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RESEARCH PAPER

Tree Quality in Agroforestry Systems Managed by Small-Scale Mayan Farmers in Chiapas, Mexico

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Abstract Increasingly, plantations for food, fiber and wood, are necessary to provide a growing world population. Agroforestry systems become more and more important, however these systems usually develop in marginal conditions, limited land, restricted funding, occasional technical support and above this, there is limited documentation and evaluation of innovated traditional systems in indigenous and small-scale contexts, which challenge forest scientists. The aim of this research was to assess the quality of trees in plots managed by Mayan indigenous farmers who planted agroforestry systems with fine wood species to increase the value of land and labor in localities with highly-marginal social conditions in Northern Chiapas, México. Twenty oldest plots were selected within a group of previously established plots (eight with improved fallow, six with shaded coffee and six with maize crop associated to trees) where forest inventories were carried out in nested 100 and 1000 m^2-circular plots. In all plots tree diameter, height, quality indicators and the incidence of the pest *Hypsipyla grandella* were measured. Trees in the maize-associated-to-trees system are favored by the practices applied to annual crop during the first 3rd–5th years, a period in which they are free from the interference of other trees and benefit from favorable light conditions, weeding and a higher intensive care from the farmer while shaded coffee and improved fallow have higher tree densities and a more closed canopy condition than maize associated to trees. In consequence, maize associated to trees shows 68.1 % stems with good form; shaded coffee and improved fallow averaged 40.5 and 39.7 % of good quality stems, respectively; improved fallow exhibited a greater number of suppressed trees than

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shaded coffee and maize associated to trees ($p < 0.0001$). In addition, maize associated to trees showed the highest proportion of trees with commercial value with 56.9 %, followed by improved fallow with 28.2 %, and shaded coffee with 11.8 % ($p < 0.0001$); the rest were trees with domestic uses. However, maize associated to trees significantly result with high incidence of *H. grandella* probably due to the crown exposure. Timber volume averaged 92.9 ± 68.9 m^3 for improved fallow, 77.3 ± 24.8 m^3 for shaded coffee, and 52.5 ± 39.7 m^3 for maize associated to trees. The value of the fine wood represents increment in income, variety of products and self-employment for households. Nonetheless, improved fallow and coffee plantations might benefit from the elimination of competitors from larger trees to favor promising immature ones and pruning, while maize crop associated to trees might benefit from opportune pruning for controlling the stem borer as well as tree replacement to achieve long term replacement and harvesting.

Keywords *Acahual* · Community forestry · Improved fallow · *Ixim'te* · *Milpa* · Shaded coffee

Introduction

Agroforestry is practiced for the purposes of reforestation, natural resource conservation and productive diversification. Combining multipurpose trees with crops and/or animals in agroforestry systems can simultaneously produce food, goods and services, helping to diminish deforestation in adjacent areas (Tschakert et al. 2007; Kalame et al. 2011).

According to the FAO (2014), approximately one-third of the world's population, and a higher proportion of the poorer people rely on wood for fuelwood, timber and other domestic purposes. In this context, wood from agroforestry systems represents a strategic opportunity for small-scale farmers to produce timber for self-supply and for regional or global market besides producing food (De Sousa et al. 2015). However, tree performance and forest product quality under different small-scale management strategies have been little studied (Guariguata and Sáenz 2002; Baynes et al. 2015).

It is expected that agroforestry systems yield high quality products. In timber, for example, one anticipates straight stems, clean, unbroken logs without damage and predictable tree diameter and height averages over time. Whether the timber is for domestic or commercial use, these attributes are important for transformation into secondary and high-value products. However, this is dependent upon the features of the species as well as the relationship between environment and management (Nyland 2002). Management is particularly important when comparing different systems under similar conditions. Stand stocking, species associations, weeding, pruning, pest controlling, and thinning are management main factors due to their influence on quality and growth. High light-demanding species in very densely planted stands will compete for a canopy position that influences the light gathering and photosynthetic capability of the tree and consequently its crown shape, stem form, growth and volume (Hutchinson 1981). Emergent trees will have better survival, growth and timber quality compared to those that have been suppressed and which may have higher mortality rates and a risk of deformation that would render the timber unsuitable for commercial purposes. Therefore, practices such as the elimination of competitors from larger trees to favor promising immature ones ("liberation" sensu Hutchinson and Wadsworth, Hutchinson and Wadsworth 2006), harvesting selected trees, thinning or pruning (Wadsworth and Zweede 2006) may help to obtain good quality wood products. Pest damage also impacts quality and tree growth, as in the case of the Meliaceae borer *Hypsipyla grandella* Zeller.

In Chiapas, Mexico, indigenous farmers from Chol and Tseltal Mayan ethnic group established the following agroforestry systems: shaded coffee plantations, improved fallow and maize crop associated to trees (*Ixim te* in Mayan language or Taungya abroad). They planted native fine wood species (*Swietenia macrophylla* G. King (mahogany), *Cedrela odorata* L. (Cedar), *Pinus chiapensis* (Martínez) Andresen (an endemic pine called "taj"), *Tabebuia rosea* (Bertol) DC (maculis), *T. pentaphylla* (L.) Hemsl. (primavera), and *Cordia alliodora* (Ruiz & Pav.) Oken (laurel), supported by a program of carbon sequestration called *Scolel'te* (the growing tree in Mayan language).

Farmers in this region, typically devote land to the production of maize based on the traditional *milpa* rotational system (maize associated with beans, pepper, pumpkin, cultivated and spontaneous trees and shrubs) which covers approximately 1 ha each. Traditional "milpas" usually feature about 210 pioneer trees ha^{-1} that contribute to the acceleration of secondary succession and improvement of site conditions in the rotational system; this "cultivation break" stage is regarded as a traditional fallow period, known locally as "acahual" which currently lasts between 7 and 10 years. It is a phase during which secondary succession restores the soil capacity to produce corn and beans rotationally (Diemont and Martin 2009; Ford and Nigh 2015). Improved fallow comprises abandonment of the crop in which the fine wood trees were established before the 5th year from the abandonment, and the plot also contains previously grown spontaneous trees derived from secondary succession (Soto-Pinto et al. 2011, in press). The maize-crop-associated-to-trees system refers to the association of crops with high-value native timber trees for a 3–7-year period while the canopy remains relatively open, after which the crop is abandoned allowing the standing trees to mix with spontaneous trees produced by secondary succession (Soto-Pinto and Armijo-Florentino 2014). Shaded coffee, on the other hand, consists of traditional shaded coffee plantations planted with high-value timber trees mixed with spontaneous shade species (Soto-Pinto et al. 2010; Soto-Pinto and Aguirre-Dávila 2015).

