

Carbon losses and soil property changes in ferralic Nitisols from Cuba under different coverages

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ABSTRACT: The transformation of primary forestlands into lands under cultivation exerts an impact on the physical and chemical properties of the soils, leading to loss of carbon from the soil. The aims of this study were (1) to estimate the impact of different land use on organic carbon stock (OC-stock) and (2) to determine the clay percentage, the dispersion factor, and bulk density with regard to soil management. Thirty soil profiles were sampled as follows: four under primary forests with 80-100 years (old growth); two under secondary wood forests with 45-50 years; eight under secondary young forests with 15-25 years; four under pasture land with 15-20 years; and 12 under continuous cultivation for > 50 years. We determined the changes in OC-stock in the soils under different land-use conditions in relation to the primary forest variant. There was a difference in the OC-stock of the continuous cultivation variant compared to the remaining land-use variants for all soil-thickness layers. The greatest loss of cultivated soil was in the 0-20 cm layer of the primary forest OC-stock. In the 50-100 cm layer, the OC-stock of the cultivated soils diminished significantly. As regards physical properties, such as clay percentage, dispersion factor, and bulk density, we observed significant differences between the cultivated soils compared to the remaining land-use variants.

Keywords: degradation, carbon reserves, physical properties, tropical soils

Introduction

The transformation of primary forest land into land under cultivation exerts an impact on the physical and chemical properties of soil, leading to loss of carbon from the soil and its emission into the atmosphere in the form of CO₂, which enriches the greenhouse-effect gases that are currently ushering in climate change (Don et al., 2011; Xiong et al., 2014). There are estimates that the conversion of natural ecosystems into agrosystems is responsible for approximately 24 % of worldwide CO₂ emissions (IPCC, 2007).

In Cuba, there are extensively weathered tropical forests (Ferralsols, Nitisols, Oxisols, Lixisols, Acrisols, and Alisols). The most extensive area is composed of ferralic Nitisol soil, especially in the western plains (in the provinces of Artemisa, Mayabeque, Matanzas, and Ciego de Ávila), which, because of its profound and friable soil characteristics, has been the main source of food production for the inhabitants of this region.

There are antecedents in the study of red ferralitic soils, and changes in the properties of these soils occur under different forms of land use (Hernández et al., 2013). However, a fresh analysis of these studies produced a classification of the following three general patterns: forests of > 40 years; forests conserved as pasture land (PL); and forests under permanent cultivation (CU). However, the results presented by Batjes (1996) demonstrate that variation in organic carbon is attributable to its relationship to soil types and their management. For example, Olson (2013), and Olson et al. (2014) mentioned that tillage systems influence soil organic carbon

(SOC) distribution, storage and loss in the surface and subsurface soil horizons. Other factors that affect the dynamics of SOC are land use, climate, and soil landscape processes (Olson et al., 2011, 2012). One essential point to consider is the depth at which soil samples are taken since the interaction between the root system and the soil profile has an influence on soil carbon accumulation (Olson and Al-Kaisi, 2015). Also, organo-mineral interactions are an important factor in SOC storage (Grand and Lavkulich, 2011). Soil texture affects carbon retention capacity, and fine-textured soils usually have more carbon retention capacity than sandy soils (Angers et al., 2011). Based on the latter, the aims of this study were (1) to estimate the impact of different land uses on the organic carbon stock (OC-stock) and (2) to determine the clay percentage, the dispersion factor, and the bulk density together with its implications for soil management.

Materials and Methods

The study was carried out in the Mayabeque Province, which is located in the western region of Cuba, between 22° 34', 23° 12' North Latitude and 82° 28', 81° 40' West Longitude, and is bordered on the west by the Artemisa Province and on the east by the Matanzas Province. This province comprises an area of 3,732.7 km² under a sub-humid tropical climate with an annual precipitation of between 1,300 and 1,500 mm, a mean temperature of 24.5 °C, and a plain relief. The material of origin consists of Miocene-age hard limestone.

