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Research article

Soil carbon stocks of inceptisols under different land use in the Northern tropical humid region of Honduras

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Abstract: Soil organic carbon (SOC) is important in the carbon cycle and studies in the field are gaining relevance because of its relation to global climate change. In this paper, we report a study of SOC stock (0-200 cm) from a 50 years old secondary forest and a pasture under inceptisols in a floodplain in the tropical humid Caribbean coast of Honduras. Samples were collected at the depths 0-20, 20-40, 40-80, 80-120, 120-160, and 160-200 cm. Total SOC stocks were 89.2±10.9 Mg ha^{-1}, and 72.5±10.0 Mg ha^{-1} for the secondary forest and pasture respectively. The estimated annual increase of SOC stock in the forest is 0.34 Mg C ha^{-1} year^{-1}. SOC stock values were 50.3% and 47.9% of the total (0-200 cm) in the 0-20 cm layer for forest and pasture respectively. SOC distribution at a depth of 0-20 cm were 21.26 g kg^{-1} and 12.09 g kg^{-1} for forest and pasture respectively. Soil texture at the 0-20 cm depth were clay loam, and sandy clay loam, in the forest and pasture respectively. SOC stock in these ecosystems would be reduced if they were converted back to conventional agriculture, particularly in the forest. The forest had higher SOC values because of higher litter input as compared to the pasture, particularly in the upper soil layers, at deeper layers there are no significant differences ($p < 0.05$) and SOC values are low. Compared to most other studies in tropical regions, SOC stock in our study were lower in both ecosystems, this may be due to high precipitation (*ca*. 3200 mm year^{-1}) and high temperatures, rate of decomposition of litter input, general low clay content, and possibly priming effects which we have not addressed. More studies on the SOC stock in Central America with a similar climate are needed to improve our understanding of SOC dynamics and help reducing uncertainty in SOC models.

Keywords: Land-use change, Humid tropics, Soil carbon concentration, Inceptisol, Tropical rainforest, Honduras.

INTRODUCTION

Soil organic matter has received increased attention for its role in the sequestration of CO_2 from the atmosphere. In the C cycle, soil organic carbon (SOC) stock is the largest pool of terrestrial organic carbon, with approximately 2344 Pg (1 Pg = 10^{15} g = 10^9 Mg) at the top 300 cm (Jobbágy & Jackson, 2000), *ca*. 3 times larger than the amount of C stored in above-ground plant biomass (Post *et al*., 1982; Eswaran *et al*., 1993; Jobággy & Jackson, 2000). SOC storage is regulated by the balance of C inputs from biomass and outputs through decomposition (Jenny, 1941; Schlesinger, 1977). Tropical soils store about 30% (384-506 Pg) of the global SOC pool down to 100 cm depth (Eswaran *et al*., 1993; Batjes, 1996). It is estimated that about 1.0 Pg C yr^{-1} from the soil is emitted as CO_2 into the atmosphere, mainly by tropical deforestation (Le Quéré *et al*., 2013). For the decade of 2009-2018, the annual rate of emission from tropical deforestation and other land-use changes was 1.5 ± 0.7 Pg C yr^{-1} (Lal, 2020).

In the search to identify options to limit the global atmospheric warming to 1.5°C (IPCC, 2018) there has been a growing interest in the potential of soils to absorb atmospheric CO_2 and mitigate the warming (Houghton, 2005; Lal, 2016; Lal, 2020). Currently, there is an ambitious goal to increase SOC by 0.4% per year to help mitigate climate change which results from the ratio of total C emissions to the atmosphere and the total SOC stock, 8.9 Pg/2400 Pg (Minasny *et al*., 2017). In the Paris Accord, stakeholders agreed in a voluntary action plan to implement practices that maintain or enhance SOC stocks (Chambers *et al*., 2016; Lal, 2016).

Research on SOC in the humid tropics in Latin America, as indicated by the small number of published studies (Powers & Schlesinger, 2002; Jimenez *et al*., 2007; Chacón *et al*., 2015; de Oliveira, 2017) has not kept pace with studies in temperate climates. Research in humid climates indicates that with increase in temperature, rates of production and decomposition of organic matter increase, but the relative increases of the latter are greater (Schlesinger, 1977; Oades, 1988). Field observations of SOC stocks with tropical land-use changes are highly unrepresentative of most tropical landscapes (Powers *et al*., 2011), in Central America so far, most of the studies were undertaken in Costa Rica as indicated by published studies.

Studies of SOC stock in different regions of the world have traditionally provided results to 100 cm depth (Jobbágy & Jackson, 2000) which may be sufficient in most mineral soils because organic C content declines with an increase in

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soil depth (Scharlemann *et al*., 2014) and it may facilitate comparison of results but it has the disadvantage that not the whole soil-carbon stock is taken into consideration. Currently, there is the need to quantify SOC stock at deeper layers (Sayer *et al*., 2019; Lal, 2020). The contribution of carbon in the deep subsoil-below 100 cm to the total carbon pool is important, particularly, in soils of the tropics which are generally deep to very deep (Sayer *et al*., 2019). The additional amount of SOC stock contained is 47.4% in 0-100 cm and 63.4% in 0-200 cm compared to that in the 0-30 cm layer (Lal, 2020). Even though, some SOC at deeper layers are stable which may not be affected by a change in land use (Sombroek *et al*., 1993) some proportion of it has a relatively fast turnover and might act as a carbon source if temperature increases (Jobbágy & Jackson, 2000) and it raises important issues for global carbon budgets and for carbon sequestration strategies (Batjes, 1996).

