Scientific Research Publishing

Soil Carbon Storage in Experimental Forest Plantations with Tropical Species

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Abstract

Forest ecosystems represent a third of the total organic carbon (TOC) stored in the soil. However, studies still need to be carried out to generate reliable information on its soil carbon storage potential in an experimental plantation. Therefore, the objective of this research was to determine the storage of total organic carbon (TOC) in the soil in two experimental forest plantations with tropical species, located in the state of Nayarit, México. The research was carried out in two experimental plantations with tropical species, located at the Santiago Ixcuintla Experimental Field (CESIX) and at the El Verdineño Experimental Site (SEEV). The established species are *Swietenia macrophylla* King (mahogany), *Cedrela odorata* L. (cedar) and *Tabebuia rosea* Bertoil (pink trumpet-tree). In addition, data from dasometric variables were used in order to define if any of these variables had a similar variation to the soil TOC stock by species. The sampling was done under a randomized block experimental design in each experimental forest plantation (CESIX and SEEV). Nine composite samples were collected in the soil under the tree species at a depth of 0 - 30 cm, and 1.5 m distance from the tree. To determine the soil TOC, an elemental analyzer with a thermal conductivity detector Thermo Scientific (Flash 2000) was used. The results showed that TOC presented mean values of 103.60 and 219.98 t·ha⁻¹ at a depth of 0 - 30 cm in CESIX and SEEV respectively. The highest TOC was obtained in soil under mahogany; 142.95 t·ha⁻¹ in CESIX and 284.41 t·ha⁻¹ in SEEV. The analysis of the differences in TOC between the two plantations was highly significant. In the analysis of the species, it showed a statistically significant difference ($p < 0.0001$), defining that the soil under the mahogany, in general, presented the highest stock of TOC. Regarding the TOC in the soil plantation and the dasometric

variables, none of the variables analyzed showed the same behavior in its variability.

Keywords

Carbon Sequestration, Dasometric Variables, Tropical Trees

1. Introduction

In recent decades, the importance of forest ecosystems has been recognized in mitigating global climate change, due to their high carbon capture and storage capacity. Specifically, these ecosystems have the capacity to store between 1.3 and 2 times the amount of CO_2 present in the atmosphere C (Lorenz & Lal, 2009; Houghton, 2007).

Due to the importance of forest ecosystems in mitigating global climate change, in recent decades worldwide, commercial forest plantations have been promoted (CONAFOR, 2011; Cotler et al., 2020). An example of its importance is that they can store 39.4 and 64.5 t C ha^{-1} (Cerda Bustillos et al., 2013; Andrade et al., 2013).

On the other hand, the tree structural attributes are especially important in a forest plantation, the fundamental tree variables involving in a forest productivity plantations are; diameter at breast height, mean height, basal area and volume. Moreover, abiotic factors such as; climate, annual average temperature and annual precipitation are correlated with forest productivity either to soil carbon stock (Amundson, 2001; Kuznetsova et al., 2021).

Nevertheless, tree species in a forest plantation has been reported an important factor related to soil C storage, because the litter inputs in soil may vary depending on tree species in the same plantation (Binkley & Giardina, 1998; Chen & Li, 2003; Framstad et al., 2013; Lukina et al., 2020). Another, authors have been reported the correlation between tree species and C and N stock in the soil (Chen & Li, 2003; Han et al., 2017; Augusto et al., 2002). Besides, soil type and parental material (Angst et al., 2018), type of vegetation (Galicia et al., 2016) and the age of the forest site (Casiano-Domínguez et al., 2018), are important for soil carbon storage.

Therefore, estimates of C stocks in forests soil have become relevant at global, national, regional and local scale (Li et al., 2012; Han et al., 2017; Kim et al., 2017).

In this context, research regarding soil C in natural forest has been reported by several authors; Jordán et al. (2007) mentioned about 124 t·ha^{-1} (in the Los Alcornocales Natural Park in Cádiz, Spain) at a depth of 0 - 30 cm, in clay and/or calcareous soil. The authors also mentioned C stock between 76 and 115 t·ha^{-1}, in soils of alluvial origin. Martínez-Navarro et al. (2020) evaluated the soil organic carbon concentration in a temperate forest (Pinus - Quercus spp. stratum, Q = Quercus spp. Stratum) of the Hueyapa River watershed, within the

upper 30 cm. They reported soil organic carbon (SOC) fluctuation between 32.71 and 96.68 t C ha⁻¹, an average of 65.52 t·ha⁻¹.

Moreover, the tropical forest potential to sequester C in soil is of particular interest. According to (Jobbágy & Jackson, 2000) about 30% of the soil carbon stock in the planet is in tropical forest. The carbon sequestration potential particularly in tropical forests, is mainly thru conservation of existing forests, reforestation and agroforestry (Lasco & Pulhin 2003). Lewis et al. (2009) and Malhi (2010) stated that the tropical forest can sequester about 1.3×10^9 t C yr⁻¹.

