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Changes in Agroecosystem Structure and Function Along a Chronosequence of Taungya System in Chiapas, Mexico

L. Soto-Pinto[1] & C. Armijo-Florentino[2]

[1] El Colegio de la Frontera Sur (ECOSUR), Carretera Panamericana y Periférico sur s/n San Cristóbal de las Casas, Chiapas, México

[2] Universidad Autónoma Chapingo, Carretera México-Texcoco Kilómetro 38.5, Chapingo, Estado de México

Correspondence: Dr. L. Soto-Pinto, El Colegio de la Frontera Sur (ECOSUR).Carretera Panamericana y Periférico sur s/n San Cristóbal de las Casas, Chiapas 29292, México. Tel: 52-967-674-9000. E-mail: lsoto@ecosur.mx

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Abstract

The shifting cultivation system was widely used in the past; however in recent times it is no longer sustainable. In Mexico, a group of Mayan farmers established Taungya system (*Ixim'te*) as alternative to shifting cultivation. The system consists of the rotational association of crops with cultivated and spontaneous timber trees. The aim was to evaluate the changes in ecological structure and functions, and economic value along a chronosequence of 2 to 13 years. Twenty farmer's plots were selected. In each plot, structure, function and economic indicators were evaluated. Along the chronosequence cultivated trees (*Cedrela odorata*, *Swietenia macrophyla*, *Tabebuia rosea*, *Cordia alliodora* and *Enterolobium cyclocarpum*) mixed with crops and spontaneous trees, forming a sort of diverse garden containing 75 plant species. Tree diameter, tree height, total biomass, carbon stock, timber volume, timber value and present value significantly increased along the chronosequence. Two harvests of maize and beans were obtained yearly. According to interviews in the early years maize and beans yielded about 2400 kg and 600 kg ha^{-1}, respectively, maize was reduced with each crop cycle at a rate of approximately 280 kg ha^{-1} yr^{-1}, no reductions for bean yield were reported. The number of woody species per 500 m^2-sampling area showed a minimum of 4 species on the first years and a maximum of 34 species on the last years. At years 11-13 carbon aboveground stock averaged 45.4 Mg C ha^{-1} and stored 3.9 Mg C ha^{-1} $Year^{-1}$. The timber volume reached 110.7 m^3 ha^{-1}; the timber value was estimated in 4261.7 USD ha^{-1} and the present value in 5665.7 USD ha^{-1}. Most of the plots presented low levels of soil nitrogen and phosphorus. The studied system increased in complexity, productivity, carbon stocks, and economic value. However, this system may require inputs in organic matter in order to restore soil nitrogen and phosphorus.

Keywords: agroecology, agroforestry, Ch'ol, *Ixim'te*, maize, Maya, milpa

1. Introduction

Some traditional farming systems have been robust and resilient for thousands of years such as slash-and-burn agriculture. However, these systems have been progressively displaced into marginal and unproductive lands, becoming less and less sustainable (Fischer & Vasseur, 2000; Palm et al., 2005; Gehring et al., 2005). In shifting cultivation system, the plots are temporarily cultivated with grains and then abandoned during a period of fallow (tree phase without grains). During the fallow the natural vegetation grows, while the farmer moves to another plot to continue growing basic grains (Nations & Nigh, 1980). The crop period is traditionally short due to a gradual decaying site quality which is overcome through a long fallow period (Ewel et al., 1981). The natural process of secondary succession occurring during the fallow helps to restore the site capacity (Brady, 1996; Quintana Ascencio et al., 1996; Sánchez, 1999; Gehring et al., 2005; Palm et al., 2005; Diemont et al., 2006, 2011; Diemont & Martin, 2009; Schmook, 2010; Chazdon, 2014). However, a long fallow period is considered unproductive by small farmers who, having no other options, lengthen the crop period shortening the fallow. This has motivated farmers and scientist to develop agroforestry innovations such as Taungya system, in order to obtain grains along with timber products as is the case of Nigeria, Kenya, Tanzania, Burkina Faso and Ghana among other African countries (Chamshama et al., 1992; Adekunle et al., 2004; Blay et al., 2008; Kalame et al., 2011; Mullah et al., 2012). Others have maintained old traditional practices with the same multipurposes. For example, the *Lacandon Milpa and* the *Telom Huasteco* in Mexico (Diemont & Martin, 2009; Cheng et al., 2011; Altieri, 2012), the *Quesumgual* in Honduras (Alcorn et al., 2003), the *Shamba* system in Kenya (Oduol, 1986), or the *Tumpangsari* system in Java (Wiersum, 1982). In these systems people use to tolerate, promote and cultivate trees associated with crops in a rotational scheme, involving the association of trees and crops for three to four years. The association remains as the trees grow and close the canopy. Maize, beans, cassava, potatoes, rice, squash, carrots, peas, wheat and cabbage are known to be associated between the rows of highly valued timber or fruit trees (Nair, 1993; Adekunle & Bakare, 2004).

