Chapter 15
Trees on Farms for Livelihoods, Conservation of Biodiversity and Carbon Storage: Evidence from Nicaragua on This "Invisible" Resource

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1 Introduction

More than 2 billion people are reliant on smallholder agriculture throughout the tropics, representing 83% of the world's agricultural population, many of whom are also among the world's poorest (Lowder et al. 2014). Climate change is currently affecting agriculture and food security and is putting millions of people at risk of hunger and poverty in different regions of the world (FAO 2016). For example, assessments carried on the coffee sector in Mexico, Brazil and Nicaragua predict that impacts associated with climate change will be even more severe than those from the drop in coffee prices. For instance, Laderach et al. (2011) estimate a reduction in land suitable for coffee production in Nicaragua between 20 to 60% by 2050 as rising temperatures will force the abandonment of low-altitude cultivation areas. Expansion of coffee cultivation into higher altitudes will put additional pressure on the conservation of important protected areas and headwaters of major river systems. The livestock sector will also suffer from a reduction in the productivity and quality of pastures and an increase in parasites and diseases which can both be attributed to climate change (FAO 2016).

Agroforestry systems, and in general, trees on farms (TonF), and trees outside the forest (De Foresta et al. 2013) can be a good alternative for achieving sustainable and climate-smart agriculture. Decisions on the management of tree cover in

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the farm are usually made at the household level, but most scientific and technical agroforestry literature focuses on the agroecosystem level. Noteworthy examples include food crops, shaded coffee and cocoa, home gardens, swidden agriculture, and silvopastoral systems (Somarriba et al. 2013; Vaast and Somarriba 2014). More research is needed on the extent and management of TonF at the household level. Observation at this scale is necessary because: the household is the final beneficiary and evaluator of success or failure of the farming operation; it is the link between markets and the governance of the territory/watershed; and it is also the link between plot-level interventions (for instance, changes in tree cover in crop fields and pastures) and impacts at the landscape level, for instance, in biological connectivity and regulation of the hydrological cycle (DeClerck et al. 2010).

Trees on farms are widespread all over the world, but are generally not included in regular inventories of tree and forest resources (Perry et al. 2009; Sloan and Sayer 2015). In Central America, for instance, 54% of agricultural land has up to 30% of tree cover (Zomer et al. 2009, 2014). TonF are the result of three processes: (1) retention of residual trees from the natural forest; (Harvey and Haber 1999), (2) selection (and protection) of valuable trees from natural regeneration (Somarriba 2012; Pinoargote et al. 2016) and (3) active planting of selected species at specific locations on the farm (Somarriba and Beer 2011; Somarriba et al. 2016). Trees can be dispersed or in lines (Chacón and Harvey 2008), in patches or in regular plantation arrangements, solitary or in groups, with variable or regular density. They are present in pastures, in agricultural fields, in linear plantings (boundaries, internal divisions, on both sides of roads and water courses, in windbreaks), and in patches of forest. Tree-crop interaction may occur simultaneously, as with shade trees in a coffee plantation, or sequentially, as in the numerous fallow systems around the world (Cairns 2007).

TonF offer farmers a regular flow of valuable goods (Cerda et al. 2014), provide soil cover and help to maintain soil fertility and crop productivity, diversify the production of goods (timber, fruits, etc.) and reduce the financial risk of the household, reduce vulnerability to contingencies (Chambers and Leach 1989; Ramirez et al. 2001), store carbon in wood, and provide other cultural and aesthetic benefits (Kuyah et al. 2016b). At the landscape level, TonF increase biological connectivity (Chacón and Harvey 2008; Harvey et al. 2008) and help to regulate the hydrological cycle. Approximately two-thirds of wood fuel in developing regions comes from TonF (Smeets and Faaij 2007). TonF contribute to the supply of timber, and may reduce deforestation (Iiyama et al. 2014). TonF are also an asset, a savings account that increases farm value and that can be drawn upon to cope with unexpected needs (Chambers and Leach 1989). Farmers actively use and manage their TonF (Amores 2016; Pinoargote et al. 2016; Somarriba et al. 2014, 2016), and have considerable knowledge on tree management (Haglund et al. 2011; Cerdán et al. 2012). However, many studies also point out the ample room for improvement, especially in the proper use of basic silviculture and tree husbandry to increase yield, quality and value of tree products (Jiménez 2012; de Sousa et al. 2016). TonF are important in land sparing strategies to avoid the loss of natural forests (Quandt 2016).

Despite all these benefits, TonF are still invisible to land use planners, decision makers, governments, and extension staff providing technical assistance to farmers. In this chapter we demonstrate, with quantitative data, the presence and contributions of TonF to farmers' livelihoods (tree production and its value), conservation of tree biodiversity (species richness and abundance), and carbon storage in aboveground tree biomass in 90 farms covering 781 ha and five major land uses in two municipalities of North-Eastern Nicaragua. Our study assessed the (1) botanical composition, species richness, abundance and size distribution of TonF at both the farm and land use level, (2) contribution of TonF to family livelihoods, conservation of tree biodiversity and carbon storage, and (3) how different combinations of land use, tree cover and diversity, and crop and tree production and value result in different farm typologies. The study area is part of the Nicaragua-Honduras "Sentinel Landscape", a long term observatory of the impact of land use intensification and other drivers affecting the presence of trees and forests on farms and in the landscape (http://www.cifor.org/sentinel-landscapes).

2 Study Sites and Methodology

2.1 Location and Sampling

We studied TonF in two rural municipalities in Nicaragua: El Tuma-La Dalia (TLD) and Waslala (13.08° – 13.20° N, 85.22° – 85.44° W), both located between 400–720 m altitude, and with 2200–2500 mm year^{-1} rainfall respectively (PDTW 2014; Dávila et al. 2017). Soils are classified as alfisols and ultisols with a clay-loam texture, pH between 5.8 and 6.2, and medium to high fertility (Leguía et al. 2014; Ayestas 2013). Population density in TLD (96 inhabitants km^{-2}) is more than double that in Waslala (37 inhabitants km^{-2}); food for family consumption is produced in the farm in Waslala and bought in TDL (Leguía et al. 2014). Pastures, field crops for the production of rice-maize-beans (generically referred to as "basic grains"), and home gardens are present in most farms in both municipalities, whereas shaded coffee is prevalent in TLD and cocoa plantations in Waslala.

We inventoried trees in 90 farms, including 781 ha of cultivated area. Trees present in five major land uses were fully censused: (1) pastures with native and introduced grass species, (2) shaded coffee plantations, (3) shaded cocoa plantations, (4) crop fields planted to basic grains and (5) home gardens. Trees were not censused in forests patches, fallow fields, and small plots of minor crops, however the surface area of these land uses was measured. In this chapter, the term "farm area" refers to cultivated farm area; the terms "total farm area or whole farm area" refer to the summation of the cultivated areas plus forests (fallows, old secondary forests, riparian, and mature forests) and other farm areas such as swamps, gorges, minor crops, etc. Total farm area measured in this study amounted to 952 ha. All land use areas were calculated based on a detailed map of each farm (perimeter, all internal divisions and fields) elaborated in close cooperation with the farmer using GPS and ArcGIS 10.1.

2.2 Field Measurements and Calculations

All trees were identified to the species level, and they were sorted according to uses (timber, fruit, firewood, services) and dbh (diameter at breast height, 1.3 m above the ground). Height was measured for all trees with dbh ≥ 10 cm or dbh ≥ 5 cm for fruit trees. Additionally trees were sampled for the estimation of aboveground carbon using transects of 2000 m^2. Carbon stored in aboveground tree biomass was estimated using dbh measurements and species-specific allometric equations for 61% of tree species found in the farms; a generic allometric equation was used for the remaining tree species (details on Caicedo 2016).

Detailed interviews with farmers provided information on crop and tree management practices, yields, costs, and prices of tree products in local markets. Standing timber volume was estimated using dbh, commercial tree height, and a commercial form factor of 0.6 (Amores 2016). Timber harvest volume was assessed by counting all tree stumps in the farm, dating the year of harvest (with the aid of the farmer), and measuring the diameter of the stump. Further methodological details are provided elsewhere (Amores 2016; Caicedo 2016; Oblitas 2016).

We assessed the contribution of tree products to both farm income and self-consumption in terms of gross income (GI), net income (NI), net cash flow (CF), value of domestic consumption (VDC), and family benefit (FB), which represents the total benefits considering sales and on-farm consumption (Imbach 1987; Cerda et al. 2014). Financial indicators are given in United States of America dollars (USD).

2.3 Analytical Methods

Tree diversity was evaluated in term of species richness, abundance and botanical composition, using pooled data from both municipalities. Species richness in 1 ha of farm area was estimated based on a subset of 53 plots with sampling transects covering exactly 1 ha (Amores 2016; Caicedo 2016; Oblitas 2016). Similarity between land uses in terms of tree species, botanical composition and abundance was evaluated with analysis of variance using Bray-Curtis distance matrices and non-multidimensional scaling ordination. All analyses were performed using the R packages Vegan and DiversityR. The taxonomic similarity between farms was also evaluated with the Morisita-Horn similarity index (Magurran and McGill 2011).

Comparisons between land uses in terms of tree population density, stand basal area, carbon stocks, agroforestry production, and financial indicators were carried out using generalized and mixed linear models using farm as random effect. Means were compared using Fisher's LSD test at $p = 0.05$. Statistical analyses were performed using Infostat (Di Rienzo et al. 2011). Additional methodological details are presented in Amores (2016), Caicedo (2016) and Oblitas (2016).

Given that crop and tree outputs (agroforestry and financial) at the farm level depend on the particular combination of land uses, area by land use, and management intensity level, farming system typologies were developed using 37 farm-level indicators that spanned (1) farm size and distribution of land uses in the farm; (2) agricultural productivity; (3) financial productivity; (4) tree abundance and tree products; and (5) tree carbon (C) stocks, and species diversity. Farm typologies were developed using a hierarchical clustering analysis with Ward's method and Bray-Curtis distances. All variables, with the exception of proportions, were skewed and therefore transformed using $\log_{10}$. All variables were standardized before clustering.

