# Evaluation of carbon sequestration potential in mangrove forest at three estuarine sites in Campeche, Mexico.

Cerón-Bretón R.M., Cerón-Bretón J.G., Sánchez-Junco R.C., Damián-Hernández D.L., Guerra-Santos J.J., Muriel-Garcia, M., and Cordova-Quiroz, A.V.

***Abstrac:-***This study assesses the carbon storage rate in mangrove forest soils located within the Natural protected are named "Terminos Lagoon" in Atasta Peninsula, Campeche-México. Twelve sampling areas were considered within mangrove forests located in Nuevo Campechito, Puerto Rico y Xicalango, respectively, in Atasta peninsula. Samplings were carried out from February to August during 2009 and 2010 at 30 and 60 cm depth during three different climatic periods ("Norths" season, dry season and rainy season). Seasonal variations in the different physico-chemical parameters analyzed were: CE (4-14.8 dS/m), pH (6.5-8.2), Nitrogen (0.05-0.27%), Carbon (1.5-9%), C:N (33.0-44.0), C.A (59-190 Kg C m-2) and soil granulometric classification: Sand (29-71%), Silt (5-30%), and Clay (22-41%). The carbon storage was high and influenced by type of vegetation. Soil with associations of red and black mangrove speies showed the largest carbon storage (350 Kg C m-2 ) while the lowest carbon storage was found in buttonwood mangrove (45 Kg C m-2). The ratio C/N showed a low degradation rate of organic matter in all sampling sites studied. The obtained results in the studied ecosystem are the first estimates of carbon storage in the zone, and suggest the potential of this site as a carbon pool.

***Key-Words***- Carbon Storage rate, Carbon pool, ratio C/N, Mangrove soils, Campeche, Mexico, Physico-Chemical parameters.

## I. Introduction

THE greenhouse effect is a phenomenon that occurs naturally in the planet as a means of retaining heat, however, due to human activities, such as the use of fossil fuels for energy production and processes resulting from the change land use, have increased the accumulation of greenhouse gases (GHGs) having as a consequence the global warming. Since the industrial revolution there was a dramatic increase in the atmospheric concentrations of carbon dioxide ($CO_2$) and others GEI ⇨1⇨. $CO_2$ has both natural and anthropogenic sources and it is the most important GEI due to the quantities emitted and because it contributes in a percentage of 55% to the global warming [2]. Carbon dioxide concentration in the atmosphere has increased from 280 ppm in 1750 to 367 ppm in 1999 (31%), this observed increase is due to predominantly to the oxidation of organic carbon from burning fossil fuel and deforestation ⇨1⇨. Scientific community, concerning about this environmental global problem, is looking for alternative solutions to mitigate the resulting global warming. The role that forestry systems play in the carbon cycle and its strategic importance as solution has been recognized anywhere ⇨1, 2⇨. In spite of wetlands constitutes the main carbon sink, the most of carbon storage studies are focused to terrestrial ecosystems. The most important carbon reservoirs are in tropical soils and wetlands, between 1400 and 1600 Pg of C are stored as organic matter (M.O), ⇨3⇨; however, soils can act as a source or as a reservoir of atmospheric $CO_2$ depending on land use practices, climate, texture and topographic conditions ⇨4,5⇨.

The mangrove ecosystems have the capacity to store great amounts of organic carbon; significant enrichments of organic carbon have been reported even at several meters of depth, ⇨6⇨ mainly due to a aquifer level near to the surface, the high productivity and the low decomposition rate due to the slow diffusion of oxygen in these soils ⇨7⇨. In addition, estuarine wetlands have the capacity to store organic carbon in approximately one magnitude order greater than other wetland systems⇨8]. This carbon storage is an efficient process with a minimal emission of greenhouse gases ⇨9]. Previous research works about carbon storage have studied mangrove soils as homogeneous systems [10], however, some authors have found significant differences depending on the dominant specie of mangrove present in soils ⇨11], suggesting that mangrove ecosystem is a system constituted by forest vegetation, fauna and flora inter-related within the physical media where this complex ecosystem is developed ⇨12]. The structure and productivity of mangrove are influenced by nutrients availability, mostly stored in soils ⇨13]. Quality and quantity of sediments and the amount of organic matter exported depend on the kind of mangrove forest, the productivity and some physical and biological factors ⇨14]. In spite of their ecological, economical and social importance, the last two decades, the surface of mangrove around the world have decreased in approximately 35 percent. This deforestation process has been associated to the direct impact from economical activities like fisheries and tourist development ⇨14]. It has been reported for Mexico that mangrove forest in Yucatan Peninsula covers 51 percent of total mangrove surface in Mexico ⇨15].