The general objective of this study was to estimate the SOC stock to 200 cm depth in a tropical humid region in the Caribbean coast of Honduras under two land uses: a secondary forest (50 years old) and a pasture. The specific objectives were: (1) to determine the distribution of SOC concentration to 200 cm depth, and (2) to determine SOC stock and their depth distribution to 200 cm.

MATERIALS AND METHODS

Study area

This research was undertaken at the Centro Universitario Regional del Litoral Atlántico (CURLA) which is part of the National Autonomous University of Honduras (UNAH), in the Caribbean floodplains of northern Honduras, in La Ceiba Municipality (15° 46′ N, 86° 47′ W). CURLA is located at the outskirts of the La Ceiba city. For the study, two ecosystems located next to each other were selected (Fig. 1). A 50 years old forest (22 ha) consisting mainly of *Vochysia guatemalensis* Donn. Smith, this area before 1967 was an agricultural land dedicated to monocrops. The second site is a pasture area (1.5 ha) located next to the forest, it has been pasture for approximately the last 10 years, before that it was devoted to agriculture. In the Holdridge system the area is classified as tropical wet forest. The elevation is approximately 5 m a.s.l. and slope is less than 2%. Soils are classified as inceptisols (Typic Dystrudepts) under the USDA Soil Taxonomy classification system, the soil parent materials are derived from Quaternary alluvial deposits (Weyl, 1980). Over the period 1972-2018, annual precipitation averaged 3176 mm. Monthly precipitation is 264 mm, November is the wettest month with an average of 542 mm, and the less rainy month is May with an average of 90 mm. The mean annual temperature is 26 ºC, with an average minimum and maximum of 21ºC and 31ºC respectively (2014-2018). This small annual variation on temperature is mainly due to the influence of the sea.

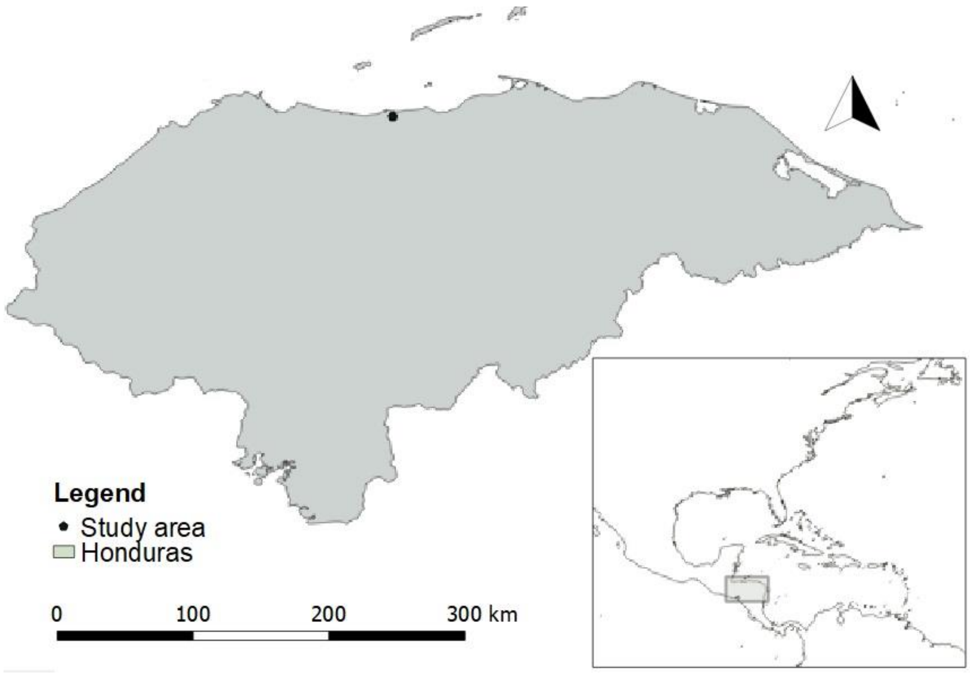

Figure 1. Study area.

Soil sampling and analysis

In each ecosystem, 10 sampling points were positioned along two transects that were located at least 50 m apart from each other, and the distance between sampling points were at least 30 m. At each sampling point, a soil pit was opened manually with a depth of 200 cm, and 6 samples from each depth class (0-20 cm, 20-40 cm, 40-80 cm, 80-120 cm, 120-160 cm, and 160-200 cm) were collected. At each sampling point two samples were collected, one for soil organic carbon (SOC) and another for bulk density. A total of 240 samples were collected, of this, 120 samples (2 land uses x 10 pits x 6 depths) were obtained for SOC analysis, and 120 (2 land uses x 10 pits x 6 depths) were obtained for bulk density analysis. All samples were collected between the 10^{th} October and 30^{th} of November in 2018, on days with no rain.

Soil samples collected for SOC analysis were air dried at ambient conditions the same day of collection, once dry, samples were ground and passed through a 2-mm sieve, and they were kept in sealed plastic bags and sent for analysis to the Soil Laboratory at CURLA.

Separate samples for bulk density were collected by hand held, hammer driven, 278 cm^3 cylinder core samplers. Cylinders were inserted horizontally into the walls of the soil profile at each designated depth, carefully excavated and cleaned from soil adhering to the ring. Soil samples inside the ring were placed in plastic bags. All samples were dried at 105ºC for 48 h, and then weighted. Stone content was important at deeper layers at most sites, and it was determined. Roots were negligible and were separated manually.

