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INFLUENCE OF MANGROVE ECOSYSTEM ON SOIL CARBON SEQUESTRATION AND GLOBAL WARMING AT THE WESTERN STRAND OF THE RED SEA, EGYPT

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ABSTRACT: Soil carbon sequestration is a riskier long-term strategy for climate mitigation than direct emissions reduction as it plays a main role in closing carbon emission gaps. Mangrove ecosystem is a natural wetland that allocated at Red Sea and extended for 500 km at the Egyptian western coast. Five sampling sites were investigated at the north near to the city of Hurghada beginning from the Abu Monquar Island (27° 12′ 58″N, 33° 52′ 34″E). This work investigates the impact of the original population of Mangrove type *(Avicennia marina)* on the soil carbon sequestration. Obtained results of the mean values of measured soil bulk density (SBD) at the soil surface (0-30 cm) were revealed that the lowest values of the SBD was at Abu Monquar Island with 1.31± 0.02, g cm^{-3} and at Safaga with 1.53 ± 0.05 g cm^{-3}. While at El Gouna 1, 2 and at Hurghada the SBD values varied from 1.63 to 1.75 g cm^{-3}. In addition, the soil dry bulk density at the control site (beach without plants) was 1.75± 0.05g cm^{-3}. On the other hand, the highest values of the Calcium carbonate were obtained Abu Monquar island with 168.20 gKg^{-1}, while the Calcium carbonate values were 26.60 gKg^{-1}, 69.30 gKg^{-1}, 58.50 gKg^{-1}, 91.90 gKg^{-1} and 26.90 gKg^{-1} for Gouna1, Gouna2, Hurghada, Safaga, and the control, respectively. The mean values of measured soil organic carbon pool (SOCP) at the soil surface (0-90cm) revealed that the lowest values of the SOCP was at Hurghada with 8.81± 0.12 $Mgha^{-1}$ and the highest values at Abu Monquar island with 59.75 ± 0.15 $Mgha^{-1}$. While at El Gouna 1, 2 and at Safaga the SOCP values were 14.48, 12.86, and 39.98 $Mgha^{-1}$, respectively. In addition, the SOCP at the control site (beach without plants) was 6.62± 0.25 $Mgha^{-1}$. Thus the Mangrove ecosystem has a great potential to sequestrate the soil organic carbon and reduce the atmospheric CO_2.

Key words: Mangrove ecosystem, soil organic carbon, carbon sequestration, Island, Red Sea.

INTRODUCTION

Soil is a major terrestrial C reservoir that contains a carbon stock of 2500 Gt (1 Gt=10^9 t), in which organic and inorganic soil carbon approximately comprise 1550 and 950 Gt, respectively in the first 1-m depth (**Tan *et al.*, 2004a**). Thus, small deterioration in this large pool would reveal important impact on future carbon dioxide concentration and hence the greenhouse gas (GHG) concentrations in the atmosphere (**Smith *et al.*, 2008**). Climate and land-use changes may affect SOCP (**Hontoria *et al.*, 1999)** as well as the atmospheric CO_2 reservoir of the earth. Relations between land-use, site variables, and SOCP are important in formulating C models and assessing the impact of changes in climate and land-use (**Post *et al.*, 1996**). Climatic variable impacts on soil organic carbon (SOC) dynamics have been widely identified on local scales, with SOCP being decreased with high temperature and increased with precipitation (**Jenny, 1980**). Soil texture, clay content, has significant impact on SOC sequestration (**Abuhashim *et al.*, 2016**). Primary role of soil texture on SOC sequestration was related to the consistence rate of passive C (**Parton *et al.*, 1994**), while the secondary one

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was through its effect on soil hydrologic properties (**Schimel *et al.*, 1994**). Land use changes that influence the SOCP rates should account the site characteristics and the spatial variability that effect on the SOCP on a large scale. **Tan *et al.* (2004a)** reported that SOCP at 30 cm depth of the soil surface was mainly affected by land use, soil texture, and drainage (**While Tan *et al.*, 2004b; Alvarez and Alvarez, 2000)** observed significant variations in SOCP values that associated with land use changes and in soil taxa on state scales. Due to the strong impact of site and land use, a greater precision could be achieved if SOC sequestration was established for individual soil types within different land-use categories on a regional scale.

