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CHANGES IN ORGANIC CARBON STOCKS IN SOILS UNDER DIFFERENT PLANT COVERS

Cambios en las reservas de carbono orgánico del suelo bajo diferentes coberturas

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ABSTRACT. The reserve of organic carbon in soils and their changes over time is a current environmental issue, besides, the loss of soil organic carbon (SOC), that occur with the conversion of natural ecosystems to agricultural systems, contribute to emissions of greenhouse gases, to global warming and climatic change. The objective of this study was to evaluate the changes in SOC reserves under different plant covers that occur in the Mololoa river basin, in the state of Nayarit, Mexico. The analysis was performed by differences in time of sampling, using samples from the top 20 cm of the soil profile, coming from 13 soil profiles under different coverage: two with oak forest, two with pine forest, one under grass, one with avocado orchard and seven under sugarcane cropping. The soils under grass had the greatest reserve of SOC with 2,65 Mg ha^{-1} $año^{-1}$, followed by: oak forest (0,40 and 0,47 Mg ha^{-1} $año^{-1}$), pine forest (0,15 and 0,38 Mg ha^{-1} $año^{-1}$) and avocado orchard (0,29 Mg ha^{-1} $año^{-1}$). Soils with sugarcane crop had a decrease in SOC (between 0, 12-0,84 Mg ha^{-1} $año^{-1}$).

Key words: carbon capture, soil plant covers, carbon dioxide

RESUMEN. Las reservas de carbono orgánico en los suelos (COS) y sus cambios en el tiempo son un tema ambiental de actualidad, asimismo las pérdidas de COS que ocurren con la conversión de ecosistemas naturales a agrosistemas, contribuyen con emisiones a la atmósfera, al calentamiento global y el cambio climático. El objetivo de este trabajo fue estudiar los cambios en las reservas de COS bajo diferentes coberturas de la cuenca del río Mololoa, Nayarit, México. El análisis de los cambios se realiza por diferencia en las reservas de COS en los primeros 20 cm de 13 perfiles de suelos con diferentes coberturas, dos en bosques de encino, dos en bosques de pino, uno en pastizal, uno en cultivo de aguacate y siete en terrenos cultivados con caña de azúcar. Las coberturas estables de bosque y pastizal generan ganancias en las reservas de COS; siendo el pastizal el que registra la mayor cantidad (2,65 Mg ha^{-1} $año^{-1}$), seguido por el bosque de encino (0,40-0,47 Mg ha^{-1} $año^{-1}$), el bosque de pino (0,15-0,38 Mg ha^{-1} $año^{-1}$) y la arboleda de aguacate (0,29 Mg ha^{-1} $año^{-1}$). Mientras que la cobertura de cultivo de caña de azúcar generó pérdidas en las reservas de COS, entre 0,12-0,84 Mg ha^{-1} $año^{-1}$.

Palabras clave: captura de carbono, cobertura del suelo, dióxido de carbono

INTRODUCTION

Soil organic carbon is a current research topic. It is estimated that soil organic carbon stocks are two thirds of the earth carbon stocks (1). Moreover, it is known that by changing soil usage a large par of this element has been lost by emissions to the atmosphere as CO_2, which greatly contribute to enrich Greenhouse Effect Gasses (GEI), and consequently global climate change (2, 3, 4, 5). There are estimates outlining the conversion of natural ecosystems into agricultural systems which approximately contributes 24 % of world's CO_2[A] emissions.

On the other hand, soil organic carbon is important because as it is part of the organic matter, influence on soil properties like structure, cationic exchange capacity, apparent density, porosity and infiltration.

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[A] IPCC. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assess- ment Report of the Intergovernmental Panel on Climate Change* [en línea], (ed. ser. Pachauri, R.K. y Reisinger, A.), Geneva, Switzerlan, 2007, p. 104, [Consultado: 19 de junio de 2015], Disponible en: <https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_frontmatter.pdf>.

That is, the change of land usage and the continued intensive agricultural exploitation with the application of machinery and fertilizers, brings about the loss of organic matter and organic carbon which leads to the degradation of these properties with a reduced soil productivity (6, 7, 8, 9).

Soil carbon losses in soils in the last 200 years due to agricultural activities are around 78 ± 12 Pg of atmospheric C (10). This problem of carbon loss in soils is more intense in the warms regions of the planet, so edaphological research towards maintaining an adequate carbon content in soils very much exposed to interperism, are so important (11, 12, 13).