Campeche is the first state in the country with a greater cover of protected areas, mainly located in the protected natural area named "Terminos Lagoon" with a total mangrove cover of 259 000 ha. Atasta Peninsula is located in the core of this protected area ⇨16], being the different economical activities developed in this region like agriculture, fisheries, oil and gas industry and demographic development, the main threats for mangrove forest. Taking in account the ecological and economical importance of this region, this preliminary study reports the first results about carbon storage rate and other physico-chemical parameters needed to know which conditions carbon is stored in mangrove soils in Atasta Peninsula, Campeche, Mexico.

## II. Methodology

### A. Site description and sampling procedure

The study area is located at the northeast of Campeche State (fig.1), the zone geomorphology is characterized by swamps and wetlands. Soils in this area have mainly a sandy texture with a high fertility, associated with a dominant vegetation of red mangrove (*Rizophora mangle)*, black mangrove (*Avicennia germinans*), white mangrove *(Laguncularia racemosa)* and button mangrove *(Conocarpus erectus)* ⇨16]. Climatologic conditions in this zone show three climatic periods well defined: Dry season (from March to May), rainy season (from June to October) and cold fronts season named "Norths" (from November to February). Station sites selected for this study were the following:

- Puerto Rico (PR) is located at 18º 36' 55" N and 91º 56' 35" W, samples were taken in areas with dominance of black mangrove (N), associations of black and white mangrove (N-Bl), associations of black and red mangrove (N-R) and associations of red and white mangrove (R-Bl).

- Xicalango (XC) is located at 18º 37' 02" N and 91º 58' 20" W, samples were taken in areas with dominance of black mangrove (N), white mangrove (Bl) and button mangrove (Bo).

- Nuevo Campechito (NC) is located at 18º 38' 28" N and 27' 29" W, samples were taken in areas were button mangrove (Bo) and white mangrove (Bl) were the dominant specie.

Sampling campaigns were performed along the Atasta Peninsula between 2009 and 2010 during the dry, rainy and "Nortes" seasons. Based on visual inspections, transects were established in a representative area of mangrove forest.

Sampling sites were selected to assure representative regional samples, taking in account the type of vegetation, easy access and the hydrology.

In each transect, three sampling points were located, and samples were taken at 0.30 and 0.60 m depth, by using a 193.3 cm3 soil sampler ⇨17] in an area of 48 m2. The descriptions for these sites are showed in Table 1. After samples extraction, soil cores were labeled, sealed and sent to the laboratory for their chemical analysis.