Several researches have been carried out in forests with tropical species. Lasco & Pulhin (2006) reported a SOC about 30 to 43 t·ha⁻¹ in the plantations at La Mesa Watershed near Manila. Also, Pulhin (2007) in Lasco & Pulhin 2006 mentioned 14 t·ha⁻¹ soil C in a tropical forest with mahogany. Racelis et al. (2019) reported SOC of 72.63 t·ha⁻¹ in a large leaf Mahogany forest plantation, where an increment of 142% was detected in a 10-year period, corresponding to 42.58 t·ha⁻¹. Furthermore, the C amount increases to 104 t·ha⁻¹, adding soil and necromass sinks. Sierra et al. (2012) studied the accumulation rates of total carbon in a regrowing tropical forest in the Porce region of Colombia, they reported soil carbon average of 66.5 ± 28.1 t C ha⁻¹, in the first 30 cm which represented the second most important ecosystem carbon pool in the research. Saimun et al. (2021), conducted a research at two tropical-protected areas in Bangladesh, the Satchari National Park (SNP), and Khadimnagar National Park (KNP). The authors mentioned soil carbon about 77.1 t·ha⁻¹ in SNP and 130.5 t·ha⁻¹ in KNP.

According to the above, most of the publications related to the total organic carbon in tropical forest plantations were done in Asia and South America, in México there is scarce information about the topic. In this context, more studies are necessary to generate reliable information on the potential for carbon storage in the soil, under different scenarios of tropical forest plantations. The objective of this research was to determine the amount of total organic carbon stored in the soil, under different tropical species, of two experimental forest plantations located in the state of Nayarit, México. In addition, data from dasometric variables was comparatively analyzed in relation to each species, to define if its variation is similar to the variation in the soil C stock.

2. Materials and Methods

2.1. Study Area Location

The experimental forest plantations included in this research were established in the Experimental Field "Santiago Ixcuintla" (CESIX), and the Experimental Site "El Verdineño" (SEEV), belonging to the Forestry, Agricultural and Livestock Research National Institute (INIFAP). The Santiago Ixcuintla Experimental Field is located in the Municipality of Santiago Ixcuintla, Nayarit, at km. 6 of the México-Nogales International Highway (Figure 1).

The plantations were established in August 1994, with genetic material obtained from the "Camichín de Jauja" forest nursery (Tepic, Nayarit), and were
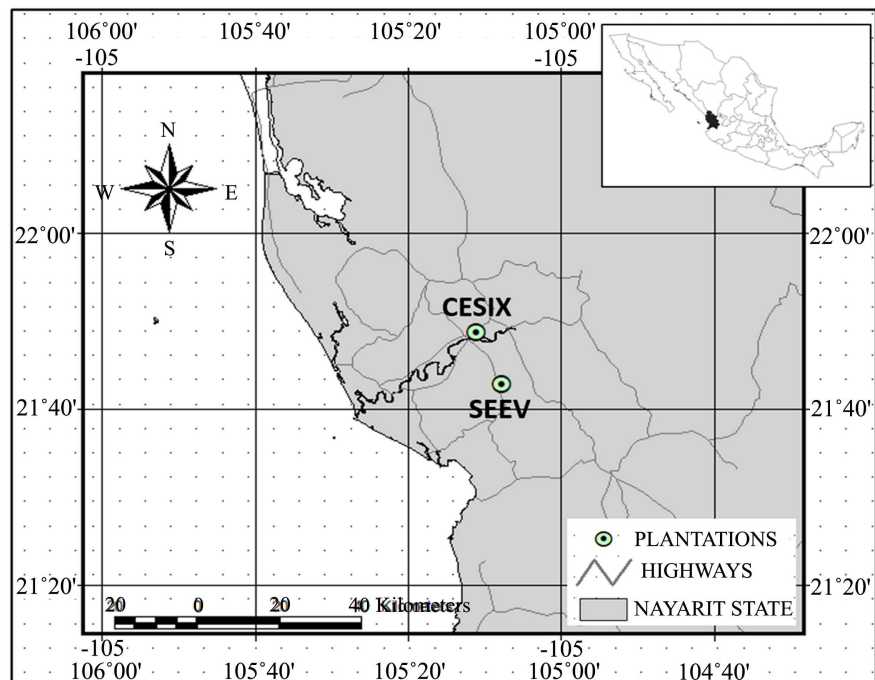
Figure 1. Forest plantations location: "Santiago Ixcuintla" Experimental Field (CESIX) and "El Verdineño" Experimental Site (SEEV).

established under checkered design, with a distance between lines and trees of 4 × 4 m. The species in the two experimental forest plantations are: *Swietenia macrophylla* (mahogany), *Cedrela odorata* (cedar) and *Tabebuia rosea* (pink trumpet-tree). Table 1 shows the characteristic of the two study location.

2.2. Experimental Design

Since we wanted to determine if there was a significant difference between plantations and between species, the sampling was done under a randomized block experimental design in each experimental forest plantation (CESIX and SEEV). Three subsamples (which were mixed to obtain one composite sample) were collected in the soil under the tree species (mahogany, cedar and pink trumpet-tree), whose individuals were grouped within each plantation, in total, 9 composite samples were obtained for each locality for a total of 16 samples analyzed. The samples were collected at a depth of 0 - 30 cm, at a distance of 1.5 m from the tree.

2.3. Samples Collection

The samples collection for the determination of total organic carbon (TOC) was carried out in September 2019. They were collected in a soil profile of 0 - 30 cm, with the arrangement mentioned in the experimental design. The samples were duly identified and placed in plastic bags for their transfer to the laboratory and their subsequent analysis in the Soil Fertility laboratory of the Experimental Field (Santiago Ixcuintla, Nayarit).

Table 1. Characteristics of the two study locations. CESIX = Santiago Ixcuintla Experimental Field; SEEV = El Verdineño Experimental Site.