The soils under study (ferralic Nitisol) form part of the so-called "Red Grasslands of Havana," which cur-

rently cover the central-southern part of the Mayabeque and Artemisa Provinces, which were created three years ago. For more than two centuries, this area was cultivated, initially with tobacco and later with sugar cane, coffee, and other crops. Its natural formation under forests resulted in fertile soils that are rich in organic matter, which have been reported in other studies as storing a great amount of carbon due to the time factor involved in their formation and to the fact that they are profound and friable soils (Morisada et al., 2003).

These soils have ABtC profiles, a deep red color and are made of clay. Table 1 presents a number of the chemical and physical characteristics of the soils for the A and Bt horizons for each land use condition. These are soils with high base saturation. The range of pH values is from slightly acidic (6.70) to slightly alkaline (7.30) in the A horizon. However, in the Bt horizon, the range is from strongly acidic (5.40) to neutral (6.90). Clay is from 69 % in the A horizon to 87 % in the Bt horizon (argillic horizon).

The amount of calcium is predominant with total exchangeable bases from 10.10 to 18.18 cmol (+)/kg and these soils have high saturation. All of these characteristics demonstrate that the soils are eutric, lixic, and ferralic Nitisols.

In total, 30 ferralic Nitisols soil profiles were studied under five conditions of coverage and land use which were grouped into various categories as follows: four under primary forests (PF) 80-100 years old (two of these with ferro-manganese staining at a depth of 70-80 cm); two under secondary wood forests (SF) 45-50 years old; eight under secondary young forests (YF) 15-25 years old; four under pasture lands (PL) 15-20-years old; and 12 lands under continuous cultivation (CU) for > 50 years.

The soils were identified by the World Reference Base for Soil Resources (WRB) classification (International Union of Soil Sciences (IUSS), Working Group, 2014). The soil samples were analyzed at San José de las Lajas, Mayabeque, Cuba, in accordance with the following analytical methods: organic matter according to Walkley & Black; carbon by dividing the percentage of organic matter by 1.724; mechanical composition by the

Bouyoucos method, utilizing sodium pyrophosphate to destroy the microaggregates and sodium hexametaphosphate as dispersant; microaggregate composition by the Bouyoucos method but without chemical reagents; and the dispersion factor (the k value) by dividing the percentage of clay obtained by mechanical analysis multiplied by 100.

Bulk density was determined by the cylinder method (100 cm³, volume).

An estimation of the carbon reserves (Mg ha⁻¹) was conducted using the following formula:

$$CR = C (\%) \times Vd (\text{kg/dm}^3) \times \text{Layer depth (cm)}$$

where: CR = Carbon reserves; C = Carbon; and Vd = Volume density.

The CR were calculated for depths of 0-20, 0-50, and 0-100 cm.

We carried out an analysis of variance (ANOVA) on the results considering a completely random design in which the profiles of each category were considered repetitions and each of the five conditions were considered treatments. We also carried out a means test (Duncan, 0.05) to evaluate the significance of the land management over the OC-stock. Additionally, to test whether the data were normally distributed, we ran a Shapiro-Wilk (W) statistic test. The statistical procedures were conducted using PROC GLM and PROC MEANS in SAS (Statistical Analysis System, version 9.1).

Results and Discussion

The results demonstrate that the soils in this study, when under permanent coverage, have a content of over 100 Mg ha⁻¹ of organic carbon at a depth of 0-100 cm (Table 2). The soils under the primary forests (80-100 years old) have a higher OC-stock level (153.25 Mg ha⁻¹), followed by the secondary forests (45-50 years old) with 143.00 Mg ha⁻¹; next, the young forests (15-25 years old) with 124.00 Mg ha⁻¹, and finally the soils under the pasture land accumulate 123.50 Mg ha⁻¹. The forests and pasture land accumulate more organic matter than the

Table 1 – Chemical and physical characteristics of soils for the A and Bt horizon under each land use condition.

