Short-temporal variation of soil organic carbon in different land use systems in the Ramsar site 2027 ‘Presa Manuel Ávila Camacho’ Puebla

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The soil organic carbon (SOC) was determined in 40 sites at two depths (0–10 and 10–20 cm) for different uses of soil during one year (February 2014–February 2015). The total SOC stored in the analysed soil from the Ramsar site was 9.67×10^5 t, from which 40% was stored in induced pasture, followed by the red oak forest with shrubbery secondary vegetation, rain-fed agriculture and human settlements (24%, 23%, and 13%, respectively); the last was evaluated to determine how the proximity of the city impacts the SOC. The SOC concentrations present significant differences with respect to soil depth ($p = 0.0$) and land use ($p = 0.0$). The temporal distribution maps showed that SOC did not present significant variations in the short-term. A relation between SOC and bulk density was found ($r = -0.654$, $p = 0.00$), with respect to other physicochemical properties. Moreover, a significant relation between SOC and stored total nitrogen ($r = 0.585$; $p = 0.00$) was found. This work represents the first study that analyses the current condition of the soils in the Ramsar site ‘Presa Manuel Ávila Camacho’.

Keywords. Soil organic carbon (SOC); Ramsar site; spatial maps.

1. Introduction

There is growing public and scientific concern regarding the potential carbon sequestration of the terrestrial ecosystems, as carbon dioxide (CO₂) emissions into the atmosphere have increased in recent years, mainly due to anthropogenic activities (Singh *et al.* 2015). One of the most important elements to lessen atmospheric CO₂ is the soil, given that it can act as an important CO₂ pool, which contributes significantly in reaching the

levels committed to in the Kyoto Protocol regarding the stabilization of the CO₂ atmospheric concentration (Huang *et al.* 2016). The soil's capacity for carbon sequestration varies in accordance with the soil type and its physicochemical characteristics, management, and environmental factors (McGrath and Zhang 2003; Singh *et al.* 2015). The manipulation of some factors, especially those related to the management, can be used to keep or enhance the content of soil organic carbon (SOC) (McGrath and Zhang 2003). Therefore, in order

to mitigate the effects that cause the increase in the CO₂ concentration in the atmosphere, it is necessary to carry out practices that increase the production of vegetal biomass or that reduce erosion, both of which are effective in improving carbon sequestration. This challenge can be tackled only through the implementation of new soil usage alternatives. It is well known that flooded soils, which are characteristic of wetlands, are an important reservoir of organic carbon (Bao *et al.* 2011; Yu *et al.* 2012; Pal *et al.* 2016). However, it is also considered important to know the conditions of the soil that surround the wetlands to contribute to their conservation and to promote their management and payment of environmental services. It is also known that the soils are capable of annually storing 10% of the annual CO₂ emissions (Yadav *et al.* 2009). Soils naturally contain 3150 Pg C stored, four times more than that stored in the vegetation (650 Pg C) (Hobley *et al.* 2016; Assefa *et al.* 2017). Thus, it is important to know the current state of a site from a spatial and temporal way to contribute on the application of tools as conservation, adaptation and reduction of climate change policy (Jones *et al.* 2017; Sayoud *et al.* 2017).

Ramsar convention is an inter-governmental treaty adopted on February 2, 1971, in the Iranian city of Ramsar, for conservation and sustainable use of wetlands (Ramsar Convention Secretariat 2013). To attain the objectives of the convention, it is necessary to first evaluate the space-temporal variation of the vegetation coverage, the land use change and the content of organic carbon in different sites of the Ramsar (Juman and Ramsewak 2013; Mabwoga and Thukral 2014; Pal *et al.* 2014, 2016). The principal results reveal that the natural vegetation of the sites has decreased mainly due to human activities, agricultural growth and climate change, and yet, despite these conditions the wetlands are highly capable of storing organic carbon. Hence, research in the field is important, as it takes the appropriate measures that slow down higher degradation extents. However, this research is the first study related to the Ramsar site 2027 'Presa Manuel Ávila Camacho' that may be taken as a starting point for future temporal and space studies that relate to their capacity of storing carbon.