Taungya has been shown to be an alternative practice to shifting cultivation, as the fallow period may favor secondary succession through a process of restoration and economic value addition (Chamshama et al., 1992; Adekunle et al., 2004; Blay et al., 2008; Mullah et al., 2012). Economic and environmental benefits offered by the Taungya system contribute significantly to livelihoods increasing the net present value to more than ten times compared to systems with only trees (Kalame et al., 2011); Taungya improve survival and growth of trees (Chamshama et al., 1992; Imo, 2009), improves the nutrient uptake by maize through the effect of weed reduction (Chamshama et al., 1992; Jordan et al., 1992); the temporary abandonment of the crop period favors desirable successional effects for vegetation restoration (Quintana Ascencio et al., 1996; Gehring et al., 2005; Vieira et al., 2009; Diemont & Martin, 2009; Chazdon, 2014); and increases the carbon sequestration capacity (Roncal-García et al., 2008; Soto-Pinto et al., 2010). In Mayan system *Lacandon milpa* more than 30 tree species have been recognized as potential facilitators of forest regeneration; the trees *Ochroma pyramidale* and *Sapium lateriflorum* have been demonstrated to improve soil organic matter accumulation and phosphorus concentration, respectively (Diemont et al., 2006, 2011). *Ochroma pyramidale* has also demonstrated its potential as facilitator in the restoration of degraded tropical forest areas (Douterlungne et al., 2008). Moreover, it is known that Taungya can reduce establishment cost since labor applied to crops can be shared with trees reducing labor costs; it increases revenues; provides food and forest products; provides employment for rural families; and in turn, can act as a buffer in reserve areas (Adekunle & Bakare, 2004; Witcomb & Dorward, 2009; Idol et al., 2011). *Shamba* system in Africa plays a leading role in the economy and provides more food and biodiversity than other systems for these areas (Oduol, 1986).

In Mexico, a group of farmers involved in the program *Scolel 'te* (tree growing in Mayan language) established a sort of Taungya system with the purposes of getting food, timber, other products and services, including the environmental service of carbon sequestration (De Jong et al., 1997; Soto-Pinto et al., 2010). Mayan traditional farmers usually tolerate pioneer trees in the corn fields, abandoning the land for restoration for periods between 7 and 12 years, but in this case, the innovation consisted of plant high-value-timber trees in rows, systematically planted and managed, to what we have called *Ixim'te* (trees with maize in tseltal language). Land and trees are owned by farmers who decided voluntarily to establish trees, select the species and the spatial and temporal arrangements. The high-value-timber tree species include the following: cedar (*Cedrela odorata*), mahogany (*Swietenia macrophyla*), "maculis" (*Tabebuia rosea*), "bojón" (*Cordia alliodora*) and "guanacastle" (*Enterolobium cyclocarpum*), associated with traditional "milpa" (traditional polyculture that includes maize, beans, squash, hot pepper, cassava, palms, fruit trees and other edible tubers).

Farmers have adapted the system to their own cultural and natural environment. However, it is known that the exploration on indigenous strategies is scarce (Cairns & Garrity, 1999). This research aimed to evaluate changes in ecological structure and function, and economic benefits along a chronosequence of the *Ixim'te* system in Chiapas, Mexico.

2. Materials and Methods

2.1 Study Area

The study was conducted in the tropical lowland Tseltal and Ch'ol Municipalities in the Mayan area of Chiapas, Mexico, in Chilón and Salto de Agua, respectively (Figure 1). The study plots were located at an average altitude of 450 m above sea level, with warm-humid climate, and tropical rainforest as the natural vegetation. Soils were classified as Regosols, Leptosols, and Cambisols. Land tenure is called "ejido", a property endowed by the State, with ownership, and decision of use by the farmers. Land is mainly devoted to maize and coffee production; however livestock is becoming important in the lowlands, especially in the Ch'ol communities.

