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CONTENTS OF SOIL ORGANIC CARBON UNDER DIFFERENT AGRICULTURAL AND VEGETATION COVER

Contenidos de carbono orgánico en suelos bajo diferentes coberturas vegetales y de cultivo

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ABSTRACT. Soil organic carbon (SOC) represents the major soil reservoir in the terrestrial ecosystems. The deforestation and the intensive agriculture use increases the CO_2 emissions to the atmosphere, promoting the processes related with global climatic change. The objective of this work was to measure the content of SOC under different vegetation covers at the Mololoa basin in Nayarit State, Mexico. Using geomorphological regionalization and land use maps by geographic information system, 27 sampling sites were established. For each soil sampling of 30 cm depth, with three replicates in each site. The samples obtained were analyzed for bulk density, the organic carbon concentration and the carbon content within the top 30 cm depth. The was calculated oak forest had the highest SOC content (140 Mg ha^{-1}). The SOC contents under grassland, secondary vegetation, pine forest, crop land and tropical forest were similar among them (99, 83, 73, 53 and 53 Mg ha^{-1}, respectively). The land cover with higher SOC content were oak forest for its higher SOC concentration and the crop land for its higher area occupied within the studied basin.

Key words: primary forests, tropical forests, land use

RESUMEN. El carbono orgánico del suelo (COS) representa el mayor almacén de carbono (C) en los ecosistemas terrestres. La deforestación de las coberturas vegetales naturales y el uso agrícola intensivo incrementan las emisiones de CO_2 a la atmósfera y por tanto aceleran los procesos del cambio climático global. El objetivo de este trabajo fue cuantificar los contenidos de COS bajo diferentes coberturas vegetales y de cultivo en la cuenca del río Mololoa, en el estado de Nayarit, México. A partir de la cartografía de regionalización geomorfológica, de las coberturas y uso del suelo existentes y con el apoyo de un sistema de información geográfica, se establecieron 27 sitios de muestreo. En cada uno se colectaron muestras de suelo de 0 a 30 cm de profundidad con tres repeticiones por cada sitio. A las muestras obtenidas se les determinó la densidad aparente, la concentración de COS y se calculó el C almacenado en los primeros 30 cm de profundidad. El mayor contenido de COS se encontró en los bosques de encino (140 Mg ha^{-1}). Los contenidos de COS de los pastizales, vegetación secundaria, bosques de pino, cultivos y selvas fueron estadísticamente iguales con 99, 83, 73, 53 y 53 Mg ha^{-1}, respectivamente. Las coberturas con suelos que tienen los mayores contenidos de CO fueron el bosque de encino por tener la mayor concentración, y las zonas de cultivo, por tener la mayor superficie ocupada dentro de la cuenca.

Palabras clave: bosques primarios, bosque tropical, uso de la tierra

INTRODUCTION

In the terrestrial carbon cycle, the soil contains the highest amount interacted with the atmosphere. Around 1,500 Pg C at 1 m deep and about 2,456 Pg C at 2 m deep are estimated; both the vegetation

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(650 Pg) and the atmosphere (750 Pg) store considerably less quantities than soils (1). Organic carbon flows between the soil and the atmosphere are significant, because they provide CO2 emissions and thereby global warming (2, 3).

Organic carbon accumulated in the forests is essential for greenhouse gas capture and emissions, due to changes in land use and land cover affect carbon amount stored in the vegetation and the soil (4). In Mexico, the sector including land cover and land use is considered the second source of greenhouse gas emissions after fossil fuel consumption (5). Therefore, it is important to know carbon amount stored in ecosystems, its dynamics and changes, especially under high anthropogenic pressures.

Land cover and land use play a significant role on SOC and its changes, because they control the quantity and quality of organic compounds supplied to the soil and, also, they determine the sensitivity to intrinsic temperature of organic matter decomposition (6). Most natural covers have SOC profits, while changes in land use have SOC losses (7).

