

# Carbon Storage in Soil-Size Fractions under Cacao Agroforestry Systems in Bahia, Brazil

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## INTRODUCTION

Cacao (*Theobroma cacao*)-based agroforestry systems (AFS) cover an area of more than 0.7 million ha in Brazil. Cacao is grown under two AFS: the traditional "cabruca" in partially cleared forest (Fig. 1A) and the more recent one involving planted shade trees (Fig. 1B).

Cacao AFS contain high amounts of soil carbon (C) because of the high amounts of plant litter (estimated to be 10 Mg ha<sup>-1</sup>) that is added annually (Fontes, 2006). These systems are therefore considered to be efficient in terms of nutrient cycling and soil protection.

The amount of C that is sequestered in the soil is dependent on the relative amounts of various soil-size fractions (Haile et al., 2008): C associated with macroaggregates (> 250 μm) is more labile and represents the light organic matter, while the C associated to microaggregates (< 250 μm) is more recalcitrant and represents the more stable fraction. Furthermore, C can be occluded in soil aggregate, which is not strongly associated to soil particles.

In order to understand the C sequestration potential of cacao AFS, it is important to know the extent of soil C storage in different soil -size-fractions and soil aggregates in different soil layers; furthermore, the deep-rooted nature of cacao and shade trees make it targeted.

## OBJECTIVES

To determine the extent of soil carbon storage in different soil-size-fractions and within larger fractions (2000 – 53 μm) in different soil depths up to one meter depth in two types of cacao agroforestry systems and an adjacent natural forest in Bahia, Brazil.

## MATERIALS E METHODS

**Study area:** The study was conducted on the Center of Cocoa Science, Itajuípe, in the southern region of Bahia, Brazil (14° 0' S and 39° 2' W); the region has a humid tropical climate with a well-distributed rainfall of 1500 mm per year. The soils are reddish-yellow Oxisols.

Soil samples were collected from three land-use systems:

- Thirty-year-old stand of cacao with Erythrina (*Erythrina poeppigiana*) as shade trees: Erythrina and cacao were planted in alternating rows, with 3 m between rows of cacao and 3 m between cacao plants within a row; 1111 cacao plants per ha.
- Thirty-year-old stand of cabruca system: cacao was planted in partially cleared forest land where some large trees were retained (average about 70 trees per ha) as shade trees for cacao; average number of cacao plants = 550 per ha.
- An adjacent natural forest.

**Soil Sampling and Analysis:** Soil samples collected from four depth classes (0 – 10, 10 – 30, 30 – 60, and 60 – 100 cm); soil bulk density for each depth interval measured by the core method. Three sets of composite samples were prepared for each soil depth under each land-use system.

After air-drying and 2-mm sieving, the composite samples were physically fractionated by wet-sieving using disruptive forces of slaking and wet-sieving through a series of two sieve sizes (250 and 53 μm) to obtain three fraction size classes: macro (2000-250 μm), micro (250-53 μm), and silt- and clay- sized fraction (<53 μm).

Sonication was performed on the two larger size-fractions (2000-250 and 250-53 μm) in a water-soil system with a Sonic Dismembrator (model 500, Fisher Scientific, Hampton, NH). The suspension was then passed through the same-sized sieves used to obtain the size-fraction. The soil organic matter passing through the sieve (aggregate organic matter) was released after aggregate disruption (Sarkhot et al., 2007). The total soil C in soil size-fraction and soil aggregate were determined by dry combustion in a Leco CHNS/O Analyser.

**Statistical analyses:** A complete randomized design with land-use as a factor was used. Planned-comparison ANOVA with Tukey's studentized range test was used to compare the mean differences between land-use on SOC in whole soil, macro-sized, micro-sized, and silt- and clay- sized fractions at three sites. Statistical analyses were performed separately for all depth classes. All statistical tests were performed with SAS, and differences were considered significant at  $p < 0.05$ .

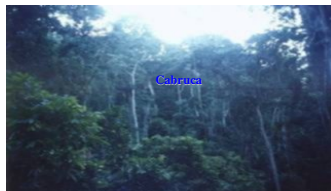


Fig. 1A. In the traditional cacao AFS of southern Bahia called "cabruca," cacao is planted under a thinned natural forest and is shaded by forest trees; their vegetation structure and stratification are similar to those of natural forests.

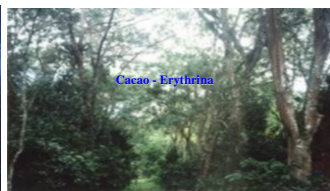


Fig. 1B. During the past 50 years, a new cacao system has been developed where the original forests are cleared and cacao is planted along with shade trees, the leguminous *Erythrina* trees being the most common. In this system, the cacao stand density is about two times that of cabruca systems.

## DISCUSSION

Soil organic carbon stock of cacao agroforestry systems was not statistically different from that of natural forest in the entire 0 – 100 cm soil layer; The distribution of size fraction classes did not vary among soil depth classes and land-use systems. Macro-sized fraction was the most abundant fraction with high amount of C in these soils in the 0 – 100 cm, followed by micro-sized fraction and silt-and-clay sized fraction; The constant addition of organic materials via litter fall, coupled with the absence of tillage and use of machinery (no-till) in cacao AFS, helps maintain the binding effect and increase the number of water stable macroaggregates. Furthermore, higher root density of trees and greater leaf biomass result in increased soil organic matter and hence higher percentage of mega and macro-sized fraction Overall, about 70% of SOC in cacao AFS were located inside the macroaggregates and 30% inside the microaggregates at all soil depths and for all the three land-use systems

### References

Fontes, A.G. 2006. Cicloagem de nutrientes em um sistema de cacao no sul da Bahia, Campos dos Goytacazes, RJ. Universidade Estadual do Norte Fluminense, 2006. 71p. Tese (Doutorado em Produção Agrícola). Universidade do Norte Fluminense, Campos dos Goytacazes, RJ.