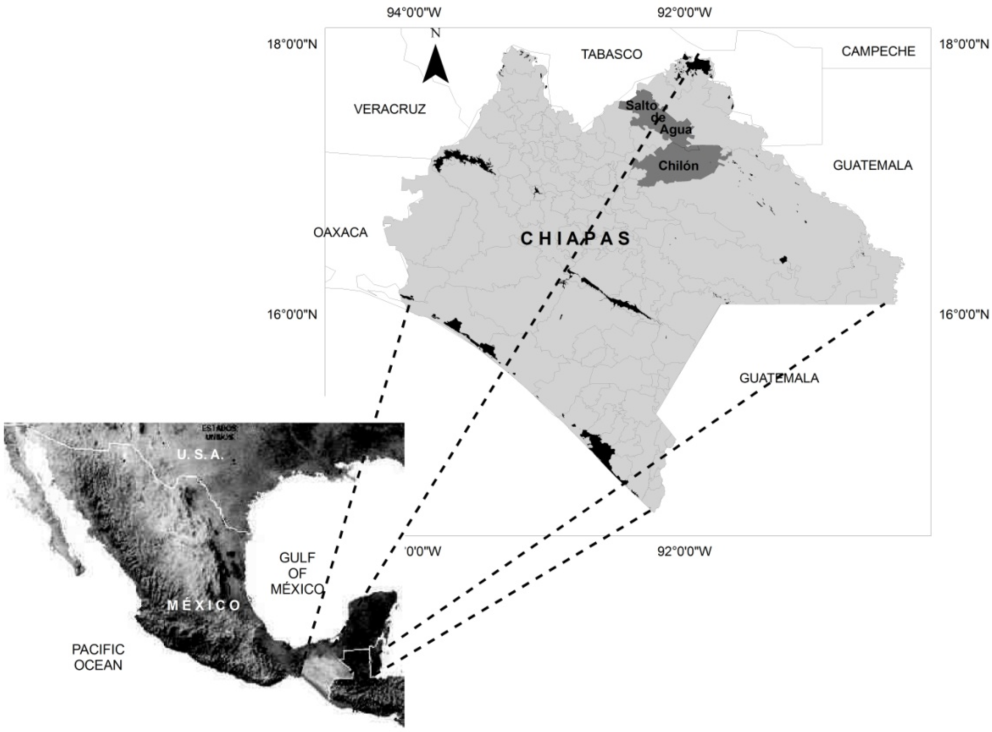

Figure 1. Study area

2.2 Selection of Plots and Sampling

Forty farmers established Taungya system in their plots as part of the program *Scolel'te* of carbon sequestration. Out of these, 20 farmer's plots were selected in a chronosequence between the ages of 2 to 13 years after tree establishment. In each plot, structure and function indicators were assessed. Tree diameter, tree height, basal area, tree and sapling density were evaluated as structure indicators; biomass, species richness, species diversity, timber volume, carbon stock, and timber value were estimated as functional indicators (Begon et al., 1990; Guariguata & Ostertag, 2001).

The plots were located in 20 to 40% slopes, with soils averaging 6.9 (± 0.7) pH; 5.5% (± 2.7) organic matter; 0.27% (± 0.1) of total nitrogen; 8.5ppm (± 5.2) of phosphorus; and 364.2ppm (± 192.3) of potassium. Most farmers incorporate crop tillage residues to the soil to grow maize.

In each plot, a forest inventory was carried out in 500 m^2-rectangles where tree height was measured with a Haga hypsometer; diameter of adult trees (trees > 0.1 m) and saplings (trees < 0.1 m) were measured with diametric tape and caliper, respectively. Tree and sapling species were collected and identified.

Aboveground biomass was estimated from the diameter and height of each adult and sapling trees using the following allometric formula (Chave et al., 2005):

$$AB = \exp\,[-2.997+\ln\,(\rho D^2 H)] \quad (1)$$

Where:

AB = Biomass (kg dry weight); ρ = Timber density for species; D = Diameter at breast height (0.13 m); H = Height (m).

Root biomass was estimated through the following allometric formula (Cairns et al., 2000):

$$RB = \exp\,[-1.0587 + 0.8836\,\ln\,(AGB)] \quad (2)$$

Where:

RB = Total biomass of roots (kg dry weight); AGB = Aboveground tree and sapling biomass (Mg ha^{-1} of dry matter).

Four samples of litter (freshly fallen, dry litter and humus) were collected from circles of known area. These samples were oven dried at 70 °C for 72 h and processed to determine carbon content according to standard laboratory procedures (IPCC, 2003).

2.3 Soil Sampling

In each plot a sample composed of 20 soil subsamples was taken. These were processed and analyzed in the laboratory for nitrogen by the Kjeldahl method and phosphorus by the Olsen method (CSTPA, 1980).

2.4 Timber Volume, Timber Value and Present Value

The timber volume was estimated using the diameter and height of all standing trees using the following formula proposed by CATIE (Tropical Education and Research Agronomic Center) for species of mountain forest (R^2 = 0.98) (Segura & Venegas, 1999):

$$\text{Ln}V = -9.1833 + 2.0107(\text{Ln}D) + 0.7455(\text{Ln}H) \quad (3)$$

Where:

V = Timber Volume in m^3; D = diameter in m; H = height in m.

Timber value was estimated as harvestable wood, classifying tree stems into diametric classes, and commercial or use value classes; value for ≤ 0.1 m-stems were assumed as firewood; value for 0.11-.029 m stems were assumed as poles; and value for ≥ 0.3 m stems were assumed as commercial timber. The value of timber was inferred from wholesale selling prices ($1.92 USD for m^3 fuelwood, $30.0 USD for m^3 poles; $51.30 USD for m^3 pine timber, $128.37 USD for m^3 red cedar, $123.32 USD for m^3 other tropical species according to CONAFOR http://www.conafor.gob.mx:8080/documentos/docs/39/4749Reporte%20de%20Precios%20de%20Productos%20Forestales.pdf visited, 2014).

The present value was estimated through the following formula; fruits and other foods were qualitatively recorded:

$$PV \text{ in USD per hectare} = TV + FV + PES \quad (4)$$

Where:

PV = Present value per ha in US dollars; TV = Timber value; FV = Food value (The price for maize and beans yielded during the first four years); PES = Payment for the ecosystem service of carbon sequestration ($1404 USD per contract, amount payable in five expeditions during the first ten years according to Ambio Cooperative (Quechulpa Pers. Com.).

2.5 Interviews

Every owner of the selected plots and seven additional farmers were interviewed in order to describe the system management, land size, land tenure, inputs to the system, labor nature, labor calendar, seed types, tool kind, practices, products, species uses, and maize yields and markets, among other information about the system.

2.6 Statistical Analysis

Correlations between age and structure and function variables (Proc Corr) and analysis of regression (Proc Reg) between the age of establishment and the following response variables were carried out: tree diameter, tree height, basal area, tree and sapling density, biomass, species richness, timber volume, carbon stock, timber value and present value. Species frequency was produced by Proc Freq and variable tables with Proc Means with SAS (SAS, 2008).

3. Results

3.1 System Description

The *Ixim'te* system is managed by farmers as a rotational low-input system, it is usually established in plots averaging 1ha, using manual tools, local seeds and family labor. Maize is grown for self-consumption and frequently sold within the community when exceeds the amount needed by the family. Two harvest of maize and beans were obtained yearly, one first in the rainy season (summer) and the second during the winter. This last (locally named "tornamil") is grown in the winter, with residual moisture, when some associated tree species lost their leaves, allowing the association of crops (Figure 2).