Mangroves ecosystems contribute to occupied 0.7% of the global coastal zone which can sequestrate of 25% of soil carbon (**Alongi, 2007; Kathiresan and Bingham 2001**). In Egypt, two main mangrove species grow; the first type is *Avicennia marina* which distributed along the Red Sea coast, while the second is *Rhizophora mucronata* that grow and distributed mainly in the southern part of the Red Sea coast beginning from the city of Shalatein of Latitude 23°28′N, and southward to the city of Mersa Halaib with Latitude 22°10′ N, (**Zahran and Wilis, 2009**). The *Avicennia marina*, along the northern coast of Red Sea, potential to sequestrate the soil carbon have been conducted in Egypt, where the mean carbon sequestration was identified as 85 Mg C ha^{-1}, nevertheless the mean potential of carbon sequestration was estimated as 0.061 Mg C ha^{-1} year^{-1} (**Eid and Shaltout, 2016**).

In addition, **Mashaly *et al.* (2012)** investigated the effect of mangrove vegetation at the Gulf of Aqaba–Egypt on the stored soil carbon, and they estimated as 41.9, 70.3, 109.3 Mg C ha^{-1} at the shoreline, salt plain habitats and intertidal, respectively. The mangrove carbon sequestration potential and the other coastal plant ecosystems on the Gulf of Aqaba had of 2.4, 1.04, 0.545, 0.81 and 0.14Mg C ha^{-1} year^{-1} of intertidal, salt plains, shoreline, hypersaline ecosystems and mudflats, respectively (**El-Hussieny and Ismail, 2017**), that had effects on the different soil hydro-physical parameters.

The rate of soil water infiltration and consequence the water movement in its matrix are important consideration in developing the agro-ecosystems and the land-management practices (**Bouma *et al.*, 1982; Michel *et al.*, 2010**) that aims to preserve a relevant soil water environment crucial for a favorable plant and soil health (**Abuhashim *et al.*, 2009; Awotoye *et al.*, 2013; Abuhashim *et al.*, 2021**). The loss of soils by sealing is important parameter that affects the water cycle negatively. Soil sealing threats at the coastal zone is considered one of the main effects on the soil biodiversity loss, erosion, soil contamination, and organic matter decline, (**Abuhashim, 2011**). In addition, soil sealing could be identified as the deterioration of the soil infiltration capacity that could be pronounced by the soil surface sealing or the soil compaction. In comparison, the hydraulic properties of soil have received little attention, maybe due to the difficulties in providing accurate soil physical measurements (**Abuhashim and Abdel-Fattah, 2012**).

The present study was conducted to identify the impact of mangrove planting on soil organic carbon pool SOCP in the west of the Red Sea as well as land use changes.

MATERIALS AND METHODS

Description of Study Area

The Red Sea geographical range between 12° 39′ N at the south, where Bab El Mandab strait, and extends to the north at 27° 43′ N with "Ras Mohammed", then divided into two gulfs; Aqaba Gulf at the East and Suez Gulf at the West (**Google Earth Pro, 2017**). At the Egyptian coast, the Red Sea extends in SE–NW orientation almost for 830 km, and for 870 km of coastline for the Suez and Aqaba Gulfs. Thus, **El-Hussieny and Ismail (2017)** found that the total length of the Red Sea at the Egyptian coasts considering the both Gulfs is 1700 km.

