Scientific Paper

Changes in organic carbon stocks in pelic Vertisols, according to their management

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Abstract

Objectives: To evaluate the changes in the organic carbon stocks in a Vertisol pelic mulched soil under *Mangifera indica* L. grove with *Paspalum notatum* Flüggé grassland in the Campo Florido to Jaruco pediplain, Mayabeque province, Cuba.

Materials and Methods: The research was based on the characterization and diagnosis of a soil profile in 2006. Two soil profiles with different management conditions were selected and duplicate sampling was carried out to determine the organic carbon contents by the method of cutting cylinders of 100 cm^3, in 2020. Organic matter was quantified by the Walkley and Black wet combustion method. The comparison between both samplings allowed obtaining organic carbon gains or losses in the soil.

Results: Soil organic carbon gains after fourteen years under conserved conditions were +0,43; +0,21; +0,14 Mg ha^{-1} yr^{1}. Losses under continued cultivation for ten years showed values of -0,64; -1,40; -1,92 Mg ha^{-1} yr^{1} for the 0-10, 0-20 and 0-30 cm layers of the top soil thickness, respectively. According to management, under conserved conditions, the accumulation of organic matter and organic carbon in the prismatic blocks was higher on the surface with regards to the inner part. However, under agricultural conditions, the concentrations resulted lower and reached the same value on the surface as in the inner part.

Conclusions: As in the case of Ferralitic and Brown soils, organic carbon stocks in vertisols decrease due to continued cultivation, which in turn leads to deterioration of their properties.

Keywords: climate change, carbon dioxide sequestration and storage, soil cover

Introduction

Currently, the problem of soil organic carbon (SOC) is of great interest, since in ecosystems, soils are the most important component for carbon (C) capture and sequestration, especially if it is considered that with the implementation of good management practices, CO_2 emissions to the atmosphere can be reduced, which contributes to climate change mitigation (Guerra, 2021). It is known that with continued cultivation, losses of OC take place in soils; while when conserved under forests, pastures and fruit trees with grasslands, OC increases (Carnero-Lazo *et al*., 2019; Shakoor *et al*., 2021; Wang *et al*., 2020).

The joint action that can be caused by C losses in ecosystem soils and climate change, which synergistically influence agricultural production, must also be considered. In the world, agricultural soils have lost between 30 and 75 % (30 to 40 Mg C ha^{-1}) of SOC reserves (Lal *et al*., 2007), which contributes to the increase of greenhouse gases (GHG) and global warming, causing not only natural disasters such as extreme droughts and floods, but also large losses in agricultural production (Amores-Mena, 2020).

In Cuba, OC losses due to land use change are reported in continuously cultivated leached Ferralitic red soils, with values between 50 and 55 % of SOC for the 0-20 cm layer of the top soil thickness (Hernández-Jiménez *et al*., 2017). In addition, depending on the management, OC losses per year are estimated (Carnero-Lazo *et al*., 2019). Likewise, the negative impact of OC losses on soil mesofauna and macrofauna has also been studied (Hernández-Fundora *et al*., 2020).

There are also reports available on OC losses from cultivation in Vertic brown soils, which can reach -0,60 t ha^{-1} yr^{1} in the first 20 cm of the upper soil thickness (Vargas-Blandino *et al*., 2022).

Regarding climate change, it is known that in Cuba the increase in the average temperature of the plains by 0,9 °C (Paz-Castro, 2019) has its cause, in part, in the increase of pH in red Ferralitic and

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leached red Ferralitic soils of the Red Plain of Havana, which includes the Mayabeque and Artemisa provinces (Hernández-Jiménez *et al*., 2020a). In addition, a hypothesis has been developed that in Cuba climate change and continued cultivation in leached red Ferralitic soils has a negative impact on other soil properties, as is the case of the formation of a compact layer in the Bt horizon which, according to the characterization that has been made of it, tends to increase its thickness over time (Grandio-de-Armas *et al*., 2020; Hernández-Jiménez *et al*., 2020b).

Notwithstanding the above, the problem of OC and its reserves in Vertisol soils has been little addressed in Cuba. This type of soil constitutes part of the country's agricultural land, with an area of 9 060 ha, and among them, pelic vertisols occupy an area of 8 200 ha (Hernández-Jiménez, 2021). Vertisols, together with Brown, humic, calcimorphic and Ferralitic red, are the main agricultural soils in the country. In addition, they are relatively extensive in the ecosystem of the pediplain from Campo Florido to Jaruco in the Mayabeque province (Reyes-Pérez *et al*., 2024).

