Cultivos Tropicales, 2018, vol. 39, no. 4, pp. 27-33 October-December

ISSN impreso: 0258-5936
ISSN digital: 1819-4087

Ministerio de Educación Superior. Cuba
Instituto Nacional de Ciencias Agrícolas
http://ediciones.inca.edu.cu

ORGANIC CARBON RESERVES IN SOIL FROM THE FLUVIAL PLAIN CALCETA-TOSAGUA, MANABÍ, ECUADOR

Reservas de carbono orgánico en suelos de la llanura fluvial Calceta-Tosagua, Manabí, Ecuador

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ABSTRACT. The Soil Organic Carbon (SOC) is one of the most important issue nowadays in Soil Science from two points of view. One of them is the reserves of SOC in soils in relation with climate change and the other is in relation with other soil properties because its conditions dependent of SOC content, to have high SOC content that improve other soil properties as volume density, porosity, biological activity and others. In Manabí, Ecuador there are few and disperse results about this thematic, practically there are no results in the northern coast part of the province. So that, in soil investigations that are making in the Escuela Superior Politécnica Agropecuaria de Manabí (ESPAM), in the last five years, in the Carrizal-Chone System. In this region there are four Referential Soil Groups, Feozems (Mollisols), Fluvisols (Fluvents), Cambisols (Inceptisols) and Gleysols (Aquents). The nature soil formation in this region is Feozem and Fluvisols, the Cambisols are formed by degradation from the Feozems because its cultivation during many years. The Feozems has the higher content of SOC reserves, 52 mg ha^{-1}, in the 0-30 cm layer of the upper part of soil profile. Fluvisols, Cambisols and Gleysols have a medium content (32-36 mg ha^{-1}) of SOC reserves. There are also in this paper some recommendations to continue this studies in the region. That permit management technology in agricultural production that improves soils and keed good yields.

Key words: soil degradation, alluvial plain, feozem, fluvisol, cambisol

RESUMEN. El carbono orgánico en los suelos (COS) constituye hoy día uno de los problemas de actualidad en la Edafología. Su estudio se analiza desde dos puntos de vista; uno como parte de los problemas del cambio climático y las posibilidades de captura y secuestro de carbono en los suelos; y el otro, en relación con la conservación de un contenido de carbono para mantener buenas propiedades del suelo que mantengan una producción agrícola adecuada. En Manabí, Ecuador, estos estudios se realizaron esporádicamente, con muy pocos resultados. En el caso de la región costera norte prácticamente no hay resultados al respecto. Por esto, en los estudios edafológicos que viene realizando la Escuela Superior Politécnica Agropecuaria de Manabí (ESPAM) en los últimos cinco años, se profundiza en esta temática, dentro de las investigaciones realizadas para los suelos del Sistema Carrizal-Chone. Entre los resultados se tiene, que en esta región, los Grupos Referenciales de Suelos son Feozem (Mollisol), Fluvisol (Fluvent), Cambisol (Inceptisol) y Gleysol (Aquent). La formación natural de los suelos en esta región es de Feozems y Fluvisoles. Los Cambisoles se han formado por degradación de los Feozem cámbico. Los suelos Feozem son los que acumulan mayor cantidad de carbono orgánico, con 52 mg ha^{-1}, para la capa de 0-30 cm del espesor superior del perfil; mientras que los Fluvisoles, Cambisoles y Gleysoles tienen un contenido mediano (32-36 mg ha^{-1}). Se hacen una serie de recomendaciones para investigaciones futuras que permitan lograr tecnologías de manejo en la producción agrícola que mejoren los suelos y mantenga buenos rendimientos.

Palabras clave: degradación del suelo, llanura aluvial, feozem, fluvisol, cambisol

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INTRODUCTION

The study of organic carbon in soils (SOC) has been carried out in many countries in recent years. In general, it is argued that the importance of carbon in soils is related to the mitigation of climate change (1). In relation to carbon losses in ecosystem soils. However, they suggest (2) that they are important, not only in relation to CO2 emissions and the increase of Greenhouse Gases (GHG) to the atmosphere, but also with the productivity of soils.

