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Soil organic carbon pool under native tree plantations in the Caribbean lowlands of Costa Rica

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Abstract

We evaluated the soil organic carbon (SOC) pool and selected physico-chemical soil variables in a plantation with native tree species established in a degraded pasture of the Caribbean lowlands of Costa Rica. Studies on the rate and accumulation of aboveground biomass and C have been conducted in native tree plantations of Costa Rica. However, more studies on the SOC pool are needed since only few works provide information on the subject. The tree plantation was established in 1991 on a 2.6 ha. degraded pasture (*Ischaemum* sp.) Four species were selected: *Vochysia guatemalensis* Smith, *Calophyllum brasiliense* Cambess, *Stryphnodendron excelsum* Poeppig et Endl. and *Hieronyma alchorneoides* Allemao. Average SOC concentration ranged from 44.9 to 55.2 g kg^{-1} (0–10 cm), and decreased with depth up to 12.7–16.8 g kg^{-1} (40–50 cm). The highest SOC pool was measured under *H. alchorneoides* and *V. guatemalensis*, i.e. 131.9 and 119.2 Mg C ha^{-1}, respectively, whereas in the pasture it was 115.6 Mg C ha^{-1}. The SOC pool has not changed significantly under the tree species evaluated 14 years after establishment. A multivariate ordination technique named between-within class principal component analysis was used to determine the factors and trend that explain the variability in the data. The effect of vegetation in the SOC and selected soil variables measured in this study was only detected for *H. alchorneoides*. The information presented herein about the depth distribution of the SOC fraction improves our knowledge for further developing prediction models.

Keywords: Soil organic carbon; Native tree plantations; Costa Rica; Carbon sequestration; Land management; Ordination analysis

1. Introduction

The soil organic carbon (SOC) pool is the third largest C reservoir in interaction with the atmosphere. The biotic (560 Pg) and the atmospheric (760 Pg) pools are considerably smaller than the pedologic pool (Lal, 2004). The SOC pool can be depleted by 15–40% in a 2-year period to 1-m depth when tropical forest is converted to agricultural land use (Ingram and Fernandes, 2001) or as much as 50–75% (Lal, 2004; Post and Kwon, 2000). Such depletion of the SOC pool creates the potential to accumulate (sequester) C in soils upon adoption of a restorative land use and less harmful agricultural practices.

Native tree plantations have become an extensively used land use management option in Costa Rica during the last 20 years as a restorative tool for degraded lands and also because their potential use as providers of ecosystem services (FAO, 2006). A rapid land use change occurred in the northeastern part of Costa Rica between 1950 and 2000, with the dominant change being the conversion of forests to pastures (Read et al., 2000). The usefulness of native tree plantations' establishment in degraded pastures has been recognized (Butterfield, 1995), although some researchers argue the viability of this land use in degraded pastures to restore soil quality (Sánchez et al., 1985). Nevertheless, most studies in native tree plantations have dealt with aboveground biomass (Fisher, 1995; Montagnini and Sancho, 1990; Montagnini and Porras, 1998; Stanley and Montagnini, 1999; Tornquist et al., 1999). Several studies have provided estimates of the SOC pool sometimes assuming that the soil bulk density do not change through the soil profile, which seems not to be the valid procedure.

In Costa Rica, studies on soil C dynamics have been mainly focused on changes in total soil C following conversion of

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forests to pastures (Veldkamp, 1994; Veldkamp et al., 1992; Powers and Schlesinger, 2002; Powers, 2004; Powers and Veldkamp, 2005). The SOC pool may also decrease slowly upon conversion of rain forest to pasture (Veldkamp, 1994), probably because of higher root biomass production under improved pastures (Lugo and Brown, 1993); however, Van Dam et al. (1997) indicated the opposite trend and found a significant C accumulation in rich volcanic soils after clearance of the natural forest for pasture establishment. Reiners et al. (1994) reported the SOC pool at 16 Mg C ha^{-1} under pasture (0–10 cm depth) compared to 15 and 21 Mg C ha^{-1}, respectively, under 5–10 and 10–15-year-old regrowth forest. Under tree plantations the research data on the rates of SOC sequestration in Costa Rica are not abundant in the literature. Available data indicate that SOC pool does not always increase under tree plantations (Lugo et al., 1986; Bashkin and Binkley, 1998; Tornquist et al., 1999). Furthermore, the data on SOC concentrations, including in the particle-size fractions and its stabilization upon conversion to tree plantations are needed to develop rational decision support systems for adopting judicious land uses. Physical fractionation methods allow us to study the factors involved in the associations between soil mineralogy and soil C differing in composition and function (Cristensen, 2001).