The labor applied to trees consisted of: planting the seedlings on rows, weeding, pruning with the purpose to form the stem and to control the pest damage in case of attack by the borer of the Meliaceae (*Hypsipila grandella*); all of them were carried out with manual tools and family labor. Trees and maize shared the labor.

After three to seven years of cropping, the plot was abandoned (tree phase without maize) in a sort of fallow. Once tree closed the canopy, some farmers cultivated coffee and edible palms under the shade of trees, using the space and shade conditions left by trees, shifting the rotational pattern to a permanent agrisilvicultural system; others cultivated grasses and introduced cattle under the trees, changing toward an agrosilvopastoral system (Figure 3).

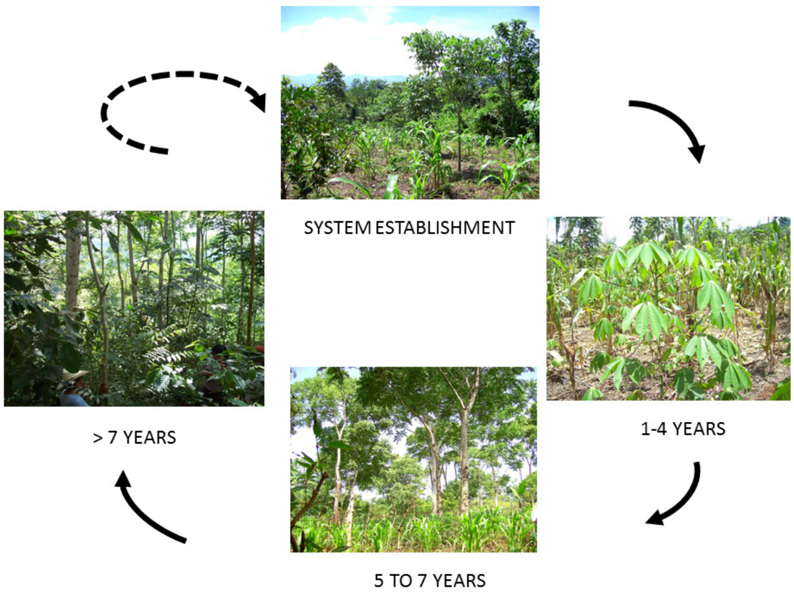

Figure 2. The cycle of Ixim'te (Taungya system) in Mayan region of Chiapas, Mexico

Figure 3. Thirteen-years-old Taungya system (Ixim'te) in Mayan region, Mexico

3.2 Structure and Species Composition

The tree species established were: cedar (*Cedrela odorata*), mahogany (*Sweitenia macrophyla*), "maculis" (*Tabebuia rosea*), "bojón" (*Cordia alliodora*) and "guanacastle" (*Enterolobium cyclocarpum*). Throughout the early years after establishment, cultivated trees mixed with crops and spontaneous trees, remaining associated to maize for a period varying from 3 to 7 years, forming a sort of diverse garden containing herbaceous plants, shrubs and trees. Some example of vegetables recorded were *Brassica* spp, *Piper auritum*, *Capsicum* spp. or

Lycopersicum esculentum; fruit trees such as *Annona muricata*, *Leucaena brachicarpa*, *Cajanus cajan*, *Persea americana*, *Musa acuminata M. sapientum*, *Psidium guajava*, *Citrus limonum*, *Citrus sinensis*, and *Pouteria sapota*; tubers such as *Colocasia esculenta*, *Xanthosoma sagittifolium*, and *Manihot esculenta*; leguminous species such as *Phaseolus* spp., plants for edible flowers such as the palm *Astrocaryum mexicanum* or *Erythrina* spp. Seventy five species were recorded among herbs, shrubs, palms and trees (Table 1). These species were introduced in succession, according to farmer's knowledge about light and space requirements and deciduousness, based their experience and observations.

In the course of the first years after establishment, only saplings were recorded. Along the chronosequence tree density increased while tree saplings decreased ($P < 0.05$; $r^2 = 0.57$; $P < 0.05$; $r^2 = -0.54$ respectively) averaging on the last years of evaluation a proportion of 59.5% of saplings and 40.5% of trees (Figure 4).

Along the chronosequence, tree diameters and heights significantly increased ($P < 0.001$; $r^2 = 0.7$; $P < 0.05$; $r^2 = 0.51$ respectively) (Figure 4). The maximum total height and diameter reached by trees in the oldest plantations of the study (11-13th years) averaged 11.8±2.7 m and 0.257±0.45 m, respectively.