In Mexico, some studies on carbon content have been conducted referring to vegetation (4, 8-10) and only a few of them take into account the soil. In Mexican soils, an average of 56,1 Mg ha^{-1} SOC is reported within the first 20 cm deep; besides, rainforests are notable for ecological regions with 110,5 Mg ha^{-1}, mangroves (106,1 Mg ha^{-1}) and cloud forests (104,9 Mg ha^{-1}), followed by dry forests (69,6 Mg ha^{-1}), coniferous and oak forests (65,5 Mg ha^{-1}) and wetlands (62,0 Mg ha^{-1}) (11).

In temperate forests of this country, SOC contents are reported for *Quercus* (121,3 Mg ha^{-1}) and *Pinus* (119,4 Mg ha^{-1}) forests in preserved soils from the Federal District (12); preserved pine-oak stands (103±35 Mg ha^{-1}) of the monarch butterfly biosphere reserve in Michoacán (13), as well as in shallow forest soils of different pine species from protected natural areas of *Pinus rudis* (180 Mg ha^{-1}), *Pinus pseudostrobus* (110), *Pinus douglasiana* (105), *Pinus patula* (102), *Pinus hartwegii* (102) *Pinus teocote* (94), *Pinus montezumae* (76), *Pinus* spp. (71), *Pinus ayacahuite* (21), *Abies vejarii* (131) and *Abies religious* (92) (14).

In grassland ecosystems, SOC contents of 90 Mg ha^{-1} are recorded at the Federal District (12), while in 30, 20 and 10 year-old grasslands, under semi-arid climates of Tamaulipas, SOC contents are of 8,03, 7,33 and 4,13 Mg ha^{-1} respectively (15).

In cultivated soils, SOC contents of 46,1 Mg ha^{-1} are reported (12), while in four coastal landscape soils of Nayarit state, SOC contents are at 20, 50 and 100 cm deep (16). In the upper floodplain, there are two Cambisol profiles: one with sorghum crop of 26,1 Mg ha^{-1} at the first 20 cm deep whereas the second one with grassland (40,7). In the middle plain, there are four profiles: two of Phaeozems developed in a semi-deciduous tropical forest with 53,7 and 67,1 Mg ha^{-1}; one Cambisol with sorghum crop of 32,2 Mg ha^{-1} and a Solonetz with induced grassland (27,7). In the low floodplain, there are two Cambisol profiles: one with mango crop (33,2 Mg ha^{-1}) and the other with sorghum and corn (10,9). Finally, in the coastal bar landscape, there are four Arenosol profiles: one with land cover of semi-deciduous tropical forest (10,8 Mg ha^{-1}); two with coconut plantations (0,82) and tomatillo (0,96), and one in coastal dunes (3,89).

The aim of this study was to estimate SOC contents in different land covers and land use of Mololoa river basin, involving 34 towns from Tepic, Xalisco and Santa Maria del Oro municipalities, at Nayarit state, Mexico.

MATERIALS AND METHODS

Studied area

Mololoa river basin takes up 618 km2 of Santiago-Aguamilpa river basin, at the central part of Nayarit state, Mexico; it is located between 21º44'15'', 21º16'13'' North Latitude and 105º39'01'', 105º00'53'' West longitude. It is delimited by isolated volcanic structures, mainly from San Juan, Coatepec, Tepeltiltic, Sangangüey and Calderas de Tepic volcanoes (all of them originated from the Quaternary on a Tertiary base). The studied area has six morphogenetic environments: volcanic mountains with steep slopes of San Juan volcano, volcanic shield with boilers, volcanic mountains with volcano stratum, hills, hill surfaces and slopes of the lower basin and floodplain. The first five environments correspond to erosive areas represented by mountains and volcanic shields, slopes and hills of San Juan, Sangangüey, Calderas de Tepic and Tepeltitic volcanoes, while the latter to Matatipac valley-floodplain (17).