The current research focused mainly on the mangrove that localized and grow at the Egyptian Red Sea coast in different islands and coasts near to Hurghada city (Figure 1). The mangrove sites were investigated that the study area identified from Abu Monquar Island (27° 12′ 58″N, 33° 52′ 34″E) and extended northly near to Hurghada city with five sampling sites. This work aimed to compare the impact of the pure population of *Avicennia marina* on the soil hydro-physical properties. Site 1 and 2 reflect the

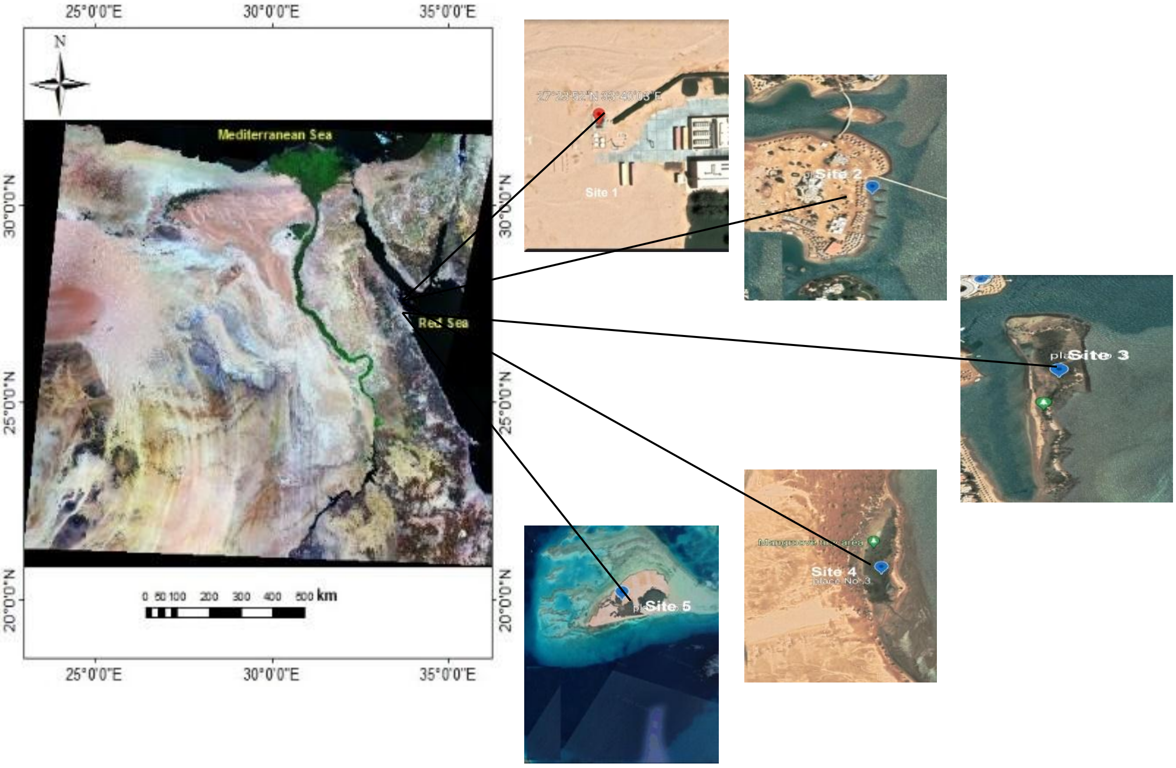

Figure. 1. Sample locations of the mangrove sites along the Egyptian Red Sea coast

Mangrove planting ages of 10 and 5 years at El-Gouna village. Sites 3, 4, and 5 reflect the sampling sites of the mangrove at Hurghada, Abu Monquar Island, and Safaga, respectively. The climate conditions at the selected areas has a mean annual temperature of 25°C, mean annual solar radiation is 28.9 Mj m^{-2}, and annual rainfall with a mean of 5.9 mm $year^{-1}$ (**Weatherbase.com 2020**).