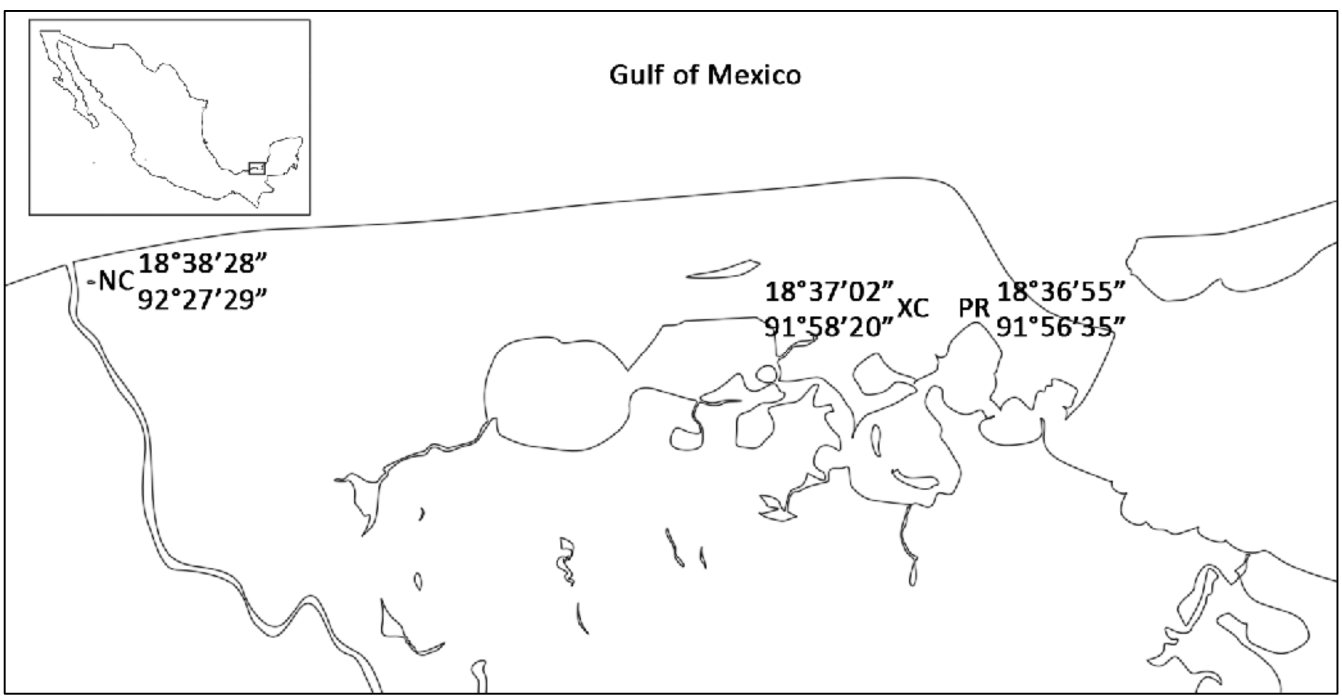


Fig. 1. Study area and sampling sites (NC: Nuevo Campechito, PR: Puerto Rico and XC: Xicalango) in the mangrove wetland located in Atasta peninsula.

### B. Analytical Procedure

When he soil cores were removed from the tight-fitting end caps. Free water was drained away and all biomass and solid materials (shells, roots, leaves, and so on) were removed; then, samples were grinding, dried at ambient temperature and sieved to pass through a 2 mm mesh.

Table 1. Texture class and dominant species.

| Sampling Area | Station Sampling | Dominant Species | Texture Class |
|---|---|---|---|
| 1 | Nuevo Campechito | *Rizophora mangle and Laguncularia racemosa* | *Sandy Clay Loam* |
| 2 | Nuevo Campechito | *Laguncularia racemosa* | *Sandy Clay Loam* |
| 3 | Nuevo Campechito | *Conocarpus erectus* | *Sandy Clay Loam* |
| 4 | Puerto Rico | *Avicennia germinans* | *Sandy Clay Loam* |
| 5 | Puerto Rico | *Laguncularia racemosa and Avicennia germinans* | *Sandy Clay Loam* |
| 6 | Puerto Rico | *Rizophora mangle and Avicennia germinans* | *Clay Loam* |
| 7 | Puerto Rico | *Rizophora mangle and Avicennia germinans* | *Clay Loam* |
| 8 | Puerto Rico | *Avicennia germinans* | *Sandy Clay Loam* |
| 9 | Puerto Rico | *Rizophora mangle and Laguncularia racemosa* | *Sandy Clay Loam* |
| 10 | Xicalango | *Laguncularia racemosa* | *Sandy Clay Loam* |
| 11 | Xicalango | *Conocarpus erectus* | *Sandy Clay Loam* |
| *12* | *Xicalango* | Avicennia germinans | *Sandy Clay Loam* |

Organic carbon (C.O) was quantified by using the ignition method, organic matter (M.O) was determined by warming soil samples at 550 °C during 4 h ⇨18] and the content of organic carbon is estimated multiplying by a factor of 0.4 ⇨19].