The climate of this region is warm sub-humid with summer rains and a winter rainfall rate of 4 %; it presents a local diversity from tempered sub-humid at the top of volcanos (12-18 ºC), semi-warm in the middle part of the basin (Matatipac valley) (18-22 ºC) to warm in the lower section towards Santiago river mouth (higher than 22 ºC), with a mean annual rainfall of 1 180 mm (18).

Soil formation depends on reliefs and types of volcanic rocks; on the side of San Juan volcano, which had eruptions of pumice and ashes within its latest stages, develop Andosols, Cambisols and Regosols, meanwhile in the other basin slopes are Leptosols, Alisols, Luvisols, Feozems and Cambisols. Regarding valley depressions, where drainage is poor, there is gleying process and Gleysols are formed. In general, all soils have acid pH (between 4,9 and 6,9) (19).

In addition, 38 % surface area has natural vegetation and 44 % are arable lands (mainly of sugarcane, avocado and corn), whereas the rest are secondary vegetation, buildings and water bodies. The main land covers are oak and pine forests, spread over the higher elevations of volcanoes with a deforestation rate of 0,1 ha year^{-1} (20); forests and grasslands are located in the lower part of the basin with a loss rate of 0,3 ha year^{-1} (20).

Dominant species in each cover are: for pine forest (*Pinus devonian, Pinus montezumae* and *Pinus pseudosptrobus*), oak forest (*Quercus glaucescens, Quercus laeta* and *Quercus obtusata*), secondary vegetation (*Belotia mexicana, Bocconia arborea, Byrsonima crassifolia, Cecropia peltata, Cochlospermun vitifolium, Croton panamensis, Guazuma ulmifolia, Helicteres guazumaefolia, lantana camara, Luhea candida, Trema micranta, Psidium sartorianum, Psidium guajava, Tecoma stans, Montano akarvinski, Phitolacca rugosa, Rauwolfia heterophylla, Solanun mtorvum, Waltheria americana* and *Zanthoxylon fagara*), grasslands with different genus species (*Aristídia, Bouteloua, Panicum, Eragrostis, Stipa, Trachypogon* and *Trisetum*) and crops (*Saccharum officinarum, Persea americana* and *Zea mays*) (21).

Selecting sampling sites

For selecting sampling sites, the geomorphological regionalization of Mololoa river basin at the level of morphogenetic environments, geomorphological landscapes and types of reliefs was taken into account (17), besides the study of land cover and land use (20). Supported by ArcView 3.2 geographic information system and based on the units of six geomorphological landscapes, the units of four large cover groups were firstly superimposed, in this case of natural vegetation, secondary vegetation, farmlands and wastelands; however, water bodies (dams and rivers) and human settlements were not included in this study, followed by the units of seven cover groups of oak (Be), pine (Bp), forests (Se), secondary vegetation (scrub) (Vs), grassland (Pa), crops (Cu) and bare soils (Sd) (Figure 1).