Therefore, it is essential, first of all, to know the status of organic carbon in different soils, its performance by changing land usage, mainly the organic carbon stocks in relation to plant covers in order to find adequate agricultural management alternatives that maintain and enrich soil organic carbon (14). The objective of this study is to evaluate the changes in SOC stocks under different stable plant covers including sugarcane growing. The study area has been the Mololoa river basin, in Nayarit, Mexico.

MATERIALS AND METHODS

The study site was the Mololoa river basin (570 km^2), located in the central part of the State of Nayarit, Mexico, at the coordinates 21° 43' 26" North Latitude, 104° 56' 46" West Longitude and 21° 16' 12" North Latitude, 104° 43' 06". West Longitude. It covers an area of 618 km^2 and is part of the hydrological system Lerma-Chapala-Santiago.

This region includes 34 localities and nearly 40 % of the population of this area depends from the ecosystem to receive fresh water, produce foods (sugar, corn, rice, vegetables, avocado and lemon, mainly) as well as those of animal origin (sheeps and goats, pigs and poultry); and provide services that regulate climate, nutrients cycle and recreation sites.

The ecosystem is characterized for its volcanic origin, with structures that limit the runoff area, volcanos like San Juan (the highest, with 2,240 meters above sea level), Coatepec, Tepetiltic Sangangüey and the Tepic pot, all of them from the Quaternary and developed on a base from the Terciary. At the middle of these structures there is an extensive valley (Matatipac) crossin the Mololoa river, until flowing into the Grande de Santiago river to the Northwest. The basin is long and asymmetrical with pronounced slopes, it is intermediate in size and the average slope is 39 % with 127 micro basins (15).

The climate of the region varies according to the diversity of landscapes, most of the volcano sides and the valley are semiwarm (76,84 % of the total basin), at the top of volcanoes is Temperate (1,46 %), and towards the mouth of the river, climate is Warm subhumid (21,70 %). The studied area has a rainfall regime in summer (June to October), of 1 274 mm annual average, annual mean temperature is 22,4 ^{o}C, with an average maximum of 29,3 ^{o}C in May and minimum of 16,4 ^{o}C in Jannuary, thermal oscillation is 12,9 ^{o}C (16).

The studied area has five geomorphological landscapes (volcanic range with steep sides of the San Juan volcano, volcanic shields with pots, volcanic range with volcano strata, hills with very much eroded surfaces at the low part of the basin) and an accumulative landscape at the Matatipac valley (17). Due to the characteristics of the landscape, Andosols, Alisols, Luvisols, Feozems, Regosols and Gleysol soils have developed, the most extended ones are Andosols formed in the most recent landscapes, of AC profile, from quaternary deposits of pumice and ashes from the San Juan volcano; followed by Alisols, that are soils of AbtC profile, more evolved, formed in stable landscapes and older from the point of view of materials from basic rocks of the Sangangüey volcano (18).

The main soil covers are crop lands (44 %), followed by the natural vegetation (38 %); the rest, is secondary vegetation, constructions and water bodies. The main vegetable communities are oak and pine forests distributed at the highest volcanoes and with a deforestation rate of 0,1 ha year^{-1}; jungles and pasture lands located at the low part of the basin with a loss pace of 0,3 ha year^{-1} (19).

From existing data[B] and the soils profiles previously described (18, 20), 13 sampling sites were chosen: two at the oak forests, two at the pine forest, one in pasture lands, another one in an avocado grove, and seven in sugarcane plots.

[B] *Conjunto de datos vectorial Edafológico escala 1: 250 000 Serie II* (*Continuo Nacional*) [en línea], *INEGI*, [Consultado: 19 de junio de 2015], Disponible en: <http://www.inegi.org.mx/geo/contenidos/recnat/edafologia/vectorial_serieii.aspx>.

In order to look at the organic carbon stocks from March 2012 to August 2013, samples were taken in the top 20 cm of each chosen site and the density of field volume was measured by the cylinder method (21); likewise, organic carbon was measured by the method of Walkley & Black, described in the Official Mexican Standard NOM-021-SEMARNAT-2000 (AS-07) (22).

The SOC calculation was done through the equation:

$$COS = CO\ (Da)\ m \qquad (1)$$

where:

COS = Total organic carbon on the soil per surface (Mg C ha^{-1})

CO = Total organic carbon (%)

Da = Volume density (Mg m^{-3})

m = Soil depth (cm)

Annual exchange rates of SOC were identified by calculating carbon stocks in time 1 and 2, and the result was divided between the number of years observed.

