmental services such as C storage and biodiversity conservation, secondary forests and forest fallows contribute to improved local ecological conditions, including erosion control and watershed protection (Smith and Scherr, 2003).

However, gains from secondary forest expansion are perceived to be evanescent due to the agricultural practices of shifting cultivators. Shifting cultivation, also referred to as

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slash-and-burn or swidden–fallow agriculture, is practiced by smallholders who clear forest lands for the purpose of crop production. The productivity of the system relies on the temporary increase in nutrient availability of the soil, the buffering capacity of ash, and the regenerative capacity of fallow periods (Fujisaka et al., 2000). After cropping, land is often converted to pasture and agroforests are left in fallow in anticipation of future cultivation. In Panama, shifting cultivation, which has been practiced regionally since 5000 BC, is responsible for much of the country's current deforestation, having reached an annual rate of 51,000 ha in 1990 (Fischer and Vasseur, 2000). Once regarded as a singularly destructive and unsustainable practice, swidden–fallow agriculture is now considered to be a key element of peasant farming portfolios with the potential for sustainable development and enhanced livelihoods among the rural poor (Abizaid and Coomes, 2004; Coomes et al., 2000; Toledo et al., 2003; Vosti and Witcover, 1996). As such, improved swidden–fallow systems could not only reduce rural poverty, but also contribute to societal goals of the Kyoto Protocol. In tropical agriculture, the key to realizing local and global benefits is seen to lie in agricultural intensification and improved fallow management; reduction in the area in cropland while intensification of agricultural production; adoption of agroforestry; expansion of the extent of fallow land or delaying of forest conversion; lengthening of fallows and enhancement of forest species composition; and raising the value of secondary forests through diversification of forest products as well as the commercialization of environmental services (Albrecht and Kandji, 2003; Coomes et al., 2000; Montagnini and Nair, 2004; Place and Dewees, 1999; Scatena et al., 1996; Smith et al., 1999).

Researchers are recognizing increasingly that initiatives focusing on appropriate or improved management in slash-and-burn agriculture are unlikely to succeed without a fuller understanding of the socio-economic context and logic that underlies peasant farmers' land use decisions (de Jong et al., 2001; Smith et al., 1999; Tomich et al., 1998; Vosti and Witcover, 1996). Land use and management decisions are typically made at the household level, according to the constraints these households face, their assets, and the objectives they set. How households manage their productive assets, including different types of physical, financial, and cultural capital (Bebbington, 1999), clearly shapes economic and environmental outcomes. Despite this recognition, factors that drive forest fallowing behavior among smallholders in the tropics remain poorly understood, particularly among traditional and indigenous farmers (Gleave, 1996; Scatena et al., 1996; Coomes et al., 2000; Abizaid and Coomes, 2004). Critical aspects such as differences in access to agricultural land, burning frequencies, labor availability, urgent food needs, and benefits from secondary forests are too often overlooked in existing assessments of carbon offset potentials and other environmental services. Indeed, researchers working with peasant farmers stress the challenge of understanding households as 'moving targets,' with specific sets of resource endowments, diversification strategies, domestic life cycles, risk perceptions, and knowledge bases (Perz and Walker, 2002; Scatena et al., 1996; Barrett et al., 2005). Recognition of the heterogeneity of asset holding among peasant farmers and, thus their capacity to invest or participate in environmental improvement schemes, points to the potential importance for uneven distribution of benefits/costs and attendant ethical concerns regarding potential losers and winners of improved management and land use options (Brown et al., 2004, 2003a; Coomes et al., 2002).

This paper seeks to bridge the empirical gap between land use/management behavior of indigenous smallholders and actual options for carbon sequestration in tropical swidden–fallow systems. The focus of our study is the *Tierra Colectiva* of Ipetí–Emberá in eastern Panama. The paper is divided into two major parts. The first part assesses the role of household characteristics in shaping agricultural practices and forest fallow management. In the second part, we estimate current and potential future carbon stocks of cropped and fallowed fields. Specifically, we answer the following questions: (1) What are the main household characteristics and livelihood diversification strategies? (2) What are the main cropping and fallowing practices and who uses them? (3) What are current soil and biomass C stocks for different crop types and fallow fields of different ages? (4) What C gains can be expected from improved secondary forest fallow development? (5) Which groups of farmers are most likely to participate in improved land use management programs?

2. Research area and methods

2.1. *Site description*

The study was conducted in the indigenous *Tierra Colectiva* of Ipetí–Emberá in eastern Panama (78°30′–78°34′ W, 8°55′–9°00′ N). The community is located directly adjacent to the Pan-American Highway and holds collectively a total of 3168 ha of land (Fig. 1) with elevation ranging from 50 to 300 m above sea level. The Emberá, one of three indigenous groups in eastern Panama, migrated from Colombia to the Bayano region in the 1950s, today a watershed for a major hydro-electrical dam roughly 25 km north of Ipetí. In the early 1960s, the first Emberá settled in what is today the *Tierra Colectiva*, followed in the 1970s and 1980s by those displaced due to the construction of the dam (Dalle and Potvin, 2004). In 2004, Ipetí–Emberá comprised of 71 households (about 550 individuals).

The climate in this region of Panama is of the Am type (Köppen classification) with average daily temperature between 24 and 26 °C and annual precipitation of 2000–2500 mm (ANAM, 1999). From January to April there is a distinct dry season with only sporadic rainfall. According to the Holdridge life-zones, the most prevalent vegetation type in the study area is tropical wet or, more specifically, seasonal yet evergreen tropical rain forest (Holdridge et al., 1971). The dominant soils are mainly ultisols and alfisols with average organic matter contents of less than 5% in crop–fallow systems. Mean bulk density values are 0.48–0.81 g cm^{-3} for the 0–10 cm soil horizon and 0.54–0.81 g cm^{-3} for the 30–40 cm layer. Values for pH in crop–fallow systems range from 5.8 to 7.5.

As in many other regions of the tropics, land use within the *Tierra Colectiva* is largely determined by swidden–fallow cycles initiated by the conversion of primary forest to agricultural land. Most fields in Ipetí are elongated *parcelas*, ranging between 1 and 100 ha in size. While individual parcels are

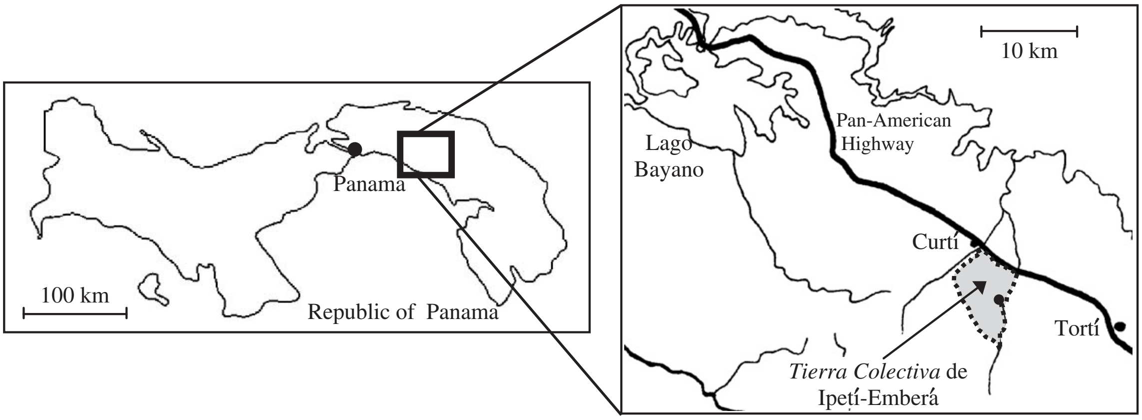

Fig. 1 – Map illustrating the location of the *Tierra Colectiva* of Ipetí–Emberá in eastern Panama.