The establishment of these systems was carried out by farmers with the purpose to increase land and labor value in communities with less of 7 ha of land per capita, devoted to growing maize and beans (traditional milpa) mainly produced for self-supply, applying traditional practices such as shifting cultivation, based on manual tools, local knowledge and seeds, and family labor. The municipality of Chilon is characterized by having 66.4 inhabitants/km^2, and Salto de Agua by 46.6 inhabitants/km^2; both of them composed by small, mainly rural localities with high poverty indices. Population lacks of labor alternatives and usually look for extra-communitarian employment in medium or large cities, or even, abroad.

Based on their own traditional practices, farmers carried out a participatory a diagnosis and design process, followed by the establishment and adaptation of the systems. These farmers were supported with tools for pruning, and some external scientific knowledge to carry out their silvicultural practices.

The aim of this study was to analyze and compare tree quality among three different agroforestry systems: improved fallow, shaded coffee, and maize crop associated to trees, in order to evaluate the influence of management factors and to make recommendations for similar small-scale contexts.

Materials and Methods

The study was carried out in the Mayan zone located in northern Chiapas, Mexico, in the following communities: Muquenal, Jolcalcuala, Alan Kantajal and Cololteel in the Municipality of Chilón; and Arroyo Palenque in the Municipality of Salto de Agua (Fig. 1). The study area at an average altitude of 940 m a.s.l. is characterized by a warm humid climate, abundant summer rains, tropical rainforest vegetation, and, Regosol, Leptosol, and Cambisols as soil types.

Twenty nine-year-old plots were randomly selected: eight of improved fallow, six of shaded coffee and six of maize crop associated to trees; these were the oldest plots within a set of plots of different ages. In every agroforestry plot (covering usually 1 ha), we conducted inventories on randomly located concentric 100 m^2 and 1000 m^2 circular plots (Olvera-Vargas et al. 1996; CATIE 2000). The 100 m^2-circle were used to record samplings (3–10 cm in diameter) and the 1000 m^2-circle for adult trees (>10 cm in diameter) where tree diameter (DBH) and total height were measured. For each adult individual, visual indicators of quality were recorded: stem form, position in the canopy and crown shape. We used five categories of stem quality: (1) currently profitable, $\geq$30 cm DBH, not deformed; (2) potentially profitable, 10–29.9 cm DBH, not deformed; (3) deformed; (4) damaged or rotten; (5) broken, under 4 m in height (Hutchinson 1993). For position in the canopy, the following categories were used for trees: (1) emergent; (2) fully-vertical illuminated; (3) partially-vertical illuminated; (4) laterally illuminated; (5) suppressed trees. For crown shape, the following categories were used: (1) circular and symmetric crown; (2) irregular circle; (3) half circle or thin crown; (4) less than half circle; (5) few sparse branches (Hutchinson 1993). Local names were recorded for saplings and adult trees, and voucher specimens were collected and identified. Two categories for use were considered: (1) domestic value (locally known species, mainly for rural construction, fuelwood and other domestic purposes), and (2) trees with commercial value (widely known valued species). In total, 2170 trees were measured. For all of the cedars (C. *odorata*) and mahoganies (*S. macrophylla*), we recorded the incidence of the shoot borer (*H. grandella* Zeller) based on the presence of buds showing signs of attack.

Timber volume was estimated following the equation proposed by CATIE (Tropical Education and Research Agronomic Center) for tropical vegetation with