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## RESULTS

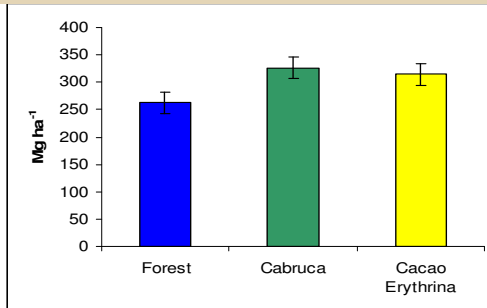


Fig.2. Soil organic carbon storage in the 0 – 100 cm soil layer under forest, cabruca and cacao + erythrina systems in Bahia, Brazil.

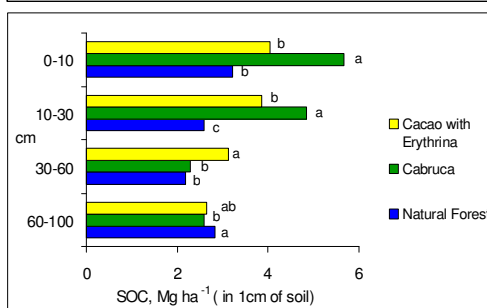


Fig.3. Soil organic carbon storage at different depths in three land-use systems in Bahia, Brazil. Values followed by the same letter (s) within each depth are not significantly different according to the Tukey test ( $P = 0.05$ ).

Table 1. Total soil organic carbon in different size-fractions at varying depths in three land-use systems in Bahia, Brazil

Depth (cm)	Size fraction (μm)	Carbon (Mg/ha in 1cm of soil)		
		Forest	Cacao-Cabruca	Cacao-Erythrina
0-10	2000-250	2.95 b	5.45 a	3.37 b
	250-53	0.60 a	0.95 a	0.55 a
	<53	0.16 b	0.44 a	0.22 ab
10-30	2000-250	2.30 b	4.30 a	3.66 a
	250-53	0.55 c	1.15 a	0.91 b
	<53	0.21 b	0.44 a	0.33 ab
30-60	2000-250	2.10 b	2.10 b	2.82 a
	250-53	0.66 a	0.69 a	0.85 a
	<53	0.21 a	0.26 a	0.30 a
60-100	2000-250	2.83 a	2.41 b	2.53 ab
	250-53	0.86 a	0.79 a	0.72 a
	<53	0.30 a	0.28 a	0.27 a

The C concentration in macro-sized, micro-sized and silt + clay fraction are 45.34, 44.72 and 50.20 g kg<sup>-1</sup> soil. Values followed by the same letter (s) within size-fraction and within each depth are not significantly different according to the Tukey test ( $P = 0.05$ ).

Table 2. Aggregate soil carbon of soils under three land-use systems in Bahia, Brazil

Sites	Depth	Size Fraction	C content in soil aggregates			
			C content in soil size-fraction	C content in soil aggregates	% ‡	
Natural Forest	0-10	2000-250	43.10	30.22	70	
		250-53	8.80	3.16	36	
	10-30	2000-250	33.42	24.37	73	
		250-53	7.96	2.79	35	
	30-60	2000-250	28.47	18.96	67	
		250-53	8.99	3.47	39	
	60-100	2000-250	27.87	18.55	67	
		250-53	8.48	3.05	36	
	Cabruca	0-10	2000-250	45.54	29.60	65
			250-53	7.88	2.62	33
		10-30	2000-250	31.94	20.30	64
			250-53	8.55	2.90	34
30-60		2000-250	27.24	17.98	66	
		250-53	8.97	2.83	32	
60-100		2000-250	26.42	17.82	67	
		250-53	8.57	2.40	28	
Cacao with Erythrina		0-10	2000-250	45.29	33.00	73
			250-53	7.32	2.64	36
		10-30	2000-250	32.26	22.05	68
			250-53	8.11	3.17	39
	30-60	2000-250	28.46	19.55	69	
		250-53	8.55	3.22	38	
	60-100	2000-250	27.90	19.00	68	
		250-53	7.86	2.70	34	

‡ Average % of C inside the aggregates for each size-fraction.

## CONCLUSIONS

This study indicates that cacao AFS accumulated high amounts of SOC comparable to that of natural forests. Seventy percent of C in these systems was retained within soil aggregates that are physically protected form of C. The vast majority of SOC in was in macroaggregate fractions throughout the soil layers up to 1 m depth. Although SOC inside the macroaggregates is more subjected to disturbance than that in the other two fractions, the extent of such disturbances is low in cacao systems; therefore C contained in this fraction can be expected in time to become more stabilized in the system.

Thus, in addition to reducing deforestation and restoring degraded soils, the cacao agroforestry systems seem to play an important role in environmental protection by mitigating GHG emission through storage of high amounts of well-protected organic carbon in the soils. Trading of soil carbon could offer an economic incentive to cacao producers.

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