The change in land use is important for the SOC content, especially in soils under continuous cultivation and in those regions where conversion of forests to cultivation regions has taken place. The majority of the soils under continuous cultivation, worldwide, have had a reduction in the organic carbon reserves between 25 and 75 % (1). From the time of the 90s, until now, in many countries, studies are carried out on the state of carbon content in soils, the impacts on other properties of soils, the causes of their reduction and the search for measures to improve that degradation of the soil.

In Cuba, it has been found that the red Ferralitic soils leached from the plains of Cuba (licit, rhodic, clayey Nitisols), under intensive cultivation have lost on average between 50 and 55 % of the carbon reserves, in the layer of 0- 20 cm of the top thickness of the soil, in relation to the forest (3-5). At the same time, this work demonstrates how carbon losses worsen soil properties, such as volume density, dispersion factor, mycorrhizal activity, structural stability, upper limit of productive humidity.

Attention has also been given to the dependence of the carbon content in the soils of the formation factors, mainly with the climate and the amount of rainfall, taking into account different scenarios it was shown that the amount of rainfall is determinant for the reserves and depth distribution of the SOC (6,7).

On the other hand, in recent times results have been obtained on the change of SOC content, according to the coverages that they present by comparing, results obtained in different time slots. In this way, the gain or loss of SOC was obtained in the Mololoa River Basin, Nayarit, Mexico (8).

In other researches carried out (9), the effects of the change in the use of forest soils in the natural carbon reserves of the Mediterranean were studied (9). In South Dakota, the United States (10), as a result of its investigations, it was found that the difference in the organic carbon content of the soil between pastures (grasslands) and agricultural lands show a decrease of 18% in cultivated lands.

The relationship between the decrease in organic carbon in the soil and the production of glomalin has also been seen. Glomalin is a product of the activity of arbuscular mycorrhizal fungi and very important for the formation of a good structure in soils. In research carried out in Cuba, it is demonstrated that in leached Red Ferralitic soils (licit ferralic Nitisols), degraded by the crop, there is a significant decrease in the decrease of glomalin (4). In the same way, the affectation of glomalin is determined in relation to the decrease of the organic carbon of the soil and its affectation in other edaphological properties (11).

Due to this problem of soil degradation due to the loss of organic carbon, results are beginning to be obtained on the improvement of the organic carbon content in the soil, with different management practices. For example, in Cuba, taking into account the degradation of Red Ferralitic soils leached by continuous cultivation, results were obtained in the improvement of the degraded variant of red Ferralitic soils leached by continuous cultivation (12), which even presents a plow floor. In three years of experimentation, with application of 1 and 2 mg ha^{-1} of cow manure, an increase of 0.2 mg ha^{-1} of SOC reserves was obtained, in this soil, with an increase in maize yield (*Zea mays*) (of 5 and 7 mg ha^{-1} in relation to 2.25 mg ha^{-1} in the control). Also, in Fuyang County, East China, some authors determined, in soils of urban agriculture areas, increases in the content of Organic Soil Carbon between 1.73 % in 1979, 1.85 % in 2006; due to the application of organic fertilizers in the production of vegetables and flowers (13).

In Turkey, in the semi-arid region, with reforestation based on black pine and cedar on 2 420 000 ha; an increase in the organic carbon reserves was obtained (for layers 0-10 and 10-20 cm in 18,20 mg ha^{-1} and 16.33 mg ha^{-1} and 23.54 mg ha^{-1} and 12, 38 mg ha^{-1}, respectively (14).

As shown, great attention is paid to the content of the SOC, from different aspects, both in relation to GHG emissions to the atmosphere and its impact on climate change, as well as the change in land use and carbon losses in the region. ecosystems and, in recent years, the quantitative determination over time of the carbon content in ecosystems according to their use, either by continued cultivation or by the change of agricultural land to secondary vegetation.