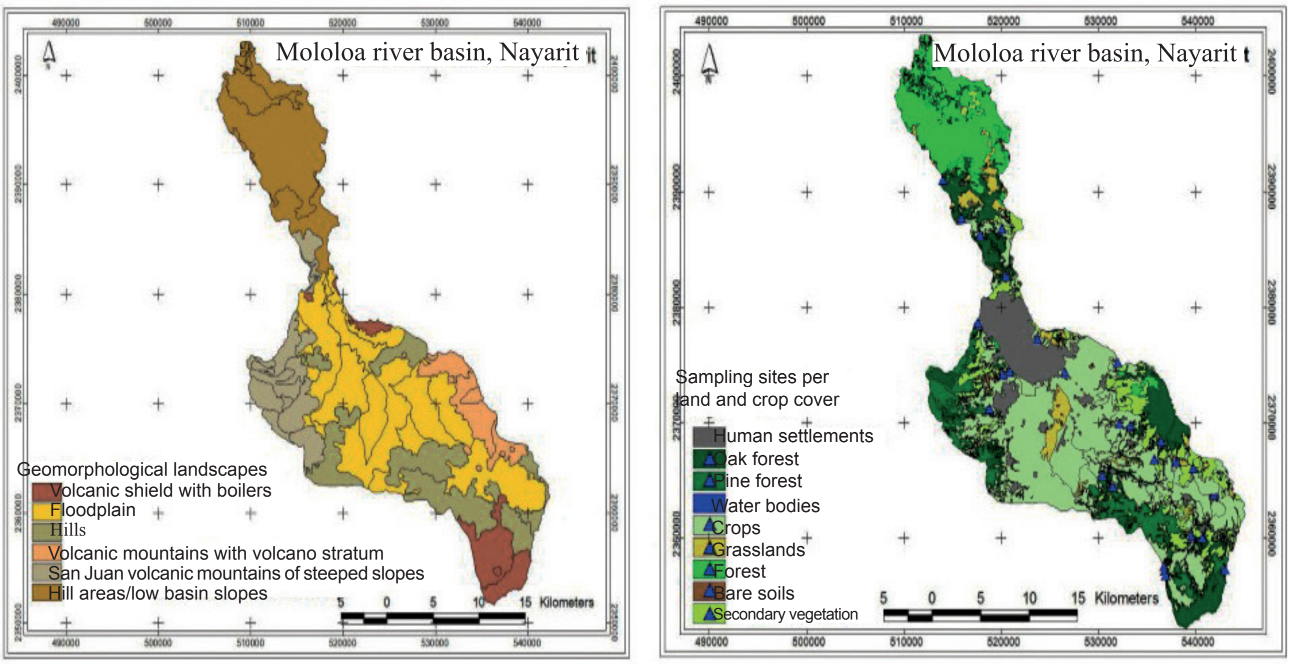

Figure 1. SOC sampling sites resulting from superimposing units of geomorphological landscapes and cover groups, land use of Mololoa river basin, Nayarit, Mexico

The criteria for selecting sampling sites was at least a sample made up by different reliefs in each cover group, which resulted a total of 27 sites: six Be, three Bp, two Se, six Vs, three Pa, six Cu and one Sd. Sites were distributed according to the reliefs that affected each group of land cover and crop. A triangle of 10 m side was drawn in every selected site and individual soil samples were taken at 30 cm deep on its apexes, to determine bulk density by the cylinder method (100 cm^3).

Soil organic carbon (SOC) determination

For SOC determination, soil samples were prepared according to AS-01 method (22), so that they were air dried to further remove fine soil gravel through 0,5 mm sieving. Soil organic matter was determined by Walkley and Black method (AS-07), based on SOC oxidation using a potassium dichromate solution and the reaction heat generated when mixed with concentrated sulfuric acid. Then, 1,298 (1/0,77) was applied as a correction factor.

SOC amount was estimated by means of the following equation:

$$SOC= OC\ (Da)\ m$$

where:

SOC= total organic carbon in soil surface (Mg ha^{-1});
OC= total organic carbon (%)
Da= Bulk density (g/cm3)
m= soil depth (cm)

Data analysis and presentation

A variance analysis was performed to SOC values under a randomized complete design, considering the types of cover as treatments. The statistical value of normality (Shapiro-Wilk) was of 0,924 (<0,0001). A multiple range test (Duncan α= 0,05) was applied to mean carbon contents (Mg ha^{-1}) by using SAS software version 9.1 (23).

The average contents of different land and crop covers were represented by GIS (Figure 2). Moreover, taking into account the area that comprises each type of land and crop cover within the basin, SOC contents contributing to the study area were calculated.

RESULTS AND DISCUSSION

The highest SOC content was recorded in oak forest cover (140,4 Mg ha^{-1}), compared to soils with other covers. SOC contents of grassland, secondary vegetation, pine forest, crop and forest covers were statistically the same with 99,0, 83,5, 73,5, 53,5 and 53,2 Mg ha^{-1} respectively. Finally, the bare soil had the lowest SOC content of all covers studied with 16,3 Mg ha^{-1} (Table).