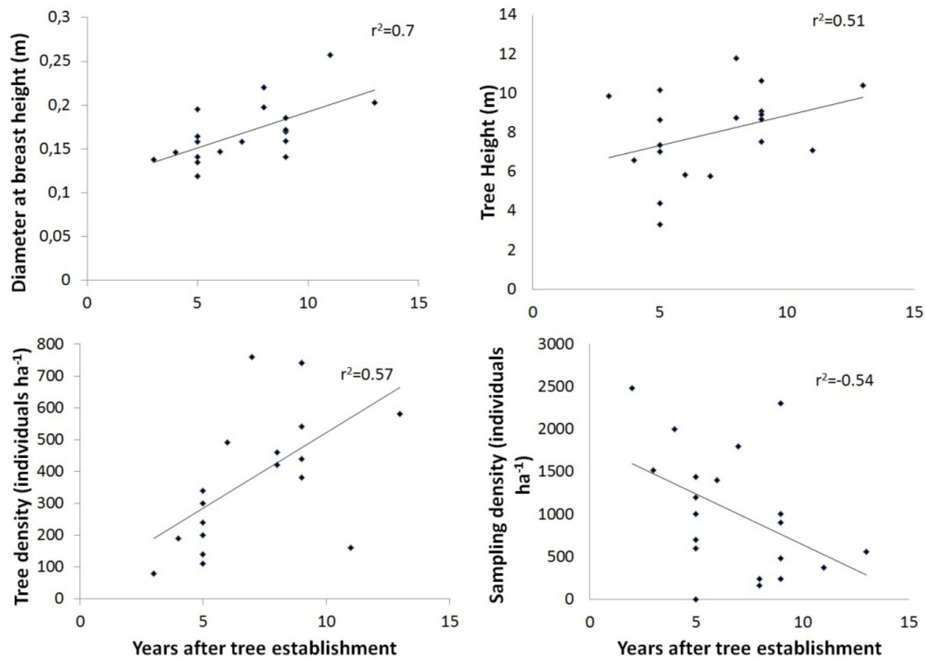

Figure 4. Relationships between age and structure indicators in Taungya plots, Mayan region of Chiapas Mexico

3.3 Functions

The main uses reported for the species recorded were food, forage, timber for rural construction and handicrafts, fuelwood, and medicine. Out of the total 75 species, 58 were woody species and 17 herbs (Table 1). According to the interviews, domestic and wild animals also habited the system, as well as multipurpose weeds, mushrooms, epiphytes and other plants (not accounted), showing the potential of this system to yield forest and food products.

Two harvests of maize and beans were obtained yearly. According to interviews in the early years maize and beans yielded about 2400 kg and 600 kg ha^{-1}, respectively (total for summer and winter harvests), maize was reduced with each crop cycle at a rate of approximately 280 kg ha^{-1} yr^{-1}, no reductions for bean yield were reported.

Farmers made a continuous low-to-intermediate-intensity logging of different sizes stems, depending on their domestic needs for self-supply.

The number of woody species per 500 m^2-sampling area showed a minimum of 4 species on the first years and a maximum of 34 species on the last years, this correlation was not statistically significant ($P > 0.05$; $r^2 = 0.42$) (Figure 5).

Total biomass ($r^2 = 0.82$, $p < 0.0001$), carbon stock ($r^2 = 0.69$, $p < 0.001$), timber volume ($r^2 = 0.78$, $p < 0.0001$), timber value ($r^2 = 0.57$, $p < 0.05$) and present value ($r^2 = 0.57$, $p < 0.05$) significantly increased with age (Figure 5). The litter presented a polynomial relationship along the chronosequence with top amount between the 5 and 7th years ($r^2 = 0.52$ for fresh litter; $r^2 = 0.41$ for dry litter; $r^2 = 0.51$ for humus) (Figure 6). At 11-13th years, the average total carbon stock was 45.4±1.61 mg C ha^{-1}, significantly increasing along the chronosequence at a rate of 3.9 mg C ha^{-1} $year^{-1}$; the timber volume reached 110.7±75.63 m^3 ha^{-1}; the timber value was estimated in 4261.7±3080.54 USD ha^{-1} and the present value in 5665.7±3080.54 USD ha^{-1}. Farmers received a payment for environmental service of carbon sequestration of $1404 USD during the first ten years of the plantation.

Considering the levels required by maize as the main crop, 60% of the soils had adequate levels of soil nitrogen and 20% of the plots had an adequate level of soil phosphorus (10 to 13 kg ha^{-1}).