In the province of Manabí, Ecuador, there are few studies in relation to the contents of SOC, especially in the northern coastal region, where agriculture has a very large weight. In recent years some results have been obtained in this regard, on the characteristics of the soils, the carbon reserves and their impacts on their properties, in the Parroquia Membrillo, of the Cantón Bolívar, in relief wavy pre-mountainous lining (15,16) .

The objective of this work was to carry out an inventory, based on a soil map of the organic carbon reserves in the plains of the Carrizal-Chone system, in the northern coastal area of Manabí province, where there are many crops such as cacao (*Teobroma cacao*), banana (*Musa paradisiaca*), corn (*Zea mays*), pumpkin (*Cucurbita pepo*) and rice (*Oryza sativa*) mainly.

MATERIALS AND METHODS

117 soil profiles were studied, in an area of 7500 ha, which includes the cities of Calceta and Tosagua and towns such as La Estancilla and Bachillero. These profiles were described and classified by the World Reference Base classification system (17). The profiles studied by GRS are the following: Feozems, 35 profiles; Fluvisols, 53 profiles; Cambisoles 25 profiles; Gleysoles four profiles.

From each soil profile, a sample was taken per horizon, to which different analytical determinations were made for its characterization. To determine the SOC reserves, the following analyzes were made:

- ♦ Determination of organic matter by the Walkley & Black method
- ♦ Determination of volume density by the cylinder method in the field, using cylinders of 100 cc volume
- ♦ Estimation of organic carbon stocks of soil (RSOC), are determined by the proposed formula:

RSOC=percentage of C xDv x espesor del horizonte in cm x (1-I)

where:

The percentage of CE, was determined by dividing the percentage of MO, by one factor (1,724)

Dv: is the volume density in Mg m^{-3}

I: it is the percentage of inclusions (gravel, stones, and ferruginous nodules), expressed in relation to unity. It does not apply in this work, since there are no inclusions in the studied area

A soil map of the RSOC was made for the 0-30 cm layer, through the application of an ARGIS Geographic Information System 10 (Photo 1).