RESULTS AND DISCUSSION

The results show that soils under permanent covers of pine, oak, avocado and pasture have an annual exchange rate with carbon gains, while those with sugarcane has a negative rate (Table I).

Table II shows the values of the changes in SOC stocks by plant cover and soil unit (0 a 20 cm). These data show gains and losses at the soil unit and the determining factor, in this case, is the type of soil cover and not the type of soil. Taking into account the above, the most important thing is the annual rate in Mg ha^{-1} of changes (losses or gains) in SOC by plant cover at the studied area.

The approximate exchange rate, given the same annual contribution of plant residues is maintained, starts a carbon accumulation process on the soil as a result of the lowest mineralization rate. It happens during a period of time till a new balance is reached. Because of this, increased carbon content is very fast in early years and turns lower in subsequent years (23).

Table I. Annual exchange rate (%) of SOC stocks under different plant covers

Profile key	Plant cover	Time 1	Time 2	% C (t1)	% C (t2)	Annual exchange rate (%)
INEGI 52	Oak forest	2003	2013	1,050	1,820	0,077
UAN 5	Oak forest	2006	2013	1,030	1,610	0,083
SAN JUAN 10	Pine forest	1993	2013	4,830	5,170	0,017
UAN 16	Pine forest	1993	2013	4,090	4,120	0,002
SAN JUAN 7	Avocado grove	1993	2013	1,030	1,640	0,031
INEGI 12	Sugarcane	2003	2013	0,706	0,320	-0,039
INEGI 29	Sugarcane	2003	2013	1,950	1,920	-0,003
UAN MATATIPAC	Sugarcane	1983	2013	1,870	1,820	-0,002
UAN 69	Sugarcane	1996	2013	0,926	0,507	-0,025
SAN JUAN 12	Sugarcane	1993	2013	1,030	0,830	-0,010
SAN JUAN 6	Sugarcane	1993	2013	0,980	0,850	-0,007
INEGI 38	Sugarcane	2003	2013	1,886	1,269	-0,062
UAN 62	Pasture	1992	2013	0,410	1,320	0,043

Table II. Changes in SOC stocks by plant cover and Soil Units (0-20 cm) at the basin of the Mololoa river, Nayarit

Plant cover	Soil unity	Gain/Losses Mg ha^{-1} year^{-1}	Years
Pine forest	Molic andosol (eutric)	+ 0,15	20
		+ 0,38	20
Oak forest	Haplic Cambisol (eutric, cromic)	+ 0,40	07
		+ 0,47	10
Avocado	Andic Cambisol (humic, distric)	+ 0,29	20
Pasture	Andic Cambisol (eutric)	+ 2,65	10
Sugar cane	Molic andosol eutric	- 0,41	30
		- 1,27	10
		- 1,71	19
	Andic Cambisol (humic, distric)	- 1,71	10
		- 0,58	19
	Haplic Regosol (eutric)	- 0,12	21
		- 0,84	10

However, for stable plant covers, the highest gain rate in carbon stocks is recorded on the soil with pastures as cover crop. With the oak forest there is a higher annual uptake than with the pine forest, while in avocado, it is a little higher.

The contribution done by the pine forest with a relatively low annual growth rate is because pine forests do not accumulate significant quantities of carbon. The literatura reports an accumulation rate for this type of cover equivalent to 0,182 Mg ha^{-1} $year^{-1}$ (5).

The little carbon uptake by the soil on a pine forest is related to the type of leaf rich in lignin that forms a little degradeable litter. The degradeability of the litter is an important regulator of its decomposition (24, 25). The degradation of structural carbohydrates like lignin can be critical for the decomposition rate of the litter and for the accumulation of organic matter on the soil (26).

The type of vegetation and plant phenology is directly related to the quality of the litter. Some authors (27) report the persistence of organic matter on the soil is due to complex interactions between organic matter and the environment as the interdependence of chemical compounds, reactive mineral surfaces, climate, water availability, soil acidity, the redox status and the presence of potential degraders at the immediate micro medium.

The oak forest uptakes a little more carbon on the soil than the pine forest. The oak forest has leathery leaves that do not decompose eaily and although the soil has an annual carbon gain rate higher than the pine forest's, the uptake does not coincide with the quantity other forest species like eucalyptus does.

The highest potential of carbon uptake was found in pasture covers (2,65 Mg ha^{-1} $year^{-1}$) due to the root system of pasture species can reach up to 1 meter deep differently from the types of oak and pine forests whose contribution of organic matter to the soil is made through their leaves that in both cases are difficult to decompose, mainly on a temperate warm climate.