Characteristics	CESIX	SEEV
Geographical location	21˚49'24"N 105˚11'3"W	21˚42'12"N 105˚07'48"W
Elevation (meters)	10	50
Climate	Aw1	Aw1
Average annual temperature (˚C)	25.0	22.0
Tmax (˚C)	39.0	32.0
Tmin (˚C)	8.5	18.0
Precipitation (mm)	1300	1200
Soil type	Fluvisol eutric (medium texture)	Pelic Vertisol (fine texture)

Source: Medina et al. (1998).

2.4. Sample Preparation

Drying of the samples. The soil samples were spread in stainless steel trays, to avoid contamination. They were placed in a ventilated and sunny area for approximately five days, the time necessary for it to dry.

Initial weighing of the samples. Two types of weighing were carried out for the soil samples: 1) Wet weight, and 2) Dry weight. Due to the fact that the samples were transferred in plastic bags, unlike what is indicated in the AS-01 protocol (Preparation of the soil sample for mainly physical and soil fertility determinations) issued by SEMARNAT (2002), it is advisable not to weigh the bags immediately, but until after the soil is dry. In this way, the bags are weighed without soil residue.

Cleaning of samples. First, coarse particles and all material that could contaminate the sample, such as plants, roots and trunks, were manually separated.

Crushing and sieving of the samples. Each sample was placed in a grinder and subsequently sieved through a No.10 sieve (2 mm). The gravels and rock fragments, which did not pass through the sieve were removed from the rest of the sample. These coarse particles (>2 mm) were separated and weighed; Bulk density of the soil, estimated by the graduated cylinder method, was also estimated.

The soil fraction less than 2 mm was the sample that was analyzed for carbon. This was passed through a cracker to homogenize it and obtain 15 g of soil, which were ground in an Agate mill that allowed obtaining fine soil, which was passed through a No. 100 sieve (149 microns) (ISO Standard). This sample was placed in envelopes for later analysis.

2.5. Sample Analysis

To determine the soil TOC, an elemental analyzer with a thermal conductivity detector Thermo Scientific (Flash 2000) was used, according to the protocol

proposed by the National Network of Laboratories for the Analysis, Use, Conservation and Management of Soil (REDLAB).

Between 30 to 40 mg of each soil sample were weighed, which were placed in tin capsules, then in a sample plate that feeds the equipment. Once the equipment was stabilized, the relevant instructions for the corresponding analysis were activated.

2.6. Dasometric Variables Data

The dasometric variables results utilized in this research were from filed data obtained in 2018, in the two plantations under study. Table 2 shows the dasometric variables, the method and the equipment.

2.7. Statistical Analysis

The evaluations of soil TOC stock were evaluated based on a factorial design (2 × 3): 1) two forest plantations; and 2) three species for each plantation. In this way, a series of variance analyzes were carried out, where first the ANOVA ($p \leq$ 0.05) corresponding to the factorial design was determined. Subsequently, it was defined if there was any statistically significant difference between the species corresponding to each plantation.

Once the ANOVAs regarding soil TOC stock were determined, the following dasometric variables of each species were analyzed: crown radius, clean stem height, stump diameter, normal diameter, total height, crown height, crown area and crown volume (The results of the dasometric variables of an evaluation carried out in 2018, in the two plantations were used). This in order to define if any of these variables had a similar behavior to the soil TOC stock. These analyzes were made for each of the forest plantations (CESIX and SEEV).

3. Results

The average results of the determination of total organic carbon in the soil of the two plantations under study are shown in Table 3. On average, the TOC presented values with marked difference in the two locations, in such a way that the

Table 2. Dasometric variables used in this research, method and equipment.

Variable	Method	Equipment
Clean stem height	Angle measurement	Clinometer
Stump diameter	Direct measurement	Diameter tape
Normal diameter	Direct measurement	Diameter tape
Total height	Direct measurement	Stadal
Crown height	Angle measurement	Clinometer
Crown area	Area equation	Linear tape
Crown volume	Volume equation	Linear tape/clinometer
Crown radius	Direct measurement	Linear tape

Table 3. Soil total organic carbon, by plantation and by species. CESIX = Santiago Ixcuintla Experimental Field; SEEV = El Verdineño Experimental Site.

Plantation	Species	Common name	t·ha⁻¹
	Cedrela odorata	Cedar	83.49
CESIX (Fluvisol Soil)	*Swietenia macrophylla*	Mahogany	142.95
	Tabebuia rosea	Pink trumpet tree	84.37
			103.60 ± 34.07
	Cedrela odorata	Cedar	190.78
SEEV (Vertisol Soil)	*Swietenia macrophylla*	Mahogany	284.41
	Tabebuia rosea	Pink trumpet tree	184.75
			219.98 ± 55.87

TOC in SEEV represented more than double that of the TOC contained in the soil of CESIX. The results showed that the highest TOC amount were obtained in the soil samples collected under mahogany, both in the CESIX and in the SEEV. However, again, the TOC stock under mahogany soil was more than double in SEEV, compared to CESIX mahogany, resulting in a difference of 141.46 t·ha⁻¹.

On the other hand, the average TOC stock in soil under cedar and pink trumpet-tree, in the CESIX plantation, presented a minimum difference of 0.88 t·ha⁻¹. A similar trend was presented in the SEEV, with a difference of 6.03 t·ha⁻¹.