Oak and pine forest covers of the highest parts of San Juan, Sangangüey and Tepeltiltic volcanoes take up more than 12,000 ha of Mololoa river basin and resulted with SOC levels of 140,49 and 73,5 Mg ha^{-1} respectively, quite above the average presented for coniferous and oak forests of 66,5 Mg ha^{-1} in Mexico (11), just like in preserved pine and oak stands from

Table. Mean carbon content in soils per vegetation and crop cover group, stored in Mololoa river basin, Nayarit state, Mexico

Cover group	Sample number	Mean SOC (Mg ha^{-1})	Basin area (ha)	SOC contents (Mg)
Oak forest	18	140,49 a	6630,4	931504,9
Grassland	9	99,03 b	2554,3	252952,3
Secondary vegetation	21	83,55 bc	5686,0	474782,7
Pine forest	9	73,58 bc	5470,0	402482,6
Crops	18	53,52 c	22566,5	1 207759,1
Forests	6	53,21 c	8427,0	448400,7
Bare soils	3	16,31 d	207,6	3385,9

SOC= soil organic carbón VC= 44,75 % SE= 6,35 R2=0,68
Note: Stadigraphs come from variance analysis subjected to a randomized complete block design (with different number of repetitions) considering covers as treatments

where:

VC= variation coefficient of data
SE= Standard error of mean SOC contents (Mg ha^{-1})
R2= Determination coefficient and the value explaining treatment variation, i.e., types of covers

monarch butterfly biosphere reserve in Michoacán (103±35 Mg ha^{-1}) (14) and oak forests in the preserved soil from the Federal District (121,3 Mg ha^{-1}) (12). With regard to the pine forest from the basin studied, the average content was lower than in Pinus forest (119,4 Mg ha^{-1}) in preserved soils from the Federal District (12) and those reported for different pine forest species from protected natural areas of Mexico, in the case of *Pinus pseudostrobus* (110 Mg ha^{-1}) and *Pinus montezumae* (76 Mg ha^{-1}) (13).

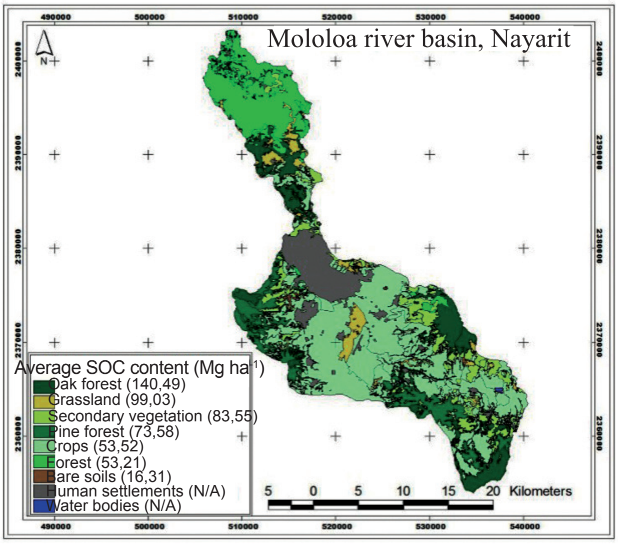

Figure 2. Average SOC contents under different land and crop cover in Mololoa river basin, Nayarit, Mexico

Pine/oak forests store between 40 and 80 % SOC in soil horizons A (13); also, SOC values are reported in this paper for benefited (39 Mg ha-1) and disturbed (13 Mg ha-1) pine/oak forests. These results indicate the importance of keeping them under their natural condition.

Mololoa river basin rainforests occupy 8,427 ha and have average SOC contents (30 cm layer) of 53,21 Mg ha^{-1}, below dry forest (69,6 Mg ha^{-1}) and rainforest (110,5 Mg ha^{-1}) records of Mexico (11); similarly, they are lower than soil contents (0-20 cm layer) with deciduous tropical forest from the coastal plain of Nayarit (16) and red Ferralitic soils with rainforests of Cuba (67 Mg ha^{-1}) (24).