allocated to households by the traditional community authority, decisions with respect to land use and management on the parcel are taken entirely at the level of households or, in some cases, close kin groups. Farmers usually use machetes, axes, and fire to open the forest and plant subsistence crops such as rice, corn, yam (*ñame*), yuca, banana, plantains, and beans. After a short cultivation cycle (2–3 years), the plot is left in fallow and farmers shift to another site within their parcel. The duration of a fallow period varies from 2 to 31 years before the same plot is used again for cultivation. Unlike neighboring colonists, whose primary objective is to clear forests for pasture and cattle raising, farmers in Ipetí have converted some of their crop–fallow plots to pasture or perennial tree crops (coffee, cacao, citrus fruits). Home gardens, established shortly after the initial arrival of community members, are a direct result of forest conversion rather than from the crop–fallow systems. Approximately half of the entire *Tierra Colectiva* is still forested; the other half has been cleared, mainly for fields under crop–fallow rotation and pasture. The swidden–fallow agriculture practiced in the community can best be described as a ‘multi-fallow cultivation system’ (Scatena et al., 1996; Smith et al., 1999) whereby farmers cultivate fallow plots of all ages in various cropping combinations and sequences.

The farmers in Ipetí typically make a distinction between *rastrojo bajo* (1–4 year fallow), which refers to both weedy and brushy vegetation, and *rastrojo alto* (≥ 5 years of fallow). This second type of fallow includes differential successional stages of secondary forest fallow and secondary forest. According to the Panamanian Forestry Law (Ley No. 3 de febrero de 1994, Resolución No. JD-05-98), fallow (*rastrojo*) consists of herbaceous, shrubby, and woody vegetation and also trees of 1–5 years of age and not higher than 5 m. Woody vegetation beyond that is considered *bosque secundario* or secondary forest. We use the term secondary forest according to this definition.

Like many other smallholders in marginal environments, the Emberá of Ipetí participate in a dual economy. They produce goods for the market, primarily timber, beef and yams, and purchase goods with cash. At the same time, they produce basic goods for their own consumption. Overall, residents can be described as economically poor and largely dependent on natural resources for their livelihoods. Median annual income in Ipetí–Emberá, including both subsistence and market production, amounts to roughly $1100. Field labor is shared along kinship lines and day wage opportunities are available along the Pan-American Highway.

2.2. *Methods*

2.2.1. *Household surveys*

A participatory wealth ranking exercise (Adams et al., 1997; Bellon, 2001; Chambers, 1994) was conducted in February 2004 to permit a stratified sampling of all 71 households of Ipetí along locally defined wealth criteria. Nine women and nine men participated in the exercise, recommended by community leaders to capture the full spectrum of wealth within the community. The wealth criteria identified by the participants included absence or presence of land owned, household electronics, livestock, walls, floors, and tin roofs of existing dwellings, as well as relative availability of household labor and income. Based on these criteria, all households were stratified into three resource-endowment groups (poorer, medium, and richer). A total of 36 households (half of the sample universe), 12 per group, was then selected, taking into account four distinct geographical sections of the community. Concurrently, a household asset inventory was conducted in all households of the *Tierra Colectiva*, focusing on productive capital (i.e., chain saws, motors, shotguns, etc.), non-productive capital (i.e., consumer durables, houses owned outside of the community, etc.), livestock (i.e., cattle, horses, pigs, and poultry), and agricultural land. Total capital value for all tangible assets was based on prevailing unit prices for individuals to acquire each item, either locally, at regional markets, or in Panama City.

In a second step, an in-depth household survey was carried out from March to April 2004. Four young Emberá women were selected by community leaders to participate in a brief training workshop and to administer, together with the senior author, structured questionnaires to each sample household. The questionnaires focused on household demographics, land use, management and history, parcel holdings and plot sizes, agricultural production and distribution, animals, agricultural equipment, social networks, household income and expenditures, and risk management. The latter two were assessed through participatory visualization

(Chambers, 1997; Smith et al., 2000), also accounting for gender differences. At the same time, a participatory mapping exercise took place in Ipetí to quantify and georeference the amount of land per land use type and household for the entire *Tierra Colectiva* (Lebel, unpublished data). The results from this exercise allowed triangulation of data on individual land holdings and land use types for the sample households in the in-depth survey.

2.2.2. *Soil and biomass C measurements*

Soil and biomass carbon (C) measurements in crop–fallow systems were carried out from September to October 2003, at the end of the annual maize harvest. They involved field data collection on 32 crop and fallow sites and the expanded training of community members who had before sampled other land use types in the *Tierra Colectiva* (Kirby, 2005). C was measured above and below ground in four types of cropped fields (rice, maize, yam, and banana) and four types of fallowed fields, ranging from 1 to 15 years of age. The 32 sites were selected using stratified random sampling to ensure that they spanned the totality of the study area. The total sample area per plot was 1414 m^2 and the area per land use type 2.26 ha. C was estimated from exhaustive biomass inventories for above ground storage components while soil carbon content was assessed directly.

At each sampling site, two concentric circles of 15 m radius were established, with a distance of 40 m or less between their center points, depending on the overall plot size. Within each circle, diameter at breast height (DBH), species names, and usages were recorded for large live and dead trees and palms (DBH≥10 cm). Within a smaller circle of 6 m radius, medium live and dead trees (DBH≥5 cm and <10 cm) were measured. Downed woody debris was recorded along two 15 m transects within the larger circles. Small trees (DBH<5 cm), lianas, and shrubs were sampled within two 9 m^2 quadrats. Understorey and crop residues left on the fields after harvest were collected within two 1 m^2 quadrats and litter within 0.25 m^2 quadrats.

Biomass was calculated using allometric equations based on DBH for live trees and basal-diameter (BA) for palms. The various allometric equations used (Brown, 1997; Chave et al., 2001; Hughes, 1997; Putz, 1983) are listed in Table 1. No differentiation was made between wood densities of individual tree species. Carbon stocks in standing dead trees were estimated based on length, mean DBH, and an average wood density of 0.4 g cm^{-3} (Fujisaka et al., 1998). For banana/plantain biomass, classified as herbaceous, we used an equation based on pseudostem diameter as discussed in van Noordwijk et al. (2003). Biomass for downed woody debris was estimated based on the line intersect method (Brown and Roussopoulos, 1974; Van Wagner, 1968). Debris was classified into fine sound and rotten (≤7.6 cm diameter) and coarse (>7.6 cm diameter) debris. Wood densities for the established classes were assigned according to Clark et al. (2002), using 0.453 g cm^{-3} for fine and sound coarse debris and 0.319 g cm^{-3} for rotten coarse debris. In the case of slopes, transect length was corrected by using a correction factor of 1.02–1.06 for slight to steep tilt. Collected field biomass samples, including residual crop biomass, were oven-dried and dry weight recorded. It was assumed that all biomass pools contained 47.5% C (Fujisaka et al., 1998; Kotto-Same et al., 1997). Detailed description of the sampling methodology and calculations of C stocks can be found in a companion paper (Kirby, 2005).