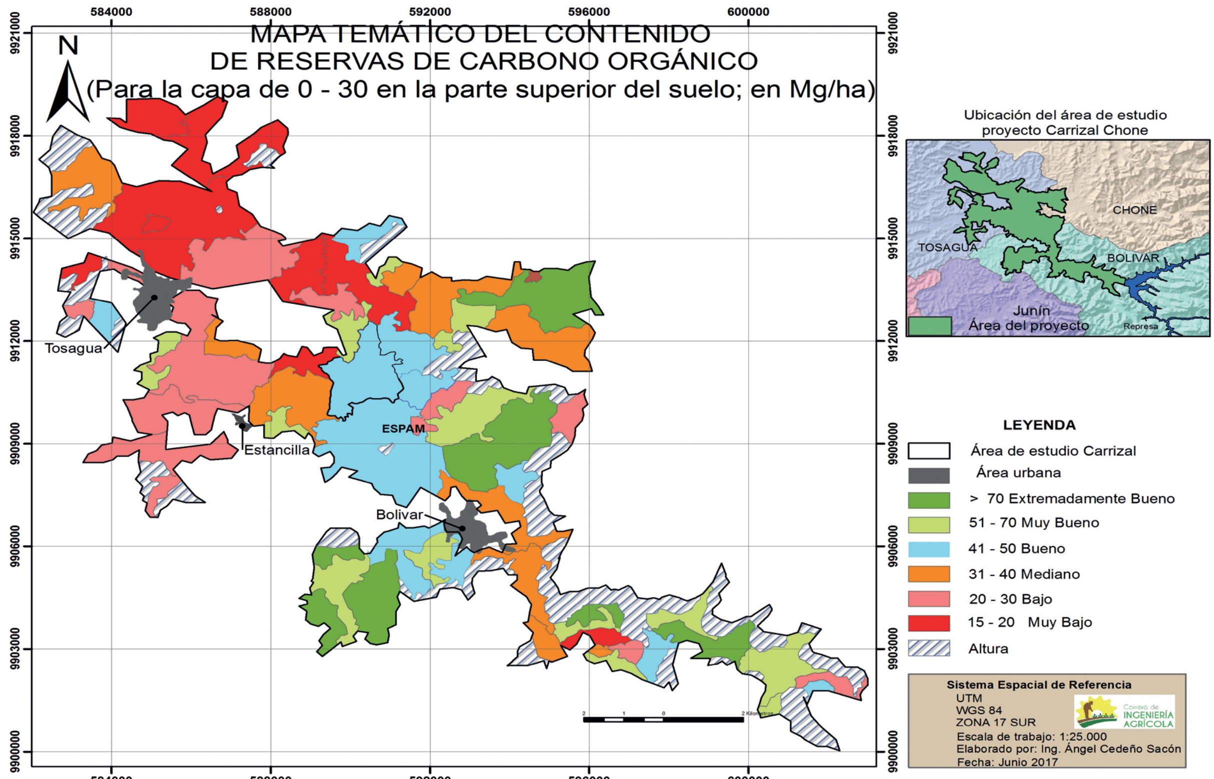

Photo 1. Thematic map of the content of organic carbon reserves

The categories for classifying the contents in RSOC were generated by Vera (18) (Table 1). These categories were made by calculation, for the layer of 0-30 cm, according to the contents in organic matter (19).

Table 1. Categories of the content of RSOC in soils (for the layer of 0-30 cm)

Carbon reserve content (mg ha^{-1})	Category
Extremely high	> 70
Very high	51-70
High	41-50
Mediu,	31-40
Low	20-30
Very low	< 20

In addition, the results were created by Referential Group and Unit of Soil, which were determined in the layer of 0-30, 0-50 and 0-100 cm of the upper thickness of the profile.

RESULTS AND DISCUSSION

The Reference Groups of Soils that were identified in the region are Feozems, Fluvisols, Cambisols and Gleysols, which present different qualifiers that are expressed in the soil map.

The results obtained in the map by category of RSOC are presented in Table 2. These results showed the losses of RSOC that these soils had, since the contents of low and very low reach almost 40 % if we add the one of medium, they reach around 55 %.

In the region, the agriculture carried out is intensive, continuous and without taking into account any form of soil management to conserve or improve its properties. It is necessary to implement measures of proper management of soils could increase the carbon reserves in them and the improvement of their properties.

The exploitation of the soils of the less rainy areas with the cultivation of cotton led to the impoverishment of the soils and the formation of structure with large blocks in the surface layer. It is currently where rice and corn are planted; continue with intensive practices of these crops will impoverish these soils.

Rice cultivation causes the greatest degradation in soil properties (20,21); thus, the hydromorphic influence and the puddling, as the change of the oxidation-reduction conditions of the soil, lead to the rapid destruction of the structural aggregates of the soil, with the formation of horizons in the form of blocks with spots of iron and manganese reduction . Due to this anthropogenic formation caused by rice cultivation, the WRB soil classification includes diagnostic horizons that are used to classify these soils. This has also been adopted in the Classification of Soils of Cuba (22).

For the above, for the province of Manabí in general and for the study region in particular, it is necessary to begin to study the content and behavior of carbon in soils and at the same time, introduce measures of application of green fertilizers, biofertilizers, compost and organic fertilizers, which could favor the increase of carbon in the soils, as well as the development of a root system that would bring a good content of organic matter to the soil.

In the quantification of the RSOC by different layers for soils by the Reference Groups of Soils, it was observed that the Feozem soils are the best in terms of the RCO content (Table 3), which influences other properties (color, structure, consistency, fertility) and gives rise to that in these soils there is a mollic horizon on the surface, with a thickness greater than 18 cm in thickness, which characterizes them as GRS.