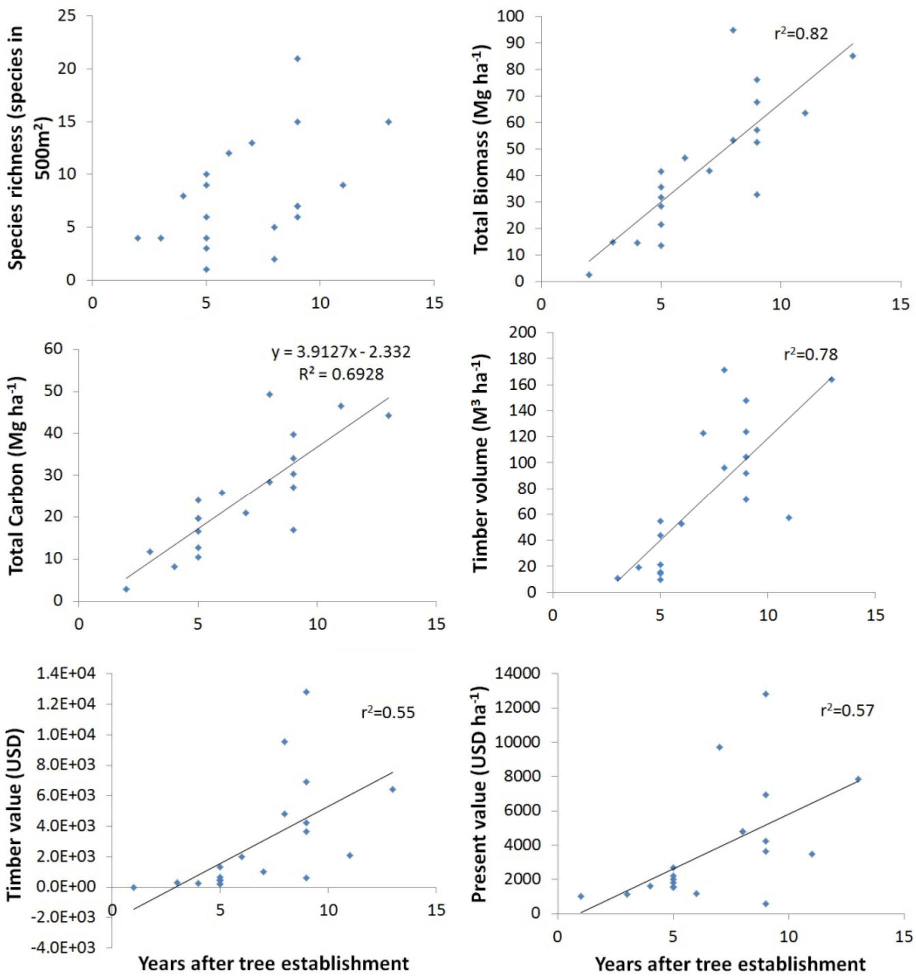

Figure 5. Relationships between age and function indicators in Taungya plots, Mayan region of Chiapas Mexico

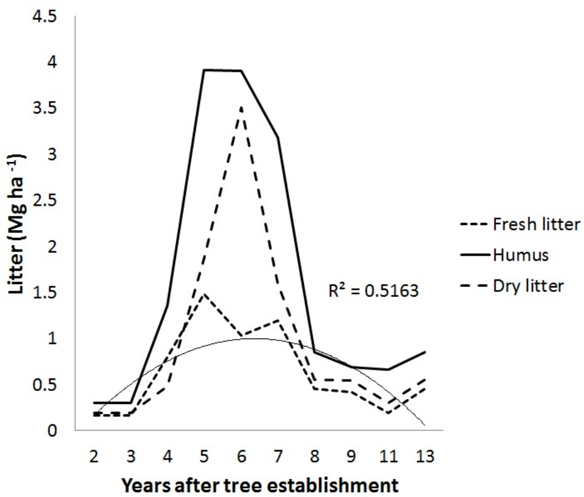

Figure 6. Polinomic relationship between age of establishment and litter in Taungya plots, Mayan region of Chiapas Mexico

Table 1. List of species, life forms and uses recorded in the Taungya system practiced by small indigenous farmers in Mayan region in Chiapas, Mexico

Family	Scientific name	Common name	Life form	Uses
Actinidiaceae	*Saurauia villosa*	Ajoj'te	1	5
Anacardiaceae	*Manguifera indica*	Mango	1	1
Annonaceae	*Annona muricata*	Guanábana	1	1,5
Apiaceae	*Coriandrum sativum*	Cilantro	3	1
Araceae	*Colocasia esculenta*	Camote	3	1
Araceae	*Xanthosoma sagittifolium*	macal	3	1
Arecaceae	*Astrocaryum mexicanum*	Chapay	2	1,9
Bignonaceae	*Tabebuia rosea*	Maculís	1	3, 4
Bombacaceae	*Ceiba petandra*	Ceiba	1	3
Boraginaceae	*Cordia alliodora*	Bojon	1	3,4,5
Brassicaceae	*Brassica* spp	Repollo	3	1
Bromeliaceae	*Ananas comosus*	Piña	3	1
Burseraceae	*Bursera simaruba*	Luluy	1	5
Capriforliaceae	*Viburnum hartwegii*	Chijalap'te	1	2
Cecropiaceae	*Cecropia obtusifolia*	Guarumbo	1	3
Compositae	*Eupatorium aff. sordidum*	Pom'te	1	5
Compositae	*Liabum discolor*	Tzuy	2	5
Cucurbitaceae	*Cucurbita pepo*	Calabaza	3	1
Cucurbitaceae	*Sechium edule*	Chayote	3	1
Cupressaceae	*Cuppresus*	Cipres	1	3,4,5
Euphorbiaceae	*Croton draco*	chich'bat	1	7
Euphorbiaceae	*Manihot esculenta*	Yuca	3	1
Fabaceae	*Cajanus cajan*	Chícharo de árbol	2	1, 9
Fabaceae	*Enterolobium cyclocarpum*	Guanacastle	1	2, 3, 4, 5, 9
Fabaceae	*Erythrina americana*	Colorín	1	1, 3, 9
Fabaceae	*Inga micheliana*	Chalum	1	5
Fabaceae	*Inga pavoniana*	Coquil ‘te	1	1, 5, 7
Fabaceae	*Inga punctata*	Tzelel	1	1, 5, 7
Fabaceae	*Inga radians*	Machetón	1	1,3,5,7
Fabaceae	*Leucaena brachicarpa*	Guash	1	1,2,3,5