Organic carbon

Titration of soil samples was performed using the Walkley-Black $K_2Cr_2O_7$ method (Walkley & Black, 1934) and SOC value was estimated using the equation proposed by the Mexican Official Norm NOM-021-RECNAT-2000 (Secretaría de Medio Ambiente y Recursos Naturales, 2002).

Texture

Particle-size distribution was measured for all sampling points and for all depths, via the Bouyoucos method after pretreatment with sodium hydroxide to disperse soil aggregates.

Bulk density

Dry soil samples were sieved with a 2 mm sieve and stones were weighted for correction. Bulk density was calculated with Eq. 1 (Pearson *et al*., 2007).

$$BD = \frac{ODW}{CV - \frac{CF}{PD}} \quad \text{Eq. 1}$$

Where, BD: Bulk density of the <2 mm fraction (g cm^{-3}), ODW: Oven dry mass of fine fraction <2 mm in g, CV: Core volume (cm^3), CF: Mass of the coarse fragment (>2 mm) in g, PD: Density of rock fragment (g cm^{-3}) or particle density given as 2.65 g cm^{-3}.

Soil organic carbon (SOC) stock

SOC data were converted to SOC stock in units of Mg C ha^{-1} (also referred to as inventories or storage) by multiplying the concentration by bulk density, and depth interval, as in Eq. 2 (Pearson *et al*., 2007), in this equation %SOC is expressed as a decimal fraction.

$$SOC\ \left(\frac{Mg}{ha}\right) = bulk\ density\ \left(\frac{g}{cm^3}\right) x\ depth\ (cm)\ x\ \%OC\ x\ 100 \quad \text{Eq. 2}$$

Cumulative soil C content (0-200 cm) was calculated by summing contents for the six depth layers.

Soil organic carbon (SOC) stock in terms of CO_2 equivalent per unit area

To convert the mean SOC stock to CO_2 equivalent per unit area the following equation given by IPCC (2003) was applied:

$$C_{soc}\ \left(\frac{eq}{ha}\right) = SOC_{mean}\left(\frac{Mg}{ha}\right) x\ \frac{44}{12}$$

Where, C SOC is the mean SOC in terms of CO_2 equivalent ha^{-1}, SOC mean is the mean SOC Mg ha^{-1}, 44/12 is the ratio of molecular weight of CO_2 to molecular weight of C.

Statistical analyses

Normality of data distribution was performed for soil separates, bulk density, organic carbon, and organic carbon stock, for both ecosystems with the Shapiro-Wilk normality test. A two-way analysis of variance (ANOVA-GLM procedure) was performed to test for significant differences with ecosystems and sampling depth as the fixed factors for SOC stock. When differences were significant, multiple post-hoc comparisons of means were tested with Tukey HSD at $p < 0.05$. Correlation analysis was performed with the Pearson test between soil separates and SOC. Data analysis and graphics were performed with RStudio Version 1.2.5033.

RESULTS

Soil texture at the study site varied from clay loam and sandy clay loam. In the forest, the texture was clay loam in the upper soil layers and sandy clay loam in the deeper layers; whereas in the pasture, it was sandy clay loam in the uppermost layers, clay loam in the middle, and again sandy clay loam in the deeper layers (Table 1).

Table 1. Soil texture, soil bulk density, and soil organic carbon at different depths, CURLA, Atlántida, Honduras.

Ecosystem	Soil depth (cm)	Soil bulk density ($g\ cm^{-3}$)	Soil organic C ($g\ kg^{-1}$)	Soil separates (%)			Textural class
				Sand	Silt	Clay	
Forest	0-20	1.09	21.26	35.5	33.6	30.8	Clay loam
	20-40	1.31	6.01	33.3	31.8	34.8	Clay loam
	40-80	1.44	1.81	35.2	30.0	34.8	Clay loam
	80-120	1.59	1.23	50.9	22.4	26.6	Sandy clay loam
	120-160	1.42	0.96	49.7	23.6	26.8	Sandy clay loam
	160-200	1.58	0.96	52.3	23.2	24.6	Sandy clay loam
Pasture	0-20	1.46	12.09	48.2	24.6	27.2	Sandy clay loam
	20-40	1.53	3.16	51.9	23.5	24.6	Sandy clay loam
	40-80	1.50	1.58	39.7	31.4	28.9	Clay loam
	80-120	1.58	1.23	39.6	31.3	29.1	Clay loam
	120-160	1.49	0.92	49.0	25.5	25.5	Sandy clay loam
	160-200	1.48	0.90	56.3	21.4	22.3	Sandy clay loam

Soil organic carbon (SOC) stock was significantly higher ($p < 0.05$) in the forest ecosystem (89.22±10.95 Mg ha^{-1}) than under pasture (72.54±10.03 Mg ha^{-1}) at a depth of 0-200 cm (Table 2). The magnitude of SOC stock was dependent on the analyzed soil layer. Values decreased significantly with depth ($p < 0.05$, Tukey HSD test) in both ecosystems. Results of multiple post-hoc comparisons ($p < 0.05$ Tukey HSD test) are shown in figure 1. In the forest ecosystem the SOC stock was 44.84 Mg ha^{-1} (50.3% of total) at a depth of 0-20 cm, and it increased to 60.00 Mg ha^{-1} (67.26%) at a depth of 0-40 cm; whereas in the pasture SOC stock was 34.75 Mg ha^{-1} (47.91%) at a depth of 0-20 cm, and 44.41 Mg ha^{-1} (61.22%) at a depth of 0-40 cm (Table 2).