Sample Analysis

Soil profile of each selected site was investigated down to 90 cm soil depth. Soil samples were collected for the physical and chemical analysis in three lines transects. Each transect composed of five locations in which the soil samples were mainly representative at three horizons (0-30 cm, 30-60 cm, and 60-90 cm). Collected soil samples were air dried from each horizon for the different analyses. Soil dry bulk density at field locations at each soil depth, was prepared for in situ measurements that the soil samples were collected by hammering using sample rings with a fixed volume of 100 cm^3 into the soil matrix.

The soil samples were air-dried at laboratory temperature, and then grounded to pass a 2-mm sieve. Soil pH parameter was investigated at (1:2.5) extract using Hanna with a pH-meter model PH211 to measure the hydrogen activity. Electrical conductivity (EC) was assessed, for the salinity concentration, in an extract of soil paste using conductivity meter. The total calcium carbonate was determined using the methods of **Page *et al*. (1982)**. Using the international pipette method. the particle size distributions were determined. Saturation percent, field capacity, and the soil density calculations were prepared depending on **Klute (1986)**.

The soil samples were air-dried at room temperature and were ground to pass through a 2-mm sieve. Soil pH (1:2.5) was measured using a Hanna model PH211 microprocessor-based pH-meter. Electrical conductivity (EC) was assessed in soil paste extract using a conductivity meter **Page *et al*.** (**1982**). Organic matter was determined using the Walkley and Black method available N was extracted with K_2SO_4 and quantified by means of the steam-distillation procedure using MgO-Devarda alloy and available P was extracted with 0.5 N $NaHCO_3$ at pH 8.5 also quantified calorimetrically using the ascorbic acid method, and available K was extracted with 1.0 N ammonium acetate at pH 7.0 and quantified using a flame photometer according to **Pageb *et al.* (1982)** Particle-size analysis was performed using the international pipette method (**Klute, 1986**). Saturation percentage and soil density calculations were carried out according to (**Corey, 2002**).

Physicochemical Parameters of Soil Samples and Soil Organic Carbon Pool Calculation

Soil coarse fraction content (particles >2 mm in diameter) was determined according to **Lal *et al.* (1999) and Post and Kwon (2000**): gravel content (%) = (weight of coarse materials/ weight of coarse and fine materials) × 100 (1)

Calculation of the SOCP was carried out as a parameter of SOC concentration (**Lal *et al.*, 1999; Laganiere *et al.*, 2010**). The content of soil organic matter (SOM) for each horizon was first converted to SOC percentage by multiplying the SOM by a factor of 0.58 (**Lal *et al.*, 1999; Abuhashim *et al.*, 2016**). For each soil horizon, SOCP (kg C m^{-2}) was calculated by multiplying the SOC percentage by the soil depth (30 cm), soil bulk density (Mg m^{-3}), and soil fraction (<2 mm in size) **(Lal, 2003)**:

SOCP = [L x B.D x SOC x (1- F/100)] /10 (2)

Where SOCP is the soil organic carbon pool for each soil horizon (kg m^{-2}), L is the thickness of the soil layer (30 cm), SOC is soil organic carbon content (wt %), F > 2 mm coarse soil fragment (wt %), and B.D is the soil dry bulk density (Mg m^{-3}). Based on the soil organic carbon sequestrated in soil surface, emitted carbon dioxide (CO_2) was calculated using the following equation of **IPCC (2007)**:

Emitted CO_2 = Amount of Sequestrated Soil Organic Carbon X 3.67 (3)

The factor 3.67 equals molecular weight of CO_2 divided by atomic weight of carbon. IPCC did not use 44 and 12, respectively, but the weighted average of molecules containing the several carbon isotopes found in the atmosphere, mainly 12C and 13C.