Table 1 – Allometric equations used to estimate aboveground dry biomass (kg ha^{-1})

Plant group	Regression equation	Reference
Large trees (≥10 cm DBH)[a]	exp[−.00 + 2.42 ln(DBH)]	Chave et al. (2001)
Medium trees (≥5 cm and <10 cm DBH)[a]	exp[−2.134 + 2.53 ln(DBH)]	Brown (1997)
Small trees (<5 cm DBH)[a] and shrubs	exp[3.79 + 2.48 ln(DBH)]	Potvin (in prep.)
Palms (1–10 cm DBH)[a]	{exp[0.9285 ln(DBH2) + 5.7236]1.05001}/10^3	Hughes (1997)
Lianas[b]	base10[0.12 + 0.91 log$_{10}$(BA)]	Putz (1983)

[a] DBH = diameter at breast height; [b] basal-area.

Below-ground C measurements included only soil organic C, but not C in roots. Soil samples were taken in the form of small cores at 0–10 and 30–40 cm depth from within each litter quadrat. With eight treatments and 32 sites, this amounted to eight samples for each treatment and depth, resulting in a total of 128 samples. Soil bulk density was estimated for each sample. A subsample was tested for pH in a soil–distilled water suspension of 1:2:5. Total C and N were determined from ground subsamples, using an automated LECO CHN-1000 elemental analyzer (LECO, 1993). Samples with values for pH >8.2 and/or C/N mass >13.00, suggesting high amounts of calcium-carbonates from nearby limestone, were excluded as outliers. Soil C values for the 10–30 cm layer were extrapolated from the 30–40 cm numbers, following Jobbágy and Jackson (2000).

Field owners or managers were invited to assist the C sampling teams and provide information regarding the farming portfolios for each sampled field. These field surveys included questions on field size, crop and fallow history, fire frequencies, agricultural production and distribution, management practices, problems encountered, and anticipated future land use. Finally, a short ecological inventory was carried out at each sampling circle, including GPS-recorded geographical coordinates, slope, and tree cover.

3. Results

3.1. *Households, land use characteristics, and diversification strategies*

Results from the household surveys reveal an average of 6.3 individuals per household, a mean land holding size of 44 ha, non-land asset values of roughly $2000, and median annual income of $1236. Although Ipetí–Emberá might appear on first sight as a fairly egalitarian indigenous community, striking differences with respect to basic household and farm characteristics are observed (Table 2).

Households grouped by wealth endowment, according to the wealth ranking exercise, show marked differences in

Table 2 – Basic characteristics of sample households (mean values, unless indicated)

	Poorer HH ($n=12$)		Medium HH ($n=12$)		Richer HH ($n=12$)		ANOVA
	Mean	St dev	Mean	St dev	Mean	St dev	F value
Total household size	5.4	1.9	6.6	2.4	8.3	4.5	2.598
Male household labor (15–64 years)	1.2	1	1.8	1.3	2.6	2.1	2.832
Female household labor (15–64 years)	0.7	0.4	1.4	0.9	2.1	1.2	4.248*
Age of household	12.3	11.7	10.5	12.5	21.5	12.3	2.840
Arrival head of the household	1981	11.2	1974	13	1974	9.7	–
Total land holding (ha)	21.8	30	35.6	31	74.3	32.7	9.096***
Total value of non-land assets ($)	293	290	584	407	5091	4530	12.545***
Value livestock ($)	81	134	279	299	3100	3451	8.547**
Value productive capital ($)	125	252	83	233	781	689	9.319***
Value consumer durables ($)	87	150	221	218	1209	2628	1.938
Total annual income ($), median	967	–	1010	–	3495	–	11.677***

Significance level *<0.05, **<0.01, ***<0.001.

land holdings, non-land wealth and mean annual income but not generally in demographic characteristics. Land holdings varied significantly between poorer households and richer households from 21.8 to 74.3 ha, the value of non-land assets from $293 to $5091, and median annual income from $967 to $3495 (ANOVA, $p<0.001$). While richer households tend to have higher mean values for total household size and labor availability than medium and poorer households, these differences are not or barely statistically significant. The same is true for the average ratio of household labor to total household size being lowest for poorer families (0.35) and highest for richer households (0.56) with intermediate households in the middle (0.48). Statistically significant differences were also found in the value of livestock and productive capital, though not consumer durables. Tukey HSD multiple comparisons revealed that the primary distinction in asset holding lies between richer households and the rest, i.e., medium and poorer households. As such, the community seemed to be divided in terms of wealth in two groups rather than three groups. Nonetheless, we retain three groups for our analyses, given that – as shown below – land use practices vary notably across all three.

A closer examination of household income shares by wealth endowment reveals that households pursue distinct farm and non-farm strategies to ensure food and income security and satisfy other livelihood needs (Table 3). Average income shares are provided for household terciles (based on total income) and the three resource-endowment groups, as well as Gini coefficients, correlation coefficients and variance for the sum of all households.

Poorer households are largely dependent on low-return activities, such as handicraft production, unskilled-farm labor, small livestock, and subsistence production. By contrast, richer households, although they diversify only slightly more than poorer ones (the Herfindahl–Simpson concentration index indicates less income source concentration), tend to enjoy higher income shares from more lucrative activities such as cattle raising, timber extraction, small business and commerce, and service provision. Most medium households manage to engage in field and tree cash crop production, particularly of yam, yuca, coriander, ginger, and coffee. Based on this observation, we propose a distinction along criteria of wealth-differentiated diversification behaviors, similar to those described by Barrett et al. (2005) for rural Africa. The first category includes "peasant farmers" (i.e., high dependence on subsistence production, unskilled farm labor, and small livestock), "market-oriented farmers" (i.e., heavier reliance on income from cash crops and cattle), and "farmer entrepreneurs" (i.e., major income shares from lucrative off-farm activities).

The Gini coefficients are high in all cases, indicating that income from each source tends to be concentrated among a small portion of the population. High correlation coefficients denote that primarily the wealthier households enjoy access to the high-return options. Low or negative values reflect the disproportionate dependence of the poorer households on the less lucrative options. This trend is reinforced by the variation (%) that shows high-return options contributing substantially to the total variance in household incomes. Low-return activities such as handicrafts, farm labor, and retained output, although widespread, contribute only negligibly. Thus, not only does the difference in overall income separates households, but also, even primarily, the uneven benefits from income sources and the unequal access to the more lucrative diversification options.