3 Results

3.1 Farms and Land Uses

The farms were small, averaging 10.57 ha, with pastures accounting for 53% of total area, followed by forest patches and basic grains (13% each); if fallows are included as part of the cropping cycle of basic grains, the area dedicated to the production of grains increases to 16.5% of total area (Table 15.1). This study included farms up to 100 ha in total farm area, but most farms were less than 13 ha (Fig. 15.1). The particular combination of land uses is apparently affected by farm size. For instance, home gardens are significant for farms up to 25 ha in size and basic grains represent a significant portion of cultivated farmland for farms of up to 30 ha but especially so for farms with fewer than 15 ha of total cultivated area. The fraction of cultivated farmland under pastures increased with farm size (Fig. 15.2).

Table 15.1 Number of farms inventoried with a given land use, area inventoried by land use, percent (%) over total area inventoried, and average area by land use (Mean ± standard deviation)

Land uses	N	Area (ha)	%	Mean ± sd
Pastures	60	508.0	53.39	8.47 ± 13.0.4
Forests[a]	44	125.7	13.21	2.86 ± 5.0.2
Basic grains	63	123.2	12.95	1.96 ± 2.1
Coffee	41	73.3	7.70	1.79 ± 1.7
Cacao	31	59.3	5.92	1.91 ± 2.4
Fallows[a]	40	33.6	3.53	0.84 ± 1.1
Homegardens	85	16.5	1.73	0.19 ± 0.2
Other crops[a]	34	11.8	1.24	0.35 ± 0.3
Total farm	90	951.38	100	10.57 ± 12.9

[a]Trees were not inventoried in these land uses. Basic grains included maize (*Zea mays*), beans (*Phaseolus vulgaris*) and rice (*Oryza sativa*). Other crops included: bananas, cassava (*Manihot esculenta*), various vegetables, annato (*Bixa orellana*), taro (*Colocasia esculenta*), sugar cane (*Saccharum officinarum*), and small fruit orchards (*Citrus lemon*, *Citrus sinensis*, *Citrus maxima*).

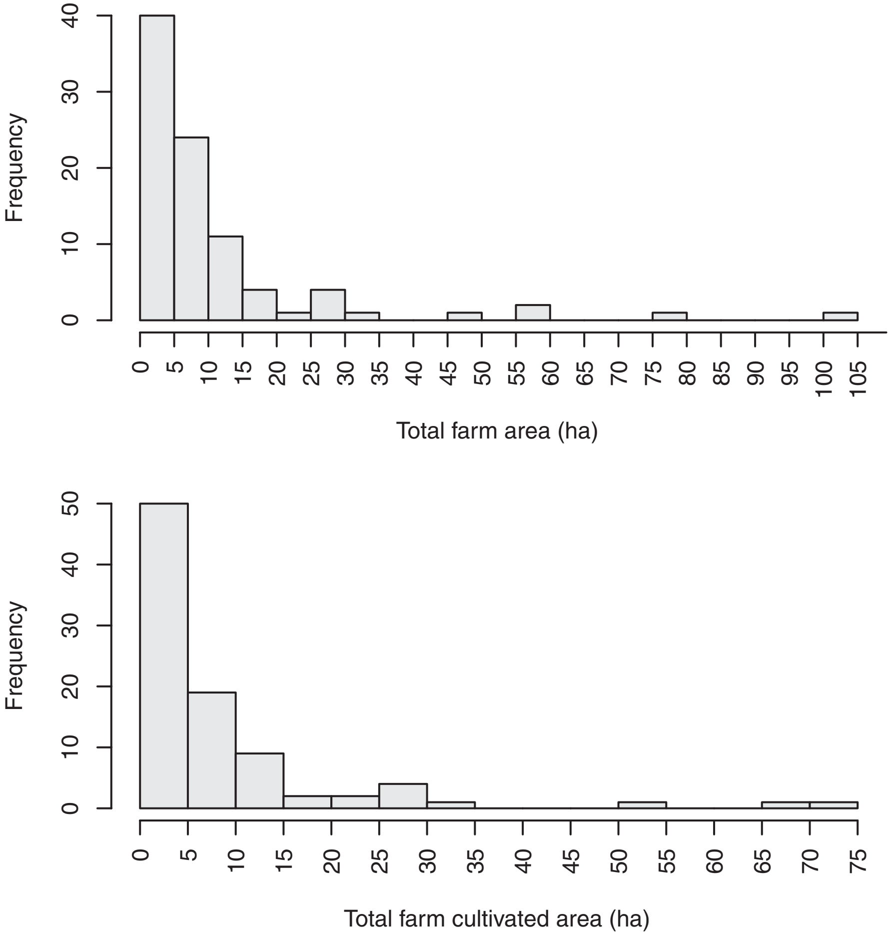

Fig. 15.1 Relative frequency distribution of farm size: total area and cultivated area (pastures, coffee, cocoa, basic grains, homegardens). Data from 90 farms in the municipalities of Tuma – La Dalia and Waslala, Nicaragua, year 2015

3.2 Trees by Farm: Stocking, Agroforestry Production, Financial Indicators and Species Richness

We identified and measured a total of 32,195 trees belonging to 264 species. An average farm (considering all sizes and land uses) had 8.7 ha of cultivated land, containing 74 trees ha^{-1}, with a basal area of 3.7 m^2 ha^{-1}. Biomass carbon stock was roughly 167 Mg C $farm^{-1}$ in aboveground tree biomass, 5.5 Mg ha^{-1} in firewood biomass and 7.8 m^3 ha^{-1} in standing timber. On average, farmers harvested 0.72

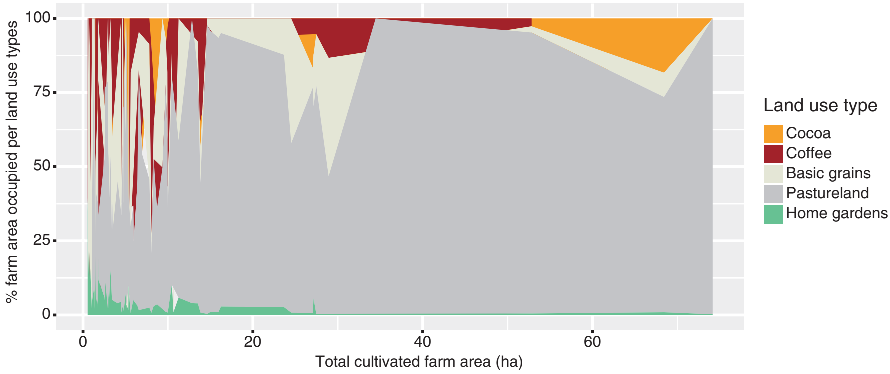

Fig. 15.2 Land use area by farm size in the municipalities of Tuma – La Dalia and Waslala. Nicaragua

trees ha^{-1} year^{-1}, consumed 1 Mg year^{-1} of firewood per family, sold 1% of total fruit produced but lost of up to 74% of total fruit production (Table 15.2).

About 36% of tree species produced timber; 29%, firewood; 17%, fruit; 14%, services (e.g., shade or restoration of soil fertility); and 4%, posts and other products. Of the species, 75–78 were identified as timber species (the most important being *Cordia alliodora, Cedrela odorata* and *Platymiscium dimorphandrum*), 36–38 as fruit species (those most frequently consumed: *Mangifera indica*, *Persea americana*, *Citrus sinensis*, *Citrus reticulata* and *Bactris gasipaes*). The most important firewood tree species were *Guazuma ulmifolia, Senna siamea, Lonchocarpus minimiflorus, Inga oerstediana, Spathodea campanulata* and *Morinda panamensis* (Amores 2016).

Trees on farm generated a family benefit of USD 544 ha^{-1} year^{-1}, of which, 86%, or USD 469 ha^{-1} year^{-1} represents on-farm consumption. The farms have some USD 6000 ha^{-1} of standing timber and USD 850 ha^{-1} of firewood. On average, by farm, fruits contribute 34% of the family benefit; firewood, 29%; timber, 28%; and posts, 9%. Farmers harvest on average one timber tree per hectare per year. Fruit trees provide a steady monthly supply of fruits for family consumption and sale all year round, helping to mitigate family food needs (Fig. 15.3). Unfortunately, farmers lose 65–82% of the fruit produced on the farm (Table 15.2). Species accumulation curves based on sampled area indicates that, at the landscape level, 76% of total species richness is recorded once 200 ha of farmland have been sampled (Fig. 15.4a, b).