Total nitrogen (NT) was determined according to the semimicro-kjeldahl method: 0. 5 g of sieve soil through 0.250 mm is weighed, then it is digested with a mixture of catalysts and sulfuric acid ($H_2SO_4$), then it is distilled with NaOH and it is titrated with $H_3BO_3$ using a Shiro-Tashiro mixture as indicator ⇨20].

To determine bulk density (Da) it was used the test tube technique. Dry sample is passed through a 2 mm sieve, then a 50 ml plastic test tube is weighed and then 20 to 50 g of sieved soil are added, after, the sample is located on a firm surface and then it is hit 30 times per second with a rubber mallet in a vertical trajectory from 0.20 to 0.30 m. Finally, the volume and sample weigh are registered [21].

Electric conductivity (CE) was measured by using a conductivity meter CL 35 using an 1:5 soil/water solution [22]. Soil pH was measured by a pH meter Thermo Orion Model 290A using an 1:2 soil/water solution ⇨23].

To estimate the carbon storage rate (C.A) the following equation was used:

$$C= CO\%\ Da\ Pr,$$

Where, C= carbon storage rate, CO% = organic carbon content, Da= density and Pr= soil depth ⇨24].

Texture determination was carried out by the bouyoucos method using a 5% sodic hexametafosfate solution as dispersant [25].

Descriptive, comparative and relational statistical analysis was performed for carbon storage rate, sampling site, sampling depth and climatic period. Mean values were obtained for the different chemical parameters, and a two-way ANOVA was performed to assess for significant differences between studied parameters.

## III. Results and Discussion

pH, CE, C.A, Nitrogen, C:N ratio and organic carbon contents for each sampling site are shown in Fig. 2. Soils were alkaline for Xicalango (XC) and Nuevo Campechito (NC) with pH values between 7.25 and 8.25, whereas in Puerto Rico (PR), soils were acid with the lowest pH values (mean pH value was 6.5). All sampling sites showed high values of CE with 6, 4.5 and 15 dS $m^{-1}$ for Nuevo Campechito (NC), (XC) and (PR), respectively.

These values indicate a high salinity to Puerto Rico site (PR) and a moderate salinity for Xicalango (XC) and Nuevo Campechito sites. High salinity is probably influenced by marine aerosols due to its proximity to the coast, likewise, the low permeability in Puerto Rico soil promotes the water accumulation increasing Sodium concentrations and contributing to a low microbiota activity in these soils. Moreover, the hydrological characteristics of this mangrove forest agree with those typical from a basin, characterized by heavy flooding, little or no contact tidal and high salinity [26].

Carbon storage rate (C.A) ranged from 59 to 190 kg C $m^{-2}$, observing values higher than values reported for other authors ⇨27,28 ]. C:N ratios were high in all sampling sites and ranged from 33 to 47.5. Mangrove soils studied by Lallier-Verges *et al* ⇨29] also showed high C:N ratios, even greater than 43. These high values of C:N ratios suggest a significant contribution of nutrients from the decomposition products of mangrove like litter.