Moreover, striking differences exist with respect to land use (Table 4). In addition to larger overall land holdings, richer households have, on average, more land in primary forest, pasture, short and long fallow, and crops. All wealth groups have a considerable proportion of their land covered with primary forest (35–53%) whereas fallow land accounts for 17–23%. *Parcelas* with large shares of primary forest among poor households are in all cases found in the remoter and higher-elevations areas of the *Tierra Colectiva* at a distance of 2.5 to 3.5 h by foot from the community center. Mean land use values also reveal fairly large shares of pasture (5–18%). Cropland, in contrast, covers only relatively small areas, accounting for 0.8–2.2 ha per household on average. However, it is worth noting that among the poorer households, cropland accounts for roughly one third of their total landholdings compared to less than 1/12 among better-

Table 3 – Income source share and characteristics

	Average income share (%)						Gini	Corr	Var %
	HH terciles			Resource-endowment groups			All HHs		
	T1 (P)	T2 (M)	T3 (R)	Poor	Medium	Rich			
	($n=11$)	($n=12$)	($n=12$)	($n=12$)	($n=11$)	($n=12$)	($n=36$)	($n=36$)	($n=36$)
Farm income:									
Retained output	19	13	8	13	14	12	0.62	0.65	0.08
Sale of field and tree crops	12	33	14	28	19	12	0.74	0.26	0.15
Cattle	0	9	19	0	6	22	0.88	0.57	0.16
Small livestock	15	6	7	8	13	5	0.61	0.21	0.04
Land rent	0	0	10	4	0	5	0.93	0.18	0.06
Farm labor	16	13	1	13	16	1	0.81	−0.10	0.04
Non-farm income:									
Handicraft	26	18	3	22	19	5	0.69	0.19	0.06
Timber extraction	7	7	9	0	10	14	0.86	0.18	0.08
Labor on short-term contracts	4	1	5	7	2	2	0.88	0.01	0.03
Small business (tienda)	0	0	14	0	0	14	0.91	0.61	0.15
Service provision	1	1	8	4	0	5	0.95	0.55	0.09
Other	1	0	4	0	1	3	0.90	0.56	0.03
Herfindahl–Simpson conc. index	0.65	0.62	0.47	0.64	0.63	0.46	0.53	1.00	0.97

Gini: Gini coefficient for that income source.
Corr: correlation of income source with total income.
Var %: share of total income variance explained by each income source (COV/V).

endowed households, a statistically significant difference (Kruskal–Wallis: 6.255, $p<0.05$). At the same time, poorer households have the lowest cropland to labor ratio (0.42), compared to 0.59 for intermediate and 0.47 for richer families. Overall, the results for all sample households show about 48% of all land under forest cover and the remaining land cleared mainly for swidden–fallow agriculture (29%) and pasture (20%).

Differences in land use across households reflect underlying patterns in land holding; a more detailed examination of overall land holding size and current land use is needed in order to evaluate alternative land use options linked to carbon sequestration. In the *Tierra Colectiva* of Ipetí–Emberá, land is rather unequally distributed. Of all sample households, 22% hold no land (or very little, i.e., $\leq$0.5 ha) whereas 20% of all households hold 52% of the land. Those who arrived earlier in Ipetí (i.e. >20 years ago) hold more land, on average 63 ha; in contrast, families who moved to the community during the last 10 years hold <1 ha, in all cases a tiny plot next to their dwelling. All households that hold more than 20 ha arrived between 1964 and 1985; the later their year of arrival, the smaller and more remote are their fields. Such limited access to land for newcomers indicates that land is now scarce in the *Tierra Colectiva*. This inequality is even more apparent when examining the distribution of pasture and old fallow land (Fig. 2a–c), where roughly 10% of all households in the survey hold 50% by area of these two land use types, and 55% of households hold none at all. The Gini coefficient for total land holdings, pasture, and old fallow is 0.48, 0.75, and 0.75, respectively.

Table 4 – Land use per resource-endowment group (average values)

	Poorer HH		Medium HH		Richer HH		ANOVA (mean)	ANOVA (%)
	Ha	% of total land	Ha	% of total land	Ha	% of total land	*F* value	*F* value
Cropped fields	0.8	34.8	1.9	5.9	2.2	3.0	1.205	6.016**
Fallow fields (1–4 years)	2.0	16.3	3.2	9.6	6.3	9.1	1.917	0.497
Fallow fields (5–15 years)	3.5	6.6	5.2	7.2	12.6	13.3	2.131	1.160
Perennial tree crops	0.3	2.7	2.6	6.7	1.3	1.8	2.340	1.999
Forest	12.3	35.2	15.2	47.8	35.4	53.1	5.123*	1.398^{1}
Pasture	2.9	4.4	6.6	20.6	16.3	19.2	3.336*	2.196
Other	0.0	0.0	1.1	2.1	0.3	0.5	2.612	4.068*
Total land	21.8		35.6		74.3	–	–	–
St dev	(30.0)		(31.0)		(32.7)			

Significance level *<0.05, **<0.01, **.
^{1}Square root transformed.

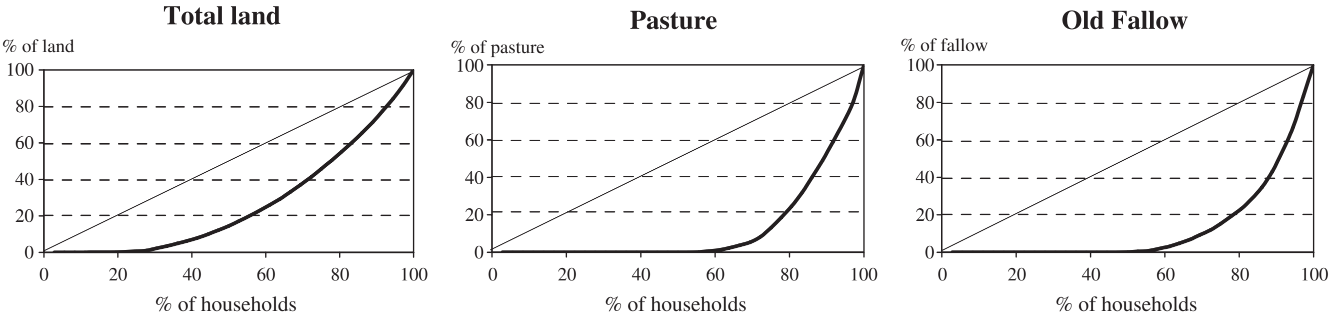

Fig. 2 – (a–c): Lorenz curves for total land, pasture and old fallow, 2004.

Furthermore, variation within resource-endowment groups is high. Among poorer households, the size of total land holdings varies markedly as does land cover: forest cover, 0–85%; fallow, 0–45%; crops, 0–100%; and pasture, 0–47%. The landless are predominantly young households that cultivate on kin land or outside of Ipetí. Among the medium households, land holdings are of 1–106 ha. Again, those who own more land within the group settled in Ipetí early on, all during the 1960s. Proportions of land use types also vary greatly: forest, 0–97%, fallow, 0–44%; crops, 0–12%; and pasture, 0–56%. Higher proportions of forest and fallow cover are also observed when fields are remote (walking distance >2 h). Finally, among the richer households, the same trends are observed, with older households owning more land (65–133 ha).