Table 15.2 Trees on farms: stocking (population density, basal area, and carbon in aboveground biomass), agroforestry production and financial indicators

Variable	Mean ± sd
Population density and carbon stock	
Cultivated farm area (ha)	8.7 ± 12.9
Population density (trees ha^{-1})	74 ± 54
Basal area (m^2 ha^{-1})	3.7 ± 2.5
Total C stocks dispersed trees (Mg C $farm^{-1}$)	111 ± 156
C stocks dispersed trees (Mg C ha^{-1})	14.2 ± 9.8
Total longitude of tree lines (m lines $farm^{-1}$)	1123 ± 1176
Longitude of tree lines (m lines ha^{-1})	190 ± 153
Total C stocks trees in lines (Mg C $farm^{-1}$)	55.6 ± 68.8
Agroforestry production	
VMP (m^3 ha^{-1})	7.8 ± 7.2
Firewood (Mg ha^{-1})	5.5 ± 4.0
Oranges (Units ha^{-1} $year^{-1}$)	3052 ± 7040
Various fruits (Units ha^{-1} $year^{-1}$)	2806 ± 4263
Various fruits (kg ha^{-1} $year^{-1}$)	234 ± 549
Timber harvest (trees ha^{-1} $year^{-1}$)	0.72
Firewood family consumption (Mg $year^{-1}$)	2.6 ± 0.3
Fruit production consumed (%)	25
Fruit production sold (%)	1
Fruit production lost (%)	74
Financial indicators (US dollars)	
CC (USD ha^{-1} $year^{-1}$)	20.2 ± 31.8
KC (USD ha^{-1} $year^{-1}$)	19.1 ± 24.8
GI (USD ha^{-1} $year^{-1}$)	42.3 ± 50.8
CF (USD ha^{-1} $year^{-1}$)	0.3 ± 40.6
NI (USD ha^{-1} $year^{-1}$)	−18.4 ± 41.5
VCD (USD ha^{-1} $year^{-1}$)	199.9 ± 203.2
FB (USD ha^{-1} $year^{-1}$)	200.2 ± 203.6
ValMP (USD ha^{-1})	1415 ± 966
VLP (USD ha^{-1})	381.9 ± 283

Pooled data from municipalities Tuma-La Dalia and Waslala, Nicaragua. Inventory 90 farms in year 2015, total surveyed cultivated farm area 871 ha. Data on C stocks are medians; remaining variables mean ± standard deviation

Various fruits measured in Units ha^{-1} $year^{-1}$ = aguacate (*Persea americana*), mango (*Mangifera indica*), coco (*Cocus nucifera*), pera de agua (*Syzygium malaccense*), guayaba (*Psidium guajava*), sonzapote (*Licania platypus*), melocotón (*Averrhoa carambola*), guanábana (*Annona muricata*). Other fruits measured in kg ha^{-1} $year^{-1}$ = pejibaye (*Bactris gasipaes*), nancite (*Byrsonima crassifolia*) and jocote (*Spondias purpurea*)

CC cost in cash, *KC* cost in kind (mostly family labor, but also some inputs and materials obtained from the farm), *GI* gross income, *CF* net cash flow, *NI* net income, *VCD* money value of domestic consumption, *FB* family benefit, *VMP* standing timber volume, *ValMP* value of standing volume of timber, *VLP* value of standing firewood

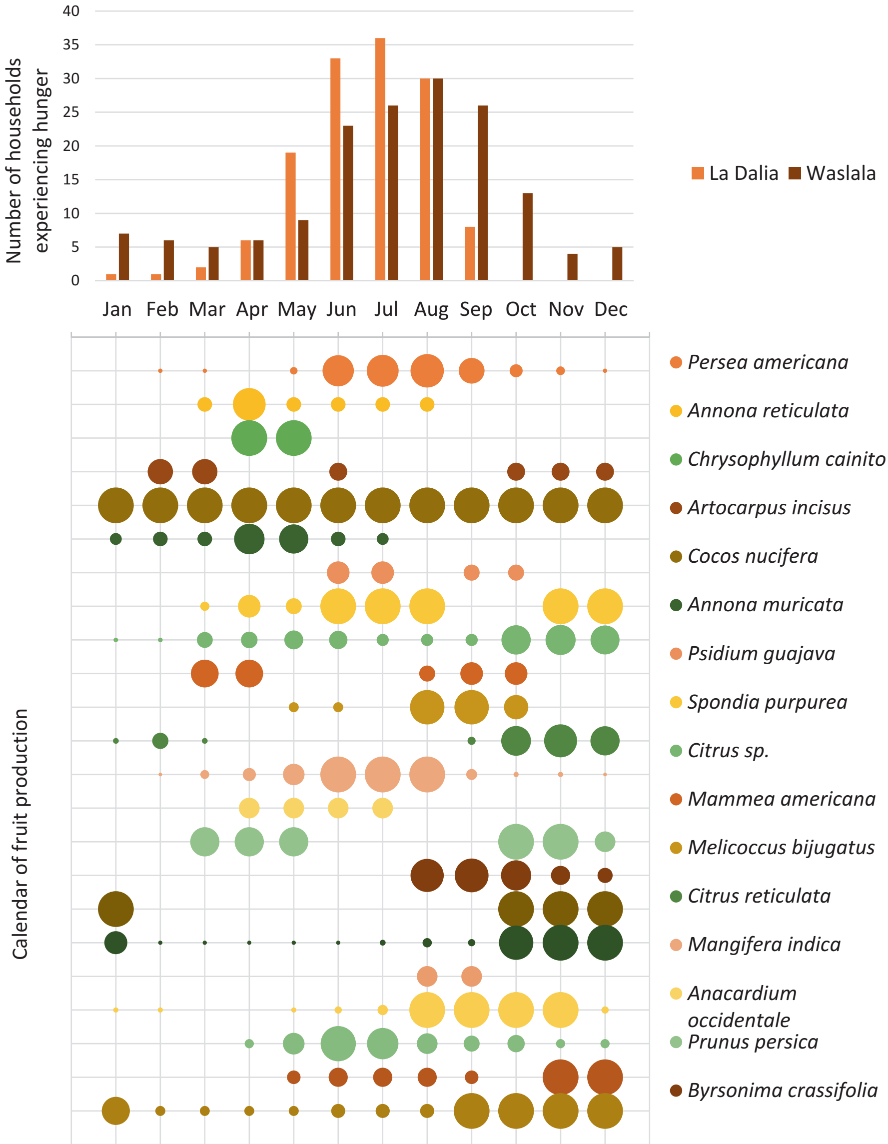

Fig. 15.3 Monthly food insecurity and availability of fruits from trees in small farms in the municipalities Tuma – La Dalia and Waslala. Nicaragua. Colors identify fruit tree species and circle size indicate the amount of fruit available in a given month

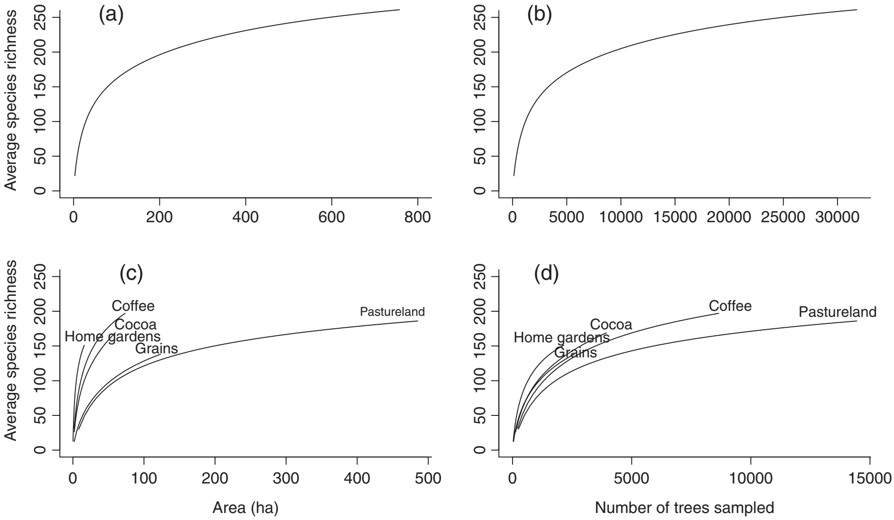

Fig. 15.4 Species accumulation curve for trees by farm (**a** and **b**) or by land use (**c** and **d**), based either on tree-counts (**b** and **d**) or in sampling area (**a** and **c**), in the municipalities of Tuma – La Dalia and Waslala. Nicaragua

3.3 Trees by Land Use: Stocking, Agroforestry Production, Financial Indicators and Species Richness

Tree stocking differed according to land use. Tree population density and basal area by land uses decreased in the following order: cocoa > coffee > grains > pastures > home gardens. For instance, tree population density (trees ha^{-1}) decreased from 138 trees ha^{-1} in coffee plantations to 31 trees ha^{-1} in grain fields (Table 15.3).

Production of fruits, standing timber and standing firewood were higher in shaded coffee plantations, followed by cocoa, pastures, grains and homegardens. Trees contributed more to on-farm consumption than to income generation. Overall family benefit derived from trees followed the same pattern of production: coffee > cocoa > pastures > grains > homegardens. In terms of cash flow, shaded coffee and homegardens were the only land uses with positive values. Tree production in all land uses presented negative net incomes (Table 15.3).

Tree botanical composition was rather similar among coffee, cacao, grains and pastures; however, homegardens had a distinct botanical composition, different from other land uses. TonF species richness per hectare followed the order: (coffee = cacao) > pastures > (grains = homegardens). The expected number of tree species in 1 ha of each land use varied between 10–30 species per hectare (Table 15.4). Rarefaction curves indicate that the sampling effort in this study does not capture total expected richness in homegardens, cocoa and coffee plantations (Fig. 15.4c, d).