Mololoa river basin grasslands are scattered and derived from land cover changes for livestock. They comprise more than 2,500 ha and have average SOC contents of 99 Mg ha^{-1}, very similar to those obtained in grasslands (90 Mg ha^{-1}) at the conservation area from the Federal District (12) and above Cambisols from the coastal plain of Nayarit (40,7 Mg ha^{-1}) (16) and red Ferralitic soils of Cuba (48 Mg ha^{-1}) (24); in addition, Tamaulipas semiarid grasslands without tillage for 30, 20 and 10 years had 8,03, 7,33 and 4,13 Mg ha^{-1} respectively (15).

Changing land use is the main cause of C content reduction. SOC losses from 30 to 50 % are estimated on topsoil, after a long cropping time; hence, when forests are deforested, there is a CO content reduction as reported by some authors (24), when comparing soils (20 cm) covered by tropical forests (67 Mg ha^{-1}), grasslands (48 Mg ha^{-1}) and crops (32 Mg ha^{-1}). Besides, when comparing profiles covered with sorghum from deciduous rainforest, SOC amount is reduced up to 60 % (16).

SOC estimates in the thorn scrub from Tamaulipas and three non-tillage grasslands for 10, 20 and 30 years are of 14,2, 8,0, 7,3 and 4,1 Mg ha^{-1} respectively. The reappearance and development through time of tree and shrub species from natural scrub in abandoned grasslands not only preserves soil, but also have a carbon storage potential (15).

Growing areas represent 44 % of the basin area studied, with more than 22,000 ha. The largest extension is of sugarcane, the average SOC estimated at the first 30 cm deep was of 53,5 Mg ha^{-1} exceeding cultivated soils from the Federal District (46,1 Mg ha^{-1}) (12), the red Ferralitic soils of Cuba (32 Mg ha^{-1}) (24) and four Cambisol profiles from the coastal plain of Nayarit with 26,1, 32,2, 33,2 and 10,9 Mg ha^{-1} (16).

Crop management is important for SOC content, since its changes on the top 15 cm of a Vertisol with different tillage forms are shown below: non-tillage (66.8 Mg ha^{-1}); with direct seeding and residues supplied after packing stubble from corn, sorghum, barley and wheat (58,8 Mg ha^{-1}); with direct seeding and total crop residues supplied (53,1 Mg ha^{-1}), as well as conventional seeding and burning of crop residues (44,8 Mg ha^{-1}) (25).

SOC content changes in a Ultisol grown with sugarcane previously covered by tropical forest and land use changes had a significant impact on its total concentration, which shows that when sugarcane is grown after a secondary tropical forest, there is a positive rate on new carbon capture, but a significant loss in the original tropical forest carbon (26). After 56 years of sugarcane cultivation, SOC concentration was lower than in tropical forest by more than 60 %; while sugarcane cultivated for 35 years had no significant reduction on SOC concentration at 1 m deep.

Results indicate that when natural forests are converted into sugarcane-growing lands, there is a continuous SOC reduction for long periods of time (26).

Finally, in bare soils, only herbaceous vegetation grows during the rainy season (June to October) and they often have fires. They take up a small basin area (207 ha) and also contain low SOC levels (16,3 Mg ha^{-1}), suggesting a high degree of damage of this ecosystem.

CONCLUSIONS

- ♦ Oak forest had the highest C content per vegetation cover group, while bare soils had the lowest storage.
- ♦ Oak forest had the most relevant cover of SOC storage amount, which also had the highest concentration and growing areas, as the area occupied within the basin represents the largest C amount stored.
- ♦ In sceneries of land use changes in Mexico, SOC is also modified (27) and changes from scrub and grassland cover to conservation tillage may be the most favorable alternative to preserve SOC storage and prevent losses as CO_2.
- ♦ In the case of land use changes from low deciduous forest to farming systems, practices with more vegetable residues, such as grasslands, should be adopted.

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