Overall, more fallow land is encountered on larger land holdings. Considerable primary forest is preserved when total lands are large and/or remote, when kin land is used for cultivation, or when a household's main sources of income are non-farm based. Modest endowments of land and also livestock – the key productive non-labor household assets – constrain the livelihood choices of poorer families to subsistence food production and low-return economic activities.

3.2. *Cropping and fallow practices*

Next, we assessed management decisions in crop–fallow systems within the *Tierra Colectiva* and how these are linked to the basic demographic and socio-economic features of households. Fallow and secondary forests cover 401 ha (25%) of the total sampling area (1580 ha) and constitute a key feature of the community's environs.

Household and field surveys revealed a complex landscape mosaic of differently aged fields and fallows, varying between 1–3 years, 1–30 years, and 1–31 years for annual crops, perennial crops (banana/plantains), and fallow fields, respectively. Mean fallow length of surveyed fields in Ipetí was 8.3 years (median 5 years), which corresponds well with the 5–8 years considered necessary by survey respondents for field recovery after cultivation. Medium and rich households tend to have fallow fields of all ages while the mean fallow length recorded for poorer households remains less than 10 years. When asked about the prospect of leaving fields in fallow for 15 years or longer, the majority of poor households cited a lack of other available land, pressing food needs, and insufficient labor to clear old fallow as major constraints while richer households responded mainly positively. Interestingly, 14 of the 36 sample households at the time of the survey did not cultivate any land (or cultivate less than 1 ha) but report holding 0–8 ha of young fallow or 0–21 ha of old fallow; many of these households rely significantly upon non-farm sources of income (i.e., "farmer entrepreneurs") and less on cropping.

Other factors that impact management decisions within crop–fallow systems are farmers' management perceptions, the availability of seeds and agricultural labor, fire occurrence, and benefits from non-timber forest products (de Jong et al., 2001; Scatena et al., 1996). In Ipetí, most farmers reported practicing shifting cultivation on at least one part of their fields every year. Only two respondents cited a lack of seeds as the primary reason for field conversion to fallow. Only one out of 16 farmers reported the application of horse manure while most of the others stated that a lack of technical knowledge prevented them from using organic inputs. Mineral fertilizer is expensive and was used on cropped fields by only two farmers; the majority reported using herbicides. Best management practices on cropped fields were thought to be the use of organic and mineral fertilizer (38% and 31%, respectively). Only three farmers considered a regular crop–fallow rotation of 3 : 5 years to be most efficient. On fallowed fields, the majority of farmers (56%) stated that better weeding would be desirable and 25% voted for more effective use of herbicides. Crop–fallow rotation and reforestation was cited only twice, respectively, as best practices. Labor constraints in Ipetí exist, mainly among younger and poorer households. Although households in all three wealth categories provide labor for food to slash older fallow, only richer families, who already have a larger labor force, can afford to hire in outside help for cash to clear land. Accidental fires have proven highly destructive for the crop–fallow systems. Community members blame careless slash-and-burn as well as colonists who set fires along weedy paths as they traverse the *Tierra Colectiva*. Benefits from secondary forest products seem of low importance for fallow management. Fruits, firewood, or timber are mainly used for home consumption and, as observed elsewhere (Smith et al., 1999) considered a 'bonus' obtained from fallowed fields.

Finally, we asked farmers to elicit their preferred future land use for the cropped and fallowed fields investigated during the C sampling. Although the obtained information does not consider what farmers would do on their other pieces of land, it illustrates general tendencies. Overall, stated future references by poor households suggest that they are more immediately concerned by subsistence production while fancying future income from cattle. This is largely explained by their current state in their domestic life cycle and the labor constraints that make diversification almost impossible. Better endowed households, on the other hand, tend to worry less about daily food and, thus, are more confident in being able to afford the 'luxury' of planting trees for environmental service provision.

The remaining questions related to improved crop–fallow systems are as follows: (1) What are current C stocks in soils and aboveground biomass for different crop types and fallow fields of different ages?; (2) What are the anticipated gains that could be achieved through changes in land use and management?; and (3) Which farmers are most likely to alter their crop–fallow systems to encourage secondary forest fallow?

3.3. *Biomass and soil carbon stocks*

Total aboveground biomass (TAGB) in crop–fallow systems in Ipetí–Emberá ranged from 6 to 115 t ha^{-1} in cropped fields and 20 to 172 t ha^{-1} in fallow fields, with a mean of 48.03±34.55 t ha^{-1} in the first and 67.89±45.00 t ha^{-1} in the latter. Mean values for crop types and fallow fields are shown in Table 5. However, the mean obscures differences between individual sites. In three fields, all of which were recently converted from forest to cropland, values for downed woody debris were clearly higher (75–104 t ha^{-1}) than on other sites. Fire, intentional and accidental, was also responsible for relatively high values in dead standing trees in two fields (8–12 t ha^{-1}). Recent slash-and-burning also explains the large amount of woody debris in a one-year fallow plot (85 t ha^{-1}) while a concentration of conserved palms explains the outlier in a two-year fallow (104 t ha^{-1}). On average, downed woody debris accounted for 58% of TAGB in cropped fields, followed by herbaceous vegetation (14%) and large (≥10 cm DHB) trees (9%). On fallow plots, large trees held 36% of TAGB, woody debris 19%, and small trees (<5 cm DBH) 10%.

Total carbon stocks in crop–fallow systems, including aboveground biomass and soil C, ranged from 55 t ha^{-1} in a mechanized rice field to 138 t ha^{-1} in a 10-year fallow plot. Mean values for annual crops amounted to 73.8±45.2 t C ha^{-1} and those for fallow plots to 89±25.6 t C ha^{-1}. It should be noted, however, that this analysis did not take into account roots, thereby underestimating total C stocks, especially for banana and yam field and plots with significant tree presence. Kirby (2005) estimate root biomass as 24% of above-ground biomass for trees >1 cm BD. The largest proportion of measured C was stored in soil C (45–73%), mainly in the 0–10 cm layer, followed by live trees and palms (2–42%), dead woody biomass (3–18%), and understorey (3–7%). Soil C in cropped fields ranged from 40 to 60 t ha^{-1} and in fallow fields from 45 to 50 t ha^{-1}. In both cases, about half of the soil C was found in the top 10 cm. High soil organic C (SOC), particularly in the upper 10 cm layer, can be explained by increased organic inputs following slash-and-burn (Nye and Greenland, 1960; Palm et al., 1996), a post-burning increase in soil microaggregates (García-Olivia et al., 1999), or elevated clay contents resulting in the stabilization of organic matter by absorption on to the clay mineral surfaces. Multivariate analysis of variance (MANOVA) shows that above-ground C stocks are significantly higher (Pillai Trace: 0.348, *df*: 5,58, $p<0.001$) for fallows than for cropland. No difference in soil C

Table 5 – Aboveground dry biomass in cropped and fallowed fields (Mg ha^{-1}), St dev in parenthesis