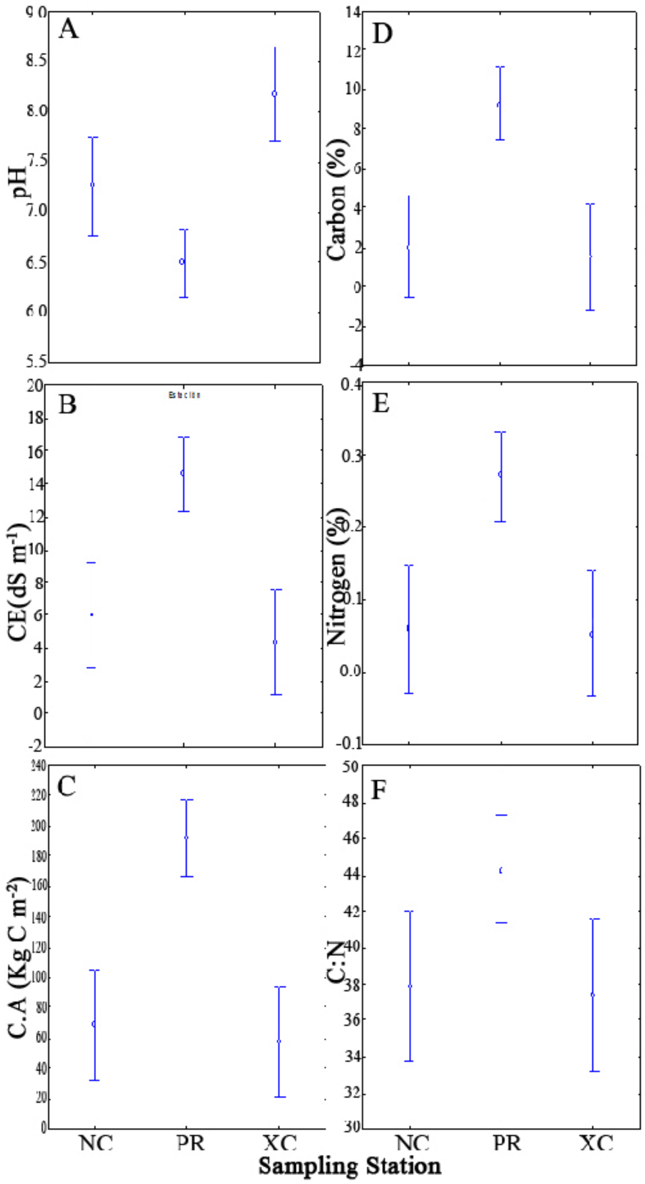


Fig. 2. Mean, minimum and maximum values for pH (A), CE (B), carbon storage rate (C), organic carbon (D), nitrogen (E) and C:N ratio (F) for the three sampling sites: Nuevo Campechito (NC), Puerto Rico (PR) and Xicalango (XC).

These results are according to Bouillon *et al* ⇨30], who reported a negative correlation between $^{13}C$ and C:N ratio, suggesting that these high ratios are related with an enrichment of nutrients from the mangrove by self. Puerto Rico site (PR) showed the greater contents for organic carbon, nitrogen, C:N ratio, CE and C.A, whereas in Nuevo Campechito (NC) and Xicalango (XC), these contents were lower.

The hydrologic characteristics in Nuevo Campechito and Xicalango are under riverine mangrove forest could to explain this decrease in MO because are found in coastal river and creek where they receive high freshwater input, sediment and nutrient that are instrumental to their growth and productivity and export a great amount of organic matter to estuarine areas⇨26, 31].

Results obtained show that all sampling sites have a good potential as carbon sinks during long time periods. The high productivity prevailing in this mangrove forest constitutes a nutrients source that acting in synergy with the low decomposition rate and the hydrology, result in the high carbon storage rates observed.

Carbon, nitrogen, C:N ratio , pH, CE and D.A contents for the three climatic periods, type of mangrove forest and their associations are shown in Fig. 3.