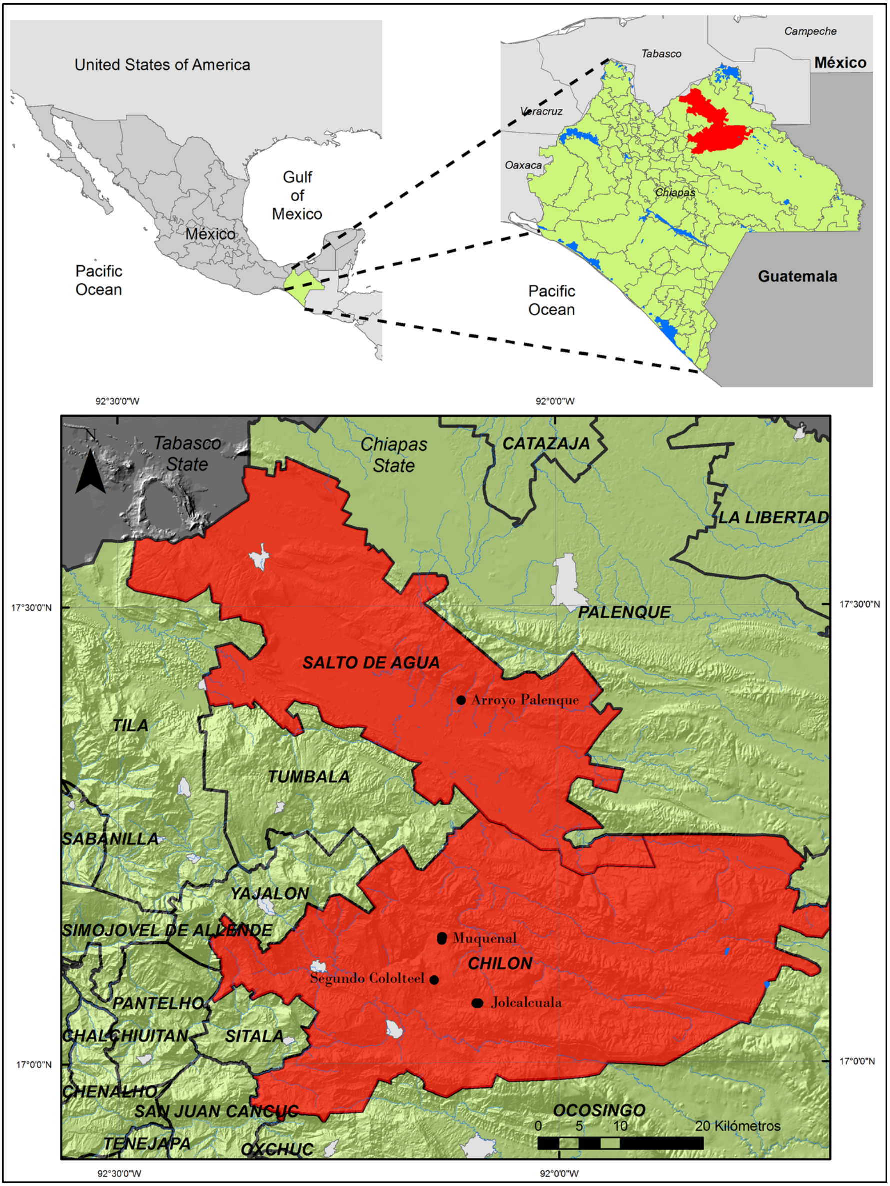


Fig. 1 The study area, municipalities of Chilón and Salto de Agua in the Northern Mayan Zone, Chiapas, Mexico

similar genera (Segura and Venegas 1999; $R^2 = 0.98$; based on Schumacher—Hall: $\ln(v) = b_0 + b_1 \times \ln(dap) + b_2\ h\ \ln(H)$):

$$\text{LnV} = -9.1833 + 2.0107(\text{LnD}) + 0.7455(\text{LnH})$$

where *V* Timber volume in m^3; *D* diameter in cm; *H* height in m.

Crosstabs were prepared to analyze the behavior of the quality categories into the various agroforestry systems. In order to identify dependency relationships among agroforestry systems and categories for stem quality, crown form and position into the canopy, and the incidence of the shoot borer in cedar and mahogany, a Chi square analysis was performed. Variance homogeneity tests were run. Tree diameter, tree height, timber volume, and pest incidence were compared among systems through mean comparison analysis using the program Statistical Analysis System (SAS 2008).

Results

Maize Crop Associated to Trees System

Farmers cultivate maize twice yearly, weeding the maize crop twice per year while pruning the trees three times yearly during this initial period. Two harvests are obtained every year, averaging 2400 kg of maize and 600 kg ha^{-1} of beans. Average maize density is 10000 plants ha^{-1}, while tree density averages 602.2 ± 293.6 trees ha^{-1} (including saplings) and 16.75 ± 7.3 cm and 8.5 ± 4.2 m in diameter and height, respectively, with 43.1 % of trees for domestic purposes and 57 % with commercial value (Table 1). After crop period which lasts 4 to 5(–7) years, the abandonment gives rise to a forest phase mainly composed of shrubs and trees forming a locally diverse system, containing up to 75 species, including edible herbaceous plants and tubers, timber and fruit trees and shrubs, plantains and palms. The most frequently recorded species are: *C. odorata*, *C. alliodora, P. chiapensis, T. pentaphyla, Annona muricata* L., *Persea americana* Mill., *Musa* spp, *Psidium*

Table 1 Growth and timber quality variables in three agroforestry systems in the Northern Mayan Zone, Chiapas, Mexico

Variables	Agroforestry systems		
	Maize associated to trees	Shaded coffee	Improved fallow
Adult tree density (individuals ha^{-1})	268.6 ± 127.5	360 ± 108.1	453.6 ± 262.7
Sampling density (individuals ha^{-1})	333.6 ± 167.7	140 ± 59.3	400.6 ± 257.8
Total tree density (individuals ha^{-1})	602.2 ± 293.6	500 ± 161.8	854.2 ± 376.6
Diameter (cm)	16.8 ± 7.3	14.9 ± 10.0	17.6 ± 9.2
Height (m)	8.5 ± 4.2	6.8 ± 4.0	7.2 ± 4.03
Emergent trees (%)	35.8 ± 17.5	17.3 ± 7.2	22.4 ± 11.4
Suppressed trees (%)	1.2 ± 0.4	0.24 ± 0.06	6.6 ± 2.3
Stems with good form (%)	68.1 ± 13.9	39.7 ± 8.9	40.5 ± 8.9
Trees with use value (%)	43.1 ± 16.9	88.2 ± 15.1	71.8 ± 26.3
Trees with commercial value (%)	56.9 ± 16.9	11.8 ± 15.1	28.2 ± 26.3
Timber volume (m^3 ha^{-1})	52.5 ± 39.6	77.3 ± 24.8	92.9 ± 68.9

guajava L., *Citrus* spp, *Pouteria sapota* (Jacq.) H.E. Moore & Stearn, *Piper auritum* Kunth, *Colocasia esculenta* (L.) Schott, *Xanthosoma sagittifolium* (L.) Schott, and *Manihot esculenta* Crantz (Fig. 2).

Improved Fallow

The improved fallow stage consists of an innovation, based on enrichment of the natural vegetation with native high-value timber trees at a density of 854.2 ± 376.6 trees ha^{-1} (including saplings), planted in 7 m-wide strips between the shrubby natural vegetation before the 5th year of maize abandonment, and leaving of the preexisting trees derived from secondary vegetation in between, with trees averaging 17.5 ± 9.2 cm and 7.2 ± 4 m in diameter and height, respectively, with two-thirds of trees useful for domestic purposes and one-third of trees with commercial value (Table 1). Pruning is applied to the crop trees once or twice during the first years of establishment and no crops were associated during this phase, except for plantain, palm and some fruit trees and shrubs, the trees are weeded at least once during this initial phase. The canopy closes promptly giving place to a mixture of established and spontaneous trees, the system, being rotational, eventually returns to its initial crop phase, otherwise it is left forested or planted with coffee and/or edible and ornamental palms to increase land and labor value (Fig. 2).