Land use	Soil horizon (Sh)	Average thickness of Sh	pH	OM	Clay	Ca	Mg	Na	K	TEB	EC	BS
											cmol kg ⁻¹	%
PF	A	17	7.27	9.12	69.3	13.2	4.2	0.04	0.74	18.18	19.2	94.7
	Bt	63	6.41	2.12	81.3	11.5	2.3	0.06	0.16	14.04	16.4	85.6
SF	A	12	6.70	5.80	72.3	10.0	2.5	0.04	0.31	12.85	15.0	85.7
	Bt	76	5.40	2.45	80.3	8.5	2.7	0.04	0.05	11.29	14.9	75.8
YF	A	18	7.30	3.59	77.3	11.7	2.5	0.08	0.10	14.38	15.2	94.6
	Bt	88	6.90	1.34	86.3	11.2	1.0	0.06	0.05	12.31	12.8	96.2
PL	A	20	6.70	4.59	77.0	10.7	3.8	0.06	0.68	15.22	16.8	90.6
	Bt	70	6.00	1.03	87.0	8.5	3.3	0.09	0.06	11.95	14.3	83.6
CU	A	20	6.90	1.51	70.0	8.6	2.8	0.10	0.73	12.23	13.2	92.7
	Bt	78	6.50	0.45	82.3	7.5	2.3	0.10	0.30	10.10	12.5	80.8

PF = Primary forest; SF = Secondary forest; YF = Young forest; PL = Pasture land; CU = Continuous cultivation; OM = Organic matter; TEB = Total exchange bases; EC = Cation exchange; BS = Base saturation.

Table 2 – Change in organic carbon stocks (OC-stocks) under Primary forests (PF), Secondary forests (SF), Pasture land (PL), Young forests (YF) and Continuous Cultivation (CU).

Depth cm	Number of profiles	OC-Stocks Mg ha ⁻¹	Loss of OC compared to PF %	Type of land coverage
0 - 20	4	76.25 a [†]	—	PF
	2	52.50 b	31	SF
	4	52.25 b	32	PL
	8	45.63 b	40	YF
	12	28.08 c	63	CU
0 - 50	4	112.50 a	—	PF
	4	88.75 a	19	PL
	2	88.50 a	21	SF
	8	87.88 a	22	YF
	12	54.00 b	52	CU
50 - 100	2	54.50 a	—	SF
	4	40.75 ab	25	PF
	8	36.13 ab	34	YF
	4	34.50 ab	37	PL
	12	22.75 b	58	CU
0 - 100	4	153.25 a	—	PF
	2	143.00 a	7	YF
	8	124.00 a	19	SF
	4	123.25 a	20	PL
	12	76.75 b	50	CU

PF = Primary forest; SF = Secondary forest; YF = Young forest; PL = Pasture land; CU = Continuous cultivation; [†]Mean values followed by the same letter do not differ between type of land use.

CU soils. Fonseca et al. (2011) found that, in Costa Rican tropical soils under secondary young forests (YF), the soil had an annual growth rate in carbon content of 1.09 Mg ha⁻¹ and that in all of the variants of different forest age, the amount of carbon accumulated in the soil was higher than in the biomass.