Table 2. Mean SOC stock and variability at different depths and by ecosystem, CURLA, Atlántida, Honduras.

Ecosystem	Depth (cm)	SOC stock (Mg ha^{-1})		Variance	%
		Mean	St. Dev.		
Forest	0-20	44.84	6.38	40.76	50.26
	20-40	15.16	3.06	9.36	16.99
	40-80	10.19	2.96	8.73	11.43
	80-120	7.84	3.92	15.33	8.79
	120-160	5.28	3.61	13.01	5.92
	160-200	5.90	5.72	32.70	6.62
Pasture	0-20	34.75	8.34	69.49	47.91
	20-40	9.66	3.56	12.69	13.31
	40-80	9.47	2.32	5.37	13.06
	80-120	7.75	2.14	4.60	10.69
	120-160	5.51	2.06	4.26	7.60
	160-200	5.39	2.03	4.11	7.44

The greater accumulation of SOC stock in the upper layers was due to the high SOC content in both ecosystems (Fig. 2), at a depth of 0-20 cm SOC were 21.26 g kg^{-1} and 12.09 g kg^{-1} for forest and pasture respectively, and low bulk density values, particularly in the forest. The minimum bulk density, 1.09 g cm^{-3}, was found at 0-20 cm and the maximum value, 1.59 g cm^{-3}, was found at 80-120 cm depth, both in the forest ecosystem (Table 1). The mean BD values at a depth of 0-200 cm between forest and pasture were significantly different ($p < 0.05$).

The Shapiro-Wilk normality test indicated that soils separates and SOC were not normally distributed. However, as normality is not required, Pearson correction was performed and reported here. A positive and negative significant correlation was observed between SOC concentration and particle size in the forest ecosystem. For clay a positive correlation was observed ($r = 0.17$; $p < 0.05$), for silt also a positive correlation was observed ($r = 0.39$; $p < 0.05$), and for sand a negative correlation was observed ($r = -0.29$; $p > 0.05$). No significant correlations were found between soil particle sizes and SOC in the pasture (Fig. 3).

Mean SOC stock in terms of CO_2 equivalents ($CO_{2\text{-eq}}$) for forest was 327.1 Mg ha^{-1} $CO_{2\text{-eq}}$ and for pasture was 265.9 Mg ha^{-1} $CO_{2\text{-eq}}$ (Fig. 3). As it is shown in figure 4, at a depth of 0-20 cm is estimated to have 50% in the forest (164.4 Mg ha^{-1} $CO_{2\text{-eq}}$) and 48% in the pasture (127.4 Mg ha^{-1} $CO_{2\text{-eq}}$).

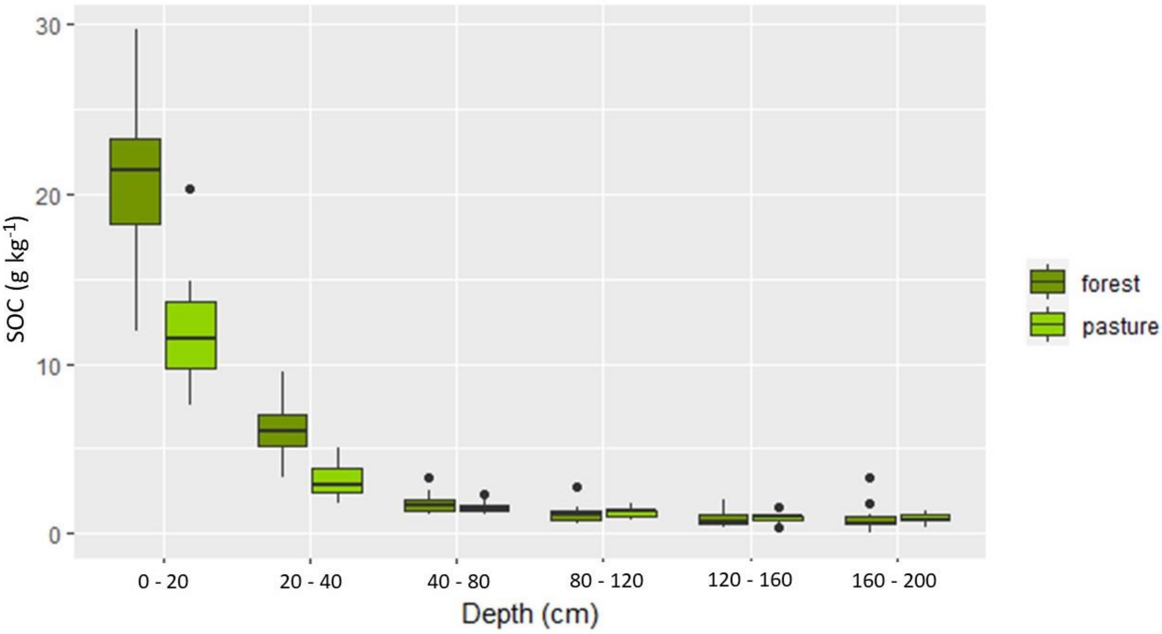

Figure 2. Box-plot of measured soil organic carbon (SOC) by depth at CURLA, Atlántida, Honduras.