The Ramsar site 'Presa Manuel Ávila Camacho' is located in the State of Puebla, México, specifically in the southern part of the valley of Puebla, and is characterized for accommodating

231 species of birds, of which 16 have a protected status (12 of special protection and four endangered species) (CIEMAD 2011). Furthermore, there are 10 species of endangered aquatic flora, and the terrestrial vegetation includes mainly pastures/agriculture, oak forests, tropical deciduous forests, and palm grove forests (CIEMAD 2011). However, in spite of its importance as a carbon pool of Ramsar sites, to the best of our knowledge there have been no studies conducted so far regarding the capacity of the soil from Ramsar site 2027 to store carbon. Therefore, the purpose of this study was to evaluate the spatial and short-temporal variation of SOC, pH, soil total nitrogen (STN) and bulk density (BD) in the Ramsar site 2027 'Presa Manuel Ávila Camacho' in order to provide the status of its carbon stored, and the effect of different physical and chemical parameters, with seasons of the year and land uses.

2. Materials and methods

2.1 Characteristics of the site

Ramsar site 2027 covers 23,612 ha in the southern part of the municipality of Puebla, México (figure 1), in the Cuenca del Alto Balsas and includes an alluvial valley formed by the Atoyac river, the 'Presa Manuel Ávila Camacho' (Valsequillo Dam), which is the largest permanent body of water in the state of Puebla occupying 2832 ha, and the forested areas of the Sierra del Tentzo. Likewise, Valsequillo is part of the bird migration corridor of America. The types of soil in the site include: Phaeozems (east and west of the Dam), Regosols (west of the Dam), Cambisols (southeast of the Dam), Lithosols (south and south-west of the Dam), Rendzinas (south and south-west of the Dam), and Vertisols (north of the Dam). The highest part is located in the southern part of the site where there are slopes greater than 30° (CIEMAD 2011). The annual precipitation in the site varies between 741 and 863 mm. The average annual temperature in the site varies between 16° and 17.5°C.

2.2 Soil sampling and analysis

According to the vegetation type map of the cartography of the National Institute of Statistics and Geography series V, which corresponds to the vegetation of 2013, a total of 40 points were selected for the sampling in soils of the Ramsar

Figure 1. Geographical location of the study area Ramsar site 'Presa Manuel Ávila Camacho' (Puebla, Mexico).

site; it is worth mentioning that this selection was also done considering the access to the area. A portable global positioning system (GPS) was used to record each sample site (figure 2). As reported, climatic conditions of each season of the year may have an effect on soil organic carbon content (Pal *et al.* 2014; Assefa *et al.* 2017). Therefore, two sampling periods were carried out in 2014, the first (Dry 1) being carried out in February, with no record of precipitation and a reported temperature of 15.9°C; the second (Rainy) was carried out in July, with 78.9 mm of rain and a temperature of 17.75°C; the third sampling (Dry 2) was carried out in February 2015, with 1.6 mm of rain and a temperature of 14.8°C. Each sample was composed of one kilogram of soil from a depth of 0–10 and 10–20 cm. A total of 240 samples were collected, including the four types of land use in the Ramsar site: rain-fed agriculture (RA, 84 samples, 5575 ha), induced pasture

(IP, 90 samples, 7207 ha), human settlements (HS, 30 samples, 4487 ha), and oak forest with shrubbery secondary vegetation (OF/sSV, 36 samples, 4115 ha). The cylinder technique was employed in order to determine the bulk density in accordance with Blake *et al.* (1986). The collected samples were dried at room temperature and sieved with a 1.73 mm sieve. Then, the percentage of organic carbon was determined through the Walkley–Black method; the percentage of total nitrogen was determined through the micro-Kjeldahl method and the pH values were determined using a pH-meter (conductronic pH).

The SOC density and SOC storage were calculated using equations (1 and 2), respectively and the STN density and STN storage was calculated with equations (3 and 4), respectively.

$$\text{SOC density} = CO \times BD \times H \quad (1)$$

$$\text{SOC storage} = \text{SOC density} \times A \quad (2)$$

Figure 2. Distribution map of the different land uses and sampling points of the Ramsar site 2027.

$$\text{STN density} = TN \times BD \times H \quad (3)$$

$$\text{STN storage} = \text{STN density} \times A \quad (4)$$

where SOC density is soil organic carbon density (t/ha), CO is the percentage of certain organic carbon in the samples, BD is soil bulk density (t/m^3), H is the depth of the soil layer (m), SOC storage is soil organic carbon storage (t), A is the area of the different land uses (ha), STN density is the soil total nitrogen density (t/ha), TN is the percentage of total nitrogen, STN storage is soil total nitrogen storage (t).