The relatively high content in the OC-stock of the soils was in agreement with other results for soils in tropical regions. In Sarawak, Malaysia, Histosols had the greatest amount of organic carbon with 1,100 t ha⁻¹ m⁻¹, followed by Oxisols with 200 t ha⁻¹ m⁻¹ and Ultisols with 160 t ha⁻¹ m⁻¹, while Entisols had approximately 90 t ha⁻¹ m⁻¹ and the last, Inceptisols, possessed the least amount, with 60 t ha⁻¹ m⁻¹. Among the mineral soils, Oxisols store the greatest amount of carbon due to the time-frame for sequestering carbon (Padmanabhan et al., 2013). Other authors report carbon capture numbers in amounts of > 100 Mg ha⁻¹ for ferralitic soils (Oxisols and Ultisols). Batjes (2008) reported a content of 129 Mg ha⁻¹ for Oxisols, and Telles et al. (2003) reported 111 Mg ha⁻¹ for Oxisols in the Amazon. Battle-Bayer et al. (2010) presented the results from different authors on OC-stock in Latosol soils (ferralitic) from the Cerrado Region in Brazil; the red Latosols, with clay content between 61 and 81 %, had an OC-stock of 123-148 Mg ha⁻¹, and the yellow Latosols, with a clay content between 43 and 68 %, had an OC-stock of 185-209 Mg ha⁻¹. In both cases, these values were determined at a depth of 0-100 cm.

Tropical soils are found under stable vegetation many years old (primary forests, secondary forests, or savannahs). They exhibit the capture of carbon that is > 100 Mg ha⁻¹ per meter of profundity; therefore, there are soils that can be very functional in terms of organic carbon sequestration. According to Cheng et al. (2011), soil carbon retention is of great importance because it can potentially compensate for the emissions of fossil fuels of 0.4-1.2 giga-tons of carbon per year.

The same occurs when deep, ferralitic-composition soils are found under CU, which is independent of the carbon capture that is carried out under natural conditions (under PF or SF), that is, the carbon content diminishes, registering the greatest impacts of anthropic action on the upper layer of the profile. In terms of our results, we observed that for the 0-20 cm soil layer, the OC-stocks manifested more significant values than for any other permanent land use (SF, YF, and PL), ranging between 30 and 40 % for the PF variant, while the greatest significance is found under CU land use (Table 2).

The difference in OC-stock in the CU variant with relation to PF is 48.167 Mg ha⁻¹, indicating a loss of 63 % of OC in the soils. This loss in OC-stock that CU soils have undergone compared to those of PF coincides with criteria from other studies. Lal et al. (2007) proposed that in the majority of soils worldwide, carbon loss, due to land-use changes, is found to be between 30 and 75 %. Additionally, for tropical soils, in the Hainan Province, China, Deng et al. (2009) found that under sugar cane cultivation over a period of 56 years, the soil lost > 60 % in OC-stock in the soil under the secondary forest.

At a depth of 0-50 cm, there is no marked difference in the changes in OC-stock compared to the PF in relation to the permanent coverages, although the OC-stock tendency is always greater in the PF variant. The statistical analysis conducted shows that there is no significant difference between the PF variant and the remaining permanent coverages (Table 2). This is possibly because, in terms of depth, coverage-change impacts are not evident, such as at a depth of 0-20 cm, and to the fact that the biological activity of 20-50 cm thickness might be homogeneous for these variants, and thus, the difference would not achieve significance in the OC-stock of the SF, YF, and PL coverages compared to the PF. Olson et al. (2011) compared the storage of SOC on sloping woodland and cropland landscapes of northwestern Illinois, and they found that the woodland landscape had higher SOC in the surface layer than that of the cropland. However, the SOC in the subsurface layers was similar under both land uses.

With respect to the CU variant for more than 50 years, significance was found in the OC-stock content compared to the PF (a loss of 52 %).

The results for the 0-100 cm layer also showed the greatest OC-stock for soil under the PF. However, the differences were not significant for permanent coverages. There were significant differences under CU management, which exhibited an OC-stock loss of 50 % compared to soils under the PF.

In the case of carbon reserves at a depth of 50-100 cm, this registered similar findings, namely, that the greatest loss was in the CU variant. Numerous investigators have demonstrated the impact that soil preparation has in tropical regions on the soil's biological properties in the soil. Tillage mechanically disperses the abiotic and biotic soil-cementing agents; thus, the aggregates and root and mycorrhizoid hyphae fragments are mechanically disaggregated (Beare et al., 2007; Carrizo et al., 2015). The work carried out by the arbuscular mycorrhizal fungal species is important in the formation of soil aggregates through the production of glomalin (Bedini et al., 2009), which is interrupted by soil-preparation work. The impact of land preparation on soil biology is aggravated when herbicides are applied because, the majority of the time, these pesticides instead of pesticides are toxic to the microorganisms.