Shaded Coffee

The coffee varieties Typica, Bourbon, Mundonovo and Caturra (C*offea arabica* L) is usually grown at a density of 2000–2500 coffee shrubs ha^{-1}, under the shade of numerous tree species, up to 31 species in total, and 500 ± 161.8 shade trees ha^{-1} (including saplings), averaging 14.9 ± 10 cm and 6.8 ± 4 m in diameter and height, respectively, with most of the trees for domestic value and one tenth of trees with commercial value (Table 1), including *Inga* spp, the tree most commonly used for shading coffee in this region. These systems are planted with 100 trees ha^{-1} using the following species: *S. macrophylla*, *C. odorata*, *T. rosea* and *Cordia alliodora*, which mix with the spontaneous trees *Heliocarpus* aff *popayensis*, *Brosimum alicastrum* Sw. subsp. *alicastrum* C.C. Berg, *Chamaedorea tepejilote* Liebm, *Zanthoxilum* aff *microcarpum* Griseb, *Vernonia deppeana* Less, *Chrysophyllum mexicanum* (Brand) Standl., *Cecropia obtusifolia* Bert., and *Bursera Simaruba* (L) Sarg., among other species.

Tree Quality and Growth

The stem quality depend on the agroforestry system ($p < 0.0001$), the position of the tree within the canopy ($p < 0.0001$), the crown shape ($p < 0.0001$), and, in the case of cedar and mahogany, on the incidence of the pest *H. grandella* ($p < 0.0001$). Maize associated to trees show the highest proportion of commercial trees (*S. macrophylla, C. odorata, C. alliodora, T. rosea, T. pentaphylla, P. chiapensis*) with 56.9 ± 16.9 %, followed by improved fallow with 28.2 ± 26.3 %, and shaded

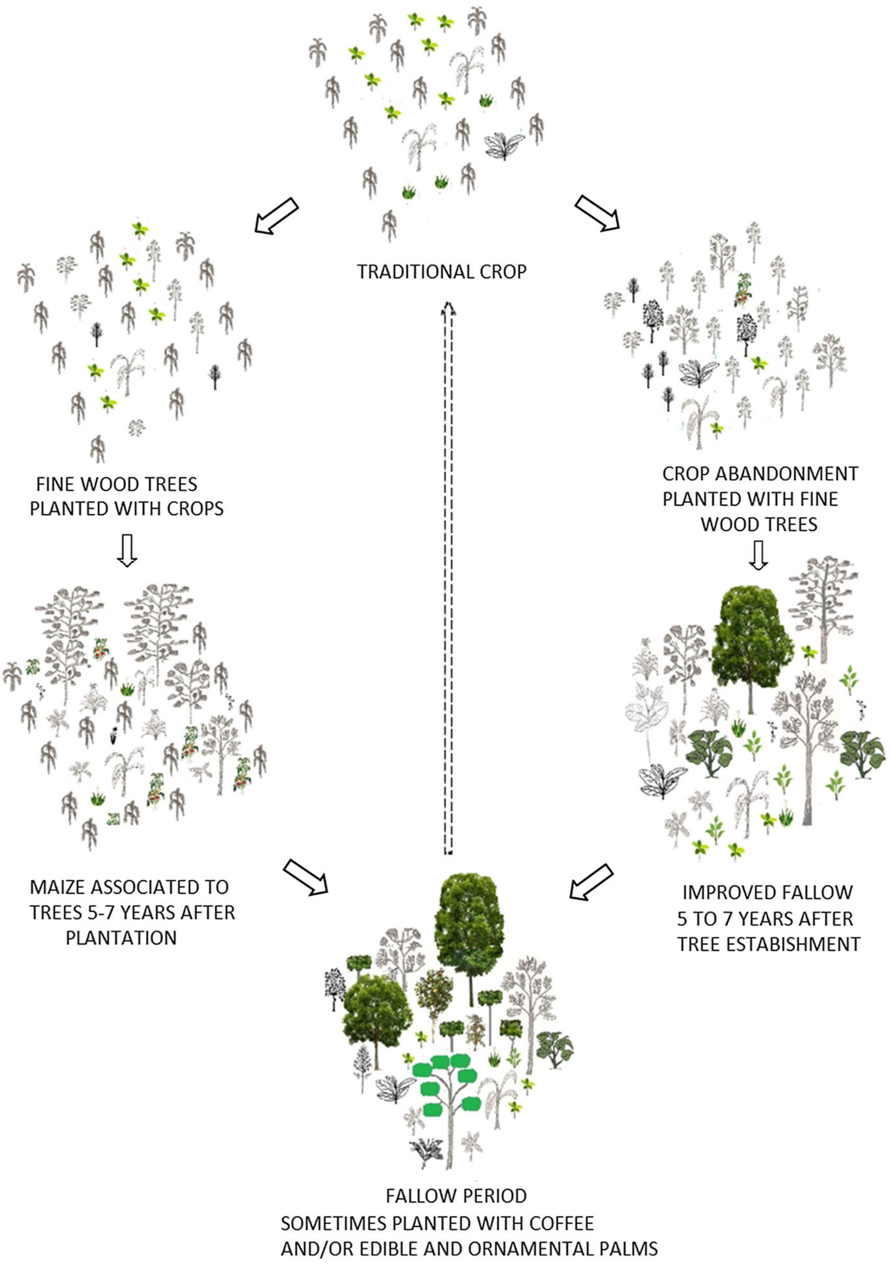


Fig. 2 Maize crop associated to trees and improved fallow systems in different stages, in the Northern Mayan Zone, Chiapas, Mexico

coffee with 11.8 ± 15.1 %. The rest are trees with domestic values (domestic purposes such as rural construction, fuelwood, tools). No differences in diameters and heights were observed among the three systems ($p > 0.05$).