2.3 Generation of spatial distribution maps

Spatial variability of SOC on Ramsar site 2027 was mapped by kriging interpolation method using Surfer 7.0, according to the measuring data of organic carbon concentration and coordinates of each sample site.

2.4 Analysis of the dynamics of land use change in the Ramsar site 2027

The cartography to analyse the vegetation coverage and the land use change was taken from official data in the Mexican government (Instituto Nacional de Estadística, Geografía e Informática 1976–2013). The maps for spatial and temporal distribution of land use were generated using the Arc View 3.2a software. Table 1 presents the classification system used, as well as the different types of vegetation and land use.

2.5 Statistical analysis

Analysis of variance (ANOVAs) was used to identify statistically significant differences in SOC, STN, BD, and pH values among the four land uses and two soil depths. Significant differences between the means among the four land uses and

Table 1. *Hierarchical legend of the land use (1976–2013).*

Types of vegetation and land use	Code
Red oak forest	OF
Red oak forest with shrubby secondary vegetation	OF/sSV
Induced pasture	IP
Rainfed agriculture	RA
Water bodies	WB
Human settlements	HS

Table 2. *Descriptive statistics of the physico-chemical parameters (SOC, STN, pH and DB) of the Ramsar site 'Presa Manuel Ávila Camacho'.*

Variable	Average	St. dev.	Coef. var. (%)	Minimum	Maximum
SOC (t/ha)	20.36	11.02	54.13	0.34	57.66
STN (t/ha)	1.67	1.14	68.37	0.04	5.96
pH	6.56	0.70	10.74	3.92	7.98
Bulk density (BD) (g/cm ³)	1.06	0.11	10.50	0.70	1.55

Table 3. *Dynamics of the land use change, 1976–2013.*

Land use	Surface (ha)					
	1976	1993	2000	2003	2010	2013
OF	356	95	341	0	0	0
OF/sSV	4810	4834	3762	4044	4249	4015
WB	2659	2496	2573	2569	2575	2559
IP	6173	6133	4626	7853	7089	7107
RA	9373	7468	9756	6516	5599	5475
HS	241	2586	2554	2630	4100	4456
Total	23,612	23,612	23,612	23,612	23,612	23,612

two soil depths were identified by the Tukey test at $P < 0.05$. All statistical analyses were performed using Minitab[®] 16.1.0. statistical software.

3. Results

3.1 Site characterization

In general, the SOC and STN values of soils found from Ramsar site 2027 is as shown in table 2. The content of SOC in the study area varies from 0.34 to 57.66 t/ha with a mean value of 20.36 t/ha $\pm$ 11.2; whereas, the STN varies from 0.04 to 5.96 t/ha with a mean value of 1.67 t/ha $\pm$ 1.14. In the case of pH, it varies from 3.92 to 7.98 with a mean value of 6.56 $\pm$ 0.70. Bulk varies from 0.70 to 1.55 g/cm³ with a mean value of 1.03 g/cm³ $\pm$ 0.11; these low values of bulk density may be due the high organic matter content or high soil porosity (Curtis and Post 1964; Tanveera *et al.* 2016).

The natural vegetation of the Ramsar site 2027 has experienced substantial changes (table 3); according to the found data, in 1976 there were 356 ha of red oak woods (OF); however, by the year 2003 they had completely disappeared. On the other hand, a decrease of the 810 ha of OF/sSV was observed from 1976 to 2013. Rain-fed agriculture has varied in an important way; in 1976, it covered 37% of the surface and in 2000 it increased by 3%, which coincided with the period of agrarian reform and with the date when the North American Free Trade Agreement (NAFTA) became effective. Nevertheless, it drastically decreased to 23% in 2013. Another point of concern is the important growth of human settlements, which increased its surface from 1% in 1976 to 19% in 2013.