3.1. Carbon Stock Variation

The analysis of the differences of the carbon stock, between the two plantations, was highly significant (Table 4), which was expected because the TOC in the SEEV soil is more than double that in the CESIX plantation. However, in the case of the analysis of the species, although, if a statistically significant difference was determined ($p < 0.0001$), the results of the Tukey test (Figure 2) defined that: 1) the lowest content of stored TOC corresponded to the ground under the trees of pink trumpet tree and cedar; and 2) on the contrary, the soil under mahogany, in general, was the species that presented the highest TOC stock.

Comparing the TOC stored in the soil under the species that are located in the SEEV, a significant difference was presented (Table 4). In accordance with this, Figure 3 shows, firstly, a different response to the one presented considering the total of the species (SEEV and CESIX). In this case, mahogany is the species under which the highest soil stock was evaluated, being different from TOC stored in the soil under cedar and pink trumpet tree. However, between the latter it was not determined that there was a statistically significant difference.

As in the SEEV, the stock of TOC stored in the soil under the species that are located in the CESIX presented a significant difference (Table 4). Similarly, it is observed that mahogany is the species under which the highest soil stock was evaluated (Figure 4), being different from TOC stored in the soil under cedar and pink trumpet-tree. However, between the latter it was not determined that there was a statistically significant difference.
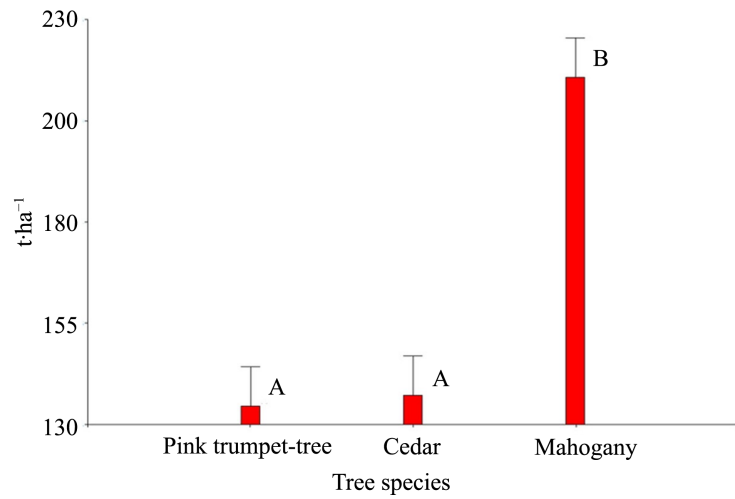
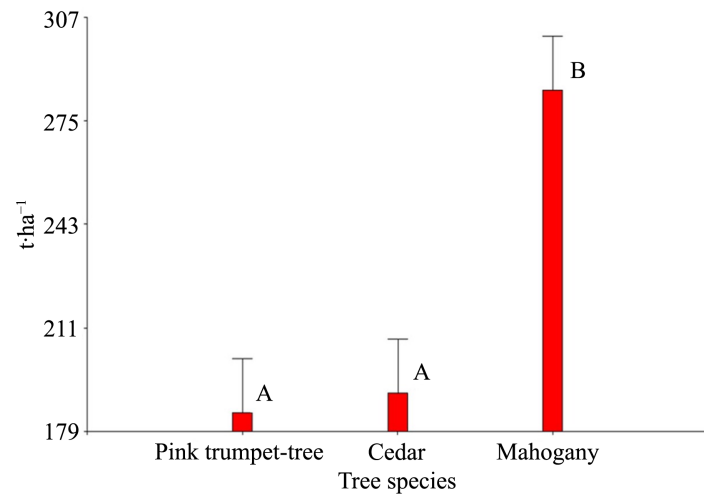**Figure 2.** Soil total organic carbon stock comparison, in the SEEV and CESIX species as a whole.

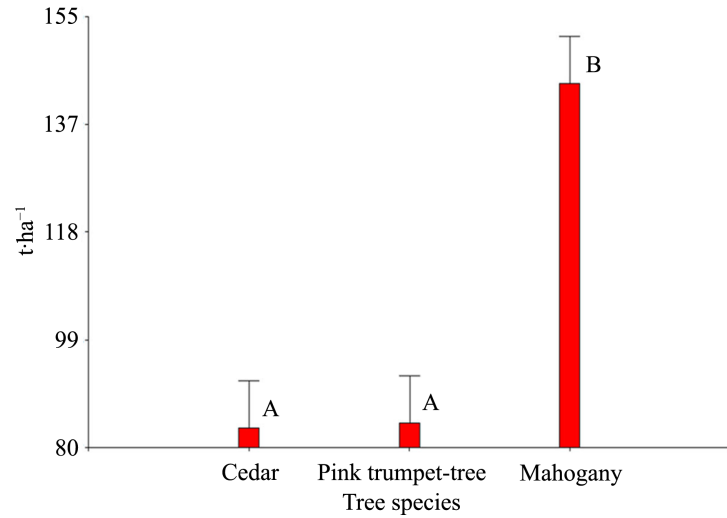**Figure 3.** Soil total organic carbon stock comparison, in the SEEV species.

Figure 4. Soil total organic carbon stock comparison, in the CESIX species.

Table 4. Soil total organic carbon, by plantation and by species. CESIX = Santiago Ixcuintla Experimental Field; SEEV = El Verdineño Experimental Site.

