International Journal of

Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

International Journal of Soil Science 6 (3): 217-223, 2011
ISSN 1816-4978 / DOI: 10.3923/ijss.2011.217.223

The Effect of Cultivation on Organic Carbon Content in the Clay Mineral Fraction of Soils

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ABSTRACT

Conversion of native land, into a cultivated system causes precipitous degradation of the soil organic matter. It is reported that C stored in the clay mineral fraction contributes more to the long-term stability of C than sand and silt fraction. This study reports on the soil organic carbon in the clay mineral fraction of some cultivated lands in Sri Lanka and how it deviates from the adjacent natural forests. The field sites included 7 cultivated lands (tea, rubber, coconut, mixed crops, potato, home garden, chena cultivation) and 7 tropical forest types (wet evergreen, semi evergreen, moist monsoon, dry monsoon, montane, dry mixed evergreen). The significant differences in carbon content of the clay fraction between the cultivated land and the adjacent forest in the same location revealed that cultivation has decreased the carbon content in all sites. The highest C content shown by the mixed crop and rubber plantations showed that minimum land management and soil tillage involved with this reduced the rate of decomposition. High temperature of dry mixed evergreen forest and dry monsoon forest may have increased the decomposition rates and lowered the SOC in the clay fraction compared to the other forests. Significant correlations were observed in forests with in clay fraction and climatic parameters but to a lesser extent in cultivated lands. Considerable variations in organic matter input in cultivated lands will be the reason for these weak relationships. The study confirmed that clay mineral fraction was also equally affected during long term cultivation although it was reported to be more stable against rapid decomposition.

Key words: Soil organic C, clay fraction, soil tillage, cultivated lands, tropical forests

INTRODUCTION

Soil is a significant long-term reservoir of organic carbon and plays a significant role in the global C cycle (Lal, 2003; Verena *et al.*, 2010). It is widely accepted that conversion of native land, into a cultivated system causes precipitous degradation of the Soil Organic Matter (SOM) due to diminished C input to the soil and increased rate of degradation of plant residue due to better aeration (Chen and Xu, 2010). About 20-40% of the native SOM is lost when virgin lands are converted to agriculture (Chandran *et al.*, 2009). The increasing conversion of native lands to croplands might reduce the capacity of soils to retain belowground C (Chandran *et al.*, 2009). The magnitude of C losses or gains after land-use conversion depends on land use and management practices, climate and soil type.

Six *et al.* (2002) explained that organic matter is stabilized by intimate association between soil mineral particles. Fine particles, particularly clays (particles<0.2 mm), are known to associate with organic compounds, thereby contributing to the formation of stable organomineral complexes. The physical protection against decomposition conferred by these stable complexes is believed to be an important mechanism that contributes to the stability of Soil Organic Carbon (SOC) (Blanco-Canqui and Lal, 2004). Solomon *et al.* (2002) reported that SOC associated with sand-size aggregates and silt fraction is often more labile than SOC in the clay fraction (Zhao *et al.*, 2006). Thus, to evaluate long term changes in SOC and SOM dynamics correctly, it is important to study SOC in clay fraction.

The limited studies on soil C storage in cultivated lands have not examined the extent of C- storage in soil clay fraction under different land-use systems involving various plant forms (trees and crops alone and in association) compared to the undisturbed forest conditions. It is important to assess the pools under native vegetation as it reflects the ecosystem's capacity to sequester C.

The objective of this study was to investigate the soil C storage in clay mineral fraction of soil in different cultivated lands and how it deviate from natural undisturbed forest conditions. An attempt was also made to study the effect of climatic conditions on the organic c content in clay mineral fraction.

Sri Lanka possesses almost all the main tropical forest types and croplands and it is a suitable place for studying C sequestration in the tropics. This unique land-use assemblage offers an excellent setting for investigating the extent of soil C storage under different land-uses compared to the natural undisturbed forest conditions.