Figure 3 shows the values obtained for SOC for all sites analysed during the three sample periods (Dry 1, Dry 2 and Rainy) at both depths (0–10 and 10–20 cm); it was important to determine these

Figure 3. Average concentration of SOC and STN (t/ha) for the three sampling seasons at both depths. Note: Dry(1) = Sample 1, Rainy = Sample 2, Dry(2) = Sample 3, SOC = soil organic carbon, STN = soil total nitrogen, rain-fed agriculture (RA), induced pasture (IP), human settlements (HS), and oak forest with shrubby secondary vegetation (OF/sSV).

values since it is well known that the climate conditions of each season have an effect in the content of organic carbon (Pal *et al.* 2014; Assefa *et al.* 2017). In the Dry 1 period, for both depths, it was observed that the land uses with highest content of SOC were of the type OF/sSV followed by IP, whereas the lowest values were those found for HS. SOC values ranged from 43 to 19.8 t/ha for 0–10 cm soil layer; meanwhile, lower values were found, as expected, for the second layer (10–20 cm), which ranged from 35 to 13 t/ha. STN values for the first soil layer showed an average value of 2.9 t/ha, higher than the second layer (1.6 t/ha); as it is already known, the soil's depth plays an important role in the SOC and STN values, where, greater the depth, lower the SOC and STN values (Marques *et al.* 2015; Hobley and Wilson 2016).

For the Rainy and Dry 2 seasons, the results showed a similar pattern to that of the Dry 1 season. As it can be seen in figure 3, these seasons exhibited the highest values of SOC and STN for IP and OF/sSV land uses; however, unlike the Dry 1 season, IP showed the highest values for both parameters at both depths. In addition, SOC values for Dry 2 and Rainy seasons showed a pronounced decrease for OF/sSV land uses compared to Dry 1 season (figure 3), which could indicate a higher sensitivity of OF/sSV to climatic variations. Effectively, Dry 1 samples were collected in February, where the lack of rain, lower temperature and

humidity of the soil could favour the accumulation of humus, increasing the SOC; the following sample period (Rainy), which was carried out in July, after frequent and abundant precipitation, showed a loss of accumulated SOC due to higher biological activity and also, there is a higher runoff during this season. Figure 4 shows the distribution of SOC for the three sampling periods at soil layers. As it can be observed in the Dry 1 season, at both soil depths, the SOC values are higher in the southern part of the study area (up to 70 t/ha), where OF/sSV land uses are found, being the furthest from the urban zone and of difficult access. On the other hand, in the Rainy season a pronounced change in SOC was observed. Highest SOC values were determined in first soil layer of the north section (up to 55 t/ha), where IP area is found; and the lowest values from the second soil layer in the same area (10–20 cm). Finally, in the Dry 2 season, high concentrations of SOC were observed in the north, where the RA and IP areas are located, and also in the south, where the OF/sSV soils are found (up to 55 t/ha).

3.2 Statistical analysis

Table 4 summarizes the SOC, STN, the pH and bulk density average values by sampling season

Figure 4. Spatio-temporal pattern of soil organic carbon (SOC) in soils of Ramsar site 2027 during the three sampling seasons.

Table 4. Average results obtained for the variables SOC, STN, pH, and bulk density.

Factor	Variable			
	SOC (t/ha)	STN (t/ha)	pH H ₂ O	Bulk density (g/cm ³)
Season				
Dry 1	25.16 ± 15.5 a	2.05 ± 1.73 a	6.54 ± 0.66 a	1.05 ± 0.13 a
Rainy	21.29 ± 11.08 a	2.82 ± 1.15 b	6.82 ± 0.74 b	1.07 ± 0.08 a
Dry 2	21.91 ± 13.24 a	1.31 ± 1.07 c	6.37 ± 0.63 a	1.06 ± 0.10 a
Depth				
0–10 cm	25.85 ± 13.82 a	2.36 ± 1.62 a	6.56 ± 0.69 a	1.04 ± 0.11 a
10–20 cm	19.85 ± 11.68 b	1.76 ± 1.28 b	6.59 ± 0.71 a	1.09 ± 0.10 b
Land use				
OF/sSV	28.44 ± 13.08 a	2.26 ± 1.25 a	6.40 ± 0.67 a	1.05 ± 0.11 a
IP	26.77 ± 14.97 a	2.29 ± 1.38 a	6.51 ± 0.78 a	1.05 ± 0.10 a
RA	20.42 ± 8.42 b	1.77 ± 1.29 a	6.62 ± 0.63 a	1.09 ± 0.87 a
HS	13.67 ± 10.42 c	1.91 ± 2.11 a	6.78 ± 0.63 a	1.07 ± 0.14 a

Points a, b, and c indicate significant differences (Tukey test).

