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Carbon Stocks in Organic Coffee Systems in Chiapas, Mexico

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Abstract

Agroforestry systems contribute to the maintenance of ecosystem functions, especially agrisilvicultural systems such as shade coffee systems. However, the role of organic crops to store carbon has been scarcely investigated. This study aimed to quantify carbon stocks in organic polyculture coffee plantations, non-organic polyculture plantations, and organic *Inga* spp.-shaded coffee systems in northern Chiapas, Mexico. Vegetation inventories were carried out in 1,000 and 100 m^2 circular plots from six agroforestry communities. Carbon stocks were estimated from living biomass and roots through allometric formulas; dead biomass and soil organic matter (0-0.3 m- in depth) were collected, dried, weighted and processed for laboratory analysis. Firstly, results showed that living biomass contributed about 30% of total carbon; soil organic carbon particularly contributed between 56 and 70%; while dead organic matter represented between 3 and 5% of total carbon in the system. Organic polyculture coffee plantations stored significantly more carbon in soil (0.1-0.3 m in depth) and tree biomass than non-organic polyculture coffee plantations. These stocks were intermediate in organic *Inga* spp.-shaded coffee system. Secondly, dead organic matter was statistically similar between systems. Thus, organic polyculture coffee plantations, non-organic polyculture, and organic *Inga* spp.-shade system stored 194.7, 134.9, and 154.3 Mg C ha^{-1} of total carbon, respectively. In the same order, these systems stored in live aboveground biomass 57.5, 53.0, and 46.9 Mg C ha^{-1}, respectively. Dead organic matter had similar amounts of C stored in the three studied systems (6.3 Mg C ha^{-1}). The amounts of total carbon stocks in organic coffee were higher than those reported for others in coffee plantations in Central America and, particularly, similar to some dry and semi-humid forests and other agrisilvicultural systems in Mexico. The results highlight the importance of coffee, especially organic coffee to provide the environmental function of carbon sequestration.

Keywords: agroecology, agroforestry, environmental services, *Inga* spp., shade coffee

1. Introduction

Agroforestry systems play an important role in mitigating climate change due to their potential in carbon sequestration (Hutchinson et al., 2007; Idol et al., 2011; Soto-Pinto & Armijo-Florentino, 2014). It was previously mentioned that agroforestry systems, especially those with high tree and cover densities can store significant amounts of carbon, depending on the agro-climatic zone, physiographic conditions, vegetation characteristics, system complexity and management (Schroeder, 1994; Kotto-Same et al., 1997; Beer et al., 1998; Albrecht & Kandji, 2003; Montagnini & Nair, 2004; Roshetko et al., 2007; Roncal-Garcia et al., 2008; Tscharntke et al., 2011).

The coffee plantations in tropics are managed with shade trees which forms a complex system with high potential to provide environmental services, especially traditional polyculture systems and rustic coffee (Van Noordwijk et al., 2002; Peeters et al., 2003; Perfecto et al., 2007; Soto-Pinto et al., 2010; Rapidel et al., 2011; Häger, 2012). Some studies have pointed out the contrast between the potential to maintain a stock of carbon between plantations with and without shade. Thus, Dossa et al. (2008) found that the total C stock ranged from 22.9 Mg ha^{-1} in full sun coffee to 81 Mg ha^{-1} in shade coffee. Moreover, Van Noordwijk et al. (2002) reported accumulation rates of 1 and 2 Mg C ha^{-1} $year^{-1}$ in full sun coffee and shade coffee, respectively. Therefore, trees, coffee shrubs, and saplings are important components that can be managed to increase carbon sequestration in coffee systems. However, little is known of the shade composition and complexity related to the potential to maintain carbon stocks (Mendez et al., 2009) and, in this sense, soil is the largest carbon component in natural and agricultural systems, but little is also known of the contribution of organic systems in this environmental function. Some authors have reported a higher potential of organic coffee to store C in soils that non organic coffee, but others reported the contrary (Mendez et al., 2009; Soto-Pinto et al., 2010; Häger, 2012).