Table 15.3 Trees on farms by land use: population density, basal area, agroforestry production and financial contribution

Variable	Cacao	Coffee	Basic grains	Pastures	Homegardens
Population density (trees ha^{-1})					
Total	108.8 ± 85.83 b	155.1 ± 87.01 a	37.66 ± 49.51 c	46.03 ± 29.24 c	183.64 ± 111.58 a
Fruits	36.59 ± 49.99 b	54.36 ± 55.83 b	6.76 ± 8.46 c	7.26 ± 10.06 c	114.55 ± 87.96 a
Firewood	29.66 ± 27.88 a	38.37 ± 21.44 a	8.87 ± 11.5 c	13.43 ± 11.3 c	35.05 ± 30.34 a
Timber	38.69 ± 35.7 b	55.19 ± 45.38 a	22.92 ± 34.24 c	23.21 ± 19.05 cd	34.98 ± 30.19 bc
Posts	3.81 ± 4.36 bc	5.97 ± 8.52 ab	2.02 ± 2.89 c	1.69 ± 2.64 c	9.29 ± 6.16 a
Service	5.0 ± 4.92 b	6.37 ± 7.53 b	2.46 ± 2.47 b	2.2 ± 2.85 b	20.1 ± 24.45 a
Basal area (m^2 ha^{-1})					
Total	5.57 ± 3.48 b	8.2 ± 4.17 a	2.15 ± 3.17 c	2.14 ± 1.33 c	6.99 ± 6.2 ab
Fruits	1.11 ± 1.69 b	1.41 ± 1.58 b	0.31 ± 0.36 b	0.25 ± 0.27 b	3.74 ± 4.47 a
Firewood	1.42 ± 0.96 a	1.8 ± 0.86 a	0.51 ± 0.65 b	0.58 ± 0.48 b	1.77 ± 2.04 a
Timber	2.81 ± 1.98 ab	3.77 ± 2.81 a	1.45 ± 2.45 cd	1.18 ± 0.87 d	2.02 ± 2.31 bc
Posts	0.54 ± 0.56 a	1.82 ± 4.25 a	0.46 ± 0.44 a	0.31 ± 0.44 a	0.74 ± 1.19 a
Service	0.59 ± 0.55 a	0.4 ± 0.39 abc	0.25 ± 0.2 bc	0.2 ± 0.32 c	0.45 ± 0.46 ab
Agroforestry production					
VMP (m^3 ha^{-1})	13.06 ± 9.89 a	17.07 ± 13.54 a	6.13 ± 10 b	5.0 ± 4.36 b	7.52 ± 9.31 b
Oranges (Units ha^{-1} year^{-1})	7578 ± 12,243 bc	10,970 ± 26,284 ab	2501 ± 4114 c	1060.7 ± 1155 c	14,255 ± 12,037 a
Mango (Units ha^{-1} year^{-1})	3997 ± 7914 abc	4768 ± 6768 ab	851 ± 935 bc	680 ± 1124 c	15,862 ± 17,643 a
Avocado (Units ha^{-1} year^{-1})	1609 ± 2044 b	1792 ± 2738 bc	849 ± 1211bc	328 ± 466 bc	5825 ± 4264 a
Other fruits1	4947 ± 8682 bc	6344 ± 7218 b	1000 ± 1567 c	1006.4 ± 1376 c	18,016 ± 18,806 a
Other fruits2	780.7 ± 1046 ab	477 ± 956 b	66.91 ± 50.04 b	144.74 ± 258 b	1224.6 ± 1577 a
Firewood (kg ha^{-1} year^{-1})	8063 ± 5740 a	10,891 ± 5778 a	2881 ± 4106 b	3616 ± 3367 b	11,187 ± 13,888 a

(continued)

Table 15.3 (continued)

Variable	Cacao	Coffee	Basic grains	Pastures	Homegardens
Financial indicators					
GI (USD ha^{-1} $year^{-1}$)	69.3 ± 74.36 b	78.25 ± 80.86 b	15.5 ± 8.84 b	9.13 ± 8.4 b	297.11 ± 281 a
CC (USD ha^{-1} $year^{-1}$)	49.69 ± 47.38 ab	48.55 ± 55.86 ab	26.37 ± 26.95 bc	12.12 ± 14.15 c	67.5 ± 109.47 a
KC (USD ha^{-1} $year^{-1}$)|	40.31 ± 57.04 b	37.76 ± 42.11 b	25.02 ± 68.22 b	7.64 ± 11.26 b	140.67 ± 240.59 a
CF (USD ha^{-1} $year^{-1}$)	−32.4 ± 41.93 b	13.34 ± 101.62 b	−22.5 ± 29.17 b	−10.5 ± 15.05 b	186.08 ± 295.68 a
NI (USD ha^{-1} $year^{-1}$)	−59.4 ± 55.44 a	−25.6 ± 95.6 a	−31.5 ± 68.29 a	−13.05 ± 15.86 a	−73.22 ± 307.81 a
VCD (USD ha^{-1} $year^{-1}$)	460.4 ± 580.68 b	384.1 ± 428.95 b	121.5 ± 162.54 b	83.46 ± 83.63 b	973.52 ± 1463.96 a
FB (USD ha^{-1} $year^{-1}$)	439.7 ± 577.33 b	394.1 ± 412.9 b	112 ± 146.96 b	77.83 ± 76.91 c	1024.3 ± 1453.33 a
ValMP (USD ha^{-1} $year^{-1}$)	4867 ± 3849.94 a	6576 ± 5210.05 a	2361 ± 3851.27 b	1924.7 ± 1683.87 b	2898.8 ± 3585.03 b
VLP (USD ha^{-1} $year^{-1}$)	564.4 ± 401.82 a	762.4 ± 404.49 a	201.7 ± 287.49 b	253.13 ± 235.73b	783.07 ± 972.16 a

Municipalities Tuma – La Dalia and Waslala, Nicaragua. 2015
Means (± standard deviation) with same letter along the row are statistically similar (LSD Fisher, $p < 0.05$). Other fruits1 (measured in Units ha^{-1} $year^{-1}$) = coco (*Cocus nucifera*), pera de agua (*Syzygium malaccense*), guayaba (*Psidium guajva*), sonzapote (*Licania platypus*), melocotón (*Averrhoa carambola*), guanábana (*Annona muricata*). Other fruits2 (measured in kg ha^{-1} $year^{-1}$) = pejibaye (*Bactris gasipaes*), nancite (*Byrsonima crassifolia*) and jocote (*Spondias purpurea*) *CC* cost in cash, *KC* cost in kind (mostly family labor), *GI* gross income, *CF* net cash flow, *NI* net income, *VCD* money value of domestic consumption, *FB* Family benefit, *VMP* standing timber volume, *ValMP* value of standing timber, *VLP* value of standing firewood, *USD* United States of America Dollars

Table 15.4 Trees on farm species diversity and carbon stock in aboveground biomass by land use types in the municipalities Tuma – La Dalia and Waslala, Nicaragua

Land use	Tree abundance	S_{obs}	S_{est}	Sampling effort (%)	S ha^{-1} ± standard deviation	Shannon	C (Mg ha^{-1})
Coffee	8656	197	275	72	30 ± 6	2.48 ± 0.45	19 (36%)
Cocoa	3942	169	267	63	28 ± 8	2.45 ± 0.66	13 (26%)
Pastures	14448	186	249	75	19 ± 7	1.75 ± 0.84	11 (22%)
Homegardens	2148	151	202	75	NA	0.55 ± 0.36	4 (8%)
Basic grains	2587	138	203	68	10 ± 6	1.04 ± 0.53	4 (7%)

Tree abundance, observed species richness (S_{obs}), jackknife estimated S (S_{est}), sampling effort based on observed and estimated S, observed species richness in 1 ha of transect-sampled farm land, Shannon diversity (± standard error), carbon stock in aboveground tree biomass (C), in parenthesis the percentage of total farm carbon stock in a given land use

3.4 Farm Typologies

Six farming system typologies (FS1–FS6), grouped in three broad farm types (T1–T3), were identified. Summaries of farm typologies were prepared using average values for all indicators and given a color scale from green to red (heath map) to show high and low values for each indicator (Table 15.5).

T1: Small diversified farms and cash crops (coffee or cacao): Characterized by small farms (0.6–10.3 ha, average ~2.6–3.5 ha), includes two sub-types:

1. ***S1: Small diversified farms***, mainly allocate land to the production of basic grains, but also include pastures and cash crops. They have high productivity of roots-tubers (*Manihot esculenta, Colocasia* and *Xanthosoma sagitifolium*) and bananas (8.6 Mg ha^{-1} $year^{-1}$), animal products (1.4 Mg ha^{-1} $year^{-1}$) and tree products such as citrus (~7300 unit ha^{-1} $year^{-1}$), fruits (~5200 units ha^{-1} $year^{-1}$ and 547 kg ha^{-1} $year^{-1}$, mainly peach palm), timber (5.1 m^3 ha^{-1}) and medium productivity of firewood (5.3 Mg ha^{-1}). These small farms with a very high density of shade of small trees (md = 114 tree ha^{-1}) and bananas in coffee and cocoa plots, have a high gross income per ha (1167 US$ ha^{-1} $year^{-1}$), but the lowest income per farm of all groups (1670 US$ $farm^{-1}$ $year^{-1}$), derived from various sources, and they have the lowest integration to markets of all groups. Tree diversity is medium (median = 34 species $farm^{-1}$) and tree C stocks per farm are low in dispersed trees (26 Mg $farm^{-1}$) and tree lines (28 Mg $farm^{-1}$) but on a per area basis, they are medium (14.3 Mg ha^{-1}).
2. ***FS2: farms that produce mainly cash crops (coffee or cacao) combined with basic grains*** with the highest productivity of basic grains (2.8 Mg ha^{-1} $year^{-1}$) and animal products (1.5 Mg ha^{-1} $year^{-1}$) and high productivity of cash crops (860 kg ha^{-1} $year^{-1}$). These farms have medium tree densities (85 tree ha^{-1}) for production of mainly timber (4.5 m^3 ha^{-1}), firewood (8.0 Mg ha^{-1}) and somewhat less for citrus (~3100 units ha^{-1}) and fruits (~2800 unit ha^{-1} and 239 kg ha^{-1}). These farms generate a medium-low income per farm (4668 US$ $farm^{-1}$ $year^{-1}$)

and the highest income per ha (1832 US$ ha^{-1} year^{-1}), derived mainly from basic grains and cash crops, and they have a medium market orientation. Dispersed tree species richness is medium (40 species farm^{-1}) and tree line plantations are almost absent. Given the small farm size, C stocks at the farm level are low (54.5 Mg farm^{-1}) but they are higher on a per area basis (18.1 Mg ha^{-1}).