In maize associated to trees the stem quality (currently-profitable and potentially-profitable trees) is significantly superior to shaded coffee and improved fallow ($p < 0.0001$). This system jointly with shaded coffee display a high number of emergent trees (Table 1). Additionally, maize associated to trees and shaded coffee exhibit a higher proportion of trees with circular and symmetrical crowns (72.7 and 87.3 %, respectively), compared to the improved fallow (58.2 %) ($p < 0.0001$). Improved fallow has a larger number of crowns in the categories 4 and 5 with less than a half circle or thin crowns ($p < 0.0001$) and the highest proportion of suppressed trees in category 5 ($p < 0.05$) (Table 2; Fig. 3).

Maize crop associated to trees reveals a greater proportion of good quality stems, i.e., good form, not deformed, damaged or broken individuals compared to the other systems ($p < 0.05$) (Table 1). Tree position within the canopy influenced diameter ($p < 0.01$), stem form ($p < 0.05$) and crown shape ($p < 0.0001$). This explains the higher proportion of trees with commercial value and the volume of timber with good quality in the Maize crop associated to trees system ($p < 0.001$) (Fig. 4).

All of the three systems have more than 70 % of trees in the range of 3–19 cm, while 6–15 % is in the range of 20–29 cm, 2–4.8 % is in the range of 30–40 cm and about 2 % is >40 cm (Fig. 5). Diameter (DBH) frequencies of between 3 and 20 cm are 58.6, 78.2 and 82 % for the Maize crop associated to trees, improved fallow and shaded coffee systems, respectively. The coffee plantations and improved fallows have higher numbers of young trees (3–20 cm), which is an indicator of replacement rate, while Maize crop associated to trees, having been associated with crops, has a reduced capability for replacement. Farmers also extract trees for rural construction and other domestic purposes using chainsaws to log and make boards, a practice which produces low quality wood products and high amount of timber waste.

Diameter and height did not resulted in significant differences among systems ($p > 0.05$). Timber volume is highly variable, averaging 52.5, 77.3, and 92.9 m^3 ha^{-1} in Maize crop associated to trees, shaded coffee and improved fallow, respectively, without significant differences ($p > 0.05$; Table 1).

Regarding incidence of the Meliaceae shoot borer, *Swietenia macrophylla* was more frequently attacked in the maize-associated-to-trees system than in the other two systems ($p < 0.05$), while cedar was more frequently attacked in maize and coffee than in improved fallow systems ($p < 0.05$) (Fig. 6).

Table 2 Tree crown shape in three agroforestry systems in the Northern Mayan Zone, Chiapas, Mexico

Agroforestry systems	Crown shape (%)					
	1	2	3	4	5	Circular and symmetric crowns
Maize associated to trees	39.63	33.11	22.24	2.01	3.01	72.7
Shaded coffee	68.36	18.95	6.84	0.78	5.08	87.3
Improved fallow	22.25	35.91	22.97	11.85	7.01	58.2

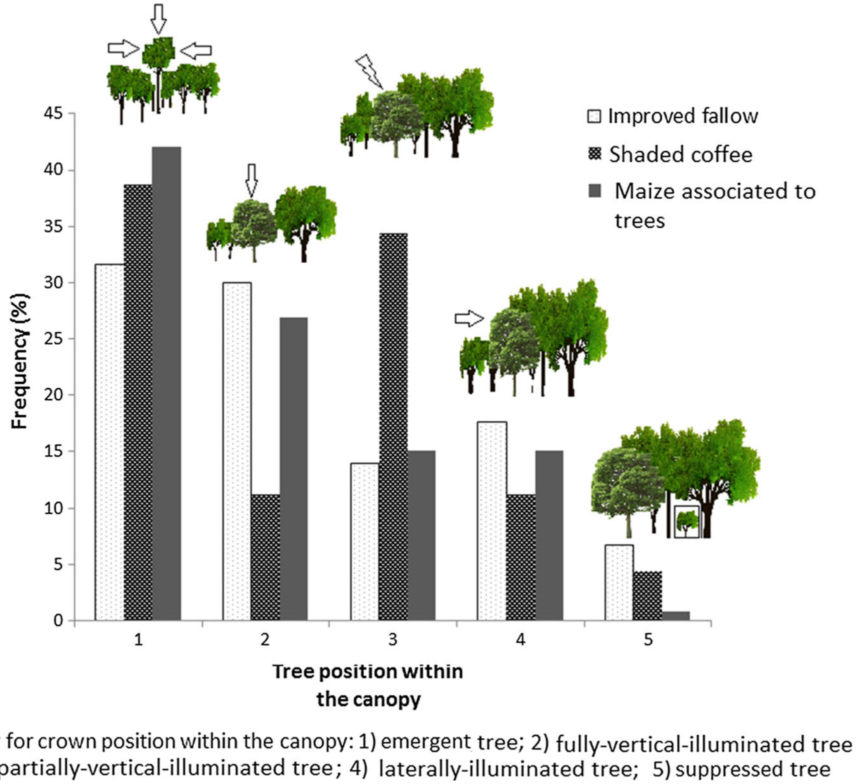
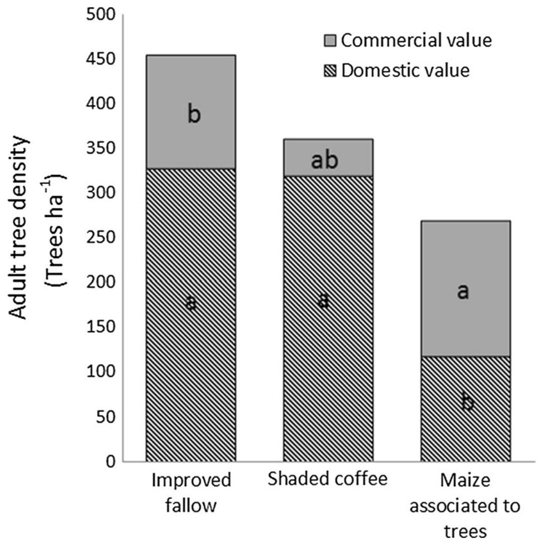