According to the previous analysis, the objective of this research was to quantify carbon stocks in three coffee systems, *i.e.*, organic *Inga spp.* shaded coffee plantations, organic polyculture, and non-organic polyculture in northern Chiapas, Mexico.

2. Method

2.1 The Study Area

This research was carried out in the agroforestry communities of Jol Cacualá and Muquenal (Chilon Municipality), Majoval (Larráinzar Municipality), Los Plátanos (El Bosque Municipality), and Altamirano (Jitotol de Zaragoza Municipality), located in northern Chiapas, Mexico (Figure 1). This Mexican region belongs to the Mayan subtropical zone where coffee is grown between 860 and 1,530 m.a.s.l. The original vegetation is cloud forest, with semi-warm humid climate, rainfall between 1,000 and 2,000 mm, and 23°C as average temperature. Soils were classified according to FAO (http://www.fao.org/nr/land/soils/soil/wrb-soil-maps/classification-key/en/#c25343) as Luvisols (with an argic horizon with a cation exchange capacity equal to or more than 24 cmolc kg^{-1} clay throughout) and Phaeozems (having a mollic horizon and a base saturation of 50 percent or more and a calcium carbonate-free soil matrix at least to a depth of 100 cm from the soil surface, or to a contrasting layer between 25 and 100 cm and no diagnostic horizons other than an albic, argic, cambic or vertic horizon, or a petrocalcic horizon 1/in the substratum).

The main economic activity in the study region is agriculture, mostly devoted to maize and coffee agriculture. Coffee is grown under the shade of trees in different structures and composition (Moguel & Toledo, 1999), as well as different management intensities (Hernández-Martínez et al., 2009). The present research was carried out in three different systems:

a) Organic Polyculture Coffee (OPC) with shade composed of various species and organic management, which use to involve compost application, tree and coffee bushes pruning, and biological pest and diseases control

b) Non-Organic Polyculture Coffee (NOPC), locally named “natural coffee”, with shade usually composed of various species with less intensive management than the OPC system, without compost applications, slight management of shade and coffee shrubs, and less intensive biological control than the other

c) Organic *Inga* spp. - shade coffee (OIS) with shade of various species, but dominated with tree species of the genus *Inga*, with the same intensive management than OPC.

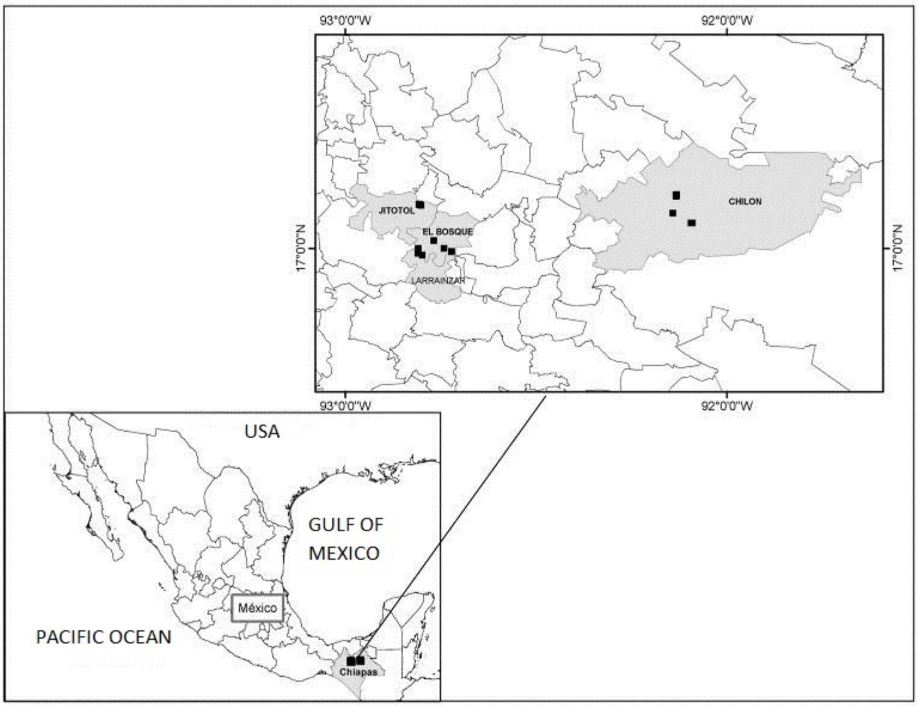


Figure 1. Situation of the study area, northern Chiapas (Mexico)