The contribution made by pasture covers to carbon uptake is documented in different research papers. For example, the clearin of the Amazon jungle to turn it into pasture lands brought about a reduction of MOS in the top 20 cm accounting for 90,0 a 68,8 Mg ha^{-1} C after two years of having established pasture covers, but MOS entries from pastures during 8 years made MOS to come back to 96 Mg ha^{-1} C, out of which 45,8 Mg ha^{-1} derived from pastures (28). It is estimated that carbon gain on pasture cover per year is 0,53-0,80 Mg ha^{-1} $year^{-1}$ C and the conversion of severely degraded lands for pastures is 0,25 Mg ha^{-1} $year^{-1}$ C and lands with pastures is 0,80 Mg ha^{-1} $year^{-1}$ C (2).

Moreover, pastures maintain adequate physical and mechanical conditions on soils. The comparison of soils from arable lands with soils of non-cultivated prairies resulted in a reduction of stable macroaggregates to water of 73 % (29).

One of the best choices to maintain a good carbon stock on the soil, after deforestation and land cropping, is the adoption of practices with a higher input of plant residues as the establishment of pasture (30).

In soils planted with sugarcane, all the results aimed at losses of annual carbon. For the specific case of this crop, when the ecosystem is exploited after cutting the forest, the soil has an organic matter content from 6 to 10 %; after a few years (3-5 years) this content is reduced to half and tends to stabilize between 3-4 % when sugarcane is harvested manually and without burning. But when the sugarcane is burned and its residues reburned, like in Mexico, there are transformations in the soil, with losses in the organic matter content which is known as global changes in soils (31). For the specific case of this study, where sugarcane growing and burning leads to carbon losses in the ecosystem accounting for 43,9 %, of the total basin surface, it would be more convenient to test other forms to improve this situation through sustainable management models like some authors have pointed out (12, 32).

According to data from some authors (33), burning one hectare of sugarcane releases 6,6 Mg $year^{-1}$ of C, equivalent to an emission of 24,3 Mg $year^{-1}$ of CO_2. This last figure, compared to the CO_2 fixing capacity by this crop, it not significant because one hectare of sugarcane with a high growth rate uptakes 80 Mg $year^{-1}$ of CO_2.

A very beneficial measure that could slow down greenhouse effect gasses in the States of Veracruz and Oaxaca, Mexico, it would be to stop burning sugarcane and reburning its residues, because if 1 hectare of burned sugarcane gives off 24,3 Mg ha^{-1} $year^{-1}$ of CO_2, then for 286 367,53 ha of sugarcane grown in these 2 States, would represent a mitigation close to 7 Mt of CO_2 per year for the emission of Greenhouse Effect Gasses (GEI) to the atmosphere, thus contibuting to the improvement of the environment by reducing GEI concentration that is favoring climate change nowadays (32).

However, as in Cuba sugarcane is not burned, there are results showing that Nitisol, ferralitic, lixic, eutric, clayish and rodic soils went through a reduction of soil organic matter stocks from 83 Mg ha^{-1} to 68 Mg ha^{-1} on the top layer of 0-20 cm; while in the layer from 0-50 cm it was 136 Mg ha^{-1} till 108 Mg ha^{-1} (34).

It means, that regardless the effects of burning on carbon emissions, sugarcane per se, leads to reduced organic matter and carbon stock on the soil. This statement coincides with data from other authors (28), that has stated that in the Brazilian Amazon jungle, the introduction of sugarcane as a crop reduced soil carbon content from 72,0 Mg ha^{-1} to 38,5 Mg ha^{-1} in 50 years, with a balance level of 0,8 % C. Such reduction in 14,4 x 10^6 ha of land, represents 0,25 % of the global atmospheric increased CO_2.

The planting of pastures on degraded areas of the study site, is acceptable for carbon uptake and for improving soil properties. Although there are other choices to increase uptake of SOC, they would have to be evaluated (3, 35, 36).

CONCLUSIONS

- ♦ The stable plant covers of forest and pastures generate gains in the soil organic carbon stocks, being pastures the one recording the highest value followed by the oak forest and the pine forest and finally, avocado trees.
- ♦ In those plots where sugarcane is burned and its residues reburned, there are losses in the soil organic carbon stocks.
- ♦ From the results of this study, it is inferred the importance of preserving stable plant covers of oak and pine forests at the studied site in order to increase SOC stocks that account for 37,7 % of the territory. Likewise, fruit crops like avocado, should be privileged for food production.

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