Fig. 3 Frequency of trees with different positions into the canopy in three agroforestry systems: improved fallow, shaded coffee and maize crop associated to trees, in the Northern Mayan Zone, Chiapas, Mexico

Discussion

Trees in the maize crop associated to trees system are favored by the practices applied to annual crops during the first 3–5 years, a period in which they are free from the interference of other trees and benefited from favorable light conditions, weeding and a higher intensity of pruning. Shaded coffee and improved fallow have higher tree densities and a more closed canopy condition. Consequently, Maize crop associated to trees exhibit the highest frequency of emergent and fully-vertical illuminated trees, a high proportion of circular and symmetric crowns and the highest stem quality at least in the first years of growing. The crop period allows trees to grow and then, when abandonment of crops occurs, as a result of canopy closure in the maize-associated-to-trees system, the high-value timber trees achieve a considerable height and can compete satisfactorily with others through the natural succession. In this system, there is a tradeoff between using the space for trees or using the space for crops, so, farmers get a balance between in numbers of trees and crops, enough to simultaneously produce food and forest products. This

Fig. 4 Frequency distribution of stem diameter in three agroforestry systems: improved fallow, shaded coffee, and maize crop associated to trees in the Northern Mayan Zone, Chiapas, Mexico



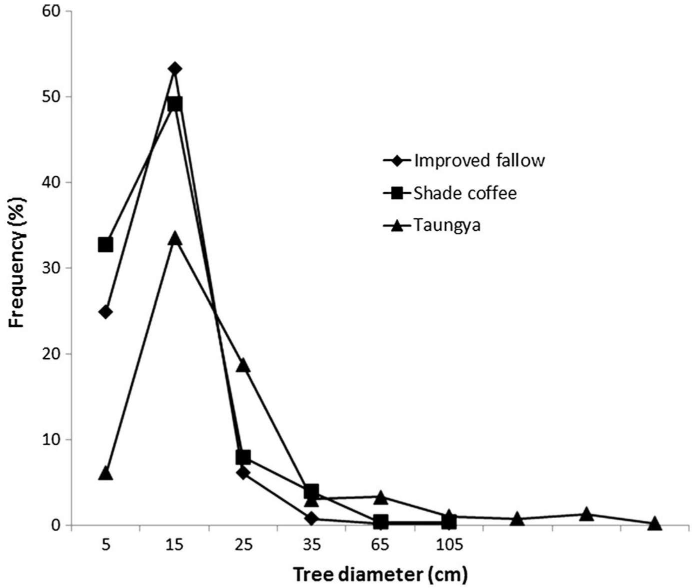


Fig. 5 Total tree density, and proportion of commercial and use-value trees in three agroforestry systems in the Northern Mayan Zone, Chiapas, Mexico. Different letters denote significant differences in commercial tree density ($p < 0.05$)

characteristic promotes the formation of high quality stems, and thus leads to the development of a higher proportion of commercial trees. Villegas and colleagues (2009) found in Bolivia that stem diameter growth increased up to 50 % with light availability and logging intensity. Imo (2009) reported that the association of trees

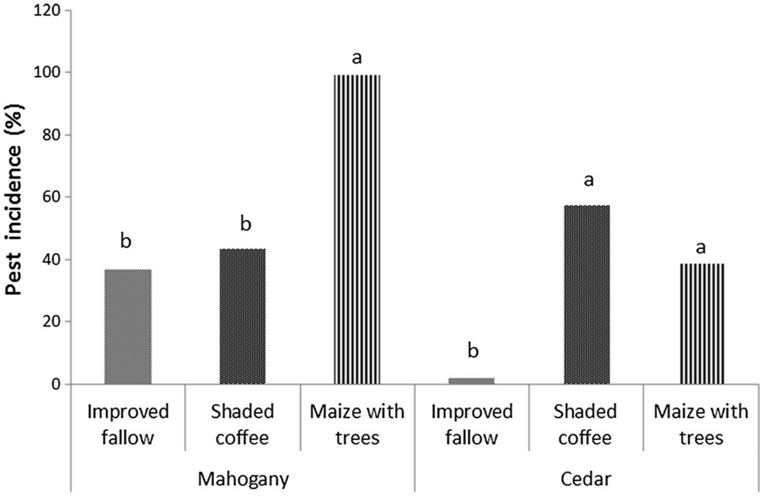


Fig. 6 Incidence of the stem borer *H. grandella* in *S. macrophylla* and *C. odorata* in three agroforestry systems in the Northern Mayan Zone, Chiapas, Mexico. Different letters denote significant differences between systems ($p < 0.05$)

to maize improved tree survival and growth due to the farmers' care to crops, which benefits the trees (Imo 2009). The fallow and shaded coffee systems, on the other hand, showed a higher proportion of suppressed trees that have lower stem quality and a higher proportion of thin, less than half circle and few sparse branch type crowns. Nevertheless, the diameter and height averages were similar among three systems, probably due to the selective logging practiced by farmers for domestic purposes.

Although the maize-crop-associated-to-trees system seems to be advantageous in terms of tree quality and timber volume, and market value, it shows a lower number of saplings and small trees (10–20 cm), a fact that merits consideration in the context of guaranteeing replacement. The number of saplings is an indicator of the sustainability of the system, i.e., the possibility of achieving replacement for long-term restoration and harvesting. Association with crops during the initial period limits this capability, probably demanding the replanting of seedlings. In addition, Maize crop associated to trees had the highest incidence of the Meliaceae borer *H. grandella*, a fact that increases production costs. This pest damages terminal and lateral buds, which necessitates the application of pruning as a remediation measure to address the stem quality and increases the cost as a consequence (Pérez-Salicrup and Esquivel 2008). Improved fallow showed the least attack; both in cedar and mahogany, and both species were similarly attacked in shaded coffee. This was probably due to the lateral shade caused by neighboring trees that acts as a physical barrier (Mahroof et al. 2002; Opuni-Frimpong et al. 2008).