Fabaceae	*Lonchocarpus* sp.	shin'te	1	5,7
Fabaceae	*Phaseolus* spp.	Frijol	3	1
Fabaceae	*Platymicium dimorphandrum*	Hormiguillo	1	3, 4
Icacinaceae	*Oecopetalum mexicanum*	Caca ‘te	1	1
Lauraceae	*Nectandra globosa*	On ‘te	1	5
Lauraceae	*Persea americana*	Aguacate	1	1
Malvaceae	*Pachira aquatica*	Sapote de agua	1	5
Meliaceae	*Cedrela odorata*	Cedro	1	3, 4
Meliaceae	*Sweitenia macrophyla*	Caoba	1	3, 4
Mimosaceae	*Pithecolobium arboreum*	Caracol	1	5
Moraceae	*Brosimum alicastrum*	Ash	1	2,4,5,6
Musaceae	*Musa acuminata*	Plátano	3	1
Musaceae	*Musa sapientum*	Guineo	3	1
Myristicaceae	*Virola Koschnyi*	Palo de sangre	1	3, 4
Myrtaceae	*Psidium guajava*	Guayaba	2	1, 5, 6
Non identified	Non identified	Om 'cho	2	5
Non identified	Non identified	Eboeshmax	2	5
Non identified	Non identified	O'och	2	5
Non identified	Non identified	Tzotzokil'te	1	5
Non identified	Non identified	Yon' chuch	1	5
Non identified	Non identified	Non identified	1	5
Non identified	Non identified	Non identified	1	5
Non identified	Non identified	Non identified	1	5
Oxalidaceae	*Averrhoa carambola*	Carambola	3	1
Pinaceae	*Pinus*	Pino	1	4,5
Piperaceae	*Piper auritum*	Hierba santa	3	1, 6,9
Poaceace	*Saccharum officinarum*	Caña	3	1
Poaceace	*Zea mays*	Maíz	3	1, 2, 3, 9
Rosaceae	*Eriobotrya japonica*	Nispero	2	1
Rubiaceae	*Blepharidium mexicanum*	Popiste	1	3, 4
Rubiaceae	*Coffea arabica*	Café	2	1,5
Rutaceae	*Citrus limonum*	Limón	2	1
Rutaceae	*Citrus nobilis*	Mandarina	2	1
Rutaceae	*Citrus sinensis*	Naranja	2	1
Sapindaceae	*Cupania dentata*	Toj pos ‘te	1	5
Sapotaceae	*Manilkara zapota*	Chicle	1	1, 3, 4
Sapotaceae	*Pouteria sapota*	Zapote mamey	1	1
Sapotáceae	*Chrysophyllum mexicanum*	Chijil'te	1	5
Solanaceae	*Capsicum* spp.	Chile	3	1
Solanaceae	*Lycopersicum esculentum*	tomate	3	1
Sterculiaceae	*Guazuma ulmifolia*	Guacimo	1	2, 5, 6
Tiliaceae	*Heliocarpus appendiculatus*	Bat	1	5,9
Tiliaceae	*Heliocarpus donnell-smithii*	Jono-han	1	5, 7
Tiliaceae	*Heliocarpus* spp.	Majahua o corcho	1	5, 7
Verbenaceae	*Lippia myriocephala*	Sac mumus	1	3

Use key: 1) Food; 2) Forage; 3) Construction and handicrafts; 4) Timber; 5) Fuelwood; 6) Medicine; 7) Shade; 8) Gum; 9) Other uses and services.

Life form key: 1) tree; 2) shrub; 3) herb.

4. Discussion

Results of the structure and function variables showed by the Taungya system called *Ixim'te* practiced by indigenous Ch'ol and Tzeltal people in Chiapas had a positive performance along the chronosequence. The structure is complex given the increment in height, diameter and positive trend of the species richness during the first 13 years from the tree establishment. Diameters increased nevertheless the continuous selective logging made by farmers, who used to remove ticker stems for domestic purposes. This selective logging seems to act as an intermediate-intensity thinning regime increasing biomass and timber volume, by increasing the illumination levels in saplings and suppressed trees of retained individuals (Guariguata & Sáenz, 2002), which in turn increase the economic value (Norgrove & Hausen, 2002; Piotto et al., 2003). However, the rate of value increment is lower than the rate of volume increment, probably due to the competence between cultivated and spontaneous trees. Some sites with very low timber value in the last years of evaluation were observed. It is assumed that a selective tree logging and high mortality of cultivated trees and dominance of spontaneous trees occurred along the chronosequence lowering economic value. This fact underlines the necessity of continuing planting and tolerating seedlings of high value timber species, during the fallow period, to ensure regeneration. Nevertheless, this depends on the farmer's plans, land availability and economic needs and benefits (Paladino, 2011).

The increment in adult trees and the trend to increase in species richness was also reported by others as a potential to restore site quality in a gradient from a degraded zone to secondary forest (Vieira et al., 2009; Mullah et al., 2012; Chazdon, 2014). Total density, including trees and saplings, in the 11-13-old plots was very similar to the density reported for 10-15-old secondary forests in Yucatan Mexico and in plots of earlier-stage-secondary forest in Kenya (Schmook, 2010; Mullah et al., 2012).

Moreover, productivity and ecosystem services represented by total biomass, carbon storage, timber volume, timber value and present value increased over time. Carbon increment coincides with the predictions made by CO_2 fix model, for a low to intermediate intensity agroforestry systems (De Jong et al., 1997; Soto-Pinto et al., 2004) and other regional data (Roncal et al., 2008; Soto-Pinto et al., 2010). The low-to-intermediate-intensity management is based on family labour, manual tools, use of local resources and knowledge, low level of chemical inputs, and tree logging for domestic purposes; all of these criteria meet the objectives and dynamic of local indigenous livelihoods (Soto-Pinto et al., 2004). This level of management is given by the similarity between this to the traditional system, as farmers in this region usually tolerate about 200 pioneer trees per hectare in the maize crop. These trees allow rapid regeneration of vegetation when the plot is abandoned. This level of intensity allows certain multifunctionality of the systems since it provides food, timber, firewood, and other useful products to rural families and ecosystem services (Wanyeki, 1980; Kagombe & Gitonga, 2005; Witcomb & Dorward, 2009). Although other non-timber resources of the plantation were not studied, it is considered that to assess the compatibility between the management of timber and non-timber products is important (Guariguata et al., 2010).