2.2 Plot Selection and Carbon Inventories

A total of twenty plots were selected in the study area according to the three coffee systems of management:

a) 7 plots under OIS in the El Bosque, Jitotol, Larrainzar agroforestry communities;

b) 6 plots under OCP in the Chilón, Larrainzar agroforestry communities;

c) 7 plots under NOCP in the Chilón, Larrainzar agroforestry communities.

In each plot of study, concentric circular areas of 1,000 and 100 m^2 were inventoried by means of analysing the following:

a) Live biomass, *i.e.*, tree, sapling and herb biomass, and root biomass (coarse and fine roots);

b) Dead organic matter, *i.e.*, fallen debris, fresh litter, dry litter, and humus;

c) Soil organic matter at 0-0.1 m, 0.1-0.2 m, and 0.2-0.3 m in depth (MacDicken, 1997; Hairiah et al., 2001; Penman et al., 2003).

The tree diameters were measured at 1.3 m height (DBH) and the total height of each tree ≥ 0.1 m were also measured. In each 100 m^2 circle, all saplings ≤ 0.1 m diameter were secondly measured. Every tree and sapling were collected and processed for botanical identification (CATIE 2000).

Aboveground and root biomass were estimated by general published allometric models; specific models were applied for palms, citric fruit trees, banana, and coffee (Table 1). For convention, the factor of 0.5 was applied as carbon density for estimating C in live aboveground biomass (Penman et al., 2003).

To estimate biomass of herbs, 0.5 × 0.5 m aluminium square (0.25 m^2) was randomly thrown eight times, in the 1,000 m^2 plot. The herbaceous material was cut and processed for analysis of carbon content. Analyses of carbon herbaceous material and litter were performed with Leco CHN 1000 ®.

The volume of fallen debris was estimated through the planar intersection method (Van Wagner, 1968); along four 25 m-transects where ≥ 0.3 m branches were measured at three stages of decomposition: fresh, dry and rotten branches; the volume was calculated with the following equation:

$$V = \pi^2 \Sigma d^2/8l \qquad (1)$$

Where, V = volume in m^3; d = diameter of the branch, in m; l = length of the sapling transect, in m.

Table 1. Allometric models used for estimating biomass in different carbon components

Compartment/species	Allometric equations	R^2	Source
Aboveground biomass	$Y = \exp[-2.977 + \mathrm{Ln}(\rho D^2 H)]$	0.99	Chave et al. (2005)
Coarse and fine roots	$Y = \exp[-1.0587 + 0.8836\ \mathrm{Ln}(AGB)$		Cairns et al. (1997)
Bactris gasipaes	$Y = 0.97 + 0.078(BA) - 0.00094(BA)^2 + 0.0000064(BA^3)$	0.96	Penman et al. (2003)
Palms	$Y = 10 + 6.4(H)$	0.96	Frangi and Lugo (1985)
Banana (*Musa* spp.)	$Y = 0.0303\ D^{2.1345}$	0.99	Hairiah et al. (2001)
Citric fruits (*Citrus sinensis*)	$Y = -6.64 + 0.278(BA) + 0.000514(BA)^2$	0.94	Penman et al. (2003)
Coffee (*Coffea arabica*)	$Y = 0.2811\ D^{2.0635}$	0.94	Hairiah et al. (2001)

Y = biomass, in kg of dry matter; D = diameter at breast height (DBH), in m (1.3 m height); H = height, in m; ρ = density of wood, in g $(\mathrm{ml})^{-1}$; AGB = aboveground biomass, in Mg ha^{-1} of dry matter; BA = basal area, in $\mathrm{m}^2\ \mathrm{ha}^{-1}$.