It is remarkable that the Fluvisols in the difference between the layers of 0-30 cm and 0-50 cm, the RCO values, are so narrow, which is due to lenses or sand layers of 30-40 cm that occur in these floors between the first 50 cm of the upper part of the profile.

Table 2. Area that has each category of the RSOC in the area studied

Content in reserve carbon (mg ha^{-1})	Category	Area by category in ha of the contents de RCOS	% of total
> 70	Extremely high	1097,6	15,2
51-70	Very high	835,9	11,5
41-50	High	1393,4	19,3
31-40	Medium	1214,3	16,8
20-30	Low	1384,2	19,1
< 20	Very low	1308,3	18,1
Total		7233,7	100,0

Table 3. Reserves of organic carbon of the soil (RSOC) in the reference groups of soils

GRS	Area (ha)	Depth A+B (cm)	pH (H_2O)	RCO (mg ha^{-1})		
				0-30	0-50	0-100
Feozem	2107	57	6,32	52	70	99
Fluvisol	3788	43	6,91	32	42	114
Cambisol	1037	37	7,35	34	47	94
Gleysol	301	35	7,26	36	59	Nd

Nd: not determined

It is known that sandy textures capture very little carbon in the soil (23). However, for the difference between 50-100 cm in these soils the RCO content is very high, which is due to the presence of ancient A horizons, buried in these Fluvisols.

The Cambisols, as expected, have a medium RCO content for the 0-30 cm layer, which is due to the fact that they are formed by the transformation of the Cambrian Feozems, by the continued cultivation, with losses of organic matter and carbon and become Cambisols.

Towards the zone of La Estancilla-Tosagua-Bachillero, where the Cambisols predominate, the RCOs are lower, which shows that in the soils of this part of the ecosystem they are relatively higher, which is related to the continued cultivation they have the soils have been subjected, especially in crops such as cotton, rice and corn and the characteristics of soils. Most of them are frank texture, sandy loam and silty loam, with sialitic composition, with a predominance of clayey minerals of type 2: 1, and little free iron content, which favors these losses, through the rapid mineralization of the material organic by cultivation and its emission into the atmosphere. This problem of soil change due to anthropogenic influence, due to continued cultivation, has been reported in other investigations (6,9,24).

In a study, some effects on the change in soil properties are explained by the anthropogenic influence, where some are not significant, and others lead to the soil until the change of its taxonomic position or completely destroy the profile, among the changes proposed by the find the change in the taxonomic level of the soil (25). Similarly, for the northern coastal plain of Nayarit, Mexico, it was demonstrated that Feozems soils are transferred to Cambisols for continued intensive cultivation (26).

It is also remarkable that in these soils, under tropical climate, there is not a very high RCO content for layers of 0-100 cm; as obtained in another study (27), in Malaysia and for the Membrillo region, in Ecuador (16), which is located in the upper parts of the study region, with the presence of hyper-humic Feozem soils (under primary or secondary) that have more than 200 Mg ha^{-1} of RCO for the 0-100 cm layer. This is due to several causes; in the first place, they are young soils, formed by recent alluvial sediments, which although they are in tropical regions, do not accumulate large amounts of RSOC. On the other hand, they are soils with alluvial influence, with layers of sand in the upper and middle part of the profile (28), which interrupts the carbon gain through the soil in a systematic and stable way and finally that the profiles were taken in areas of cultivation or pastures so that the RSOC result with less content than when they are under forests.

In this study, it was obtained that the Feozems do not have a soil unit with an ochric qualification, which is due to the fact that, with continued cultivation, they lose organic matter, reducing the carbon content and move to Cambisols, in the case of Feozems with cambic B horizon. The RSOC in each Soil Referential Groups in this investigation, showed that, the Feozems do not have soil unit with an ochric qualification (Table 4), which is due to the fact that, with the continued cultivation, they lose organic matter, reducing the content of carbon and pass to Cambisoles, in the case of the Feozems with cambic B horizon.