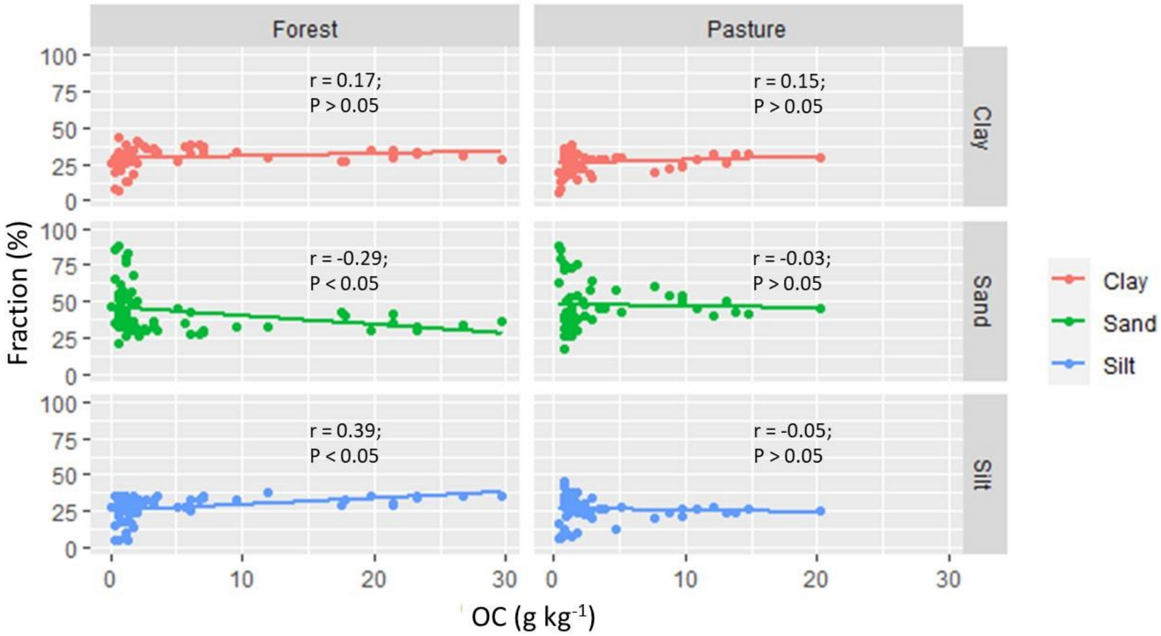

Figure 3. Correlation analysis between SOC and soil separate fraction by land use, at CURLA, Atlántida, Honduras.

DISCUSSION

Soil organic carbon (SOC) stock

Published data on SOC stock from several studies in the tropics are listed in table 2. Compared to a study undertaken by de Oliveira *et al*. (2017) in Brazil at a site with annual average of 26ºC and 2442 mm yr^{-1}, and at a depth of 0-200 cm, in which they reported SOC stock values of 98.4 Mg ha^{-1} and 64 Mg ha^{-1} for forest and pasture respectively, in our study, stock values were 89.2 Mg ha^{-1} and 72.5 Mg ha^{-1} for forest and pasture respectively. A study by Chacón *et al*. (2015) reported a SOC stock of 150.2 Mg ha^{-1} at a depth of 0-100 cm in the Atlantic tropical rainforest of Costa Rica and under inceptisols. Jimenez *et al*. (2007) in a forest consisting of *Vochysia guatemalensis* Donn. Smith also in Atlantic humid forests of Costa Rica at a depth of 0-50 cm reported 119.2 Mg C ha^{-1}, whereas in the pasture they reported 115.6 Mg C ha^{-1}. In another study in Nicaragua at a site with 1400 mm yr^{-1} and under vertisols, Ibrahim *et al*. (2007) at a depth of 0-100 cm reported 162.17 Mg ha^{-1} and 97.3 Mg ha^{-1} for secondary forest and non-native pasture respectively. Chatterjee *et al*. (2020) for a site with organic coffee with timber species and mean annual precipitation of 2600 mm $year^{-1}$ and mean annual temperature of 22ºC in Costa Rica, reported a SOC stock of 125 Mg C ha^{-1} up to a depth of 100 cm under endoaquepts and endoaquults. These latter values are considerable higher than the values obtained in our study, particularly in the forest and that these values would be much higher at a depth of 200 cm.

Compared to global estimates for the top 100 cm of mineral soil (158 Mg C ha^{-1}) our data were lower (Jobbágy & Jackson, 2000). However, in general, the values reported by de Oliveira *et al*. (2017) are in the range of our results and in both cases, studies were conducted at 200 cm depth, and climate is similar, particularly for temperature.

SOC stock depends primarily on the balance between inputs of plant biomass and losses of SOC through decomposition (Jobbágy & Jackson, 2000; Tian *et al*., 2015). In tropical regions where high temperatures, high rainfall and intense biological activity, resulting in rapid decomposition of organic matter that is added on the ground (Mielniczuk *et al*., 2003). In montane humid forests in Ecuador, Paul *et al*. (2008) reported a SOC pool of 36.4 g kg^{-1} in natural forest soils (0-10 cm) and in pastures 29.1 g kg^{-1} under sedimentary soils, values higher than those obtained in our study, these differences may be due to climate.