		Litter	Herbs	Shrubs	Woody debris	Dead standing trees	Lianas	Palms	Small trees (<5 cm DBH)	Medium trees (5–9.9 cm DBH)	Large trees (≥10 cm DBH)	Total aboveground dry biomass
Field crops (rice, maize, yam)	Mean	3.38	8.05	0.63	27.02	1.74	0.25	1.56	2.44	0.92	1.58	47.57
	St dev	1.36	5.66	0.39	28.47	4.04	0.50	2.72	4.06	1.68	2.28	32.29
Banana	Mean	3.71	2.78	0.60	26.24	0.13	0.00	2.09	0.49	0.75	12.63	49.42
	St dev	0.70	0.97	0.31	52.11	0.26	0.00	4.18	0.42	1.50	14.73	46.27
Young fallow (1–2 years)	Mean	4.51	3.41	0.78	17.98	0.77	4.45	13.53	4.26	1.14	1.46	52.30
	St dev	1.44	2.16	0.36	27.61	1.36	5.64	36.41	2.52	2.64	2.61	44.10
Old fallow (7–15 years)	Mean	4.85	4.37	0.69	7.51	0.66	1.71	0.00	9.48	7.00	47.20	83.48
	St dev	1.48	6.01	0.26	4.90	1.33	2.09	0.00	3.54	6.61	39.77	42.89
Total	Mean	4.07	5.31	0.68	19.79	1.03	1.64	4.23	4.09	2.31	13.00	55.97
	St dev	1.44	5.06	0.33	28.17	2.64	3.38	18.27	4.23	4.09	25.63	37.66

between crops and fallow was found at 0–10 and 30–40 cm depths. Univariate analyses of variance (ANOVA) of the aboveground components indicate that C in herbs, litter, and trees differs significantly for crops and fallows (respectively $F_{1,62}=7.93$, $p<0.01$; $F_{1,62}=9.98$, $p<0.01$; $F_{1,62}=12.43$, $p<0.001$).

Next, a finer analysis was undertaken to reveal differences in C stocks among different crop types and fallows of different ages. For crops, total C stocks changed from 61.8+19.9 t C ha^{-1} for banana/plantains to 84.7+33.4 t C ha^{-1} for rice with intermediate C values for maize and yam, 76.6+8.9 t C ha^{-1} and 72.2+17.6 t C ha^{-1}, respectively. MANOVA identified significant differences among the crop types for the aboveground C compartments (Pillai's Trace 0.832, *df* 15,78, $p=0.026$). Considering each component in turn, using nested ANOVA with plot as the error term for the crop main effect, two components differ significantly, C stored in herbs and trees (respectively $F_{3,12}=8.47$ and 2.38, $p<0.01$). The C associated with trees in the maize fields was significantly less than in banana stands (Fig. 3). Conversely, the herbaceous C was significantly higher in the maize fields than in any other cropped fields.

Fallows were classified into four age categories with young fallows of one and two years (*rastrojo bajo*) and older fallows of 7–9 and 10–15 years (*rastrojo alto*). On average, total C storage ranged from 79.3+27.3 t C ha^{-1} for one-year fallows to 106.1 +30.6 t C ha^{-1} for the oldest age group (10–15 years). Intermediate values were found for two and 7–9 years old fallows, 87.3+28.0 and 83.4+16.3 t C ha^{-1}, respectively. Pillai Trace indicates a significant age effect for C storage in fallows (Trace 1.24, *df* 15,78, $p<0.0001$). Nested ANOVA shows that C associated with litter and trees is significantly different among fallow age groups (respectively $F_{3,8}=2.57$, $p<0.05$ and $F_{3,8}=17.9$, $p<0.01$). A posteriori Tukey test shows that tree C storage is significantly higher in oldest fallows than in any other group (Fig. 3). Soil C is apparently not affected by the age of the fallows as we fail to find any significant differences among age groups.

To further understand the large variation in above ground C storage, we examined C storage in living trees and downed woody debris. Living trees and woody debris accounted both for 0–94% of total C storage. Since living trees are an essential component of total C stocks, we assessed the correlation between C storage (total and aboveground) and the number of trees per plot. Pearson correlation coefficients indicate highly significant relations between total C ($r^2=0.500$, $p=0.004$) or aboveground C ($r^2=0.695$, $p<0.0001$) and the number of trees with a diameter between 10 and 99 cm. Clearly, plots with a high number of trees will store more C than plots with fewer trees. No such relation was found for trees <5 cm diameter.

Again, mean values mask differences among individual fields. In the context of a C storage project, it is important to pay attention to the maximum C storage observed, estimate the potential for C sequestration, and explore management practices to achieve the potential. In the crop fields, the maximum aboveground C storage obtained from individual circles was 101 t C ha^{-1} in one banana plot compared to maxima of 60.9, 58.5 and 27.2 t C ha^{-1} in rice, yam, and maize fields, respectively. In the fallows, maximum C storage was 98 t C ha^{-1} found on one 2-year fallow while highest values for a 10–15 year, 1-year, and 7–9 year fallows amounted to 80.3, 76.7 and 49.8 t C ha^{-1}, respectively. The maximum values in cropped fields and in the two-year fallow plot were mostly related to large amount of downed woody debris due to recent conversion of forest to agricultural land or to accidental fires.

Mean C:N ratio in soils ranged from 9.4 for sites without recent burning to 12.3 for plots with annual crops, most of which had been burnt six months prior to sampling. Across all crop types, we observed significant correlations between soil pH, bulk density, percent carbon, and percent nitrogen (N). Plots with low C were also low in N (Pearson correlation 0.945, $p<0.0001$). It is therefore possible that, in the future, increased application of fertilizers may allow farmers to augment carbon storage in the soil, although caution is required due to the hidden "costs" of N fertilizer (Schlesinger, 2000).

3.4. *C sequestration scenarios — C gains, financial benefits, winners, and losers*

Given the growing scarcity of land within the *Tierra Colectiva*, potential expansion in secondary forests is more likely to

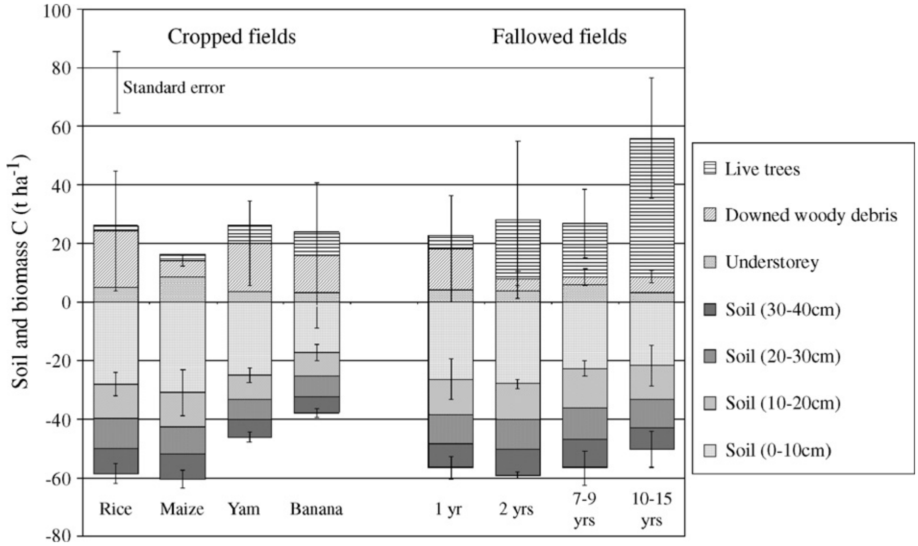

Fig. 3 – Soil and biomass C in crop–fallow systems (t ha^{-1}).