Sapling of branches in the three decomposition states were weighted and analysed for C content in the laboratory. In the 1,000 m^2 circle area, a ring of known dimensions was randomly thrown four times. In each point, the litter depth was measured. Litter was classified in three classes: fresh litter, intermediate litter, and humus (Fassbender, 1993) from which samples were taken for carbon content in laboratory.

Soil samples were taken with a Hoffer sampler from three depths, 0-0.1, 0.1-0.2, and 0.2-0.3 m. Each sample was processed for organic matter analysis through the humid combustion method (Walkley & Black, 1934). The factor 1.724 was applied for converting organic matter into C (Fassbender, 1993). Bulk density expressed in g ml^{-1} was estimated by the volume method.

2.3 Statistical Analysis

Analysis of variance (PROC ANOVA) and multiple mean comparisons (PROC MEANS) were carried out (Steel & Torrie, 1992) in order to compare carbon densities from the different compartments among the three coffee studied systems.

A t test was applied to compare organic polyculture system versus non-organic polyculture system. A Pearson Correlation (PROC CORR) was run to explore the relationship between pairs of variables. Moreover, a stepwise regression was run with the variables significantly correlated to carbon in aboveground live biomass by system in order to evaluate the importance of this relationship (SAS, 2008).

3. Results

3.1 Technical Characteristics of the Studied Coffee Systems

Structurally in the three systems coffee is grown under the shade of trees. Eighty one shade species were recorded in the 2 ha-sapling for all the three studied systems. Though, the OIS management system was dominated with 60% of Importance Value (IV) by *Inga* spp. genus (*I. pavoniana*, *I. puctata*, *I. thibaudiana*, and *I. radians*) other four species composed the shade in this system. The OPC and NOPC included individuals of the genus *Inga* spp., but these species had less importance value (*Inga* IV in OPC and NOPC was about 15 and 32%, respectively) than other 31 species (averaging 12 species in 1,000 m^2). In OPC, 397 trees ha^{-1} and 2,105 coffee shrubs ha^{-1} were recorded, while 177 shade trees ha^{-1} and 2,357 coffee shrubs ha^{-1} were accounted in NOPC; finally, 360 shade trees ha^{-1} and 2,357 coffee shrubs ha^{-1} were recorded in OIS system.

All the three systems provided an important number of products such as timber, fuelwood, food, and natural medicines for the farmer's family. Timber was usually used for rural construction and sometimes sold in the local market. Particularly, the OIS was important to farmers in terms of timber and fuelwood, while in polyculture systems (OPC and NOPC), timber and fuelwood were important in addition to fruits.

In polyculture systems, *i.e*, OPC and NOPC, the canopy presented three strata of woody species, the lowest with 7 and 14 m in height, and a third stratum which is composed of a reduced group of emergent trees around 18 m in height. In OIS management system, one to two strata of 5 and 7.6 m in height were recorded.

The most important species which composes the coffee shade in polyculture systems, both OPC and NOPC, were among the following: *Heliocarpus* aff *popayensis*, *Nectandra salicifolia*, *Cupania dentata*, *Liquidambar styraciflua*, *Croton draco*, *Cornus disciflora*, *Oecopetalum mexicanum*, and *Vernonia deppeana*, in addition to some individuals of *Inga* spp. (Figure 2).