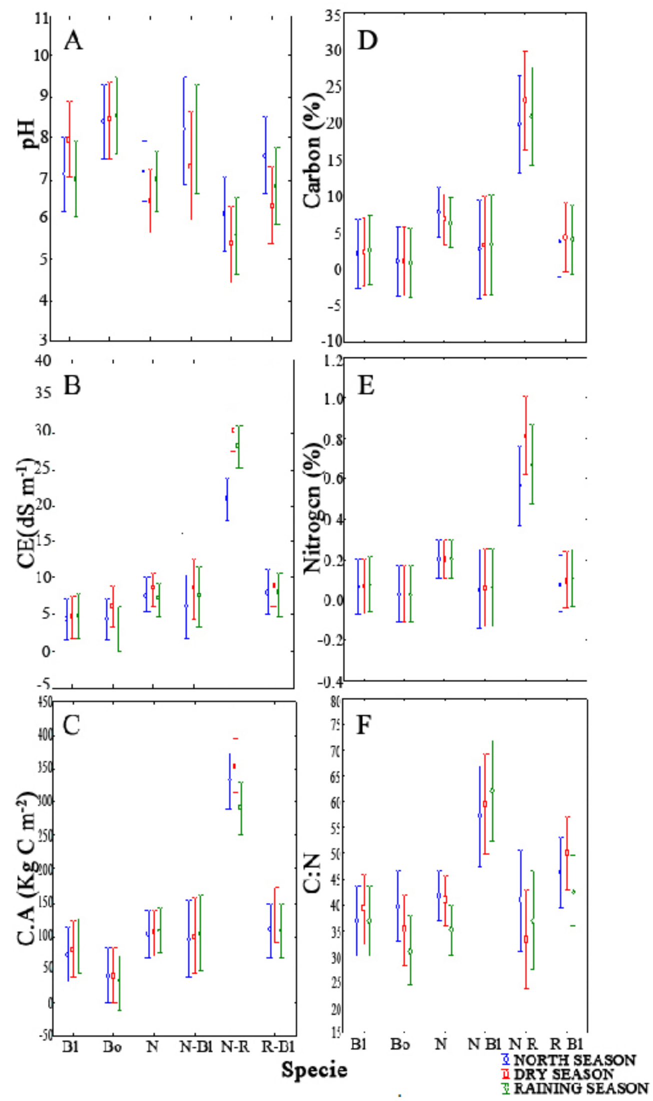

Fig. 3. Mean, minimum and maximum values for pH (A), CE (B), carbon storage rate (C), organic carbon (D), nitrogen (E) and C:N ratio (F) for the different associations of mangrove vegetation (White (Bl), Button (Bo), Black (N), Black and white (N-Bl), Black and red (N-R), red and white (R-Bl)), during three climatic periods.

The greater carbon, nitrogen and CE contents were found in mangrove forest with association of black and red mangrove (N-R), these soils were flooded all time (as a result of rains during rainy and "norths" seasons) and showed a poor drainage improving the accumulation and decomposition of organic matter.

From statistical analysis, it was found that with the exception of CE (where CE values were lower for soils with association N-R in "norths" season), there were not statistical differences ($p<0.05$) between seasons and the chemical parameters analyzed. pH values showed a great variability, soils slightly acid were found with association N-R, whereas, soils slightly alkaline were found with association Bo and N-Bl. Data obtained by Joshi and Ghose ⇨24, 32] for soils where *Avicennia alba* and *Avicennia marina* were the dominant species showed soils slightly alkaline. It is according to the results found in this study; however, when the association was N-R, pH values were lower due to the high productivity of soils and the flooding conditions prevailing in the sampling sites studied, it could improve the decomposition process in the soils.

The hydrogeology of the study area, the presence of N-R associations combined with the heavy rainfall recorded during the "norths" season, improved the flooding condition of the soil, diminishing infiltration capacity, saturing the vadose zone [33], it can explain the decreasing in CE values due to salts dissolution process.

C:N ratios were high for all associations studied, ranged from 30 to 70, and suggesting a microbial in-mobilization process of nitrogen in mangrove soils (C:N>30) ⇨34]. However, the highest C:N ratio was found for the association N-Bl.

Significant differences in carbon storage values found among vegetation species could be influenced by factors like the composition of litter in the soils, and the influence of tides. For example, in all seasons, the type of vegetation storing more carbon was the association of black and red mangrove (N-R), it suggests a continuous accumulation process of organic matter in soils where black and red mangrove are present; since, it is known that the leaves of these species are enriched with tannins [11], when these tannins are decomposed in the soil, poly-phenols concentration increases inhibiting the growth of fungi and bacteria. Moreover, due to the low decomposition rates in soils flooded all time, or due to the presence of high concentrations of salts that inhibit decomposition.

Texture analysis of the sampling areas is shown in Figure 4, and it can be observed that soil texture in sampling areas 6 and 7 (where dominat vegetation includes N-R species) is different from other areas: sand (29 to 38 %), silt (22.5-30%) and clay (30.6-41%); whereas that in the rest of the sampling areas texture analysis showed the following distribution: sand (47.5-71,5 %), silt (5-25%) and clay (22.5-41%).