MATERIALS AND METHODS

Field sites: Study sites were located in the main climatic regions of Sri Lanka (5° 54' N - 9° 52' N latitude and 79° 39' E - 81° 53' E longitude). In each location, the major crop type and the adjacent natural forest type were selected. The major croplands selected were tea, rubber, coconut, mixed crops (i.e., pepper, cardamom and cacao), potato, home garden and a chena cultivation (a kind of a slash-and-burn cultivation) (Table 1, 2). The adjacent natural forests included tropical wet evergreen, semi evergreen, moist monsoon, dry monsoon, montane and dry mixed evergreen forests (Table 1, 2).

Soil sampling and analyses: After removing the soil surface litter layer from random locations, 20 composited soil samples were collected from 0-20 cm depth at each site in year 2006. Each composite sample was comprised of 3 soil cores. Soils were air-dried and passed through a 2 mm sieve. The separation of clay was done by sedimentation method (USDA, 2005). Organic C in the clay fraction was extracted by a sequential extraction procedure (Chaudhry and Stevenson, 1957) and analysed for organic C using a colorimetric procedure (Baker, 1976).

Statistical analysis: Comparison of organic C content among different land uses was done using a GLM procedure and tukey's HSD test (SAS, 1996). A t-test was carried out to compare C sequestration between the natural forests and the adjacent cultivated lands. The relationships between organic c content in the clay mineral fraction of soils and the climatic parameters were established through correlation and regression analyses (SAS, 1996).

Table 1: Descriptive information of the field sites studied

Ecosystem	ELE (m)	MAR (mm)	MAT (°C)	Soil Great group	pH	Clay content (g 100 g^{-1})
Forests						
Tropical wet evergreen (1) (WL)	1000	5000	25.0	Haplic Acrisols	4.57	9.26
Tropical semi evergreen (IM)	700	2500	24.8	Cambisols	6.13	9.91
Moist monsoon (IU)	1300	2500	22.0	Chromic Luvisols	6.98	10.45
Dry monsoon (IL)	221	2000	27.4	Haplic Acrisols	6.08	4.23
Montane (WU)	2000	2500	15.0	Haplic Acrisols	5.74	11.34
Dry mixed evergreen (DL)	300	1400	28.4	Chromic Luvisols	6.87	4.96
Tropical wet evergreen (2) (WM)	600	3000	20.0	Rhodic Nitisols	6.37	9.03
Cultivated lands						
Rubber tree (WL)	1000	5000	25.0	Haplic Acrisols	4.63	13.96
Mixed crops (IM)	700	2500	24.8	Cambisols	5.64	9.23
Potato farm (IU)	1300	2500	22.0	Chromic Luvisols	6.07	18.56
Coconut (IL)	221	2000	27.4	Haplic Acrisols	5.19	4.49
Tea (WU)	2000	2500	15.0	Haplic Acrisols	5.06	23.57
Chena cultivation (DL)	300	1400	28.4	Chromic Luvisols	6.71	5.98
Home garden (WM)	600	3000	20.0	Rhodic Nitisols	6.00	12.69

ELE: Elevation; MAR: Mean annual rainfall; MAT: Mean annual temperature; Climatic regions: WL: Wet zone low country; IM: Intermediate zone mid country; IU: Intermediate zone up country; IL, Intermediate zone low country; WU, Wet zone up country; DL: Dry zone low country; WM: Wet zone mid country

Table 2: Some soil management practices involved in the cultivated lands

Site	Crop type	Fertilizer (kg ha^{-1}) N	P	K	No. of applications ($year^{-1}$) Fertilizer	Pesticide	Herbicide	Soil Digging/forking (No. of $times^{-1}$)
Rubber tree	P	20	20	60	1	NCNA	NA	
Mixed crops	P	120-250	140-200	95-150	4	NC	NA	NA
Potato farm	A[a]	210	50	300	6	6	2	4
Coconut	P	140	90	330	1	NC	1	NA
Tea	P	240	30	60	3-6	2	4	4
Chena cultivation	A	NA	NA	NA	NA	NA	NA	NA
Home garden	P,A	NA	NA	NA	OM	NA	NA	4