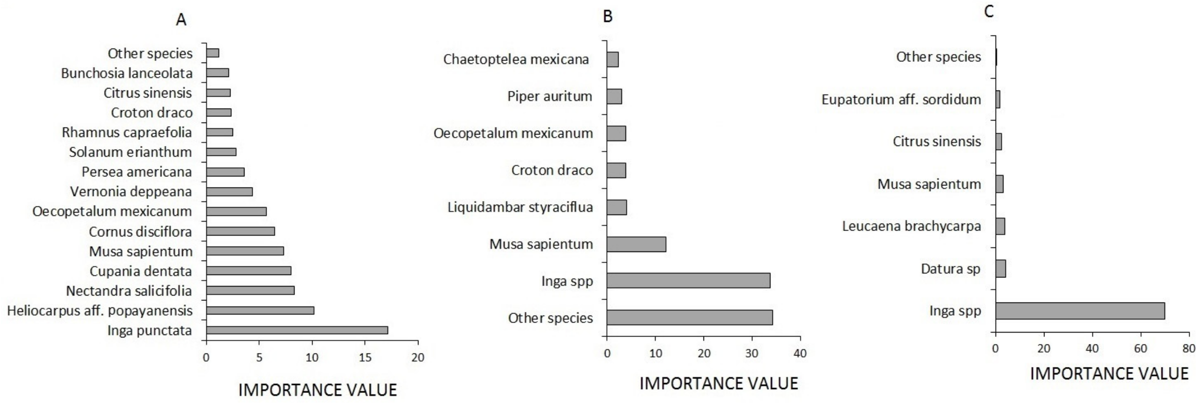


Figure 2. Importance value of the species which composes the coffee shade (A, OCP system; B, NOCP system; C, OIS system)

3.2 Carbon Stocks

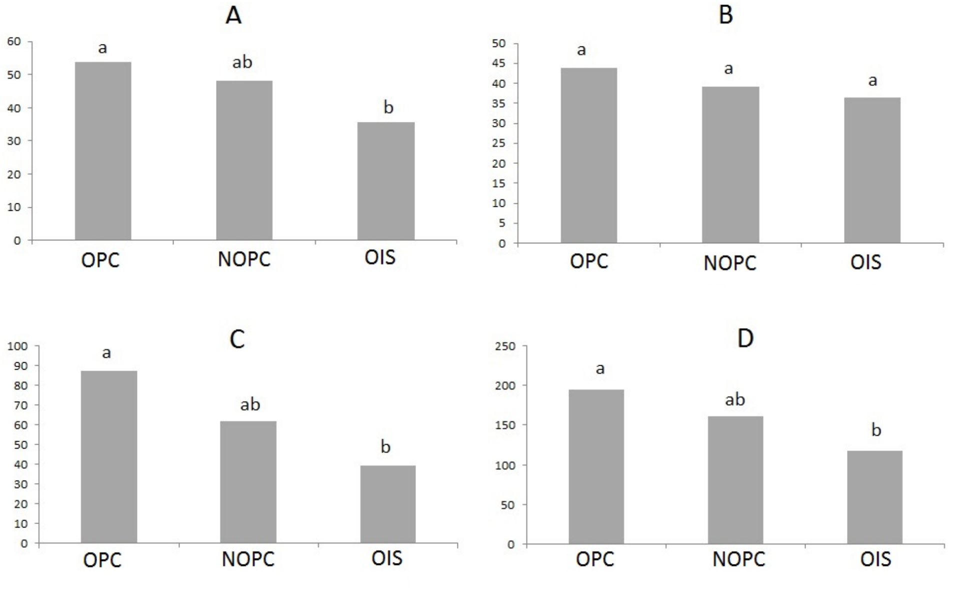
The studied systems averaged values of Total Carbon (TC) density between 134.5 and 194.7 Mg C ha^{-1}. The Soil Organic Carbon (SOC) matter was the largest reservoir in each of the three systems, with more than 50% of TC in the system. Living biomass constituted ≥ 30% and the remainder 3-5% in average was represented by the Dead Organic Carbon (DOC). As seen in Table 2, the carbon stock and the importance of its components responded mainly to organic management and in a lesser extent to shade composition ($p < 0.05$). Regarding the carbon stocks in trees and sapling biomass, and roots, the SOC and the TC parameters were higher in OPC system than in NOPC system (Table 2). These components were statistically similar in both organic systems, OIS and OPC, except in a depth of 0.2-0.3 m, where the polyculture had a higher C content than OIS ($p < 0.05$).