Table 5. Resulting *p* values of the multivariate analysis of variance at a confidence level of 95%.

Factor	Variable			
	SOC	STN	pH	Bulk density
Season	0.25	0.00	0.00	0.27
Depth	0.00	0.00	0.55	0.00
Land use	0.00	0.00	0.10	0.09
Season × Depth	0.81	0.28	0.65	0.35
Season × Land use	0.74	0.77	0.72	0.85
Depth × Land use	0.97	0.75	0.83	0.95

(Dry 1, Rainy, and Dry 2), depth (0–10 and 10–20 cm), and land uses (RA, IP, OF/sSV, and HS). ANOVAs were performed following the three factors of sampling protocol to determine the variability of soil parameters between factors (season, depths, and land use) of the site considered (table 5). For SOC values, no statistical differences were observed according to sampling seasons ($p = 0.25$), in spite of the fact that the environmental conditions such as temperature and precipitation normally hold a dominant influence on the quantity of SOC found in the soil (Pal *et al.* 2014; Assefa *et al.* 2017). However, soil depth and land use have a significant effect on the SOC values ($p < 0.05$). On the other hand, significant differences were observed for the STN values according to sampling season, soil depth and land use ($p < 0.05$). As can be seen, in the different sampling seasons and land use, there are no significant effects in the BD values ($p = 0.27$ and 0.09 , respectively). Significant differences were observed only for BD according to the

soil depths ($p = 0.00$). In the case of the pH, the average was similar in both Dry seasons, but statistically different from the Rainy season ($p < 0.05$).

No effects of the interactions between season*depth, season*land use or depth*land use were observed for any of the physicochemical parameters (p values > 0.05 , table 5). In other words, the combination of those factors do not influence the content of SOC. This analysis was performed to try to explain the influence of the different variables on SOC and STN (Aliat *et al.* 2016; Hobley and Wilson 2016), i.e., to know how SOC varies with not only one variable but with the combination of them, so that the variation could be explained and to eventually propose a measure to increase its content.

The quantity of organic carbon that a type of soil can sequester is a function of its physicochemical characteristics, as well as the use and management of the soil (Robert 2002). A Pearson correlation analysis was carried out between the determined physicochemical properties in order to find out existing relation between them (table 6). According to the analysis, there is a strong and significant negative correlation between SOC and BD ($r = -0.654$, $p = 0.00$); in addition, there is a positive significant correlation between the content of SOC and STN ($r = 0.585$; $p = 0.00$), i.e., at a greater concentration of organic carbon, greater the content of total nitrogen; furthermore, there are other minor, although significant, correlations between SOC with pH, as well as between STN with BD (table 6) and these correlations have been

Table 6. Correlation tests between SOC, STN, pH, and BD variables measured in soils from Ramsar site 2027.

	SOC	STN	pH
STN	0.58 (0.00)		
pH	-0.32 (0.00)	-0.01 (0.83)	
BD	-0.65 (0.00)	-0.37 (0.00)	0.26 (0.00)

Each test is given as the Pearson correlation coefficient and *p*-value (in parenthesis).

reported in the scientific literature (Martínez *et al.* 2008; Deng and Shanguan 2016).

4. Discussion

This study reveals for the first time some physicochemical characteristics of different land use systems in the Ramsar site 2027. A great heterogeneity in SOC and STN values were found. For STN values, 68% of variability was observed; meanwhile, for SOC values, the variability was 57%. The pH and BD values exhibited a lesser variability (10.74% and 10.50%, respectively) (table 1). This high variability is probably due to the land use changes from anthropogenic activities (Yu *et al.* 2012; Wang *et al.* 2016; Yang *et al.* 2016), due to which the lowest values of SOC and STN were found for HS, and RA areas. This Ramsar site has had changes in land use since 1976, when the predominant vegetation was OF/sSV (20%), followed by IP (26%), RA (37%) and HS (1%); unfortunately, now human settlements have grown uncontrollably, affecting the landscape drastically (17%, 30%, 23% and 19%, for OF/sSV, IP, RA and HS, respectively); and hence, it's capacity to sequester carbon. Unfortunately, there is no data on the content of carbon for previous years, which is why it is not possible to determine the decrease in the capacity of storing carbon. The effect of land use change over the capacity of capturing or sequestering carbon has already been reported in the literature (Assefa *et al.* 2017; Sohng *et al.* 2017) and the concentration of COS has also been evaluated according to the different land uses. The total SOC stored in the analysed soils of Ramsar site is 9.67×10^5 t during one year period, calculated by adding the SOC values in each sampling point; approximately, 40% of the total is stored by IP, followed by the OF/sSV, RA and HS (24%, 23%