In Cuba, Vertisols are considered relatively little productive soils, so they are mainly used for *Oryza sativa* L., *Saccharum officinarum* L. and pasture crops. However, in Mexico, they are valued as soils of great importance for agriculture and food production due to their physical and chemical properties, particularly in the Almoloya de Juárez, Ixtlahuaca, Aculco and Acambay municipalities, since they occupy a large part of the area (10,4 %, 241 485 ha) subject to agricultural productive activities (Sotelo-Ruiz *et al*., 2020).

The objective of this work was to evaluate the changes in the organic carbon stocks in a mulched Vertisol pelic soil under *Mangifera indica* L. grove with *Paspalum notatum* Flüggé grassland in the Campo Florido to Jaruco pediplain, Mayabeque province, Cuba.

Materials and Methods

Location. The study was carried out in La Rosita farm, with geographical coordinates N 365 500 E 383 700, located in the Habana del Este municipality, in the people's council of Campo Florido. It has a total area of 45,7 ha. The study area has a sub-humid tropical climate, relatively dry, with annual rainfall of 1 200 mm, average temperature of 24,5 °C and undulating relief. The source material is hard limestone of Oligocene age.

Office, field and laboratory work. Based on research from 2006 (López-Pérez, 2006), two soil profiles with different management conditions were selected. In 2020, a stratified random sampling was carried out in duplicate for depths 0-10, 0-20 and 0-30 cm. The soil classification used is the latest version of the Cuban Soil Classification (Hernández-Jiménez *et al*., 2015).

Sampling was conducted under the following management conditions:

- *Natural or conserved conditions (grove)*: pelic vertisol soil profile (Profile D-2), located in the lower part of the relief under a grove of *M. indica* planted more than twenty-five years ago, with *P. notatum* (natural grass), with no human intervention in harvesting and maintenance and no pruning. Animals do not enter this grove.
- *Agricultural conditions (intensive cultivation)*: pelic vertisol soil profile (Profile D-12), located in the lower part of the relief in preparation for planting, cultivated for ten years during which various crops were established.

SOC gains or losses were calculated by comparing the results obtained in previously studied profiles (fourteen years) by López-Pérez (2006) and the evaluations made in 2020. Dividing the reported gains or losses by the number of years that have elapsed, the annual rate of increase or loss in SOC was obtained. At the same time, in the two management conditions, prismatic blocks were taken in duplicate and the SOC content on the inside and outside of each block was determined. In both cases, the differences were compared.

Organic matter (OM) was determined using the wet combustion procedure (Walkley and Black). Then, from the percentage of OM, applying the empirical factor equivalent to 1,724, the OC percentage was determined.

The SOC content was calculated by determining the SOC reserves using the following equation:

$$SOC = Dv\ (Mg\ m^{-3}) \times OC\ (\%) \times thickness\ (in\ cm) \times (1\text{-}I)$$

where:

Dv: is the bulk density

I: is the percentage of inclusions (ferruginous nodules, gravels or stones).

The bulk density of the soil was calculated in the field by the method of the cylinder of 100 cc volume and with the determination of the humidity in an oven at 105 ºC for 24 h until reaching constant weight.

In the studied soils, there were no inclusions in the upper layers of the profile, so this part of the formula was not applied.

Results and Discussion

Vertisols are very clayey soils, with a predominance of smectite among the clay minerals, generally in flat relief, which expand in the rainy season and compact in the dry season. During their formation, they show a horizon variable in depth, but with a large prismatic structure with slicken sides (IUSS Working Group WRB, 2022; Soil Survey Staff, 2022).

In Cuba, Vertisols occur in flat relief, characterized by a vertic horizon, according to the latest version of soil classification (Hernández-Jiménez *et al*., 2015). So far, no results are reported on OC gain or loss in these soils, according to their management.

In this study, organic carbon stocks (OCS) were compared in duplicate, obtained in 2020 in a loose pelic Vertisol soil profile, under *M. indica* grove with grassland in low relief, with slope lower than 2 % (table 1). An average of 25, 40 and 56 Mg ha^{-1} was obtained.

Table 2 shows the results of the OCS determination in this profile in 2006.