Small-scale farmers in the study area did not practice systematic thinning in these agroforestry systems, as was initially planned (250 trees per hectare at the final turn). However, during this 9-year period, a certain number of trees and posts are extracted for rural construction and other domestic purposes, which served as a thinning process. It is possible that the selective logging for domestic uses is acting as a slight-intensive thinning. Additional benefits may be achieved when applying liberation and pruning practices, such as increased coffee yields in densely shaded coffee plantations as was previously reported (Soto-Pinto et al. 2000).

Tree growth potential and stem quality in these systems can be improved with appropriate management techniques. For example, suppressed trees of high timber value in improved fallows and shaded coffee can be favored through a silvicultural operation consisting of logging or pruning neighboring trees in order to improve access to light, and "liberate" sensu Hutchinson and Wadsworth (Hutchinson and Wadsworth 2006) the target trees from competition. Previous studies have documented the effects of such "liberation" practice. Wadsworth and Zweede (2006) reported an increment in 20 % of timber yields through to this practice; Hutchinson and Wadsworth (Hutchinson and Wadsworth 2006) reported a 16 % increase in growth rates, to reach twice that of non-liberated trees. The liberation practice is expected to contribute to the production of well-formed stems and crowns, higher growth rates and biomass accumulation with increased possibilities for commercialization and reduction of harvest wastes (Holbrook and Putz 1989; Lamprecht 1990).

In addition, most of the trees were distributed in small diameters while trees of DBH > 40 cm were less frequent. Harvesting the larger trees may imply a risk, since this category of tree is central for seed production and maintenance of other ecosystem functions (Chazdon 2014).

In this small-scale context, the studied agroforestry plantations had significant timber volumes that drive their permanence and maintenance. Previous studies of the maize-crop-associated-to-trees system reported an average timber volume of 110.7 m^3 ha^{-1} in 11–13 year old plantations, with an estimated value of 4261.7 USD ha^{-1} and a present net value (including maize, beans and payment for ecosystem service values) of about 5665.7 USD ha^{-1} (Soto-Pinto and Armijo-Florentino, 2014). In addition to timber benefits, farmers and their families utilize agroecosystems in an integrated manner, whereby multiple products and services are obtained, as previously indicated by other authors in similar traditional contexts (Adekunle and Bakare 2004; Soto-Pinto et al. 2007, 2012). It should be noted, however, that farmers log trees and make boards using chainsaws which produces low quality products and a high quantity of timber waste, as other authors reported (Baynes et al. 2015). However, farmers in the study area are looking for better opportunities to process timber and add value to their products. In this context, investment in machinery adapted to small-scale management is required, along with technical training, in order to achieve better product quality, optimize benefits, reduce costs and increase productivity as has been suggested by others (Bray and Merino 2005; Baynes et al. 2015; De Sousa et al. 2015).

The work of small-scale farmers in the study region is based on traditional knowledge and practices; they conduct silvicultural treatments such as weeding, liana removal and selective logging for domestic purposes, according to their own judgment and needs. It is not possible to say that any of the three systems is better than another, but complementary to each other. Decisions to choose a system and to apply silvicultural practices are taken in the study area, as in other small-scale forestry contexts, according to the individual farmer's needs, available resources and technical knowledge. Mayan farmers have vast local knowledge and traditional management techniques for obtaining products such as resins, insects, ornamental leaves, plant medicines, food and plants for ritual purposes (Wiersum 1997). Besides, including good quality wood species to their traditional systems can be a way to increase income, products, and self-employment for the household. However, to increase the quality of products, some elements such as training, tools and techniques are required.

Conclusions

The quality of trees associated to Maize is favored by the association of trees to crop which benefit from the stand stocking and permanent care given to the maize crop by farmers, i.e. weeding, selective logging, liana removal and intensive pruning compared to coffee systems and improved fallow. The stand stocking and this management was reflected on a greater canopy opening during the first years of establishment, attributes which influenced the position of trees within the canopy, stem quality, crown form and the timber volume with commercial grade. Maize crop associated to trees and shaded coffee show the highest frequency of emergent and fully-vertical illuminated trees, the highest proportion of circular and symmetric crowns and the best stem quality, while improved fallow exhibit a higher number of suppressed trees, with thin crowns. However, maize associated to trees had the highest incidence of the shoot borer pest *H. grandella*, probably due to crown exposure. The absolute timber volume was very variable and similar among the three systems. The improved fallow and shaded coffee jointly have a higher number of saplings, which is an indicator of replacement capability.

The three systems seem to be complementary and may be improved through silvicultural practices. Improved fallow and coffee plantations might benefit from the elimination of competitors from larger trees to favor promising immature ones and pruning practices, while maize crop associated to trees might benefit from timely pruning to control the stem borer and tree replacement in order to achieve long-term restoration and harvesting. Nevertheless farmers' empirical knowledge is vast to manage their agroforestry systems, training, tools and some silvicultural techniques are required in order to increase the quality of wood products. This could be common in similar areas where these elements may also be needed.

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References

Adekunle VAJ, Bakare Y (2004) Rural livelihood benefits from participation in the Taungya agroforestry system in Ondo State of Nigeria. Small-Scale Econ Manag Policy 3(1):131–138

Baynes J, Herbohn J, Gregorio N, Fernández J (2015) How useful are small stands of low quality timber? Small-Scale For 14:193–204

Bray DB, Merino LP (2005) La experiencia de las comunidades forestales en México. Mexico D. F. Secretaria de Medio Ambiente y Recursos Naturales, Instituto Nacional de Ecología, Consejo Civil Mexicano para la Silvicultura Sostenible A. C., Ford Foundation. México. p 276

CATIE (2000) Parcelas permanentes de muestreo en bosque natural tropical, guía para el establecimiento y medición. Turrialba, Costa Rica, Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)

Chazdon LR (2014) The promise of tropical forest regeneration in an age of deforestation. The University of Chicago Press, London

De Sousa K, Detlefsen G, Melo E, Tobar D, Casanoves F (2015) Timber yield from smallholder agroforestry systems in Nicaragua and Honduras. Agrofor Syst. doi:10.1007/s10457-015-9846-2