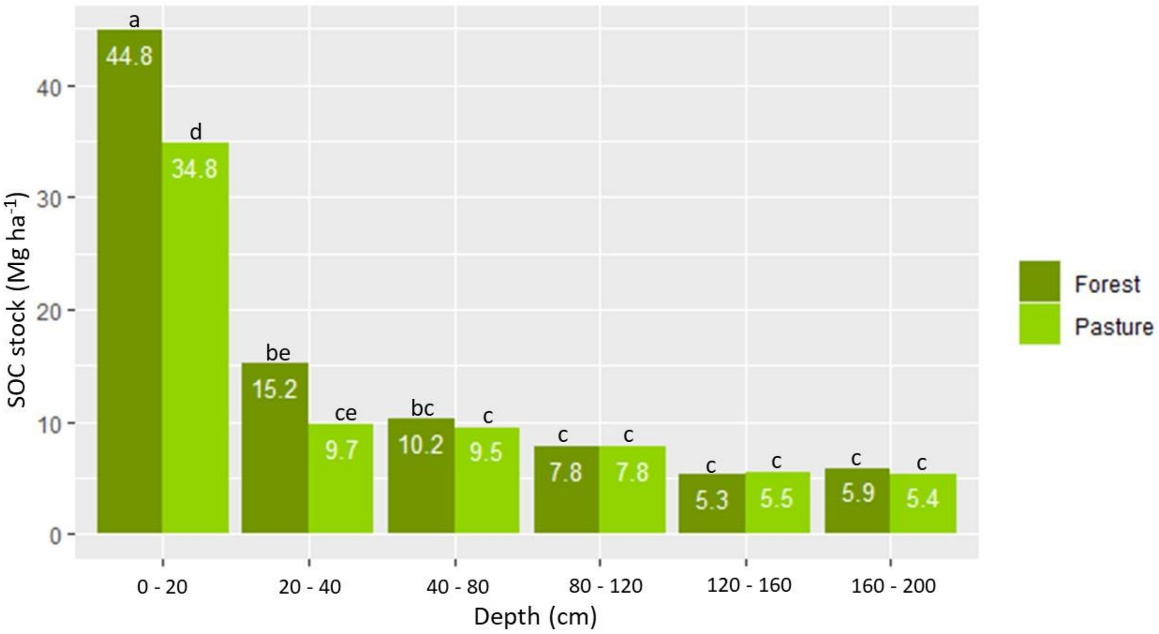

Figure 4. SOC stocks at different depths of soils under a 50 years old secondary forest, and a pasture, at CURLA, Atlántida, Honduras. Values with the same letter are not statistically different according to the Tukey HSD test (p = 0.05).

In our study, the SOC stock was higher in the forest ecosystem as compared to the pasture (Table 2). At a depth of 0-20 cm in the forest was 44.8 Mg C ha^{-1}, whereas in the pasture was 34.8 Mg C ha^{-1}, these values are significantly different ($p < 0.05$). At a depth of 20-40 cm, observed value for forest was 15.2 Mg C ha^{-1} and for pasture 9.7 Mg C ha^{-1}. At deeper layers SOC stock values are much lower and there are no differences in values between the two ecosystems (Fig. 4). The proportion of SOC stock at a depth of 0-40 cm, represents 67% and 61% of the total (0-200 cm) for the forest and pasture respectively. de Oliveira *et al*. (2017) at a depth 0-40 cm reported 77% of the total at a depth of 0-200 cm SOC stock in spodosols. Chacón *et al*. (2015) at a depth of 0-40 cm reported 58% of the total at a depth of 0-100 cm, in their study that percent would probably decrease if they had considered at a depth of 0-200 cm. Batjes (1996) reported a 60% increase in the global SOC stock when the second meter of soil was included. In our case, if the study had been conducted only to 100 cm, increases of SOC stock would be approximately 27% and 35% for forest and pasture respectively if the second meter was included.

In our study, the difference of SOC stock accumulation between forest and pasture is approximately 17 Mg ha^{-1} and it can be argued that it is mainly affected by vegetation (greater litter input in the forest), followed by the relatively higher clay content in the upper layers in the forest as compared to the pasture (Table 1). However, the amount of temporal input of litter was not addressed. Therefore, specific conclusions pertaining the role of litter input on SOC concentration after 50 years of forest establishment are not defined in this study. Another control worth noticing is soil texture variation with depth (Fig. 5). For sandy tropical soils, Yost & Hartemink (2019) reported average SOC value of 8 g kg^{-1} for the top 30 cm. In our study, the texture was clay loam, and sandy clay loam and SOC values were 21 and 12 g kg^{-1} for forest and pasture respectively, it may indicate the role of clay in retaining more C in the soil under forest. SOC stock is affected by soil texture and aggregation, and the silt and clay size fractions can protect SOC from decomposition (Gulde *et al*., 2008; Hassink, 2016). Paul (1984) found that coarse clays and fine silts stabilize the SOC the most, as compared to other soil fractions. Silver *et al*. (2000) indicates that the SOC accumulation rate in wet forests is 0.51 Mg C ha^{-1} $year^{-1}$ over a 100-year time period, in our study in the forest, this rate is ca. 0.34 Mg C ha^{-1} $year^{-1}$. A strong significantly linear relationship between SOC and forest age were reported, at least during the first 100 years after recovery (Silver *et al*., 2000). SOC monitoring in the study site in the future would be necessary to define if SOC continues increasing and when it reaches stabilization. Sayer *et al*. (2019) demonstrated that interactions between litter inputs and processes involved in the stabilization of SOC are likely to play a key role in tropical forest soil C sequestration in future and they called for further work on the underlying mechanisms.