The amount of OC-stock at a depth of 50-100 cm under the SF variant reaches higher values than those of the PF, which occurs because out of the four profiles studied in this PF soil, two presented black ferro-manganese staining at a depth of 70-80 cm, which is attributed to symptoms of reduction that diminish the biological activity under 50 cm; thus, the same amount of carbon does not accumulate.

In the CU soil variant, for the 50-100 cm layer, a considerable part of the carbon is lost (58 %) in relation to the soil under the SF.

Table 3 depicts the results obtained between land-use type and a number of the physical properties, such as the soil's clay content, the amount of clay in the microaggregate analysis, the dispersion factor, and the bulk density.

In terms of clay content, we observed that all of the profiles studied under the different coverages were clay soils, and the most clay was found under the SF, followed by the PL, CU, and YF. The least amount of clay was under the PF, and this value was statistically significant compared to the clay under the SF.

In the results obtained for the amount of clay dispersed by different soil-management actions (Table 3), we observed that the CU soil possesses 19 %, which is a significant value in comparison to the other land use. The lowest clay level in the microaggregates was found in the PF soils (9 %), with values which are not signifi-

cant when compared with other coverage types (SF, PL, and YF), that are conservation coverages. This might be because in soils under permanent coverage, soil aggregate stability is higher (Hunke et al., 2014).

For ferralitic soils, Cooper et al. (2005) determined that microaggregates are formed from clay, iron, and organic matter. With the loss of the soil's organic matter by cultivation (i.e. carbon), the macroaggregates and part of the microaggregates are fractured, and over time, clay is released from these and is maintained in a dispersed form. Therefore, in the microaggregate analysis, as the land-use changes increase from the soils under the primary forests due to continuous cultivation for many years, the amount of dispersed clay increases. At the same time, changes take place in the soil structure, including changes from a granular to a granular nuciform to a subangular-block structure, presenting very cultivated soils with a plow pan that is sometimes between 15 and 20 cm in depth.

The relationship between the clay content in the mechanical analysis and that of the microaggregate analysis allows for the determination of the dispersion factor, which, for the same soil, is greater to the extent that there is a greater amount of dispersed clay. This is an important indicator for soils whose composition is ferralitic because it permits the evaluation of the impact of CU on the transformation of the soil structure and aggregates. This value is tightly related to the stability of the soil's structure.

In the results obtained for the dispersion factor, we also observed a greater value in the CU soils. As regards to this property, there are significant differences for the CU soils in relation to the other coverage types (PF, SF, YF, and PL). The lowest dispersion value was obtained for the least altered soils, those under the PF, 80-100 years old.

Carbon loss is the result of the loss of the soil's organic matter, which is a fundamental element in soil-structure formation; the amount of organic-matter and its distribution are highly affected by soil management (Beare et al., 2007; Hevia et al., 2007). Green et al. (2007) and Noellmeyer (2008) studied the soils' structural stability in relation to its carbon content and biological activity and determined that soils under traditional cultivation had less OC content, structural stability, and biological activity, due to the action of CU.

One of the most important impacts on the affectation of the physical properties in these soils is the manner in which the clay in the structural aggregates is dispersed, which is the consequence of the aggregate rupture due to human action and land-use changes, which leads to organic matter and also to OC loss in the lands found under more natural conditions as well as in those that are more cultivated. That is, changes in land use and continuous and intensive agricultural exploitation cause the loss of organic matter and organic carbon, which in turn gives rise to the degeneration of their properties and soil productivity (Silva et al., 2010; Hernández et al., 2013).