In the Fluvisols' Ground Units, the differences in the RSOC are smaller for the 0-30 and 0-50 cm layers and also in some of the Units of the Cambisols, which as explained above, is due to the presence of layers of sand in the soil profile. In the case of Fluvisols, these layers of sand can be present in the upper thickness, between 0-50 cm and in the Cambisols they can be below in depth in the profile. For this reason both Feozems and Cambisols have the fulvic qualification, because it presents changes in the size of the particles by the profile.

Table 4. Organic carbon reserves of soil units

GRS	Soil unit	Depth A+B (cm)	pH (H_2O)	RCOS (mg ha^{-1})		
				0-30	0-50	0-100
Feozems (35 profiles)	Feozem Fluvic	48	6,62	50	70	99
	Feozem cambic fluvic	68	6,47	52	77	114
	Feozem gleyic fluvic	69	6,72	56	67	111
Fluvisoles (53 profiles)	Fluvisol eutric	48	6,63	41	51	75
	Fluvisol eutric, ocric	37	7,34	17	25	52
	Fluvisol eutric and protovertic	42	7,44	31	43	76
	Fluvisol gleyic and eutric	36	6,79	25	45	64
	Fluvisol gleyic, eutric and ocric	35	6,82	12	24	71
	Fluvisol gleyic, eutric y protovertic	34	7,95	36	49	72
Cambisoles (25 profiles)	Eutric fluvic Cambisol	68	7,31	44	59	141
	Ocric eutric fluvic Cambisol	62	7,48	21	29	47
	Vertic fluvic Cambisol and eutric	98	7,65	32	56	88
	Fluvic Cambisol, vertic, eutric and ocric	77	7,53	19	31	62
	Fluvic Cambiso, gleyic and eutric	65	6,77	29	32	51
	Fluvic Cambiso, gleyic, eutric vertic and ocric	64	6,6	18	32	67
	Fluvic Cambiso, stagnic, vertic and eutric	84	7,77	26	51	99
Gleysoles (4 profiles)	Euitric fluvic Gleysol	35	7,26	36	59	Nd

Nd: not determined

It is noteworthy that in Cambisols the higher pH values are present, which can be related to the contributions of redeposited materials from the Onzole geological formation, which predominates in the heights that surround the plain in the stretch from La Estancilla to Tosagua. The Onzole formation is a terrigenous sedimentary formation, with the presence of shales, which can be a contribution of sodium to the soils in this part of the plain, where Cambisols predominate.

CONCLUSIONS

- The soils of the region studied under the influence of continuous cultivation have lost about 50 % of the organic carbon reserves in the soil, for the 0-30 cm layer of the upper profile thickness. Within this, it is evident that the Feozems are the ones that maintain a high content in the organic carbon reserves of the soil, followed by the Fluvisols and the Cambisols result, which have the lowest content in the organic carbon reserves of the soil.
- The Cambisols are formed from the Feozems, due to the losses of SOC by the continued cultivation in these soils.
- In the Reference Groups of Soils that occur in the region, the presence of sand layers in the first 50 cm of the profile of the Fluvisols is notable, so that the SOC reserves remain low in the 0-50 layer cm of the profile.
- Within the Soil Referential Groups, the Cambisols are those that have the highest pH, with an average value higher than 7.0; while in the Fluvisols and Feozems it is maintained between 6 and 7.

RECOMMENDATIONS

To achieve a policy for the capture and sequestration of carbon in the region and at the same time maintain a sustainable increase in the levels of agricultural production, it is necessary to:

1. Determine the carbon gains or losses per year, according to the management of the soils (groves, plantations, crops).
2. Achieve land management technologies in agricultural production that does not lead to carbon losses in the soil.
3. Make a balance of the management of the soils of the Carrizal-Chone System to maintain a carbon sequestration in the region.

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Received: November 29th, 2017
Accepted: July 12th, 2018