As Figure 3 shows, the components of DOC (fresh litter, dry litter, humus, and fallen branches) did not present significant differences among management systems ($p > 0.05$). Thus, SOC content at depths of 0.1-0.2 and 0.2-0.3 m was higher in OPC system than in NOPC system ($p < 0.01$); moreover, SOC showed no significant differences between systems at 0-0.1 m in depth ($p > 0.05$), as Table 2 and Figure 3 illustrate.

The content of total SOC at 0.1-0.2 and 0.2-0.3 m in depth was positively correlated to the tree biomass ($p < 0.05$, $r^2 > 0.5$); the SOC at 0.1-0.2 m in depth was moreover positively correlated to C in roots ($p < 0.05$, $r^2 = 0.48$), which was, in turn, positively correlated to the total SOC. The three SOC strata were correlated to each other and the SOC decreased with depth in the three systems; however, the lowest rate of reduction ($r^2 = 0.99$) was observed in both organic systems OPC and OIS (-0.01245 and -0.584, respectively), while the NOPC system had the highest reduction rate (-1.0145). These statistical results are gathered in Table 3.

Table 2. Carbon stocks in different reservoirs of live biomass, dead biomass, and soil organic matter (0-0.3 m in depth) in coffee systems with different shade and management (Chiapas Mexico)

Carbon Reservoirs	**OIS**	**Percentage out of the total (OIS)**	**OPC**	**Percentage out of the total (OPC)**	**NOPC**	**Percentage out of the total (NOPC)**
Aboveground live biomass	**46.9**a	**30.4**	**57.5**a	**29.5**	**53.0**a	**39.1**
≥ 0.1 m trees	27.3ab	17.7	37.9 a	19.5	34.1 b	25.2
≥ 0.05 < 0.1 m saplings	0.4ab	0.3	0.9a	0.4	0.3b	0.2
Coffee shrubs	11.0a	7.1	8.8a	4.5	11.4a	8.4
Herbs	0.1b	0.1	0.2ab	0.1	1.1a	0.8
Roots (coarse and fine)	8.0ab	5.2	9.7a	5.0	6.2b	4.5
Dead organic matter	**6.3**a	**4.0**	**6.0**a	**3.1**	**6.7**a	**5.0**
Fallen debris	0.7a	0.4	0.3a	0.2	1.5a	1.1
Total litter	5.6a	3.6	5.7a	2.9	5.2a	3.9
Soil organic matter	**101.1**ab	**65.6**	**131.1**a	**67.4**	**75.8**b	**55.9**
0-0.1 m	39.2a	25.4	43.9a	22.5	36.4a	26.9
0.1-0.2 m	34.4ab	22.3	45.9a	23.6	23.2b	17.1
0.2-0.3 m	27.6b	17.9	41.4a	21.3	16.2c	11.9
Total Carbon	**154.3ab**	100	**194.7a**	100	**134.5b**	100



System Key: **OPC**, Organic Polyculture Coffee; **NOPC**, Non-organic Polyculture Coffee; **OIS**, Organic Inga spp. Shade Coffee

Figure 3. Carbon components in three different coffee systems in Northern Chiapas, Mexico (A, aboveground carbon; B, soil organic carbon at 0- 0.1 m in depth; C, soil organic carbon at 0.1- 0.3 m in depth; D, total carbon)

Table 3. Results of the correlation analysis of the variables aboveground carbon, root carbon and soil organic carbon in depths of 0-0.1, 0.1-0.2 and 0.2-0.3 m