Comparison	Factor	F	p-value
Between plantations	Plantation	112.53	<0.0001
	Species	22.67	<0.0001
SEEV	Species	11.36	0.0091
CESIX	Species	17.81	0.0030

3.2. Dasometric Variation (CESIX)

In the plantation located in the CESIX, 513 trees were evaluated, corresponding to the species of mahogany, cedar and pink trumpet-tree, which presented, as a whole, the following means of the dasometric variables: Normal diameter (DN) = 24.49 cm; Stump diameter (DT) = 29.48 cm; Total height (AT) = 12.54 m; Clean stem height (AFL) = 4.21 m; Crown diameter (DC) = 5.76 m; Crown area (AC) = 31.52 m²; Crown height (ALC) = 8.33 m; Crown radius (RC) = 3.52 m; Crown volume (VC) = 272.68 m³. Table 5 presents the same statistics, but for each of the species that were located in the CESIX plantation.

Each of these dasometric variables is comparatively analyzed in relation to each species, this with the purpose of defining if its variation is similar to the variation in the TOC stock in the soil (Figure 5). Where there is no significant difference between cedar and pink trumpet-tree, but there is between these two variables with mahogany. According to this, none of the variables analyzed showed the same behavior in its variability, where one would expect mahogany, (which presented the highest stock of TOC in the soil) to be the species with the largest dimensions. On the contrary, the pink trumpet-tree is the species that presents the highest values in the dasometric variables, and, in most cases, it is significantly different from the other two species. Regarding cedar and mahogany, these species alone did not present a significant difference in relation to AFL and DT. Whereas, when comparing cedar with pink trumpet-tree, there was only no difference in relation to DN, AC and RC. In the cases of AT, DC, ALC and VC, the three species were significantly different.

3.3. Dasometric Variation (SEEV)

In the SEEV plantation, 422 trees were evaluated, corresponding to the species of mahogany, cedar and pink trumpet-tree, which presented, as a whole, the following means of the dasometric variables: Normal diameter (DN) = 22.58 cm; Stump diameter (DT) = 28.21 cm; Total height (AT) = 11.23 m; Clean stem height (AFL) = 3.33 m; Crown diameter (DC) = 3.49 m; Crown area (AC) = 12.56 m²; Crown height (ALC) = 7.89 m; Crown radius (RC) = 2.84 m; Crown volume (CV) = 139.60 m³. Table 6 presents the same statistics, but for each of the species that were located in the SEEV plantation.

As in the CESIX plantation, each SEEV dasometric variable was comparatively analyzed in relation to each species, to define if its variation is similar to the

Table 5. Statistics for each species by plantation and by species. CESIX = Santiago Ixcuintla Experimental Field.

Species	Variable	n	Mean	S.D.	V.C.	Minimum	Maximum
Mahogany	DN	183	24.63	7.32	29.71	8.80	47.00
Mahogany	DT	183	28.78	7.70	26.74	10.40	50.90
Mahogany	AT	183	11.88	2.46	20.72	5.34	18.85
Mahogany	AFL	183	3.59	1.97	54.86	1.07	14.84
Mahogany	DC	183	6.34	2.45	38.56	2.20	15.78
Mahogany	AC	183	36.27	28.54	78.69	3.80	195.45
Mahogany	ALC	183	8.29	2.94	35.47	0.00	15.78
Mahogany	RC	183	3.66	1.15	31.38	0.55	6.86
Mahogany	VC	183	264.31	219.86	83.18	0.70	1353
Cedar	DN	128	21.31	6.42	30.11	7.00	41.40
Cedar	DT	128	27.48	7.35	26.75	10.00	50.20
Cedar	AT	128	10.02	2.87	28.66	3.70	14.95
Cedar	AFL	128	3.54	2.24	63.33	1.71	13.08
Cedar	DC	128	3.64	1.98	54.50	0.00	10.36
Cedar	AC	128	13.48	13.90	103.08	0.00	84.22
Cedar	ALC	128	6.48	3.06	47.32	0.00	11.98
Cedar	RC	128	2.53	1.09	43.03	0.68	5.46
Cedar	VC	128	106.7	120.12	112.58	1.33	683.22
Pink Trumpet-tree	DN	202	26.36	9.04	34.31	4.00	58.30
Pink Trumpet-tree	DT	202	31.29	10.30	32.81	6.50	68.30
Pink Trumpet-tree	AT	202	14.73	3.46	23.51	3.08	22.10
Pink Trumpet-tree	AFL	202	5.2	3.49	67.15	0.95	20.35
Pink Trumpet-tree	DC	202	6.58	2.44	37.08	0.17	12.43
Pink Trumpet-tree	AC	202	38.65	25.35	65.59	0.02	121.35
Pink Trumpet-tree	ALC	202	9.53	4.35	45.66	0.00	19.26
Pink Trumpet-tree	RC	202	4.03	1.53	37.88	0.50	7.12
Pink Trumpet-tree	VC	202	385.45	327.66	85.01	0.52	1512.72

DN = normal diameter (cm); DT = Stump diameter (cm); AT = Total height (m); AFL = Height of clean stem (m); DC = Crown diameter (m); AC = Crown area (m^2); ALC = Crown height (m); RC = Crown radius (m); VC = Crown volume (m^3).

Table 6. Soil total organic carbon stock, by plantation and by species. SEEV = El Verdineño Experimental Site.