RESULTS AND DISCUSSIONS

Mangrove Planting on the Investigated Soil Physico-Chemical Properties

Soil DBD values of the investigated sites showed that the dry bulk density values were higher at the supper soil surface profiles (0-30 cm) compared to the lower profiles. The SBD at the control site was 1.75, 1.70, and 1.70 g.cm^{-3} at soil depths 0-30cm, 30-60cm, and 60-90cm, respectively (Table 1). For site S1 at El Gouna village, the *Avicennia marina* planting since ten years, the SBD was 1.63, 1.60, and 1.50 g cm^{-3} at soil depths 0-30cm, 30-60cm, and 60-90cm, respectively, and for the second site at El Gouna village that planting the same mangrove species since five years, the SBD was 1.70, 1.64, and 1.58 g.cm^{-3} at soil depths 0-30cm, 30-60cm, and 60-90 cm, respectively (Table 1). For Hurghada site (S3), the SBD values were 1.73, 1.64, and 1.60 g.cm^{-3} at the soil depths 0-60cm, 30-60cm, and 60-90cm, respectively. For Abu Monquar Island (S4), the SBD values were 1.31 and 1.20 g.cm^{-3} at the soil depths 0-30cm, 30-60 cm, respectively and for Safaja (S5), the SBD value was 1.53 g.cm^{-3} at the soil depth 0-30 cm (Table 1). Distinct differences were detected, where Site 4 revealed an increase for value of the field capacity than the other sites at the upper soil surface. Under the site 4, volumetric water content at the field capacity was 16%, while the other sites revealed 9.54%, 12.14%, 12.22%, 11.68%, and 15.47% for control, site1, 2, 3, and 5, respectively. The results were appropriated with (**Oquist *et al.*, 2006; Abuhashim *et al.*, 2016; El Hussieny *et al.*, 2021**).

Calcium carbonate content is the main indicator of the calcareous soils in northwestern Egypt, and this reveals interesting results about long-term cultivation. The results of Table 2 reveal that the calcium carbonate ($CaCO_3$) values were higher at Abu Monquar Island with 16.82%, while the calcium carbonate values were 2.66%, 6.93%, 5.85%, 9.19% and 2.69% for Gouna1, Gouna2, Hurghada, Safaga, and the control, at the soil surface (0-30cm), respectively (Table 2) The results were appropriated with (**Oquist *et al.*, 2006; El Hussieny *et al.*, 2021**).

Table 1. The investigated soil physical properties under the Mangrove planting

Site	Sand (%)	Silt (%)	Clay (%)	Soil Texture	Bulk Density	W.P. (%)	F.C. (%)	SOC (%)	SOCP $Mgha^{-1}$
C (A)	94.33	4.40	1.27	Sand	1.75	4.77	9.54	0.123	5.17
C (B)	95.00	3.87	1.13	Sand	1.70	4.65	9.29	0.180	7.34
C (C)	95.00	3.65	1.35	Sand	1.70	4.71	9.42	0.180	7.34
S1 A	93.00	4.63	2.37	Sand	1.63	6.07	12.14	0.324	12.67
S1 B	94.33	3.60	2.07	Sand	1.60	6.11	12.22	0.314	12.06
S1 C	94.00	3.60	2.40	Sand	1.50	5.65	11.30	0.520	18.72
S2 A	93.33	3.97	2.70	Sand	1.70	6.11	12.22	0.229	9.34
S2 B	93.33	4.03	2.63	Sand	1.64	6.15	12.31	0.296	11.65
S2 C	92.33	4.00	3.33	Sand	1.58	5.69	11.39	0.464	17.59
S3 A	93.50	3.78	2.73	Sand	1.73	5.84	11.68	0.200	8.30
S3 B	93.50	4.25	2.25	Sand	1.64	5.90	11.81	0.213	8.38
S3 C	93.00	4.25	2.75	Sand	1.60	6.03	12.06	0.254	9.75
S4 A	78.50	12.50	9.00	Sandy loam	1.31	8.01	16.01	1.847	58.07
S4 B	89.00	5.50	5.50	Sand	1.20	8.41	16.83	2.133	61.42
S5 A	90.60	4.40	5.20	Sand	1.53	7.74	15.47	1.091	39.98