Carbon components	0-0.1 m SOC	0.1-0.2 SOC	0.2-0.3 SOC	Total SOC
Trees	0.3018	0.5717	0.4952	0.5314
	0.196	*0.0084*	*0.0264*	*0.0159*
Saplings	0.0093	0.2168	0.4899	0.2851
	0.9700	*0.3726*	*0.0283*	*0.2230*
Coffee shrubs	-0.2632	-0.2162	-0.2853	-0.2915
	0.2621	*0.3600*	*0.2227*	*0.2124*
Herbs	-0.2312	-0.3401	-0.3051	-0.3382
	0.3266	*0.1423*	*0.1909*	*0.1447*
Roots	0.2159	0.4824	0.4032	0.4292
	0.3606	*0.0312*	*0.7779*	*0.0590*
0-0.1 m SOC		0.6282	0.6093	0.8410
		0.0030	*0.0044*	*<0.0001*
0.1-0.2 m SOC			0.6003	0.8903
			0.0010	*<0.0001*
0.2-0.3 m SOC				0.8238
				<0.0001

Pearson Correlation Coefficients and Prob > |r| under H0: Rho = 0 (in italics).

4. Discussion

Results showed that organic management in coffee system is a crucial factor for storing carbon, especially in the soil organic matter which was the major component of carbon stocks, as in other coffee plantations and agroforestry systems (Hutchinson et al., 2007; Roncal et al., 2008; Dossa et al., 2008; Soto-Pinto et al., 2010; Schmitt-Harsh et al., 2012). The organic polyculture system showed its ability to produce more biomass, up-taking, recycling, and storing more carbon in soil and shade vegetation than the non-organic system, as shown by the C stocks in trees, saplings and soil, confirmed by the significant correlation between the aboveground biomass and SOC content at 0.1-0.2 and 0.2-0.3 m in depth. In addition, out of the SOC stock, the upper layer (0-0.1 m) was the richest in carbon, decreasing with depth as reported in other researches (Loranger et al., 2002); however the rate of decline in the organic polyculture was lower compared to the non-organic polyculture, probably due to the contribution of composts, litter, and fallen branches.

It is known that well-managed compost may contain up to 40% of organic carbon, and falling branches and litter contribute significantly to the fertility of agroforestry systems (Palm, 1995; Sánchez et al., 1999). This can be confirmed by the significant correlation among the three soil layers assessed in this study. The contribution of litter to total carbon was as a result of the accumulation of leaves, stems, and branches, a role of trees highlighted in agroforestry (Beer et al., 1998; Schroth & Sinclair, 2003; Palm et al., 2005); in turn, litter is one of the most constant compartments in the three studied management systems. In this regard, the role of *Inga* spp. may have central importance due to its high deciduousness, even in the polyculture systems where these species reaches between 15-30% of importance value in comparison to more than 60% of *Inga* spp. shade system; however, this question has not been studied enough. The high variability in the compartment of fallen branches (> 50%) is also probably due to tree and coffee-shrubs pruning, which determine in some way the amount of woody material on the ground along with falling leaves (Palm, 1995; Dossa et al., 2008). In addition, organic production systems increased soil fertility by means of augmenting pH, P, and K compared to conventional coffee systems (Haggar et al., 2011).

Furthermore, the vegetation composition of the system was also important in determining the ability to accumulate carbon. Although, other scientific studies have reported that simple plantations, with 2-3 species, can accumulate high amounts of carbon in aboveground biomass (Palm, 1995), traditional coffee polyculture systems had ten times more biomass than simple coffee plantations (Peeters et al., 2003; Soto-Pinto et al., 2010); however, other authors have reported no differences in carbon stocks in coffee plantations with different shade composition (Méndez et al., 2009).

Apparently, different species at each site perform the same function of carbon accumulation and carbon stocks depending more on tree and sapling density, wood density, tree management, and soil management (Palm, 1995; De Jong et al., 1997; Van Noordwijk et al., 2002; Montagnini & Nair, 2004; Chave et al., 2005; Soto-Pinto et al., 2007; Häger, 2012). Nevertheless, the ability of coffee systems to provide other ecosystem services, such as biodiversity conservation, erosion control, and pollination, is closely related to its complexity and diversity (Somarriba et al., 2004; Srivastava & Vellend, 2005; Perfecto et al., 2007; Philpott et al., 2008a; Vergara & Badano, 2009; Tscharntke et al., 2005, 2011).