When comparatively analyzing the results of the two samplings (tables 1 and 2), there was a gain of 6, 3 and 2 Mg ha^{-1} of OC for the depths of 0 to 10, 20 and 30 cm of the upper soil thickness in fourteen years in the pelic mulched vertisol, conserved under *M. indica* grove with pasture. These results showed that in these soils the OC gain under conserved conditions accumulates in the first 10 cm of the profile, which is in agreement with the report by Álvarez-Arteaga *et al.* (2020), who pointed out that the same soil unit responds differentially to its management.

The results for the pelic loose Vertisol soil (Profile D-12), cultivated ten years ago, are shown in table 3. On average, 10, 18 and 27 Mg ha^{-1} of OCS were obtained, values that when compared with those of 2006 showed net losses of 9, 19 and 27 Mg ha^{-1} for the 10, 20 and 30 cm layers of the upper soil thickness, respectively.

Table 1. Organic carbon stock values in Vertisols in 2020 (Mg ha^{-1}).

Profile	Year of study	Depth, cm	OM, %	C, %	W, %	Dv, Mg m^{-3}	OCS, Mg ha,$^{-1}$	OCS, Mg ha^{-1}		
								0-10 cm	0-20 cm	0-30 cm
D-2	2020	0 - 10	3,7	2,2	38,3	1,3	28,9	29	46	63
		10 - 30	2,1	1,2	41,7	1,4	33,8			
		0 - 10	3,2	1,9	40,8	1,1	19,6	20	34	48
		10 - 30	2,0	1,1	38,4	1,2	28,7			

OM: organic matter; C: carbon; W: Humidity; Dv: volume density; OCS: organic carbon stock.

Table 2. Organic carbon stock values in Vertisols in 2006 (Mg ha^{-1}).

Profile	Year of study	Depth, cm	OM, %	C, %	W, %	Dv, Mg m^{-3}	OCS, Mg ha^{-1}	OCS Mg ha^{-1}		
								0-10 cm	0-20 cm	0-30 cm
D-2	2006	0 - 17	3,02	1,75	41,0	1,10	32	19	37	54
		17 - 29	2,41	1,40	39,0	1,18	20			
		29 - 78	2,07	1,20	37,0	1,34	79			

OM: organic matter; C: carbon; W: Humidity; Dv: volume density; OCS: organic carbon stock.

Table 3. Organic carbon stock in the pelic loose Vertisol soil cultivated ten years ago (soil was in preparation for planting).

Profile	Year of study	Depth, cm	OM, %	C, %	W, %	Dv, Mg m^{-3}	OCS, Mg ha^{-1}	OCS, Mg ha^{-1}		
								0-10 cm	0-20 cm	0-30 cm
D-12	2020	0 - 10	1,67	0,97	38,5	1,10	10,67	11	20	29
		10 - 30	1,05	0,61	41,6	1,47	17,93			
		0 - 10	1,31	0,76	32,6	1,05	7,98	8	16	24
		10 - 30	1,05	0,61	42,2	1,34	16,35			

OM: organic matter; C: carbon; W: Humidity; Dv: volume density; OCS: organic carbon stock.

It was shown that this agroecosystem of the Vertisol pelic soil in the plains, under a grove of *M. indica* with pasture, gains in OCS when it is conserved for several years. On the contrary, when it is put under cultivation it loses in its OCS (table 4).

The results of the loss or gain for both profiles are shown in table 5.

These results showed that when this type of soil is put under cultivation it loses much more OCS compared with what it gains when it is conserved. This is due to the fact that Vertisol is a very clayey soil, but with clay of the smectite group, which are highly dispersible and, therefore, in the rainy season the structural aggregates are broken and there is no strong retention of humic substances in the soil (Khan, 1969). Because of this, it can be assumed that when put under cultivation, with ploughing the prism is inverted and the underlying prismatic blocks come to the soil surface. In addition, OC is rapidly oxidized and emitted as CO_2 to the atmosphere. Similar results have been reported in a chromic vertisol in the Mayarí municipality, Holguín province, Cuba (Martín-Gutiérrez *et al.*, 2023a; 2023b).

The OM content in the prismatic soil blocks is shown in table 6. Sampling was carried out in profile D-2, preserved under *M. indica* grove with grasses. Three prismatic blocks were taken. From each one, a sample was obtained on the surface and another one in the inner part.