C: control, S1: Gouna, S2:Gouna2, S3:Hurghada, S4:Abu-Manqar, S5: Safaga A: Soil depth 0-30cm, B:Soil depth 30-60cm, C: Soil depth 60-90cm, SOC: Soil organic carbon, SOCP: Soil organic carbon pool

Table 2. The investigated soil chemical properties under the Mangrove planting

Site	EC dSm^{-1}	pH	N ($mg\ kg^{-1}$)	P ($mg\ kg^{-1}$)	k ($mg\ kg^{-1}$)	Ca ($mg\ kg^{-1}$)	Mg ($mg\ kg^{-1}$)	Cl ($mg\ kg^{-1}$)	HCO3 ($mg\ kg^{-1}$)	CaCO3 (gKg^{-1})
C (A)	8.447	9.06	442.4	3.17	34.94	126.03	496	3.73	2928	26.90
C (B)	9.792	8.86	420.0	2.98	37.00	218.90	276	3.13	2440	24.60
C (C)	10.458	8.74	327.6	2.52	37.68	238.80	414	3.60	2928	26.80
S1 A	17.887	8.89	403.2	7.06	45.60	895.50	260	5.73	2928	26.60
S1 B	21.250	8.82	257.6	7.69	52.40	895.50	240	8.00	2196	30.90
S1 C	18.167	8.05	246.4	4.38	54.56	530.67	340	6.20	2928	29.80
S2 A	13.783	8.26	476.0	3.25	32.66	199.00	840	4.87	10248	69.30
S2 B	15.783	8.50	526.4	4.30	38.56	218.90	616	5.47	4636	65.50
S2 C	17.467	8.47	548.8	4.67	43.45	192.37	608	5.80	5612	80.40
S3 A	16.400	9.38	600.6	2.85	35.88	194.03	822	4.87	2928	55.80
S3 B	16.163	9.34	466.2	2.66	36.83	233.83	711	5.60	5612	74.10
S3 C	17.213	9.21	504.0	2.87	38.86	228.85	960	6.73	3172	79.40
S4 A	88.138	8.50	567.0	10.53	79.21	2293.48	1269	29.12	6405	168.20
S4 B	26.600	8.52	537.6	13.47	54.16	278.60	1008	10.40	2928	236.10
S5 A	17.680	8.70	547.68	7.47	45.66	183.08	1132.8	6.20	4099	91.90

C: control, S1: Gouna, S2:Gouna2, S3:Hurghada, S4:Abu-Manqar, S5: Safaga A: Soil depth 0-30cm, B:Soil depth 30-60cm, C: Soil depth 60-90cm, In addition, the distribution of calcium carbonate with depth reveals that the $CaCO_3$ content increased with depth in Abu Manquar Island that characterized with sandy loam soil with 9.0% clay content at the upper surface compared to the other locations that dominated with sandy. Where the results reveals that at Abu Manquar Island, the $CaCO_3$ content at lower surface 30-60cm was 236.10 gKg^{-1} compared to upper surface 0-30cm was 168.20 gKg^{-1}. In calcareous soils, calcium carbonate was efficiently stored in the deeper layers, and the acidity created through the nitrification process was neutralized through accelerating $CaCO_3$ depletion **(Datta *et al.*, 2015)**. Dissolution of $CaCO_3$ via this anthropogenic source of acidity leads to CO_2 efflux and loss of $CaCO_3$ from the soil surface (**Abuhashim *et al.*, 2016**).

SOCP Variation with Land Use

Soil physical properties for the catchment area indicated that the dominant soil types are sandy and sandy loam soil (Table 1). Soil field capacity varied from 9.6% to 16.8%, while dry bulk density varied from 1.2 to 1.75 Mg m^{-3} (Figure 2).