In the present study, the total carbon stocks stored in trees, in all the three management systems, were higher than those found in coffee plantations in Costa Rica and El Salvador (Häger, 2012; Méndez et al., 2009) and similar to those reported for others in Togo and Guatemala (Dossa et al., 2008; Schmitt-Harsh et al., 2012). Organic coffee polyculture showed similar carbon stocks to low tropical forests in Guatemala (Schmitt-Harsh et al., 2012), medium semi-humid forest in Mexico (Orihuela-Belmonte et al., 2013), and other high covered agroforestry systems in Mexico, such as improved fallows, Taungya, and silvopastoral systems (Soto-Pinto et al., 2010; Soto-Pinto & Armijo-Florentino, 2014). Thus, the organic management could be much more important to increase not only the carbon in shade vegetation, but significantly, in the soil; litter deposition, humus content in the first soil layer, and the role of shade vegetation to preserve soil and carbon content are of paramount importance at landscape and global scales (Soto-Pinto et al., 2010; Häger, 2012; Palm et al., 2014).

Although much of the loss of carbon into the atmosphere come from the change in land use from forestry to less-coverage agriculture, loss of soil carbon are partially reversible with agriculture involving organic management and high tree cover (van Noordwijk et al., 2002; Don et al., 2011). However, it is necessary to take into account the global process, since it has been reported that coffee farmers invade forests to increase the coffee crop area (Cortina-Villar et al., 2012) or logged the forest to produce coffee, processes by which significant carbon losses may occur in both biomass and soil (van Noordwijk et al., 2002; Van Der Vossen, 2005). Conversion to other production systems with less coverage could have negative environmental consequences, such as large volumes of CO_2 emissions to the atmosphere. Thus, as an example, Moguel and Toledo (1999) reported that about 60% of the coffee areas are grown by a traditional polyculture management in Mexico. In the hypothetical event of changes in government policies or economic shocks that would lead to the elimination of some parts of this area, as product of land use change through burning living biomass and dead organic matter reservoirs, high amount of C would be emitted to the atmosphere, excluding the impacts on soil, biodiversity, and water regulation, among other negative environmental impacts.

The results highlight the importance of coffee to provide the environmental function of carbon sequestration and other services widely discussed in other scientific studies, such as conservation of biodiversity, pollination, regulation of microclimate and extremes events, pest control diseases, and cultural services (Perfecto et al., 2005, 2007; Philpott et al., 2008a, 2008b; Méndez et al., 2010; Solis-Montero et al., 2005; Priess et al., 2007; Ricketts et al., 2004; Vergara & Badano, 2009; Lin, 2007; Siles et al., 2010; Perfecto & Vandermeer, 2006; Vandermeer et al., 2009; Toledo & Moguel, 2012). According to the challenging economic situation being experienced by the coffee sector (Bray et al., 2002), it would be essential to implement new actions that promote sustainable practices and, in turn, improve farmer's income.

5. Conclusions

The coffee system structure and soil management were factors determining carbon stocks. The organic polyculture system had higher total carbon stocks, C in tree and sapling biomass, and C in soil (0.1-0.2 and 0.2-0.3 m in depth). In the present study, organic coffee polyculture, non-organic coffee polyculture, and *Inga* spp.-shade coffee systems stored 194.69, 134.49, and 154.28 Mg C ha^{-1} of total carbon, respectively.

The highest reservoir was soil organic matter, contributing between 56 and 70% of the total carbon stock in the system. Organic coffee polyculture, non-organic coffee polyculture, and *Inga*-shade coffee stored 37.9, 34.1, and 27.3 Mg C ha^{-1}, respectively, in tree biomass (only trees $\geq$ 0.1 m of DBH); approximately 6.3 Mg C ha^{-1} was stored in dead organic matter by each of the three systems.

The total carbon stock, mainly from organic coffee, was higher than those reported for other similar coffee plantations in Central America and similar to some dry and semi-humid forests and other agrisilvicultural systems in Mexico. Accordingly, the management under the organic polyculture system can be very important in order to store carbon in shade vegetation and soil, process of top significance at landscape and globally.

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