occur from converted cropland, vegetation regeneration on existing young and old fallow fields, and conversion of pasture (not discussed here) rather than from forest conversion. This seems characteristic for communities with limited land resources (Abizaid and Coomes, 2004; Smith et al., 1999). During the first commitment period, 2008–2012, under the Clean Development Mechanism, forest gardens, secondary forest development, and forest rehabilitation are eligible. Although spontaneous regeneration does not qualify, due to the 'additionality' rule, assisted natural regeneration techniques are encouraged, including protection of seed producer tress, management of seedlings, restriction of grazing and fuelwood/fodder collection, and planting of exotic or mixed native species (Smith and Scherr, 2003).

In order to estimate potential future C stocks and associated financial gains through C trading for different groups of farmers, two simple exploratory secondary forest scenarios (2000–2035) were developed. They are based on the results from the C measurements and the sample fields from the household survey. The total land area of these fields accounts for 1580 ha, about one half of the total area of the *Tierra Colectiva*. The estimates were made for the resource-endowment groups (including a separate group of poor farmers without land) and for the types of farmers characterized by their livelihood diversification strategies ("peasant farmers," "market-oriented farmers," and "farmer entrepreneurs"), based on their currently available land. Results are shown in Table 6.

The first scenario (1) assumes traditional cropping for two years in rotation with 15 years of secondary forest fallow on currently available land for shifting cultivation. It is based on a time-averaged C value of 92 t ha^{-1}, calculated according to Palm et al. (2000). The second scenario (2) implies traditional cultivation on half of the 2000 cropland and secondary forest development on the remaining parts of the available crop–fallow land. It assumes a moderate sequestration rate of 4 t C ha^{-1} yr^{-1} for secondary forests, which is consistent with the Ipetí data, although lower than the rate proposed by Kotto-Same et al. (1997). No changes in the soil pool were assumed due to the large uncertainty stemming from the results of the C measurements undertaken. An average price of $5 per ton of C sequestered (t C^{-1}) was assumed, at the higher end of current 'best guesses,' with a lower end of $2 t C^{-1}. More precise calculations on financial benefits from C offsets would be problematic, given fluctuations in the global C market and poorly defined costs for monitoring and verification for small-scale projects.

Under the first scenario, C stocks for the sample crop–fallow system increased from current 35,700 to 42,230 t (+18%). Under the second option, the gain in total C stocks amounted to 150%, reaching 89,000 t in 2035. This represents an annual C sequestration rate of 0.4 and 3.7 t C ha^{-1} yr^{-1} respectively. In terms of financial benefits, the two scenarios yielded collective gains over the next 35 years of roughly $7300–155,100 for the better-endowed group and $2300–43,300 for the poorer households. Looking at average individual gains per wealth group, estimates range from $290 to 610 ($2 t C^{-1}) and $5400–12,900 ($5 t C^{-1}) over 35 years. The highest individual financial gains could reach $29,100 over the same period, as calculated for one household with current 50 ha in crop–fallow rotation. However, annual gains, as shown in Table 6, are likely to be less impressive, ranging from $8 to 370 or 1–17% of current median incomes. They are expected to be slightly higher for the poorer and medium households.

The remaining question to be answered is which groups of farmers are most likely to adopt improved management

Table 6 – C and financial gains for crop–fallow system per resource endowment group, as a result of land management

	Poor w/ land (*n*=8)*	Medium (*n*=12)	Rich (*n*=12)		Peasant farmer (*n*=15)	Market-oriented farmer (*n*=11)	Farmer entrepreneurs (*n*=10)
2003 (current status):							
Crop–fallow system (ha)	81.0	122.6	258.4		81.5	175.0	192.7
Total C in crop–fallow system (t)	6298	9534	20,100	0	6341	13,615	14,991
Scenario 1:							
Total C in crop–fallow system (t)	7447	11,275	23,769	0	7498	16,100	17,727
Increase in C (t)	1149	1740	3,669	0	1157	2485	2736
Increase in C (%)	18	18	18		18	18	18
Individual annual $ gains (1 t C=$5)	21	21	44		11	32	39
Gain in % of median annual income	2.1	2.1	1.2		1.4	1.3	1.3
Scenario 2:							
Total C in crop–fallow system (t)	14,963	23,198	51,121		14,540	34,362	39,740
Increase in C (t)	8665	13,664	31,021		8199	20,747	24,748
Increase in C (%)	138	143	154		129	152	165
Individual annual $ gains (1 t C=$5)	155	163	369		78	269	354
Gain in % of median annual income	16.0	16.1	10.6		9.7	11.4	12.1

*Does not include poor households without land.

practices or shift land use altogether, as suggested under the two exploratory carbon-offset scenarios, and which ones are likely to be left out. We argue that different endowments, behaviors, and benefits among individual households largely determine farmers' future adoption rates.

As shown, only better endowed households in Ipetí can currently afford long fallow periods. Poor farmers, younger households, and families that arrived only relatively recently in the community are most often constrained by basic food needs and a lack of arable land and household labor, even though they recognize environmental and production benefits from longer fallow periods and secondary forest regeneration. Unless economic benefits from longer-term fallowing and secondary forest development, as assumed under the two scenarios (Table 6), can be made explicit and lucrative and/or non-land-based economic activities be introduced, these alternative land use options will most likely benefit only the richer group. It should be noted, however, that younger households are expected to increase their internal labor availability once they reach a more advanced state in their domestic life cycle, which is also likely to result in longer fallow cycles.

In terms of livelihood diversification patterns, it seems that the "peasant farmers," who currently use about one third of their available land for farming from which they obtain an equivalent share of their income, are unlikely to opt for secondary forest development on their limited cropland. The "farmer entrepreneurs," on the other hand, can be expected to be the first to sign up for carbon sequestration on their crop–fallow land. In contrast to the "peasant farmers" and "market-oriented farmers," they do not depend on cropland to satisfy their food and livelihood needs. Given their income shares from more lucrative activities, they clearly face less risk than the poorer, low-return peasant farmers. Also, those farmers who rely on cattle raising as a major source of income, most belonging to the wealthier group, might have little interest in shifting to longer-term fallows or secondary forest development with long lag times for returns. On average, they earn $1970 per year in income, which is five times more than annual gains shown in Table 6, although C gains of converted pastures will be higher. The situation is similar for most of the poorer farmers who do own pasture, although no cattle, and rent it out for an annual maximum of $1320. Cash benefits from ecosystem services on converted pasture would have to exceed current returns from rental or use, otherwise conversion is unlikely. Other benefits from non-timber forest products, biodiversity conservation, and agroforestry, also of interest to CDM investors (Naughton-Treves, 2004), remain to be examined. However, gains from agroforestry – perhaps the most promising option – as assessed for other projects in Panama, have proven small, primarily due to limited market transactions (Fischer and Vasseur, 2002).