NC: Not Common; OM: Organic Manure; NA: Not Applied; Perennial trees; P: Annual: A: [a]2 Crops annually

RESULTS

Soil organic C in the clay mineral fraction showed a wide variation among the different cultivated lands as well as the forests (Table 3). Among the cultivated lands, the tea soil showed the highest SOC content in the clay fraction (13.07 g 100 g^{-1}) (Table 3).

Chena cultivation showed the lowest value (7.6 g 100 g^{-1}). Organic C content in the clay fraction of the other land uses ranged from 9.18-11.73 g 100 g^{-1}. In the forests, the highest value was observed in the montane forests (28.5 g 100 g^{-1}) (Table 3). Dry mixed evergreen forest showed the lowest SOC content (8.99 g 100 g^{-1}) in the clay fraction.

Table 3 shows a comparison of SOC content of clay fraction between cultivated lands and the adjacent forests. There were significant differences in the SOC content of the clay fraction of the forest soils compared to adjacent cultivated lands.

Table 3: Organic C in clay mineral fraction of soils in cultivated lands and the adjacent natural forests

Ecosystem	Organic C in clay fraction (g 100 g^{-1})
Forests	
Tropical wet evergreen (1)	13.21e
Semi evergreen	15.62d
Moist monsoon	24.85b
Dry monsoon	10.47f
Montane	28.5a
Dry mixed evergreen	8.9g
Tropical wet evergreen (2)	16.82c
CV (%)	25
Cultivated lands	
Rubber tree	11.73b
Mixed crops	11.28c
Potato farm	10.71d
Coconut	9.18e
Tea	13.73a
Chena cultivation	7.6f
Home garden	11.68b
CV (%)	28

Values in the same column followed by the same letter are not significantly different at $p<0.05$

Table 4: Comparison between the organic C content in clay mineral fraction of the natural forests and the adjacent cultivated lands

Ecosystem	Organic C content
Tropical wet evergreen (1)	13.21
Rubber tree	11.73
Difference	1.48**
Semi evergreen	15.62
Mixed crops	11.28
Difference	4.34**
Moist monsoon	24.85
Potato farm	10.71
Difference	14.14**
Dry monsoon	10.47
Coconut	9.18
Difference	1.29**
Montane	28.5
Tea	13.73
Difference	14.77**
Dry mixed evergreen	8.9
Chena cultivation	7.6
Difference	1.3**
Tropical wet evergreen (2)	16.82
Zome garden	11.68
Difference	5.14**

**Significant at $p<0.01$

Significant correlations were observed with SOC content in the clay fraction in forest soils and climatic parameters (Fig. 1) but to a lesser extent in cultivated soils.

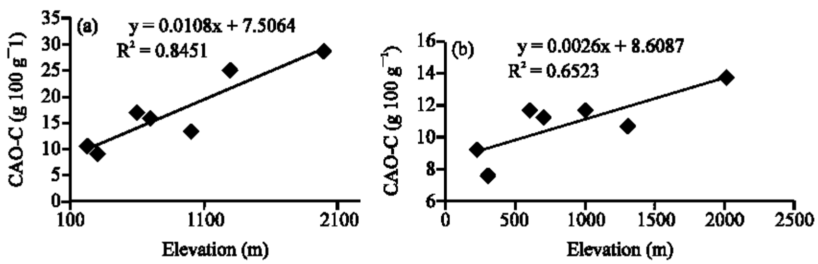

Fig. 1: Relationships between organic C content in clay fraction (CAO-C) and the elevation (m) in (a) forests and (b) cultivated lands. Each data point in the figure represents a mean of 20 composite soil samples per site