Table 15.5 Mean values per farm typology for 37 farm-level indicators that spanned (1) farm size and distribution of land uses in the farm; (2) agricultural productivity; (3) financial productivity; (4) tree abundance and tree products; and (5) tree carbon (C) stocks and species diversity

Indicators	Small farms with cash crops, diversified				Medium farms with pastures, diversified				Farms with large tree stocks			
	FS1		FS2		FS3		FS4		FS5		FS6	
Farm size and Land Use	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
Total farm area (ha)	24	2.58	16	3.49	17	8.58	11	7.46	9	8.08	13	41.11
% area basic grains	19	0.40	7	0.46	14	0.23	11	0.44	5	0.13	7	0.14
% area homegarden	23	0.07	15	0.05	17	0.05	9	0.03	9	0.02	12	0.01
% area cocoa-coffee	18	0.27	16	0.55	11	0.19	4	0.10	9	0.59	8	0.07
% area pasture	11	0.38	5	0.34	16	0.59	8	0.46	7	0.28	13	0.68
% area forest	6	0.20	5	0.20	10	0.08	7	0.21	4	0.06	12	0.18
Agricultural productivity												
Total farm production (kg)	24	3466	16	8909	17	8399	11	7255	9	8929	13	20663
Staples and pulses (kg ha^{-1})	18	1791	7	2767	14	2331	11	2348	6	1354	7	1488
Root tubers and bananas (kg ha^{-1})	19	8665	14	4994	11	4713	4	2419	8	1656	9	4346
Cash crops (kg ha^{-1})	18	384	16	860	12	200	4	278	9	1122	8	416
Animal products (kg ha^{-1})	19	1402	11	1452	17	1103	10	671	9	936	13	669
Farm livestock (AU)	4	0.3	3	0.3	11	1.2	5	1.8	5	0.5	13	6.3
Farm poultry (heads)	19	17	12	27	17	28	7	21	8	15	12	30
Financial productivity												
Total farm income ($)	24	1670	16	4668	17	4716	11	5090	9	7070	13	16073
Farm income area ($ ha^{-1})	24	1167	16	1832	17	779	11	965	9	927	13	526
Proportion income staples and pulses	18	0.36	7	0.46	14	0.27	11	0.58	6	0.11	7	0.21
Proportion income root tuber and bananas	19	0.10	14	0.09	13	0.09	4	0.04	8	0.05	9	0.03
Proportion income cash crops	18	0.16	16	0.38	12	0.11	4	0.03	9	0.57	8	0.07
Proportion income tree products	24	0.29	16	0.22	17	0.18	11	0.13	9	0.18	13	0.12
Proportion income animal products	19	0.20	11	0.09	17	0.24	10	0.16	9	0.08	13	0.38
Proportion income poultry	19	0.04	11	0.03	17	0.03	7	0.02	8	0.01	12	0.01
Proportion income livestock	4	0.16	3	0.07	11	0.24	5	0.21	5	0.07	13	0.31
Market orientation	22	0.32	16	0.55	17	0.45	11	0.43	9	0.63	13	0.69
Tree abundance and productivity												
Farm basal area	24	7.8	16	11.5	17	22.4	11	6.3	9	42.5	13	47.1
Citrus (units ha^{-1})	21	7272	16	3118	17	1343	9	518	9	2462	13	606
Fruits (units ha^{-1})	24	5286	16	2838	17	1795	11	908	9	3263	13	577
Fruits (kg ha-1)	20	547	15	239	14	134	7	86	9	79	13	20
Firewood (kg ha^{-1})	24	5348	16	8019	17	5161	11	1709	9	10735	13	2685
Timber (m3 ha^{-1})	24	5.1	16	4.5	17	2.9	11	1.0	9	6.1	13	1.6
Tree diversity and C stocks												
Spp. Richness trees dispersed	24	34	16	40	17	50	11	29	9	58	13	75
Spp. Richness trees lines	20	9	4	5	17	9	10	11	9	13	13	16
Density dispersed trees (tree ha^{-1})	24	114	16	85	17	59	11	29	9	96	13	29
Farm C stocks dispersed trees (Mg)	24	26.4	16	54.5	17	114.0	11	36.2	9	179.5	13	352.2
C stocks dispersed trees (Mg ha^{-1})	24	14.3	16	18.1	17	13.1	11	4.5	9	25.3	13	10.9
Density tree lines (tree m^{-1})	20	0.18	4	0.17	17	0.27	10	0.26	9	0.23	13	0.23
Farm C stocks tree lines (Mg)	20	27.8	4	2.5	17	45.0	10	39.9	9	94.2	13	114.1
C stocks tree lines (Mg m^{-1})	20	0.052	4	0.024	17	0.039	10	0.062	9	0.099	13	0.040

T2: Medium diversified farms with pastures with low tree cover: Characterized by small-medium farms (1.4–27.2 ha) that combine the production of basic grains with pastures, includes two sub-types:

1. ***FS3: Small scale cattle ranching*** with an average farm size of 8.5 ha, main land use are pastures and small areas for basic grains and cash crops. They have high productivity of basic grains (2.3 Mg ha^{-1} $year^{-1}$) and animal products (1.1 Mg ha^{-1} $year^{-1}$). With medium market orientation, total gross income per farm (4716 US$ $farm^{-1}$ $year^{-1}$) and per ha (779 US $ ha^{-1} $year^{-1}$) is medium-low; mainly derived from staples (27%), livestock (24%), animal products (24%) and tree products (18%). Tree densities (59 tree ha^{-1}) as well as productivity of tree products are intermediate among all groups. Thanks to their larger size, tree diversity (50 species $farm^{-1}$) and C stocks both in dispersed trees (114 Mg $farm^{-1}$) and high density tree lines (45 Mg $farm^{-1}$) are higher than those of smaller farms.
2. ***FS4: medium farms with basic grains and pastures*** with average farm size of 7.5 ha, these farms have high productivity of basic grains (2.4 Mg ha^{-1} $year^{-1}$), but the lowest productivity in all other agricultural activities. These farms have similar number of animals as the small cattle ranching farms (0.15–6.1 Animal Units, AU) but productivity of animal products is low (0.7 Mg ha^{-1} $year^{-1}$). Income is intermediate on both per farm (5090 US$ $farm^{-1}$ $year^{-1}$) and area basis (965 US $ ha^{-1}). Tree cover (basal area = 6.3 m^2) is the lowest of all groups, and tree density is low (29 trees ha^{-1}) but similar to that in large cattle ranching farms. Consequently they also have the lowest productivity of tree products, the lowest tree diversity (median = 29 species $farm^{-1}$) and low C stocks (36.2 Mg $farm^{-1}$). Albeit the lower tree cover these farms do have some high density tree line plantings (0.26 tree m^{-1}), and tree C stocks on line plantations (40 Mg $farm^{-1}$) comparable to small scale cattle ranching.

T3: Farms with large tree stock: There are two groups with rather different strategies in terms of farm sizes and land use allocation that result in the highest tree diversity, highest tree stocks, and highest C stocks at the farm level):

1) ***FS5: medium sized farms*** (6–11.3 ha) ***almost exclusively for production of cash crops*** with the highest productivity of cash crops (1122 kg ha^{-1} $year^{-1}$). These farms mostly from La Dalia are market oriented, and cash crops (coffee) is the main income source (75%), generating the second highest income per farm (7070 US$ $farm^{-1}$ $year^{-1}$) after large farms, and with intermediate income per hectare (927 US$ ha^{-1} $year^{-1}$). High tree stocks composed of high density dispersed trees (96 tree ha^{-1}) and tree lines are translated into high productivity of citrus (~2462 units ha^{-1} $year^{-1}$), fruits (~3263 units ha^{-1} $year^{-1}$) timber (6.1 m^3 ha^{-1}) and particularly firewood (median ~11 Mg ha^{-1}). Tree diversity is high (58 species $farm^{-1}$) as well as C stocks both on a per farm (180 Mg C $farm^{-1}$) and per land area basis (25.3 Mg C ha^{-1}). A sizeable amount of C is also stored in tree line plantations (94 Mg C $farm^{-1}$).

2) ***FS6: large cattle ranches*** (16–102 ha) specialized on livestock production with extensive cattle ranching systems. These farms generate the highest total production (20.6 Mg farm^{-1} year^{-1}) and income per farm (~16,000 US $ year^{-1}, derived from livestock, animal products and basic grains), but productivity per land area is low (e.g. financial productivity 526 US$ ha^{-1} year$^{-1)}$. In these farms pasture land with low tree densities (median 29 tree ha^{-1}), and tree lines are the main contributors to high C stock per farm (352 Mg C farm^{-1} in dispersed trees and 114 Mg C farm^{-1}), but with low C stocks on a per area basis (10.9 Mg C ha^{-1}). These farms have the highest tree diversity (median 75 species farm^{-1}) but the lowest productivity of tree products: citrus (~606 units ha^{-1} year^{-1}), fruits (~577 units ha^{-1} year^{-1}), firewood (md ~ 2.7 Mg ha^{-1}) and timber (md = 1.6 m^3 ha^{-1}).

4 Discussion

4.1 Importance of Trees on Farms

This study demonstrates that TonF are important for livelihoods in terms of domestic consumption and overall family benefits, but not in generating net incomes or cash flow. In order to increase income and cash flow the sale of tree products should be increased and tree management should be optimized (Mallya 2013; Cerda et al. 2014; Pinoargote et al. 2016), especially in shaded coffee and in homegardens. Our study demonstrates that tree density in all land uses is high, but there is more room to increase tree density at the farm level, especially of those species which have an attractive market, e.g. high quality timber trees. Other studies conducted elsewhere in tropical regions have shown, for instance, that farmers with larger farms are willing to manage trees for timber production (Sebastian et al. 2014). More timber trees can be retained or planted in pastures, especially in linear plantings such as living fences, farm boundaries and along internal roads and paddock divisions (Plath et al. 2010; Esquivel et al. 2014).

Farmers produce timber even in small-scale fallows (Marquardt et al. 2013; Robiglio et al. 2013). Although we found a modest timber harvest ratio at the farm level (<1 trees ha^{-1} year^{-1}), we also found a considerable standing timber volume, which indicates that timber harvest could be improved in a sustainable way. Studies in Central America with naturally regenerated *Cordia alliodora* in cocoa plantations have shown that timber is accumulated at a rate of 1 m^3 ha^{-1} year^{-1} of total timber volume for every 1 m^2 ha^{-1} of basal area of the shade canopy, and at least 3 trees ha^{-1} year^{-1} are harvested in these agroforestry systems (Somarriba et al. 2014).