4. Discussion and conclusion

The study results indicate that the indigenous smallholder population of Ipetí–Emberá is economically heterogeneous. Significant differences were observed regarding livelihood strategies, land use and management, the extent of fallow and secondary forests, the proportion of total land holdings in fallow, fallow age, and location. Such differences are consistent with findings from other studies on small-scale farmers or peasant societies in marginal environments, both in Latin America (Abizaid and Coomes, 2004; Coomes and Burt, 1997) and beyond (Shepherd and Soule, 1998; Tschakert, 2004). Compared to most of the "peasant farmers" and young households, richer families, most of them "farmer entrepreneurs," had on average more land in fallow, both relatively (25%) and absolutely (17.6 ha), their fallow periods are longer, and they have larger shares in old fallow. A similar dichotomy was observed by Coomes et al. (2000) in traditional swidden–fallow systems in Peru. Forest conversion and short fallow periods make economic sense to most smallholders in Ipetí, driven by food needs and timely returns to their agricultural efforts, as elsewhere (Vosti and Witcover, 1996). Indeed, insufficient or inadequate food supply appeared among the three most prevalent sources of risk perceived by sample households, together with risks associated with health and living conditions. Also, labor constraints, as experienced by the majority of younger and poorer households, limit their incentive and ability to increase fallow length or diversity land use types and sources of income.

In terms of current C storage, the study revealed significant amounts of carbon stored in the crop–fallow systems of the *Tierra Colectiva*. The average C stocks for the two land use types (62 and 106 t ha^{-1}, respectively), without roots, are roughly ten times higher than those known for semi-arid crop-fallow sites (Tschakert et al., 2004), but consistent with those in the humid tropics. Fujisaka et al. (1998), for instance, report 76 t C ha^{-1} for annual crops and 105 t C ha^{-1} for 2–3 year fallow plots in Rondonia, Brazil, including roots. Total system C reported for bush (2 years) and tree (8 years) fallow in the humid forest of Cameroon amounted to 90 and 225 t C ha^{-1} (Kotto-Same et al., 1997), also with roots. This is slightly higher than the 79–106 t ha^{-1} found in 1–15 year fallow plots in Ipetí. The above-ground carbon stocks (not including soil C) in fallow systems reported here (23–60 t ha^{-1}) also relate well to the Alternatives to Slash-and-Burn (ASB) benchmark sites in Indonesia, Brazil, Thailand, and Cameroon, with means ranging from 6 to 131 t ha^{-1} for 4–23 year fallows (Palm et al., 2000). Annual sequestration rates of 0.4–3.7 t C ha^{-1} yr^{-1} correspond well with the 1.5–3.5 t C ha^{-1} yr^{-1} estimate for tropical smallholder agroforestry systems (Montagnini and Nair, 2004). As for soil C, caution is required when interpreting differences between land use types due to the limited amount of samples and large spatial heterogeneity (Yanai et al., 2003). Comparisons of financial benefits across previous studies are problematic because of uncertainties in global C prices and the highly variable economic circumstances and welfare among groups of smallholders.

With respect to farmers' capacity to engage in environmental service provision, the situation encountered in Ipetí seems to confirm the innovativeness–needs paradox, as defined by Rogers (1995). Those individuals who most need the benefits from a new idea are usually the least likely to adopt, simply because they have limited capability to exercise choice and, therefore, are least likely to adopt; thus, they are also usually the last to be targeted by change agents, and they are effectively left behind. This raises the ethical dilemma of approaching richer households, who actually have land to be set aside for the expansion of secondary forests, rather than the poorer groups who perhaps need the economic benefits most (Brown et al., 2004; Brown and Corbera, 2003a,b; Coomes et al., 2002). What is needed is an expansion of the conceptual framework on best alternatives to slash-and-burn, as proposed by Tomich et al. (1998), to include wealth endowment and capability heterogeneity among landholders into the comparison of impacts of different land use systems and agricultural practices at the margins of tropical rainforests. This would also include diverse sets of choices of management practices and diversification strategies at different stages of household life cycles as well as shifts between these choices as households grow older. Ultimately, given such diversity, competing interests, and potential tradeoffs, best alternatives will not refer to a single land use system or management practice. Indeed, a dynamic landscape-level analysis would be needed, based on baskets of choices from which smallholders can choose depending on their needs and capacities (Tomich et al., 1998; Tschakert, 2004).

This need for a more synoptic approach, then, raises institutional and technical concerns. In Ipetí–Emberá, land is allocated through a traditional community authority whereas land use and management decisions are made at the individual household level. Carbon sequestration options tailored to individual household needs would most likely enhance flexibility in overall risk management, which is desirable. At the same time, transaction costs would become extremely high and differential endowments, land use, and diversification patterns would predetermine unequal participation and benefits. Collective land use and management (i.e., at the field or plot level), on the other hand, would require a radical shift in decision-making from the individual to a collective level, which certainly represents a significant institutional challenge for the community. Moreover, only few farmers are currently aware of improved land management options or have the technical capacity, resources and time to implement them correctly. Agroforestry, potentially yielding 50 t C ha^{-1} in the humid tropics and thus an increasingly favored C sequestration strategy (Montagnini and Nair, 2004), has also received attention in Ipetí. Practical training was first organized in the community in 2003 and is perceived as a step in the right direction among other land use and management considerations.

Finally, income from C trading is unlikely to be sufficient to satisfy participants' expectations. The estimated gains of 1–17% of current median incomes are consistent with results from pilot C projects across Latin America showing low financial returns (Brown et al., 2004; Grieg-Gran et al., 2005). More importantly, if the poorer households are to participate and benefit, access to more profitable niche activities and additional income-generating activities as part of a more vibrant non-farm economy are badly needed to escape the cycle of low-return options and asset poverty. One example for promoting alternative sources of income is ecotourism. So far, the sale of locally made baskets, necklaces, and woodcraft in Ipetí, mainly to tourists, is not lucrative enough. However, if it can be coupled with expanded ecotourism, it may hold promise, under the condition that poorer households can actively participate. It will be the task of the community as a whole to address these ethical, economic, institutional, and technical concerns and design a community management and investment plan that satisfies their most important priorities. Finally, considerably stronger policy support, as suggested by Niles (2002), is needed to complement local and regional investment plans.

In conclusion, most of the carbon debate on deforestation and slash-and-burn agriculture in the tropics has been concentrated on desirable practices to increase current C stocks. Our paper highlights the importance of farmers' differential capacity to participate and benefit from carbon sequestration initiatives. Acknowledging smallholder heterogeneity, both in terms of possibilities and constraints as well as with respect to livelihood priorities, is imperative for small-scale C offset projects as envisioned under the CDM. Focusing exclusively on likely beneficiaries, those farmers who have the means to participate, while leaving out those most in need, risks widening rather than reducing the inequality gap and potentially undermining the longer term political viability of carbon sequestration projects in rural communities of the developing world.

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