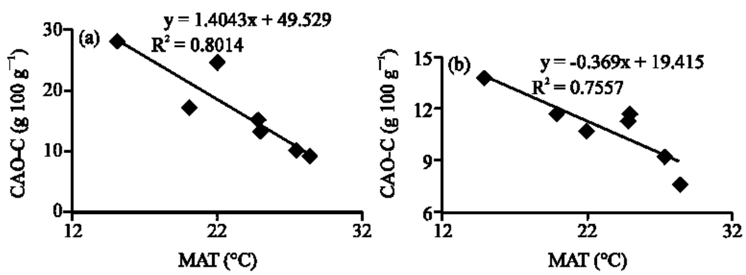

Fig. 2: Relationships between organic C content in (a) clay fraction (CAO-C) and (b) the Mean Annual Temperature (MAT). Each data point in the figure represents a mean of 20 composite soil samples per site

Elevation correlated well with organic C content of the clay fraction (Fig. 1a) in forest soils. The correlation was marginally significant for cultivated lands (Fig. 1b). Mean annual temperature was also correlated significantly with SOC content of the clay fraction forest soil (Fig. 2a). But the level of significance is low in cultivated soils (Fig. 2b) compared to the forest soils. The mean annual rainfall did not show any significant relationship with SOC content of the clay fraction in cultivated soils ($R^2 = 0.276$) nor forest soils ($R^2 = 0.003$).

DISCUSSION

Cultivated soils showed much lower SOC content than native forest soils, suggesting that cultivation has decreased the soil organic C content of the clay fraction significantly although it was reported to be stable against land use changes than the other fractions (Soloman *et al.*, 2002).

Mixed crop and rubber are tree plantations, involved with minimum land management and soil tillage (Table 2) reducing the rate of decomposition and thereby increasing the C stocks as observed in this study (Lal, 2006). It was reported that maximum potential of soil C storage is obtained from multiple cropping sequences coupled with no till soil management as the most desirable management strategy (Wright and Hons, 2004). The few reports that are available on soil C storage under agro forestry systems indicate that soil C stocks under agroforestry systems vary widely depending on ecological conditions and land use systems (Saha *et al.*, 2010). This study showed that the SOC content in clay mineral fraction was also affected by these factors though it is the stable mineral fraction of soil.

It is hypothesized that SOM increase as a result of a decreasing turnover rate of SOM with increasing clay content (Muller and Hoper, 2004). Cool-temperate climate in montane forest would promote C inputs and slow C breakdown, while helping to protect C in clay.

Comparatively high temperature in dry mixed evergreen forest and dry monsoon forest may have increased the decomposition rates and lowered the SOC content in the clay fraction (Post and Kwon, 2000). Also low clay content in these dry forests compared to the other forests may have resulted higher SOC losses (Zinn *et al.,* 2002).

In some regions, as much as 50% of the soil humus is held by clay particles in organo-mineral complexes and is thereby protected from rapid decomposition (Muller and Hoper, 2004). We found that this fraction is also equally affected during long term cultivation. It is reported that more intensive forms of agriculture and the introduction of best management practices have the potential of reducing SOC losses in agricultural lands. However, the study showed that SOC content remain significantly changed over undisturbed forests.

Considerable variations in organic matter input in cultivated lands may explain the missing or weak relationship between SOC content and other climatic parameters. However, significant relationships were obtained for forests where the organic matter inputs are constant. This further confirmed that cultivation can obscure natural relationships between climatic parameters and organic C in soils.

CONCLUSIONS

It is confirmed that the C stored in the clay mineral fraction of soil is also affected by land use change showing that regardless of the management, these soils are prone to C loss with cultivation. It was shown that although the cultivation can obscure natural relationships between climatic parameters and SOC in the clay fraction, significant relationships were shown by the forests where the organic matter inputs are constant.

The study also highlighted that Sri Lanka represents almost all main tropical forest types and croplands suggesting that it is a suitable place for studying C sequestration in the tropics.

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