Species	Variable	n	Mean	S.D.	V.C.	Minimum	Maximum
Mahogany	DN	73	21.55	5.66	26.26	10.50	42.80
Mahogany	DT	73	25.08	6.56	26.15	3.40	47.50
Mahogany	AT	73	10.11	1.45	14.39	7.15	13.10
Mahogany	AFL	73	2.57	0.91	35.34	1.31	5.20

Continued

Mahogany	DC	73	4.08	1.74	42.61	1.26	10.43
Mahogany	AC	73	15.38	13.64	88.68	1.25	85.36
Mahogany	ALC	73	7.54	1.54	20.43	2.86	10.84
Mahogany	RC	73	2.90	0.67	23.14	1.03	4.53
Mahogany	VC	73	118.75	78.47	66.08	4.58	389.07
Cedar	DN	137	18.74	5.28	28.19	6.90	31.50
Cedar	DT	137	24.61	5.78	23.49	11.00	39.50
Cedar	AT	137	9.43	2.26	23.98	3.68	14.00
Cedar	AFL	137	2.83	1.57	55.55	1.25	11.50
Cedar	DC	137	2.37	1.65	69.40	0.00	6.65
Cedar	AC	137	6.52	8.01	122.85	0.00	34.68
Cedar	ALC	137	6.59	2.32	35.22	0.47	11.27
Cedar	RC	137	2.24	0.87	38.72	0.30	4.38
Cedar	VC	137	68.38	67.13	98.16	0.11	352.58
Pink Trumpet-tree	DN	212	27.45	8.63	31.44	3.40	44.90
Pink Trumpet-tree	DT	212	34.95	11.79	33.74	3.05	75.60
Pink Trumpet-tree	AT	212	14.15	3.21	22.70	4.70	20.35
Pink Trumpet-tree	AFL	212	4.60	2.62	57.02	1.52	13.15
Pink Trumpet-tree	DC	212	4.02	2.00	49.68	0.18	8.85
Pink Trumpet-tree	AC	212	15.77	13.96	88.54	0.02	61.51
Pink Trumpet-tree	ALC	212	9.55	3.68	38.56	2.06	16.18
Pink Trumpet-tree	RC	212	3.39	1.28	37.88	0.69	6.07
Pink Trumpet-tree	VC	212	231.67	204.36	88.21	1.35	935.66

DN = normal diameter (cm); DT = Stump diameter (cm); AT = Total height (m); AFL = Height of clean stem (m); DC = Crown diameter (m); AC = Crown area (m²); ALC = Crown height (m); RC = Crown radius (m); VC = Crown volume (m³).