The polynomial relationship of litter along the chronosequence showing a peak between the 5 to 7th years seems to indicate the contribution of pruning debris to dead organic matter, since pruning was carried out between the 2nd and 5th year. However the quality supplied by pruning, litter and fallen debris may not be enough to satisfy the nutrient demand or to restore the site quality (Palm et al., 2014). Moreover, *Tabebuia rosea*, *Cedrela odorata* and *Swietenia macrophylla* have shown low litter production and slower decomposition than other tropical species due to their high lignin content, while *Cordia alliodora* has intermediate decomposition rate. Although the rates of decomposition of these species are known, their combination in different proportions is not as well known (Loranger et al., 2002; Scherer-Lorenzen et al., 2007).

Farmers who decide to keep the maize crop for more than three years after tree establishment grow it in winter (dry season) when the cedar, mahogany and other trees lose their leaves, this practice results in an adaptive management that allows the farmers to obtain basic grains continually. The permanence of maize for longer than three years is advantageous in terms of products; however yields are reduced due to low fertility. The low levels of nitrogen in 40% of the plots and phosphorus in most of the plots can be considered as a limitation for reforestation as has reported previously (Chazdon, 2014).

Furthermore, with *Ixim'te*, the effect of trees and continuous cultivation without chemical inputs could reduce maize yields between 12 and 47% during the first four years of association, depending on tree architecture, and tree physiology and phenology (Chamshama et al., 1992; Kalame et al., 2011), distance between trees and crops (Schlönvoigt & Beer, 2001; Kalame et al., 2011) and soil depth and management (Palm, 1995; Imo, 2009). Although leguminous trees compose the canopy of *Ixim'te* apparently the timber trees could be uptaking a high amount of nutrients for timber production (Palm, 1995). This limitation may be balanced using green manures as usual for crops in the Ch'ol region where people use to grow *Mucuna deeringianum* as green manure (Aguilar-Jimenez et al., 2011), using composts and/or using other associated plants such as *Tithonia diversifolia,* a frequent plant in the Mayan region, known as a facilitator for phosphorous absorption (Jama et al., 2000; Ikerra et al., 2006), or increasing the density of leguminous trees, but this should be further studied.

The system could be less effective with time as land availability is becoming constraint (Wiersum, 1982). Under these circumstances, the adaptations made by farmers are extremely important. Farmers have adapted the system through a process of social construction and learning, enabling the adoption of their systems. The practices adapted locally such as the management of growing winter crops acknowledging the tree deciduousness, the management of space and time with a diversity of annual and semi perennial crops based on local knowledge about successionality, the change toward permanent or silvopastoral system, and the continuous tree logging, are part of the local adaptation of *Ixim'te* system which allows a long-term cycle with intermediate products (Kalame et al., 2011). In addition, the adaptation of the system to local conditions and joint innovation between farmers and technicians are key factors for the process of technology adoption (Shiferaw et al., 2007).

The Ixim'te system along with coffee systems, fallow vegetation, home gardens and forest patches may contribute by adding complexity to the landscape, to offer other environmental benefits including watershed protection, windbreaks, erosion control, climate amelioration, biodiversity conservation, and opportunities for restoration as proposed by other studies (Adekunle & Bakare, 2004; Chazdon et al., 2008; Harvey et al., 2008; Vieira et al., 2009).

As observed in the region and according to interviews, *Ixim'te* has three possible future scenarios; once trees close the canopy in some plots, in highest sites, may change toward a permanent use through growing coffee and native palms under the shade of trees; others, in the lowest sites may change toward a silvopastoral system including pastures and cattle under the shade of trees; and other group may rotate to maize again, though this last one has not yet occurred, at least for the period and plots studied. The establishment of coffee and palms or cattle respond to the necessity of improving productivity and economic value; however economic and the environmental trade-offs must be studied (Duchelle et al., 2012).

5. Conclusions

Our results suggest that *Ixim'te* – a sort of Taungya system managed by Mayan farmers in Chiapas increased complexity, productivity, carbon stocks, timber volume and economic value during the first 11-13 years of establishment. It works as a low to intermediate rotational system that yields timber, food, fuel, fodder, medicines and other goods and services for the rural population. This system may contribute significantly to environmental services, with an average of aboveground carbon stock of 45.4 mg C ha^{-1} at last years of evaluation (11-13th years), accumulating carbon at a rate of 3.9 mg C ha^{-1} $year^{-1}$; achieving an estimated potential timber volume of 110.7 m^3, estimated timber harvest up to $4261.77US dollars, plus a yield of maize ranging between 1.6 to 2.4 ton ha^{-1} and a harvest of beans around 0.6 ton ha^{-1} for the first four years of cultivation. The *Ixim'te* system has potential for producing goods and ecosystems services as it provides food, timber, firewood and other useful products to rural families, increases complexity, increase carbon stocks, timber volume and timber economic value over time. The system only applies to farmers producing goods and ecosystems services through rotational schemes. It may require inputs on organic matter and tailored managements in order to restore soil nitrogen and phosphorus. As the system could be less effective with time due to the land availability constraint, the adaptations made by farmers are extremely important in terms of learning from this system.

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