Land uses influenced most of the variables measured in this study. Although our results support previous studies in that the most complex systems (i.e. coffee plantations) have a higher tree contribution in terms of species diversity and tree products, we also show that simple systems such as basic grains and homegardens contain important tree resources. For instance, homegardens maintained high tree species diversity in spite of their small size: in homegardens almost each new individual recorded in our study belongs to a different species. At the landscape level, the five land use types complemented each other in their species composition, a pattern that has also been observed in other tropical regions (Kindt et al. 2004). Cocoa and coffee shade tree species composition were more similar among them, while at the same time they were very dissimilar to the other three land uses. Understanding how farm diversification and configuration (i.e. number of land uses by farm and farm area allocated to each land use) influence the abundance and botanical composition of trees on farm and their contributions to livelihoods and the environment, will help to design productive landscape that optimize food production and the provision of other ecosystem services.

The establishment of more trees in different land uses can also increase the fuelwood supply and avoid the extraction of wood from forests (Ndayambaje et al. 2013). Most on-farm production of fruits is lost due to poor market development (Almendarez et al. 2013); home consumption of fruits and other edible products from woody species is critical for food security, as has been shown in many agroecological zones e.g. in dryland Africa (Kehlenbeck and McMullin 2015; Agúndez et al. 2016). To increase fruit sales, farmers should identify the most suitable and valuable fruit tree species, use asexual propagation techniques to ensure the reproduction of high quality trees, and identify good markets (Roshetko 2013). Fruit and timber trees are usually in high demand by farmers when asked about their preferences to plant trees in their farms (Orozco et al. 2008). In the case of fruit trees, increased emphasis should be placed on tree domestication strategies, product development, trading and marketing (Chifamba 2011). Development programs should try to promote tree planting on farms in order to reduce vulnerability by enabling lower income farmers to gain disposable assets they can use to meet contingencies (Chambers and Leach 1987).

Trees on farms are a sound strategy to sequester and store carbon in wood biomass. In our study the median of carbon stock was around 167 Mg C farm^{-1}, about 20 Mg C ha^{-1}, which is consistent when compared with specific land uses such as shaded coffee (Pinoargote et al. 2016), but lower than cocoa plantations in the same study area (Somarriba et al. 2013). Our results are similar to carbon stocks found in farms in Kenya (Henry et al. 2009; Kuyah et al. 2016a). TonF have the potential to contribute to global strategies to mitigate climate change, in comparison to schemes involving forest-based emissions mitigation (REDD), Reducing Emissions from All Land Uses (REALU), using more effective, efficient and equitable management approaches (Dogra 2011; Schnell et al. 2015b). However, small farm sizes require several farmers to organize in cooperatives or similar organizations to trade significant quantities of carbon and to be able to pay all transaction costs (Henry et al. 2009).

Despite the demonstrated contributions of TonF to domestic consumption, modest income generation, reduction of vulnerability to contingencies, conservation of tree biodiversity and carbon sequestration, more efforts are needed to promote the establishment of trees at the farm level (Lovell et al. 2010). The potential role of incentives such as payments for ecosystem services (Rudel et al. 2016), and the creation of conditions to increase the net incomes and cash flow in smallholder farm economies need to be assessed and promoted (Etongo et al. 2015). Providing farmers with sound technical advice on TonF silviculture and farmer managed regeneration may also increase the role of trees on farmers' livelihoods (Regmi and Garforth 2010; Oeba et al. 2012; Iiyama et al. 2017). Econometric studies show that the decision to grow trees is not necessarily the same as deciding the number of trees grown. Land certification, as an indicator of tenure security, increases the likelihood that households will grow trees, but is not a significant determinant of the number of trees grown. Other variables, such as risk aversion, land size, adult labor availability, and education of household head, also influence the number of trees grown (Mekonnen and Damte 2011).

4.2 Farm Typologies Influence the Contribution of TonF to Livelihoods

Farm typologies reflected well the main farming systems in the study area, when farms have a main production strategy (e.g. basic grains, coffee-cocoa as a cash crop, or pastures) but this does not hinder a high degree of diversification with various land uses in one farm. Tree cover in absolute terms was related to farm size (more clearly seen at the extremes of land sizes) but not unequivocally. Studies in temperate zones show that tree habitats on farms are dependent of farm size and biophysical conditions (Lovell et al. 2010). In parkland systems in Burkina Faso, land use and farming system strongly influence tree diversity and management (Bayala et al. 2011). Similar results have been observed in farms in Ethiopia (Mengistu and Hager 2010), and in Benin, West Africa, with tree density and diversity being inversely correlated with farm size (Fifanou et al. 2011). Studies in various countries in Africa show that farmers know what trees they want and they have specific purposes for trees within their farming system. For example, fuelwood trees are not the first choice of farmers, while they are more interested in planting fruit and/or multipurpose trees that produce poles, construction material, and perhaps fodder. The planting of trees by farmers appears also to be dependent on the wood resources available to the household: when population density is low and there is access to forest or woodland, there is not a strong incentive for the planting of trees on farms. Other factors may explain where in the farm, farmers are willing to plant trees. For example, farmers plant fruit trees in the homegarden in response to either concern about livestock grazing or fear of fire in the fallow fields (Warner 1993).

In this Chapter, the three broad farm types illustrated how farm outcomes depend on the combination of land availability, land use allocation, and management. The best results in terms of tree cover, C stocks and tree diversity were obtained in medium (minimum of 6 ha) and large farms, but with very different strategies. In medium farms the specialization towards coffee-cocoa systems with a high density of useful trees was translated into high tree cover, C stocks, diversity and tree products on both per ha and per farm basis. On the other hand, large farms with extensive cattle ranching had the lowest tree cover per ha but the highest tree C stocks and diversity at the farm level thanks to their large land areas. Very small farms have the most intensified production per unit land for crops, tree products and economic output. Still given their limited land availability, the total production per farm was low, as well as tree stocks and diversity. Medium size farms that produce basic grains and pastures have the most suboptimal performance both in crop and tree products productivity. In some cases, these medium farms have comparable or lower tree cover and C stocks than very small farms. It is important to assess the factors that underlie the suboptimal performance in these medium size farms to identify entry points for improvement.

The patterns observed in farm typologies also have implications to discuss entry points for interventions at the landscape level that aim to maintain or increase tree cover and its related services and products (Welsch et al. 2014). Very small (FS1, FS2) and medium farms with high tree cover of useful trees (FS5) are certainly hotspots for tree cover and diversity at the landscape scale, but perhaps there is a limited scope to increase tree cover and C stocks at landscape scales. For instance in many cases the limits for tree cover (shade) have already been reached and it might be difficult to extend forest areas due to constraints in management, labor and capital (medium farms) and land for the very small landholdings. In these systems increasing diversity and tree productivity is likely related to introduction and replacement of some tree species, and improved management of the existing shade. The largest scope for improvement in terms of absolute increases in tree cover, C stocks and diversity at the landscape scale seems more effective in medium size farms with suboptimal management (FS3, FS4) and large farms with extensive cattle ranching (FS6). Given the low tree cover in these farms, and their large areas, modest increases can have profound impacts at the landscape scale. Moreover it is clear that the suboptimal management and little selection of useful trees can be optimized to increase productivity of tree products.

4.3 Methods for Assessing TonF

Assessing trees outside the forests (TonF are just one example of these) has been limited by the lack of appropriate classification systems and the complex nature of the resource which involves consideration of both tree cover (on which the definition of forest is based along with plot size) and land use (Kleinn 2000). Fortunately, recent studies have provided a sound classificatory framework for classifying trees outside the forest (De Foresta et al. 2013). At local scales, this classificatory scheme has proven to be effective (Schnell et al. 2015a), however, time- and cost-efficient methods for large scale assessments of trees on farms (and other types of trees outside the forests) have yet to be developed (Kleinn 2000; Schnell et al. 2015b).

For future monitoring of the tree cover and biomass, the combination of field surveys and remote sensing appear to be the most promising (Schnell et al. 2015b). Several research studies using remote sensing for monitoring TonF have been conducted recently, but very few include comparative studies to optimize sampling strategies for TonF. Methods combining remote sensing and field surveys appear to be very favorable (Liknes et al. 2010), especially when remote sensing techniques that assess both the horizontal and vertical structures of tree resources are applied. For example, two-phase sampling strategies with laser scanning in the first phase and a field survey in the second phase appear to be effective for assessing TonF resources (Kleinn 2000; Kleinn et al. 2005). However, TonFs often exhibit different characteristics than forest trees. Thus, to improve TonF monitoring, there is often a need to develop models, e.g. for biomass assessment, that are specifically adapted to this tree resource (Schnell et al. 2015a; Kuyah et al. 2016a).

Our study highlights the importance of the analysis of economic indicators suitable for rural families, such as the value of domestic consumption and family benefit, not only the evaluation of net income. The promotion and management of trees on farms must be based in balancing synergies and tradeoffs (e.g. between provisioning and regulatory ecosystem services), and private and social net benefits (Tisdell 1985; Ndayambaje et al. 2013; Esquivel et al. 2014). Strategies to encourage smallholder farmers to increase the use of trees on their farms have to account for the farmers' ecological and socioeconomic conditions (Kuyah et al. 2016b), market prices for tree products (Godoy 1992), and knowledge on sound management practices. For instance, pastures containing the right combination of tree species can produce a temporal pattern of fruit and fodder availability to livestock during the dry season, but care must be taken to avoid excessive shading that reduces pasture productivity (Ango et al. 2014).