variation in the C stock in the soil (Figure 6). Where there is no significant difference between pink trumpet-tree and cedar, but there is a difference between these two variables with mahogany. According to this, none of the dasometric variables analyzed showed a similar behavior in its variability, where mahogany (which presented the highest stock of C in the soil) would be expected to be the species with the largest dimensions. On the contrary, as in the case of CESIX, the pink trumpet-tree is the species that presents the highest values in the dasometric variables, and, in most cases, it is significantly different from the other two species. The only exception was the crown diameter (DC) and crown area (AC), where both mahogany and pink trumpet-tree show similar variability, which differentiates it from cedar. Regarding cedar and mahogany, these species alone did not present a significant difference in relation to DT, AT, AFL, ALC and VC. While, when comparing cedar with pink trumpet-tree, a statistically significant difference was found in all variables. In the cases of DN and RC, the three species were significantly different.
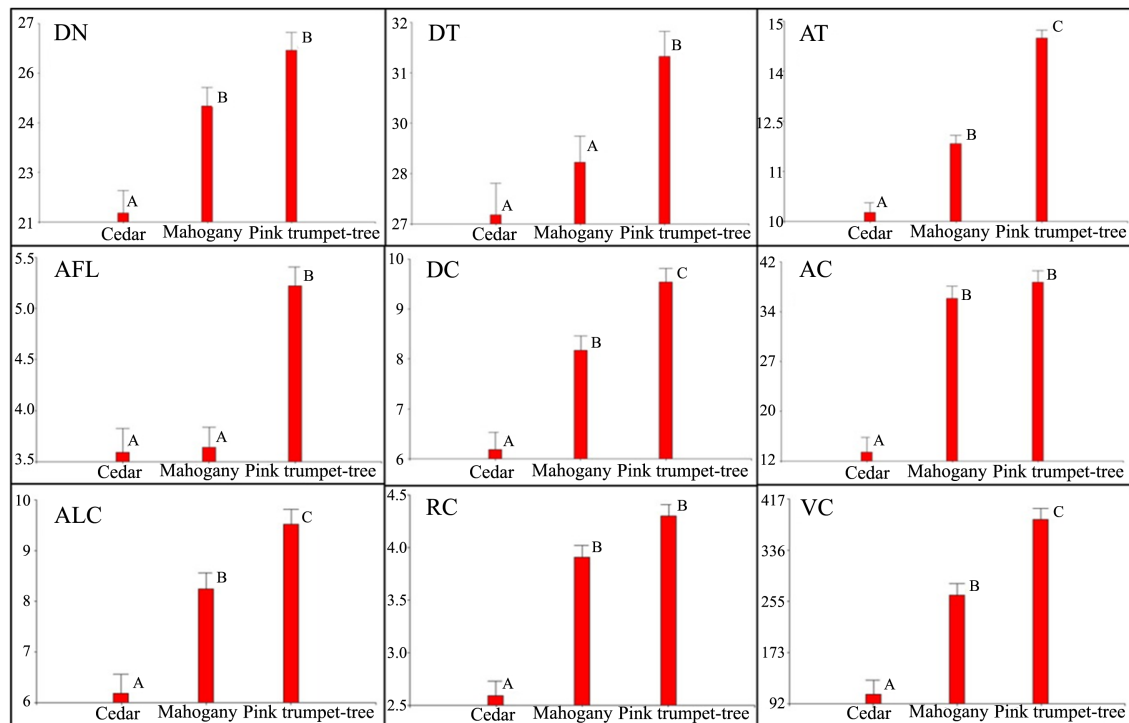
Figure 5. Comparison of the dasometric variables of the species that are located in the CESIX. DN = normal diameter (cm); DT = Stump diameter (cm); AT = Total height (m); AFL = Height of clean stem (m); DC = Crown diameter (m); AC = Crown area (m²); ALC = Crown height (m); RC = Crown radius (m); VC = Crown volume (m³).
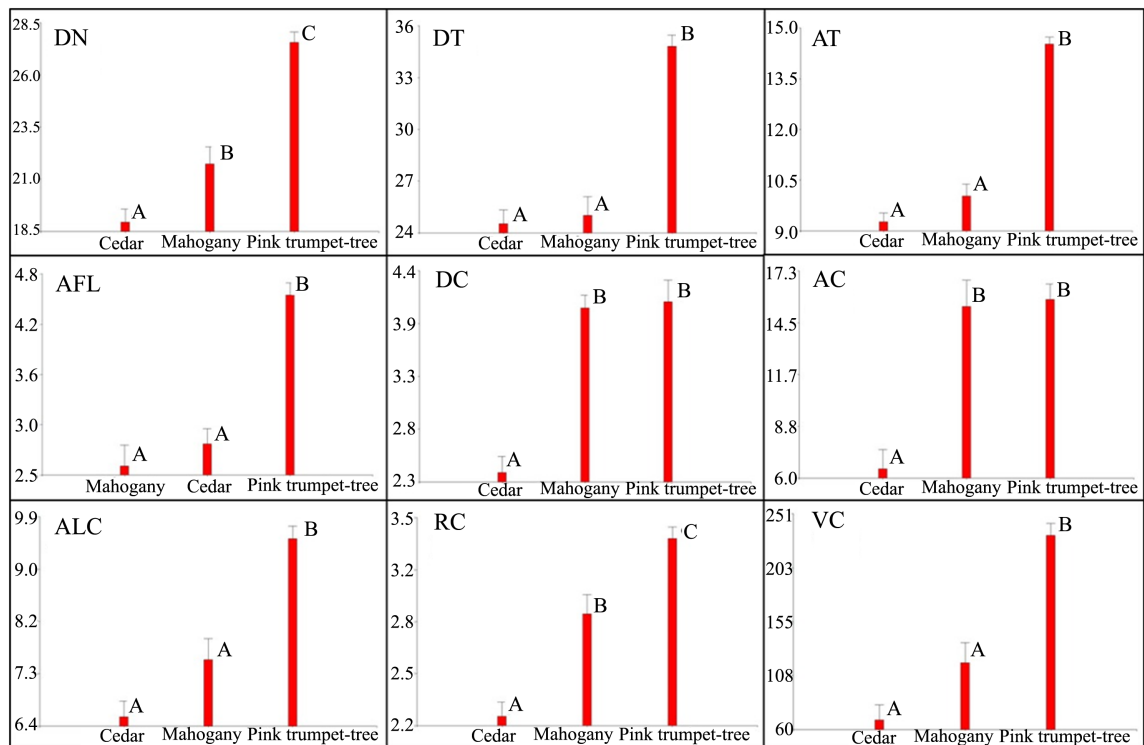

Figure 6. Comparison of the dasometric variables of the species that are located in the SEEV. DN = normal diameter (cm); DT = Stump diameter (cm); AT = Total height (m); AFL = Height of clean stem (m); DC = Crown diameter (m); AC = Crown area (m²); ALC = Crown height (m); RC = Crown radius (m); VC = Crown volume (m³).

4. Discussion

Significant differences were observed in the amount of total organic carbon between the two plantations and among the soil under the tree species. These results can be attributed to abiotic variables such as the climate and a greater adaptation of mahogany in the SEEV plantation. The stock of TOC under mahogany soil showed higher values compared to the TOC in soil under the other species in both plantation (CESIX and SEEV). It is also suggested that the type of soil may have an influence on the amount of soil C, since in CESIX the type the soil is Fluvisol eutric (medium texture) and it is varied with coarse sand in the dikes and heavy clays in settling adjacent to the river basins (Bojórquez et al. 2007). And the type of soil in the SEEV is Pelic Vertisol (fine texture) these soils are mainly located in tropical, subtropical, semi-arid to sub-humid and humid climates with high clay stock (Coulombe et al., 2000). Besides, Saimun et al. (2021), stated that soil carbon is negatively correlated with soil sand%, and Bosatta & Ågren (1997) in Saimun et al., (2021) stated that the increases of sand% in soil decreases the organic carbon decomposition. According to Bojórquez et al. (2006), Vertisols are soils with great productive potential. It is suggested that the soil characteristics could influence the higher soil C stock in SEEV plantation.

Moreover, the species at the plantation are particularly important, since the root and litter production, income higher organic inputs which eventually increases the soil carbon (Brown & Lugo, 1992). Therefore, the soil carbon accumulation rate may be influenced by environmental factors and differences in species (Brown & Lugo, 1992). In this context, the *Swietenia macrophylla*, which was the specie under the highest amount of carbon in the soil was obtained, is also called large-leaf mahogany. Therefore, the species effects must be considered in forest plantations for enhancing C sequestration. According to Racelis et al. (2019) and considering the results in the present study, mahogany has peculiarities that make it a species with high carbon accumulation in soil under the particular environmental and management conditions of this study. It can be suggested that two particular physical characteristics may contribute to the higher C amount in soil under the mahogany at the experimental plantations (CESIX and SEEV): 1) the large leaf, and 2) the high leaf density. Those two characteristics were particularly notables visually at the two plantation under study.