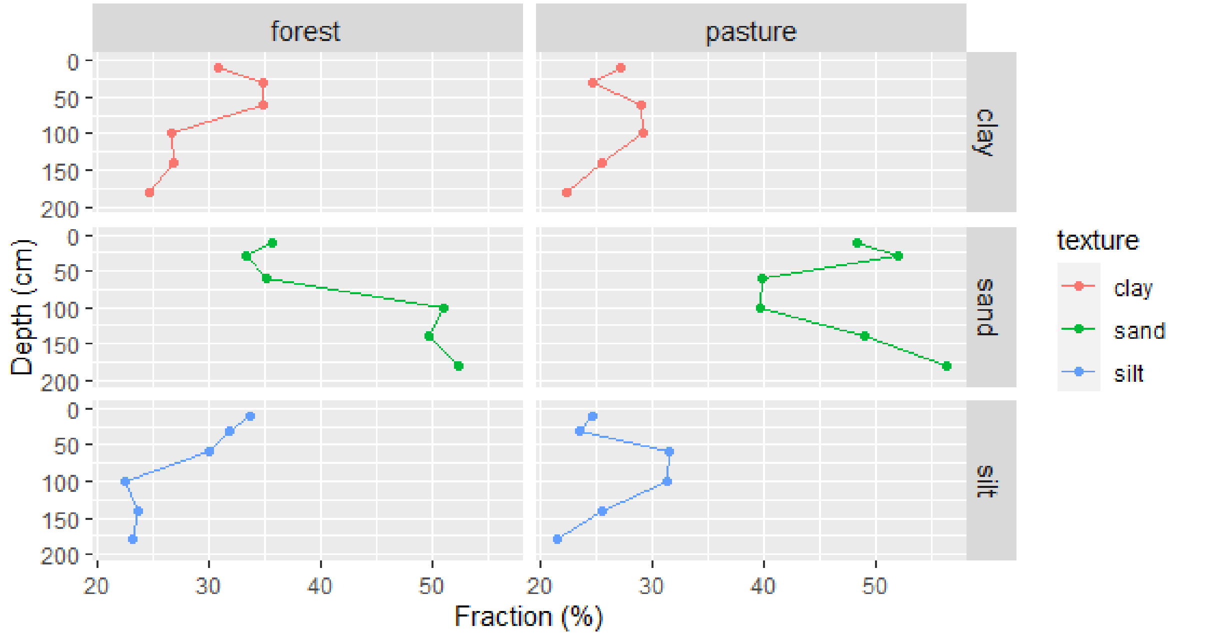

Figure 5. Vertical content of soil separates by land use at CURLA, Atlántida, Honduras.

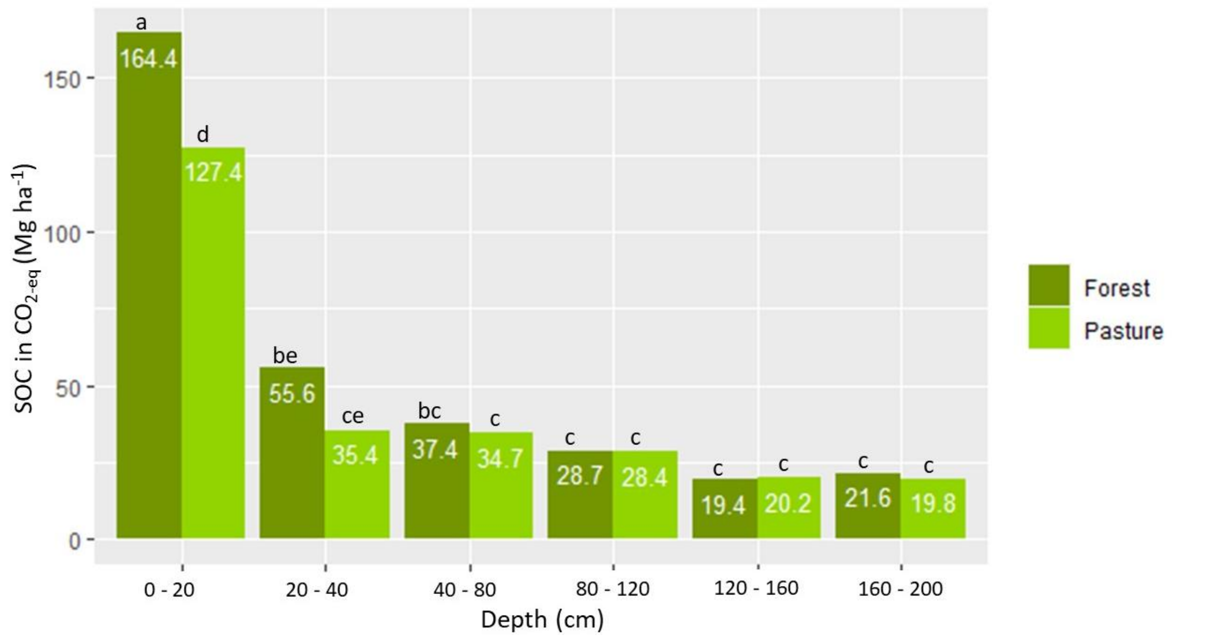

Figure 6. SOC stocks in CO_2-equivalents at different depths under a 50 years old secondary forest, and a pasture, at CURLA, Atlántida, Honduras. Values with the same letter are not statistically different according to the Tukey HSD test ($p = 0.05$).