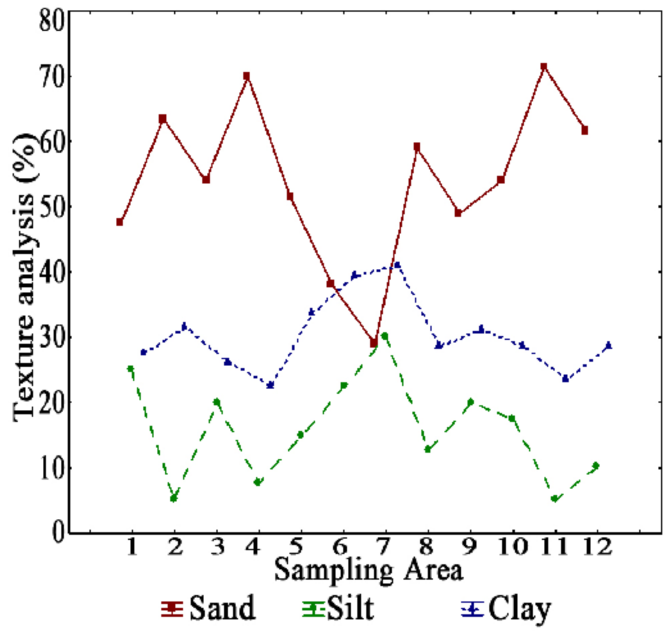


Fig. 4. Texture analysis in sampling areas.

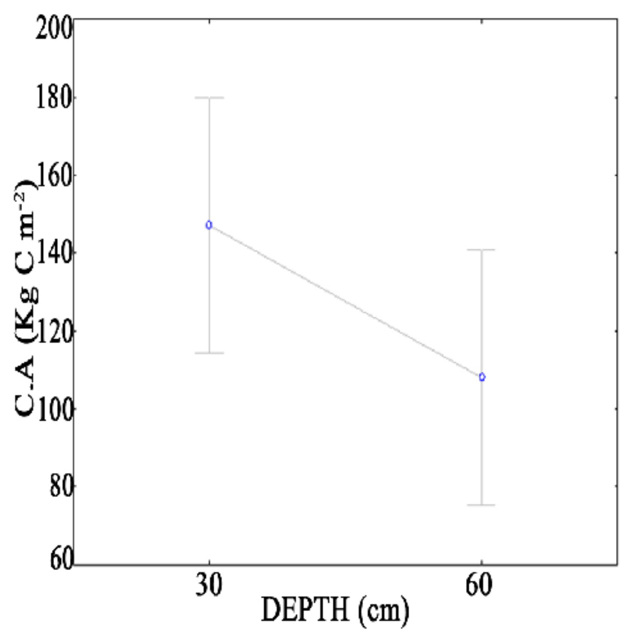

Fig. 5. Mean, maximum and minimum values for carbon storage rate at two different soil depth in Atasta Peninsula.

In spite of carbon storage rate was not statistically different with depth ($p<0.05$), from Figure 5, it can be observed that carbon storage rate decreased slightly with depth. Long periods of flooding maintained anoxic conditions; it could explain the highest organic carbon and organic matter content at 30 cm depth. Accumulation process of organic matter is enhanced in sites with abundant rainfall and deficient drainage, is the case of sites in this study.

From Table 2, it can be observed that carbon storage rate values found in mangrove forest in Campeche are higher than reported by other authors, it suggests that mangrove forest in Yucatan Peninsula has a good potential as carbon pool.

In mangrove forest, the stand age is an important factor that influence on the amount of organic carbon in soils whatever season. All mangrove individuals present in the studied forest were young to mature (stand age of approximately 15 years), therefore, it can be expected that this potential increases in the next years.