On the other hand, the results obtained in the present research at CESIX with soil TOC average of 103.60 t·ha^{-1} from the three species in the plantation, are bellow to the ranges reported by Jordán et al. (2007), which obtained values around 124 t·ha^{-1} of C in natural forest; Los Alcornocales Natural Park in Cádiz, Spain. Still, the soil TOC average at the SEEV (219.98 t·ha^{-1}) is above to the results reported by Jordán et al. (2007). Moreover, the TOC by specie at the SEEV (184.75, 190.78 and 284.41 t·ha^{-1}, for pink trumpet tree, cedar and mahogany respectively) was above to the ranges reported by Jordán et al. (2007). However,

it is important to comment that the environment and the species were different that the present study. The same tendency as the mentioned before, was observed to the results reported by Rojas-García et al. (2017) about 130 t·ha⁻¹ of organic carbon in soil forest plantation, in reference to the results in this research at the two plantations.

On the other hand, the soil TOC results in the present study were above some research carried out in forest with tropical species reported in the literature. For example, Lasco and Pulhin (2006) reported soil C about 60.1 t·ha⁻¹ in a dipterocarp forest with more than 20 years in Manila, it has to be noticed that the lower soil TOC amount in the present study was 83.49 t·ha⁻¹, value corresponding to the soil under cedar at CESIX plantation. It can be observed that is the double with respect to the Manila plantation. And is remarkable lower in comparison with the results in the soil under mahogany at SEEV with a soil TOC amount about 284.41 t·ha⁻¹. It is important to comment that even though the forest had similar age (about 20-years), the differences may be attributable to the different tree species.

Furthermore, the results reported by Pulhin (2007) in a tropical forest with mahogany were considerably different (14 t·ha⁻¹ soil C) compared to the average results obtained in the present research (142.95 t·ha⁻¹ and 284.41 t·ha⁻¹ at CESIX and SEEV respectively). Additionally, the results in the present research at CESIX, soil TOC under cedar and pink trumpet tree at CESIX plantation were close to the results reported by Racelis et al. (2019) with C of 72.63 t·ha⁻¹ in a large leaf mahogany forest plantation. However, the soil C results reported by Racelis et al. (2019) from mahogany plantation were lower in comparison with the soil TOC amount under mahogany at both plantations under study at CESIX and SEEV respectively.

On the other hand, as a secondary objective, data from the dasometric variables was used to carried out a comparative analysis in relation to each species, to define if its variation is similar to the variation in the TOC stock in the soil. The primary question was whether the mean of soil TOCC varies the same as the means of any of the dasometric variables. In this context, results at CESIX and SEEV demonstrated that, none of the variables analyzed showed the same behavior in its variability, where one would expect mahogany, (which presented the highest stock of TOC in the soil) to be the species with the largest dimensions. It is important to comment that, no literature was found to compare the results of this research regarding the dasometric variables and its similitude with the soil TOC stock. However, Saimun et al. (2021) quantify the tree and soil carbon storage capacity and explored how these carbon storages are associated with average tree height, total tree basal area and stem density in tropical forest ecosystems. They stated, a negative correlation among soil carbon and average tree height (m) ($r = -0.36$, $p < 0.001$), total tree basal area (m² ha⁻¹) ($r = -0.19$, $p < 0.05$) and stem density (trees ha⁻¹) ($r = -0.11$, $p = 0.22$) in a tropical forest ecosystem in Bangladesh. In the present study, no correlation was done among the soil C and the dasometric variables. Therefore, it is desirable to carry out these

correlations between the dasometric variables and the amount of carbon in the soil, it is suggested to do it in subsequent studies.

5. Conclusion

The storage of soil TOC stock under mahogany at the present research was higher than that reported in other forests with tropical species in Asia, even higher than those reported for the same species. According to that, it is necessary to continue investigating, to determine what the particular conditions are that affect higher soil C stock in CESIX and SEEV plantation in Nayarit.

The TOC stock was higher in the soil located under the mahogany trees, attributable to the species due to its larger types of leaf. While no significant difference was found between cedar and pink trumpet-tree. This suggests carrying out a specific analysis of the foliage and aerial biomass of mahogany, to determine if there are particular characteristics that make this species increase the amount of carbon in the soil. According to Brown & Lugo (1992), some species produce more litter and roots and thus, produce more organic inputs, which eventually influence soil carbon. Therefore, additional research is suggested to corroborate the results of this study.

Results demonstrated that the soil C under mahogany has a higher potential to store carbon under the specific environmental conditions presented in this research. Moreover, appropriate management interventions could increase the experimental plantation capacity to sequester and storage carbon in soil. It is expected that both experimental plantations increase the carbon over time, since the soil carbon increases, as the vegetation matures.

The results showed that the amount of carbon in the soil in the two plantations was closer to those reported in temperate forests compared to forests with tropical species even with the same species.

Regarding the analysis of the dasometric variables, these did not present a similar behavior to that of C in the soil, in this context, it is suggested to carry out more in-depth analyses to determine if there are correlations between the dasometric variables and the amount of C in the soil.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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