Soil organic carbon (SOC)

Similarly, vertical distribution of SOC was higher in the upper layers (Fig. 2) in both ecosystems in accordance with trends reported by Jobbágy & Jackson (2000). Our findings follow the pattern reported by de Oliveira (2017) for a tropical primary forest, however it is different in which in their study SOC values were higher, the authors reported in units of g kg^{-1} the following: 55.1 (0-5 cm), 37.8 (5-10 cm), 20.8 (10-20 cm), 8.2 (20-40 cm), 5.9 (40-60 cm), 5.1 (60-80 cm), 6.3 (80-100 cm), 2.4 (1-160 cm). In our study, average SOC values ranged from 21.26 g kg^{-1} (0-20 cm) to 0.96 g kg^{-1} (160-200 cm) in the forest, and from 12.09 g kg^{-1} (0-20 cm) to 0.90 g kg^{-1} (160-200 cm) in the pasture. At a depth of 200 cm there is still SOC and it represents approximately 6% and 7.5% of the SOC values observed at the uppermost layers (0-20 cm) of the soil profile for forest and pasture respectively. Global SOC estimations for forests and pastures, Jobbágy & Jackson (2000) indicate that even up to 300 cm there is still SOC that needs to be accounted for, even though values are low, and as a result, predictive models would be better calibrated.

Compared to other studies (Table 3), in our study climate particularly high precipitation seems to play an important role in SOC. Although, Doetterl *et al*. (2015) indicate that soil geochemistry may be more important for SOC storage than climate, particularly in warm, humid regions, such as tropical forests. In tropical forests, additional fresh plant inputs to the soil could affect SOC stock by promoting the microbial decomposition and turnover of the already stored SOC through the priming effects (Kuzyakov *et al*., 2000).

Existing SOC stock values in several tropical regions (Table 3) show considerable uncertainty, and this may be because our mechanistic knowledge of C sequestration is deficient (Schmidt *et al*., 2011). Tropical forests play an important role in the global C cycle, and yet our knowledge about SOC dynamics and storage in tropical forests is still poor, and these have influence in the large uncertainties in model projections of future C sequestration (Tian *et al*., 2015).

Table 3. SOC stock in selected studies conducted in forests and pastures in different sites in tropical Latin America.

Country	Site	Vegetation	Soil type	Soil depth (cm)	SOC stock (Mg ha^{-1})	Reference
Mexico	Chiapas	Forest	Leptosol	0-15	72.57	Aryal *et al*., 2018
	Chiapas	Pasture	Leptosol	0-15	74.37	Aryal *et al*., 2018
Costa Rica	Esparza	Secondary forest	Alfisol	0-100	297.63	Ibrahim *et al*., 2007
	Esparza	Pasture	Alfisol	0-100	139.48	Ibrahim *et al*., 2007
	Atlantic	Rainforest	Inceptisol	0-100	150.2	Chacón *et al*., 2015
	Limon	Forest	Andisol	0-50	119.2	Jimenez *et al*., 2007
	Limon	Pasture	Andisol	0-50	115.6	Jimenez *et al*., 2007
	Caribbean	Forest plantation	Ultisol	0-30	107	Fonseca *et al*., 2012
Nicaragua	Matiguas	Secondary forest	Vertisol	0-100	162.17	Ibrahim *et al*., 2007
	Matiguas	Pasture	Vertisol	1-100	97.3	Ibrahim *et al*., 2007
Brazil	Manaus	Primary forest	Oxisol	0-200	98.4	de Oliveira, 2015
	Manaus	Pasture	Oxisol	0-200	64	de Oliveira, 2015
	Manaus	Forest	Ultisol	0-200	72.6	de Oliveira, 2017
	Manaus	Forest	Spodosol	0-200	81.4	de Oliveira, 2017

Mean Soil organic carbon (SOC) in terms of CO_2 equivalents

Mean SOC in terms of CO_2 equivalents (CO_2 eq) for a depth 0-200 cm were 327.1 Mg CO_2 eq to 265.9 Mg CO_2 eq for forest and pasture respectively (Fig. 6). At the upper layers have higher values e.g. 164.4 Mg CO_2 eq (0-20 cm), 55.6 Mg CO_2 eq (20-40 cm), and 37.4 (40-80 cm) for the forest, and 127.4 Mg CO_2 eq (0-20 cm), 35.4 Mg CO_2 eq (20-40 cm), and 34.7 (40-80 cm) for the pasture. These values represent the amount of CO_2 gas molecules stored in these ecosystems in the form of SOC. This link between atmospheric CO_2 and SOC is currently important from the environmental perspective, but also for the improvement of soil quality (Lal, 2020). If these ecosystems, particularly the forest were converted back to conventional agricultural use, SOC would be considerable reduced through ploughing. This highlights the relevance of appropriate soil management (Lal, 2018) under the implementation of policies such as carbon-emissions trading in tropical countries, *i.e.* REDD+ projects (Angelsen *et al*., 2011).

CONCLUSION

Soil organic carbon (SOC) stock values at a depth of 0-200 cm in inceptisols under a 50 years old secondary forest and pasture in a tropical humid region in northern Honduras showed lower values than the reported SOC stock values for colder and drier tropical regions.

Most of the SOC is found in the upper layer (0-20 cm), both in the forest and in the pasture. However, the soil under the forest presents higher SOC values than in the pasture in the upper layers, at deeper layers there are no significant differences in SOC between both ecosystems.

More research is needed in tropical humid regions of the world, particularly Central America, to better understand SOC dynamics and stock, and this would contribute to reduce uncertainties in model projections in C sequestration for regions with similar climate as in our study.

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