The general objective of our study was to quantify the SOC pool and related key physical properties under a 14-year-old mixed tree plantation established in a degraded pasture soil in the Caribbean lowlands of Costa Rica. The area has large geographic gradients in edaphic properties such as topography, SOC concentration, soil texture, and clay mineralogy (Powers and Schlesinger, 2002). Specific objectives were to: (1) assess the depth distribution of SOC concentration up to 50 cm depth, (2) determine the trends and variations in SOC pool at the scale of the plantation, (3) establish the association of SOC with selected physical and chemical soil properties, and (4) set the determinants of the depth distribution of SOC under tree plantations.

2. Materials and methods

2.1. Study site

This study was conducted at EARTH University (10°10′N and 83°37′W; 64 m a.s.l.) at the confluence of Parismina and Destierro rivers, in the Caribbean lowlands of Limón Province, Costa Rica. The climatic zone is classified as premontane, wet forest basal belt transition (Bolaños and Watson, 1993). The terrain is flat to undulating, annual rainfall averages 3464 mm and annual mean temperature is 25.1 °C (iso-hyperthermy). Rainfall is evenly distributed and exceeds 100 mm in all months, with peaks during June, July, August, November, and December, and yearly mean relative humidity is 87%. Soils of the study site are predominantly Andisols, and have moderate to low fertility. Soil pH (H_2O, 1:1) ranges from 3.7 to 4.8 and texture from sandy clay and sandy clay loam in the surface to clay in the sub-soil layers (Table 1).

Table 1
Soil textural analysis (hydrometer method) and pH under the different tree species and pasture

System	Depth (cm)	Texture (%)			pH	
		Sand	Silt	Clay	H_2O 1:1	$CaCl_2$
Pasture (“degraded”)	0–10	54.1	11.0	34.9	4.5	4.1
	10–20	49.9	11.2	39.9	4.7	4.0
	20–30	55.5	6.0	38.5	4.7	4.0
	30–40	47.2	6.7	46.2	4.7	4.0
	40–50	48.7	9.4	41.9	4.8	4.0
Hieronyma alchorneoides (Pilón)	0–10	62.8	13.6	23.6	4.1	3.8
	10–20	56.8	10.7	32.5	4.2	3.8
	20–30	61.7	8.7	29.6	4.6	4.0
	30–40	45.4	12.7	41.9	4.6	4.0
	40–50	45.5	12.6	41.9	4.7	4.0
Stryphnodendron excelsum (Vainillo)	0–10	49.3	13.8	36.9	3.7	3.6
	10–20	21.4	9.7	68.9	4.3	3.9
	20–30	11.4	15.7	72.9	4.4	3.9
	30–40	27.4	13.8	58.8	4.6	4.0
	40–50	37.4	13.7	48.8	4.7	4.0
Vochysia guatemalensis (Chancho)	0–10	65.0	9.4	25.6	4.2	4.0
	10–20	43.7	14.8	41.5	4.1	3.9
	20–30	45.8	11.8	42.4	4.5	4.0
	30–40	31.9	13.7	54.4	4.6	4.0
	40–50	27.5	15.1	57.4	4.5	3.9
Calophylum brasiliense (Cedro María)	0–10	50.0	11.1	38.9	3.8	3.7
	10–20	22.3	16.9	60.8	4.1	3.9
	20–30	18.2	17.0	64.8	4.6	4.0
	30–40	20.6	15.8	63.6	4.7	4.1
	40–50	22.2	14.3	63.6	4.5	4.0