and 13%, respectively). The estimation of SOC stored in the first soil layer of 0–10 cm was around 56% (5.49×10^5 t), higher than in the second layer (4.19×10^5 t), mainly due to the input of fresh litter and the higher amount of roots of the existing plants.

Soil physicochemical parameters were less correlated with each other, probably due to the variability of soils and vegetation from which soil samples were extracted; some other variables should be included to find any relationship among variables (Martínez *et al.* 2008). According to several reports BD has a close relationship with the organic carbon content in soils (Curtis and Post 1964; Perie and Ouimet 2008; Tanveera *et al.* 2016), and can be determined based on carbon content by empirical regressions or using logarithmic relationships for some soils (Curtis and Post 1964; Prévost 2004). In this work, a relation was found between the BD and the SOC. Such a relation shows a negative correlation coefficient of $r = -0.65$; $p < 0.05$ and in addition, a high degree of association between both variables regarding the sampling season; in Dry 1 season, a correlation coefficient of $r = -0.58$ was observed ($p = 0.00$); on the other hand for the Rainy season, r was -0.54 ($p = 0.00$) and finally, for Dry 2 season, the calculated r was -0.71 ($p = 0.00$) (data not shown).

Reliable information of the terrestrial component of the global carbon cycle has become an issue of international concern (Bai *et al.* 2015). Accurate estimation of SOC stocks is necessary in order to know the carbon status and eventually to meet the requirements of the Kyoto Protocol (Vande *et al.* 2005). For a regional scale, SOC estimates in soils of Ramsar site 2027 are essential for the better understanding of its relevance as a carbon reservoir. In addition, appropriate SOC measures are needed to sustainably conserve Ramsar sites and therefore sustain the goods and services they provide. The soil capacity to store carbon mainly depends on the land use and management (Robert 2002). Alvarez *et al.* (2016) and Pérez *et al.* (2013) reported that the soils in oak forests can store up to 164 t C/ha and harvested stands up to 39 t C/ha. Comparing these data with those obtained in this work with OF/sSV land uses of Ramsar site 2027, it can be concluded that the SOC stored (28 t C/ha) is quite low, which indicates a low capacity of the areas to sequester carbon. On the other hand, induced pasture ecosystems can store up to 50–90 t C/ha (Wang *et al.* 2016), while in the IP area of Ramsar

site 2027, SOC stores was 26 t C/ha, suggesting once again a low capacity of the site to store carbon. Finally, soils for RA of Ramsar stored 20 t C/ha, which is lower than the values reported by Yang *et al.* (2016) and Yu *et al.* (2012), who reported average values of 35–46 t C/ha for areas with the same land use. But, this is not at all an adequate comparison because the conditions and management of the ecosystems are different; however, it is a preliminary approximation to learn about the capacity of the Ramsar site 2027 to store carbon.

5. Conclusions

The estimation of the current soil conditions of the Ramsar site 2027 could serve as a starting point for the development of a management plan for Ramsar sites in general with low storage capacity of carbon. The status of soils from the Ramsar site 2027 'Presa Manuel Ávila Camacho' presents a low capacity to capture carbon mainly due to land uses changes. However, this capacity may be increased by controlling human disturbance and implementing plans of sustainable management. Different authors agree that the application of soil management and conservation practices such as conservation tillage, soil retention barriers, agroforestry practices, to mention a few, favour the SOC increase up to 480 kg ha⁻¹ yr⁻¹ (Alvarez 2005; Scala Junior *et al.* 2012; Hamilton *et al.* 2014; Garcia *et al.* 2015).

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