Diemont SAW, Martin JF (2009) Lacandon Maya ecosystem management: sustainable design for subsistence and environmental restoration. Ecol Appl 19(1):254–266

Food and Agriculture Organization of The United Nations (FAO) (2014) State of the world's forests: enhancing the socioeconomic benefits from forests. Food and Agriculture Organization of The United Nations, Rome, Italy (State of the World's Forests)

Ford A, Nigh R (2015) The Maya forest garden. Eight millennia of sustainable cultivation of the tropical woodlands. Left Coast Press, Walnut **259p**

Guariguata MR, Sáenz GP (2002) Post-logging acorn production and oak regeneration in a tropical montane forest, Costa Rica. For Ecol. Manag 167:285–293

Holbrook NM, Putz FW (1989) Influence of neighbors on tree form: effects of lateral shade and prevention of sway on the allometry of *Liquidambar styraciflua* (sweet gum). Am J Bot 76(12):1740–1749

Hutchinson ID (1981) Sarawak liberation thinning: background and initial analysis of performance. In: UNDP/FAO, Sarawak, Malaysia, p 121

Hutchinson ID (1993) Puntos de partida y muestreo diagnóstico para la silvicultura de bosques naturales del trópico húmedo. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba

Hutchinson ID, Wadsworth FH (2006) Efectos de la liberación en un bosque secundario de Costa Rica. Recur Nat Ambiente, Costa Rica 46–47:152–157

Imo M (2009) Interactions amongst trees and crops in Taungya systems of western Kenya. Agrofor Syst 76:265–273

Kalame FB, Aidoo R, Nkem J, Ajayie OC, Kanninen M, Luukkanen O, Idinoba M (2011) Modified Taungya system in Ghana: a win-win practice for forestry and adaptation to climate change? Environ Sci Policy 14:519–530

Lamprecht H (1990) Silvicultura en los trópicos: los ecosistemas forestales en los bosques tropicales y sus especies arbóreas, posibilidades y métodos para un aprovechamiento sostenido. GTZ, Eschborn **340p**

Mahroof RM, Hauxwell C, Edirisinghe JP, Watt AD, Newton AC (2002) Effects of artificial shade on attack by the mahogany shoot borer, *Hypsipyla robusta* (Moore). Agric For Entomol 4:283–292

Nyland RD (2002) Silviculture: concepts and applications, 2nd edn. McGraw-Hill, New York **682 p**

Olvera-Vargas M, Moreno-Gómez S, Figueroa-Rangel B (1996) Sitios Permanentes para la Investigación Silvícola. Manual para su Establecimiento. Universidad de Guadalajara, Guadalajara

Opuni-Frimpong E, Karnowky DF, Storer AJ, Cobbinah JR (2008) Silvicultural systems for plantation mahogany in Africa: influences of canopy shade on tree growth and pest damage. For Ecol Manag 255:328–333

Pérez-Salicrup DR, Esquivel R (2008) Tree infection by *Hypsipyla grandella* in *Swietenia macrophylla* and *Cedrela odorata* (Meliaceae) in Mexico's southern Yucatan Peninsula. For Ecol Manag 255(2):324–327

SAS Institute Inc. (2008) SAS/STAT User's Guide, Release 9.2 edn. SAS Institute, Cary

Segura M, Venegas G (1999) Tablas de volumen comercial con corteza para encino, roble y otras especies del bosque pluvial montano de la cordillera de Talamanca, Costa Rica. CATIE, Turrialba

Soto-Pinto L, Aguirre-Dávila CM (2015) Carbon stocks in organic coffee systems in Chiapas, Mexico. J Agric Sci 7(1):117–128
Soto-Pinto L, Armijo-Florentino C (2014) Changes in agroecosystem structure and function along a chronosequence of Taungya system in Chiapas, Mexico. J Agric Sci 6(11):37–57
Soto-Pinto L, Perfecto I, Castillo-Hernández J, Caballero-Nieto J (2000) Shade effect on coffee production at the northern tzeltal zone of the state of Chiapas, Mexico. Agric Ecosyst Environ 80(1–2):61–69
Soto-Pinto L, Villalvazo V, Jimenez-Ferrer G, Ramírez-Marcial N, Montoya G, Sinclair F (2007) The role of local knowledge in determining shade composition of multistrata coffee systems in Chiapas, Mexico. Biodiver Conserv 16:419–436
Soto-Pinto L, Anzueto-Martinez M, Mendoza J, Jiménez-Ferrer G, De Jong B (2010) Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. Agrofor Syst 78(1):39–51
Soto-Pinto L, Anzueto MM, Quechulpa (2011) El acahual mejorado. Un prototipo agroforestal. El Colegio de la Frontera Sur, San Cristóbal de las Casas
Soto-Pinto L, Castillo Santiago MA, Jiménez Ferrer G (2012) Agroforestry systems and local institutional development for preventing deforestation in Chiapas, Mexico. In: Moutinho P (ed) Deforestation around the world. InTech Open Access, Rijeka, pp 333–350
Soto-Pinto L, Anzueto-Martínez M (in press) Los acahuales mejorados. Una práctica agroforestal innovadora de los Maya Tseltales. In: Moreno Calles I, Vallejo Ramos M, Casas A, Toledo VM (eds) Manejo Etnoagroforestal en México. Universidad Nacional Autónoma de México, Morelia, México
Tschakert P, Coomesb OT, Potvin C (2007) Indigenous livelihoods, slash-and-burn agriculture, and carbon stocks in Eastern Panama. Ecol Econ 60:807–820
Villegas Z, Peña-Claros M, Mostacedo M, Alarcón A, Licona JC, Leaño C, Pariona W, Choque U (2009) Silvicultural treatments enhance growth rates of future crop trees in a tropical dry forest. For Ecol Manag 258(6):971–977
Wadsworth FH, Zweede JC (2006) Liberation: acceptable production of tropical forest timber. For Ecol Manag 233:45–51
Wiersum KF (1997) Indigenous exploitation and management of tropical forest resources: an evolutionary continuum in forest-people interactions. Agric Ecosyst Environ 63:1–16