5 Conclusions and Recommendations

The evidence presented in this chapter demonstrates that trees on farms (TonF) are frequent, abundant and very important for rural livelihoods and for the environment. However, in spite of their importance and widespread presence in all farms around the world, trees on farms are invisible in global agendas (such as REDD+, FAO/FRA, UN conventions on biological diversity and on water, sustainable development goals) and in national agendas (such as legal, institutional, policy and development frameworks affecting TonF in sustainable rural development). For instance, TonF are not adequately represented in most forestry legislation and in institutional structures related to forestry and agricultural resources. They are noticeably absent in policies and public and private programs, in university and technical education plans, in training of technical extension providers to farms, and in farmer field school programs and other models of education for producing families in rural environments. Even worse, trees on farms are regulated as if they were trees in the forest, resulting in over-regulation and control (Van Leeuwen and Hofstede 1995), cumbersome bureaucracy, high transaction costs, illegality, low prices, high risks and underutilization of the resource (Sibale et al. 2013).

The lack of an enabling environment for the promotion of TonF is due to:

- lack of quantitative data on stocks and costs at scales meaningful for policymakers
- gaps in knowledge of drivers and processes influencing the presence, management and use of trees on farms
- lack of tools to assess tree-based interventions
- lack of effective communication and concerted actions among key stakeholders to achieve change.

To achieve changes in national policies and regulations, it is necessary to work with stakeholders influential in policy formulation and implementation, such as national and subnational government institutions, the Ministries of Environment, Agriculture and Forestry, NGOs working on land-use planning and development programs based on agroforestry interventions; representatives of the agricultural subsectors (coffee, cocoa, livestock, maize, beans), and all value-chain actors, farmer organizations (van Leeuwen and Hofstede 1995) and the donor community. A small set of key, immediate actions can be recommended:

1. Elevate the visibility of trees on farms in key groups at global and national levels.
2. Promote an important cultural change in farmers and ranchers: the "tree on the farm" as a crop and not as something provided by nature that needs no management.
3. Demonstrate that trees on the farm have a valuable place in the current era of intensification of agriculture and livestock, which normally leads to elimination of trees in agricultural fields and pastures.
4. Improve the legal and institutional framework of the trees on farms and include it in public policies and programs of promotion and support. Experiences from different countries should be collated, analyzed and used to develop broad recommendations applicable in a wide range of socio-cultural and economic conditions.

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References

Agúndez D, Douma S, Madrigal J, Gómez-Ramos A, Vinceti B, Alía R, Mahamane A (2016) Conservation of food tree species in Niger: towards a participatory approach in rural communities. For Syst 25(3). https://doi.org/10.5424/fs/2016253-09558

Almendarez E, Orozco L, López A (2013) Existencias de especies maderables y frutales en fincas de Waslala, Nicaragua. Agroforestería en las Américas 49:68–77

Amores F (2016) Contribución de los árboles en finca a los medios de vida rurales en dos sitios constrastantes de Nicaragua. Tesis Master. CATIE, Turrialba. http://repositorio.bibliotecaorton.catie.ac.cr:8080/handle/11554/8278

Ango T, Börjeson L, Senbeta F, Hylander K (2014) Balancing ecosystem services and disservices: smallholder farmers' use and management of forest and trees in an agricultural landscape in southwestern Ethiopia. Ecol Soc 19(1):16

Ayestas E (2013) Caracterización de árboles promisorios de cacao en fincas orgánicas de Waslala, Nicaragua. Agroforestería en las Américas 49:18–25

Bayala J, Kindt R, Belem M, Kalinganire A (2011) Factors affecting the dynamics of tree diversity in agroforestry parklands of cereal and cotton farming systems in Burkina Faso. New For 41(3):281–296. https://doi.org/10.1007/s11056-010-9222-z

Caicedo Alban JW (2016) Diversidad y almacenamiento de carbono, en dos sitios con diferente grado de intensificación de uso de suelo de Nicaragua. Tesis MSc. CATIE, Turrialba, 102 p

Cairns M (2007) Voices from the forest: integrating indigenous knowledge into sustainable upland farming. Earthscan, London. 826 p

Cerda R, Deheuvels O, Calvache D, Niehaus L, Saenz Y, Kent J, Vilchez S, Villota A, Martinez C, Somarriba E (2014) Contribution of cocoa agroforestry systems to family income and domestic consumption: looking toward intensification. Agrofor Syst 88(6):957–981

Cerdán CR, Rebolledo MC, Soto G, Rapidel B, Sinclair FL (2012) Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. Agric Syst 110:119–130

Chacon León C, Harvey CA (2008) Contribuciones de las cercas vivas a la estructura y conectividad de un paisaje fragmentado en Rio Frio, Costa Rica. In: Harvey CA, Sáenz JC (eds) Evaluación y conservación de biodiversidad en paisajes fragmentados de Mesoamérica. Editorial INBIO, Heredia, pp 225–248

Chambers R, Leach M (1987) Trees to meet contingencies: savings and security for the rural poor. Overseas Development Institute, Social Forestry Network, Network Paper 5a. London, 32 p

Chambers R, Leach M (1989) Trees as savings and security for the rural poor. World Dev 17(3):329–342

Chifamba E (2011) Cultivation and commercialisation of indigenous fruit trees to improve household food security in dry regions of Buhera Zimbabwe. J Sustain Dev Afr 13(5):95–108

Dávila K, Caldera EC, Laguna JC (2017) Una mirada histórica del desarrollo agro-educativo del Municipio El Tuma – La Dalia, Matagalpa Revista Científica de FAREM-Estelí. Medio ambiente, tecnología y desarrollo humano Año 6/N° 21:81–98

De Foresta H, Somarriba E, Temu A, Boulanger D, Feuilly H, Gauthier M (2013) Towards the assessment of trees outside forests. FAO Forestry Paper 164, FAO, Rome

de Sousa KFD, Detlefsen G, de Melo Virginio Filho E, Tobar D, Casanoves F (2016) Timber yield from smallholder agroforestry systems in Nicaragua and Honduras. Agrofor Syst 90(2):207–218. https://doi.org/10.1007/s10457-015-9846-2

DeClerck FA, Chazdon R, Holl KD, Milder JC, Finegan B, Martinez-Salina A, Imbach P, Canet L, Ramos Z (2010) Biodiversity conservation in human-modified landscapes of Mesoamerica: Past, present and future. Biol Conserv 143(10):2301–2313

Di Rienzo JA, Casanoves F, Balzarini MG, Gonzalez L, Tablada M, Robledo CW (2011) (InfoStat.). versión 24–03–2011 edn. Universidad Nacional de Córdoba, Córdoba, Argentina. http://www.infostat.com.ar/

Dogra AS (2011) Contribution of trees outside forests toward wood production and environmental amelioration. Indian J Ecol 38:1–5

Esquivel H, Ibrahim M, Harvey CA, Benjamin T, Sinclair FL (2014) Pod availability, yield and nutritional characteristics from four fruit bearing tree species dispersed in pastures as a complementary feed for animal production in the dry tropics. Livest Res Rural Dev 26(9):1–10

Etongo D, Djenontin I, Kanninen M, Fobissie K (2015) Smallholders' tree planting activity in the Ziro Province, Southern Burkina Faso: impacts on livelihood and policy implications. Forests 6(8):2655–2677. https://doi.org/10.3390/f6082655

FAO (2016) The state of food and agriculture-addressing: climate change, agriculture and food security 2016. FAO, Rome. 174 p

Mengistu F, Hager H (2010) Integration of indigenous wild woody perennial edible fruit bearing species in the agricultural landscapes of Amhara region, Ethiopia. Agrofor Syst 78(1):79–95. https://doi.org/10.1007/s10457-009-9239-5

Fifanou VG, Ousmane C, Gauthier B, Brice S (2011) Traditional agroforestry systems and biodiversity conservation in Benin (West Africa). Agrofor Syst 82:1–13. https://doi.org/10.1007/s10457-011-9377-4

Godoy RA (1992) Determinants of smallholder commercial tree cultivation. World Dev 20(5):713–725

Haglund E, Ndjeunga J, Snook L, Pasternak D (2011) Dry land tree management for improved household livelihoods: Farmer managed natural regeneration in Niger. J Environ Manag 92:1696–1705

Harvey CA, Haber WA (1999) Remnant trees and the conservation of biodiversity in Costa Rican pastures. Agrofor Syst 44:37–68

Harvey CA, Komar O, Chazdon R, Ferguson BG, Finegan B, Griffith DM, Martinez-Ramos M, Morales H, Nigh R, Soto-Pinto L, Van Breugel M, Wishnie M (2008) Integrating agricultural landscapes with biodiversity conservation in the Mesoamerican hotspot. Conserv Biol 22(1):8–15. https://doi.org/10.1111/j.1523-1739.2007.00863.x

Henry M, Tittonell P, Manlay RJ, Bernoux M, Albrecht A, Vanlauwe B (2009) Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. Agric Ecosyst Environ 129:238–252

Iiyama M, Neufeldt H, Dobie P, Njenga M, Ndegwa G, Jamnadass R (2014) The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. Curr Opin Environ Sustain 6:138–147. https://doi.org/10.1016/j.cosust.2013.12.003

Iiyama M, Derero AH, Kelemu K, Muthuri C, Kinuthia R, Ayenkulu E, Kiptot E, Hadgu K, Mowo J, Sinclair FL (2017) Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia. Agrofor Syst 91(2):271–293. https://doi.org/10.1007/s10457-016-9926-y

Imbach A (1987) Análisis económico y financiero de fincas pequeñas con sistemas mixtos de Producción: metodología y estudio de caso en fincas de Jocoro, El Salvador. CATIE, Turrialba. 72 p

Jiménez G (2012) Producción de madera y almacenamiento de carbono en cafetales con cedro (Cedrela odorata) y caoba (Swietenia macrophylla) en Honduras. Tesis MSc. CATIE, Turrialba. 122 p

Kehlenbeck K, McMullin S (2015) Fruit tree portfolios for improved diets and nutrition in Machakos County, Kenya. World Agroforestry Centre (ICRAF), Nairobi. 16 p

Kindt R, Simons AJ, Van Damme P (2004) Do farm characteristics explain differences in tree species diversity among Western Kenyan farms? Agrofor Syst 63:63–74

Kleinn C (2000) On large-area inventory and assessment of trees outside forests. Unasylva 200(51):3–10