Table 2. Carbon storage rate.

| **Reference** | **Site/Land use** | **Carbon storage rate (Kg C m$^{-2}$)** |
|---|---|---|
| [17] | Rainforest Ohio, USA | 3.03 |
| [32] | Oxysol, Brazil | 12 to 24 |
| [27] | Temperate forest, Guatemala | 13.04 |
| [34] | Mangroves: Okinawa, Japan | 5.73 |
| [28] | Coastal wetlands: Sidney, Australia | 13.9 |
| [35] | Tropical vegetation in China | 40 |
| [36] | Mangrove forest, Campeche, Mexico. | 1.2 to 22.2 |
| This Study | Mangrove forest: Atasta peninsula Campeche, Mexico.59 to 190 | 59 to 190 |

## IV. Conclusion

It can be concluded that all sampling areas showed nutrient contribution from litter decomposition. Puerto Rico was the site with the highest organic matter storage and the lowest degradation rate. Sites with black mangrove-red mangrove associations (N-R) showed the highest content of silt and clay, high values for C, N, CE, C.A. and the lowest pH values.

However, the lowest degradation rates were obtained in sites with black mangrove-white mangrove associations compared to sandy soils that showed high pH values and lower levels of C, N, CE and C.A. Hydrogeology and dominat vegetation were the parameters with greater influence on carbon storage rate.

In this study, carbon concentrations decreased with depth, this a common phenomenon observed in forests soils, suggesting that the decomposition rate is greater at the surface level due to the anoxic conditions prevailing in flooding soils.

We can conclude that studied soils are good carbon pools since that the high productivity in these forests provides a nutrient source that in synergy with the hydro-geological conditions of these sites resulted in high carbon storage rates. Therefore, it can be expected that local government promotes conservation and reforesting actions in these sites.

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*Rosa María Cerón Bretón* is a professor-researcher in the Chemistry Faculty of the Autonomous University of Carmen City since 2002. She is Chemical Engineer, has a Master Degree from the University of Veracruz in 1995, and obtained the PhD degree in Earth Sciences from the Autonomou National University of México (UNAM) in 2002. Currently, she is the technical manager of several projects on atmospheric deposition and its effects on ecosystems. She is author of numerous papers published in journals dealing with the environment, *air pollution* and earth sciences areas. Dr. Cerón is a membership of the National System of Researchers of México named as Researcher level I since 2006.

*Julia Griselda Cerón Bretón* is a professor-researcher in the Chemistry Faculty of the Autonomous University of Carmen City since 2006. has a Master Degree from the University of Veracruz in 1995, and obtained the PhD degree in Earth Sciences from the Autonomous National University of México (UNAM) in 2005. She was carried out several projects on air pollution and its effects on ecosystems and she is author of numerous papers published in refereed journals dealing with the environment, *air pollution* and earth sciences areas. Dr. Cerón is a membership of the National System of Researchers of México named as Researcher level I since 2007 and she is the leader of the Academic Group in Chemical Engineering of the Chemistry Faculty in UNACAR.

*Reyna Cristina Sánchez Junco* is a postgrade student of the Chemistry Faculty of the Autonomous University of Carmen. She is chemical engineer with a speciality in Enviromental Engineering. She has been working in Environmental issues last three years.

*Diana Lizette Damián Hernández* is a postgrade student of the Chemistry Faculty of the Autonomous University of Carmen. She is chemical engineer with a speciality in Enviromental Engineering.She has experience in lab work, specifically in environmental chemistry analysis.

*Jesús Jaime Guerra Santos* is a researcher of Autonomous University of Carmen City. Currently, he is the technical manager of several projects on proper management and conservation of ecosystems. He is author of

numerous papers published in journals dealing with the environment. He works in the Botanical Garden of the Autonomous University of Carmen City.

*Manuel Muriel García* is a researcher of the Enviromental Technology Department in the Mexican Petroleum Institute since 1996. He is author of several publications on environmental topics and He is a technological leader in projects related to the environmental impact derived from the oil industry.

*Atl Victor Córdova Quiro*z is is a professor-researcher in the Chemistry Faculty of the Autonomous University of Carmen City since 2002. He is Chemical Engineer, has a Master Degree from the University of Veracruz in 1995, and obtained the PhD degree in Sciences of Chemical Engineering from the Technological Institute of Celaya in 2002. Currently, he is a technical manager of several projects on process simulation. He is author of numerous papers published in journals dealing with chemical engineering topics. Dr. Córdova is a membership of the National System of Researchers of México named as Researcher level I since 2006.