The average OM percentage of the blocks is shown in table 7. These data showed that in the inner part of the blocks the OM content was lower than on the surface. It is assumed that this is due to

Table 4. Average organic carbon stocks (OCS) in profiles of the Vertisol pelic soil of La Rosita farm (Mg ha^{-1}).

Profile	Year of study	OCS, Mg ha^{-1}			Soil use
		0-10 cm	0-20 cm	0-30 cm	
D-2	(0) 2006	19	37	54	*M. indica* grove with grasslands
	14 (Conserved until 2020)	25	40	56	*M. indica* grove with grasslands of many years
D-12	10 Cultivated since 2010	10	18	27	Cultivated since ten years ago

Table 5. OCS gain or loss per year in pelic Vertisols, Mg ha^{-1}.

Profile	Year of study	Difference of years	Net gain or loss			Gain or loss, t ha^{-1} year^{-1}			Soil use
			0-10	0-20	0-30	0-10	0-20	0-30	
D-2	2006 Reference profile	0	0	0	0	No	No	No	*M. indica* grove with pastures
	2020 Conserved	14	+6	+3	+2	+0,43	+0,21	+0,14	*M. indica* grove with pastures
D-12	2020 Cultivated since 2010	10	-9	-19	-27	-0,64	-1,40	-1,92	Cultivation since ten years ago

Table 6. Organic matter (OM) content of the outer and inner part of the prismatic blocks.

Block	Place in the block	pH, H_2O	OM, %	C, %
1	Inner part	7,3	1,58	0,92
	Surface	7,4	2,02	1,17
2	Inner part	7,3	2,90	1,68
	Surface	7,4	3,49	2,02
3	Inner	7,2	2,73	1,68
	Surface	7,2	3,52	2,04

Table 7. Average OM content of the surface and interior of the prismatic blocks.

Place in the block	pH, H_2O	OM, %	C, %
Inner part	7,26	2,40	1,39
Surface	7,33	3,01	1,75

the fact that these blocks become compacted and hard during the dry season, so that plant roots do not penetrate them and adhere to their surface. For this reason, the enrichment in organic substances on the surface is greater.

A different situation occurs in the prismatic blocks of the Vertisol, when it is under cultivation for several years (tables 8 and 9).

With cultivation, the blocks are exposed to the surface and the oxidation of organic matter and the consequent emission of carbon dioxide into the atmosphere begins, mainly at the expense of the organic matter on the outside of the blocks which oxidizes faster than that on the inside. As a result, organic matter and carbon tend to equalize on the surface and inside the prismatic blocks.

Conclusions

The results showed that a loose pelic Vertisol, under various systems of use, presents differences in soil organic matter and carbon contents.

In this soil under conserved conditions, with grass and *M. indica* grove, there is a gain in organic carbon stocks; while under intensive cultivation conditions (ten years) there is a loss.

The prismatic blocks of the Vertisol showed a higher content of organic matter and carbon on their surface than on the outside, when the soil was under conserved conditions. However, when cultivated, the contents of organic matter and carbon were lower and reached the same value on the surface as in its inner part.

Recommendations

It is recommended to continue with these studies over time and in other regions where Vertisols are distributed, so that adequate information can be obtained to make decisions on how to best manage and use them.

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Conflict of interests

The authors declare that there is no conflict of interests among them.

Authors' contributions

- Dagoberto López-Pérez. Field sampling, interpretation of results and drafting of the manuscript.
- Alberto Hernández-Jiménez. Design and direction of the research, field sampling, interpretation of results and drafting of the manuscript.
- Greter Carnero-Lazo. Interpretation of results and drafting of the manuscript.

Table 8. Organic matter and carbon content of the outer and inner part of the prismatic blocks in profile D-12.

Block	Place in the block	pH, H_2O	OM, %	C, %
1	Inner part	7,2	1,50	0,87
	Surface	7,3	1,44	0,84
2	Inner part	7,3	1,89	1,10
	Surface	7,2	2,75	1,60
3	Inner part	7,1	2,62	1,52
	Surface	7,3	2,60	1,51

Table 9. Average OM content of the surface and inner part of the prismatic blocks.

Block	Place in the block	pH, H_2O	OM, %
Inner part	7,20	2,00	1,16
Surface	7,27	2,26	1,31

- Marisol Morales-Díaz. Interpretation of results and drafting of the manuscript.

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