Kleinn C, Ramírez C, Holmgren P, Valverde SL, Chavez G (2005) A national forest resources assessment for Costa Rica based on low intensity sampling. For Ecol Manag 210(1):9–23

Kuyah S, Mbow C, Sileshi GW, van Noordwijk M, Tully KL, Rosenstock TS (2016a) Quantifying tree biomass carbon stocks and fluxes in agricultural landscapes. Chapter 6. In: Rosenstock TS, Rufino MC, Butterbach-Bahl K, Wollenberg E, Richards M (eds) Methods for measuring greenhouse gas balances and evaluating mitigation options in smallholder agriculture. Springer, Cham, pp 119–134

Kuyah S et al (2016b) Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa. Int J Biodivers Sci Ecosyst Serv Manag:1–19. https://doi.org/10.1080/21513732.2016.1214178

Laderach P, Lundy M, Jarvis A, Ramirez J, Portilla EP, Schepp K, Eitzinger A (2011) Predicted impact of climate change on coffee supply chains. Springer, Berlin/Heidelberg, pp 703–723. https://doi.org/10.1007/978-3-642-14776-0_42

Leguía E, Rapidel B, Somarriba E, Ordoñez J (2014) Resumen linea de base CCAFS a nivel de hogar en Nicaragua y Honduras. Tesis, CATIE, Turrialba

Liknes GC, Perry CH, Meneguzzo DM (2010) Assessing tree cover in agricultural landscapes using high-resolution aerial imagery. J Terrestrial Obs 2(1):38–55
Lovell ST, Mendez VE, Erickson DL, Nathan C, DeSantis S (2010) Extent, pattern, and multifunctionality of treed habitats on farms in Vermont, USA. Agrofor Syst 80:153–171. https://doi.org/10.1007/s10457-010-9328-5
Lowder SK, Skoet J, Singh S (2014) What do we really know about the number and distribution of farms and family farms worldwide? Background paper for The State of Food and Agriculture 2014. ESA Working Paper No. 14-02. FAO, Rome
Magurran AE, McGill BJ (2011) Biological diversity: frontiers in measurement and assessment. Oxford University Press, Oxford. 344 p
Mallya BS (2013) Contribution of on-farm trees towards conservation of the biodiversity of Amani Nature Reserve, Tanzania. MSc. thesis, University of Agriculture, Morogoro, Tanzania. 105 p
Marquardt K, Milestad R, Salomonsson L (2013) Improved fallows: a case study of an adaptive response in Amazonian swidden farming systems. Agric Hum Values 30(3):417–428. https://doi.org/10.1007/s10460-012-9415-5
Mekonnen A, Damte A (2011) Private trees as household assets and determinants of tree-growing behavior in rural Ethiopia. Environment for Development (EfD), Discussion Paper Series, DP 11-14. 29 p
Ndayambaje JD, Mugiraneza T, Mohren GMJ (2013) Woody biomass on farms and in the landscapes of Rwanda. Agrofor Syst 88(1):101–124. https://doi.org/10.1007/s10457-013-9659-0
Oblitas S (2016) Intensidad agroecológica en fincas agropecuarias en dos sitios socioeconómicamente contrastante en Nicaragua. Tesis Master. CATIE, Turrialba. http://repositorio.bibliotecaorton.catie.ac.cr:8080/handle/11554/8278
Oeba VO, Otor CJ, Kung'u JB, Muchiri MN (2012) Modeling determinants of tree planting and retention on farm for improvement of forest cover in Central Kenya. International Scholarly Research Notices 2012,14 p
Orozco L, López A, Somarriba E (2008) Enriquecimiento de fincas cacaoteras con frutales y maderables en Alto Beni, Bolivia. Agroforestería en las Américas 46:65–72
PDTW (2014) Plan de desarrollo territorial del municipio de Waslala 2014–2034. https://www.avsf.org/public/posts/1703/plan-de-desarrollo-territorial-waslala_avsf_2014.pdf
Perry CH, Woodall CW, Liknes GC, Schoeneberger MM (2009) Filling the gap: improving estimates of working tree resources in agricultural landscapes. Agrofor Syst 75:91–101. https://doi.org/10.1007/s10457-008-9125-6
Pinoargote M, Cerda R, Mercado L, Aguilar A, Barrios M, Somarriba E (2016) Carbon stocks, net cash flow and family benefits from four small coffee plantation types in Nicaragua. For Trees Livelihoods 1-16. https://doi.org/10.1080/14728028.2016.1268544
Plath M, Mody K, Potvin C, Dorn S (2010) Do multipurpose companion trees affect high value timber trees in a silvopastoral plantation system? Agrofor Syst 81(1):79–92. https://doi.org/10.1007/s10457-010-9308-9
Quandt A (2016) Farmers and forest conservation: how might land sparing work in practice? Soc Nat Resour 29(4):418–431. https://doi.org/10.1080/08941920.2015.1095381
Ramirez O, Somarriba E, Ludewigs T, Ferreira P (2001) Financial returns, stability and risk of cacao-plantain-timber agroforestry systems in Central America. Agrofor Syst 51(2):141–154
Regmi B, Garforth C (2010) Trees outside forests and rural livelihoods: a study of Chitwan District, Nepal. Agrofor Syst 79(3):393–407. https://doi.org/10.1007/s10457-010-9292-0
Robiglio V, Lescuyer G, Cerutti P (2013) From farmers to loggers: the role of shifting cultivation landscapes in timber production in Cameroon. Small-scale For 12(1):67–85
Roshetko JM (2013) Smallholder tree farming systems for livelihood enhancement and carbon storage. Ph.D thesis, Department of Geosciences and Natural Resource Management, University of Copenhagen, Frederiksberg. 94 p
Rudel T, Sloan S, Chazdon R, Grau R (2016) The drivers of tree cover expansion: global, temperate, and tropical zone analyses. Land Use Policy 58:502–513. https://doi.org/10.1016/j.landusepol.2016.08.024

Schnell S, Altrell D, Stahl G, Kleinn C (2015a) The contribution of trees outside forests to national tree biomass and carbon stocks – a comparative study across three continents. Environ Monit Assess 187(1):4197

Schnell S, Kleinn C, Stahl G (2015b) Monitoring trees outside forests: a review. Environ Monit Assess 187(9):600

Sebastian G, Kanowski P, Race D, Williams E, Roshetko J (2014) Household and farm attributes affecting adoption of smallholder timber management practices by tree growers in Gunungkidul Region, Indonesia. Agrofor Syst 88(2):257–268. https://doi.org/10.1007/s10457-014-9673-x

Sibale B, Kafakoma R, Shaba A, Macqueen D (2013) Trees on-farm: removing the obstacles to enterprise: a review of current climate-smart tree-based experiences in Malawi. International Institute for Environment and Development (IIED), London

Sloan S, Sayer JA (2015) Forest resources assessment of 2015 shows positive global trends but forest loss and degradation persist in poor tropical countries. For Ecol Manag 352:134–145

Smeets EMW, Faaij APC (2007) Bioenergy potentials from forestry in 2050. Clim Chang 81(3):353–390. https://doi.org/10.1007/s10584-006-9163-x

Somarriba E (2012) The population dynamics and productivity of Acacia pennatula in the pasturelands of the Nature Reserve Mesas de Moropotente, Estelí, Nicaragua. Agrofor Syst 84(1):1–9. https://doi.org/10.1007/s10457-011-9447-7

Somarriba E, Beer J (2011) Productivity of Theobroma cacao agroforestry systems with timber or legume service shade trees. Agrofor Syst 81(2):109–121

Somarriba E, Cerda R, Orozco L, Cifuentes M, Dávila H, Espin T, Mavisoy H, Ávila G, Alvarado E, Poveda V (2013) Carbon stocks and cocoa yields in agroforestry systems of Central America. Agric Ecosyst Environ 173:46–57

Somarriba E, Suárez-Islas A, Calero-Borge W, Villota A, Castillo C, Vílchez S, Deheuvels O, Cerda R (2014) Cocoa–timber agroforestry systems: Theobroma cacao–Cordia alliodora in Central America. Agrofor Syst 88(6):1001–1019

Somarriba E, Sepúlveda N, Ayerdis JR, Cornelius J, Retamal R (2016) Frutales y maderables en patios y fincas de la zona de Los Pueblos, Nicaragua Serie Técnica. Informe Técnico 404:70, CATIE, Turrialba

Tisdell CA (1985) Conserving and planting trees on farms: lesssons from Australia cases. Rev Mark Agric Econ 53(3):185–194

Vaast P, Somarriba E (2014) Trade-offs between crop intensification and ecosystem services: the role of agroforestry in cocoa cultivation. Agrofor Syst 88(6):947–956

Van Leeuwen ACJ, Hofstede AM (1995) Forests, trees and farming in the Atlantic zone of Costa Rica. An evaluation of the current and future integration of trees and forests in farming systems in the Atlantic Zone of Costa Rica. CATIE, Serie Técnica Informe Técnico 257. Turrialba. 73 p

Warner K (1993) Patterns of farmer tree growing in Eastern Africa: a socioeconomic analysis. Oxford Forestry Institute, Tropical Forestry Papers 27. Oxford. 284 p

Welsch J, Case BS, Bigsby H (2014) Trees on farms: Investigating and mapping woody re-vegetation potential in an intensely-farmed agricultural landscape. Agric Ecosyst Environ 183:93–192

Zomer RJ, Trabucco A, Coe R, Place F (2009) Trees on farm: analysis of global extent and geographical patterns of agroforestry. ICRAF Working Paper no. 89. World Agroforestry Centre, Nairobi

Zomer R, Coe R, Place F, van Noordwijk M, Xu J (2014) Trees on farms: an update and reanalysis of agroforestry's global extent and socio-ecological characteristics. Working Paper 179. World Agroforestry Centre (ICRAF) Southeast Asia Regional Program Bogor, Indonesia. https://doi.org/10.5716/WP14064.PDF