Table 3 – Variation of the physical properties of soils in Primary forests (PF), Secondary forests (SF), Pasture land (PL), Young forests (YF) and Continuous Cultivation (CU).

Type of land coverage	Clay in mechanical analysis	Clay in microaggregate	Dispersion factor (k)	Bulk density
	%			kg dm ⁻¹
SF	75 a ¹	9 b	12.55 b	1.00 bc
PL	71 ab	11 b	14.87 b	1.07 ab
CU	68 ab	19 a	27.62 a	1.12 a
YF	67 ab	11 b	16.02 b	1.04 bc
PF	65 b	9 b	8.93 c	0.97 c

¹Mean values followed by the same letter do not differ between type of land coverage.

With respect to the volume of the soils studied, we observed that when the soils had more dispersed clay and a poorer structure, the soil became denser and less permeable; thus, it is expected that the bulk density would be greater in the soils with less OC and have a higher dispersion value. In this case, we observed the highest bulk density values in the soils under CU, being significant with the YF, SF, and PF variants and not significant with the PL variant. The lowest average bulk density value was obtained in soils under the PF variant.

Silva et al. (2010) demonstrated that anthropic action changes the physical properties of the yellow Latosol (yellow ferralitic) soil, finding that the highest bulk density values are presented at a depth of 0-5 cm. Thus, the authors conclude that anthropic action significantly changed the soil-density values, not only on the surface but also at deeper layers. The organic matter of soils and the biological activity of tropical soils exert a significant influence on their physical and chemical properties. Ralisch et al. (2010) determined that in lands prepared with the use of machinery, degradation of soil structure and compaction occur, in contrast to when the ground is prepared with animal traction.

The results obtained confirm that with CU, organic matter is lost, and thus, the soil's carbon content is lost and transformations are manifested that give rise to the degeneration of the soil's physical properties. Currently, there are results of investigations that analyze different soil preparation methods in relation to the behavior of the organic matter, the carbon in the soil, and other properties, such as bulk density, soil structure and compaction (Olson, 2013).

In this study, it is notable that physical properties, such as the dispersion factor and volume density, do not reach higher values for the CU variant, despite the fact that the soils were subjected to CU for > 50 years. The bulk density values are not as high as in other soils in other regions. This situation is mainly due to the characteristics of the soil, which has a very clayish texture and a ferralitic composition with a relatively high free-iron content. In these soils, microaggregates are formed by the action of the clay, iron, and organic matter (Cooper et al., 2005). Therefore, the iron maintains a significant content of organic matter bound to the microaggregates, which decomposes only with difficulty.

The content of organic matter, especially in the humus fraction, together with the iron, forms stable microaggregates in the upper part of the profile as part of the natural formation of Ferralsol, Nitisol, and Lixisol soils (Cooper et al., 2005), which tend to diminish due to anthropic influence when soil is subjected to intense cultivation. Deng et al. (2009) highlighted the role of iron in the formation of microaggregates in tropical soils and present results by which the authors demonstrate that in soil with 56 years of sugar cane cultivation, despite the great loss in OC, there is only a small diminution in the macroaggregate fraction.

Conclusions

Continuous cultivation causes a degradation of OC-stock in the soil profile (0-100 cm) in lixic ferralitic Nitisol soils. Soils under the primary forest (80-100 years old) have a higher organic carbon sequestration of 153 Mg ha⁻¹, followed by the secondary forest (45-50 years old) with 143 Mg ha⁻¹, then the young forest (15-25 years old) with 124 Mg ha⁻¹, the soils under pasture with 123 Mg ha⁻¹, and lastly, the soils under continuous cultivation with 78 Mg ha⁻¹.

Carbon loss leads to degradation of the physical properties in these soils, such as the soil dispersion factor and volume density. Despite these negative impacts on these soils' properties, an aggregation level is maintained due to the soils' iron and clay content.

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