Computing SOCP using equation 2 under different land uses for the whole catchment and performing the land-use area in hectares, SOCP of 1 [t ·ha^{-1}] is equal to 10 [kg m^{-2}]. The mean values of measured soil organic carbon pool (SOCP) at the soil surface (0-90cm) revealed that the lowest values of the SOCP was at Hurghada with 8.81± 0.12 t ha^{-1} and the highest values at Abu Monquar island with 59.75 ± 0.15 $Mgha^{-1}$ (Figure 3). While at El Gouna 1, 2 and at Safaga the SOCP values were 14.48, 12.86, and 39.98 t ha^{-1}, respectively (Fig. 3), and these results are relevant to the obtained DBD results at Fig. 2 (**Datta *et al.*, 2015; Jobbagy and Jackson.,2000**). In addition, the soil organic carbon pool at the control site (beach without plants) was 6.62± 0.25 $Mgha^{-1}$. SOCP degradation could encourage the CO_2 emission these results are convenient with the finding of **El-Hussieny *et al.* (2021**) at Red Sea region. Therefore, using equation 3, the emitted CO_2 to the surrounded atmosphere resulted from losing the cropland amounts to 1047.5 Gg CO_2 which are relevant with the finding of **El-Hussieny and Ismail (2017)** at South of Sinai.

Conclusion

The present study indicators at the Red Sea coast showed the mangroves that distributed and grow as discontinuous patches. Mangrove swamps (*Avicennia marina*) have several difficulties that effect the water movement into the soil, leaves, prop roots, and pneumato phores, which could affect sedimentation of the suspended particles in the surrounded areas that could affect the soil hydro-physical properties. The soil clay content reveals the main factor that effect on the different hydro-physical under the different sites. The minimum values of the dry bulk density were noticed at Abu Monquar Island that has the highest clay content compared to the other investigated sites.

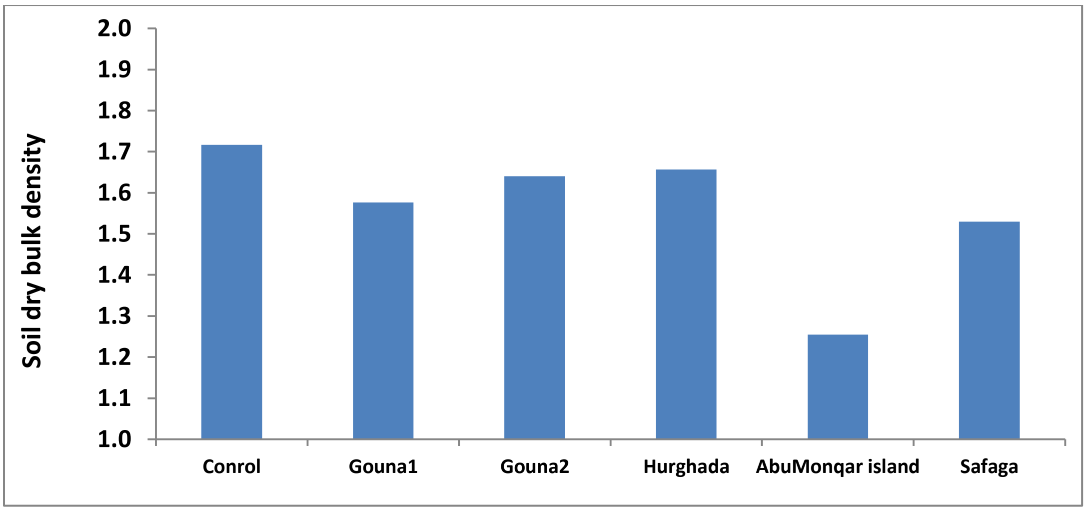

Figure 2. Impact of Mangrove growing in different sites on soil dry bulk density

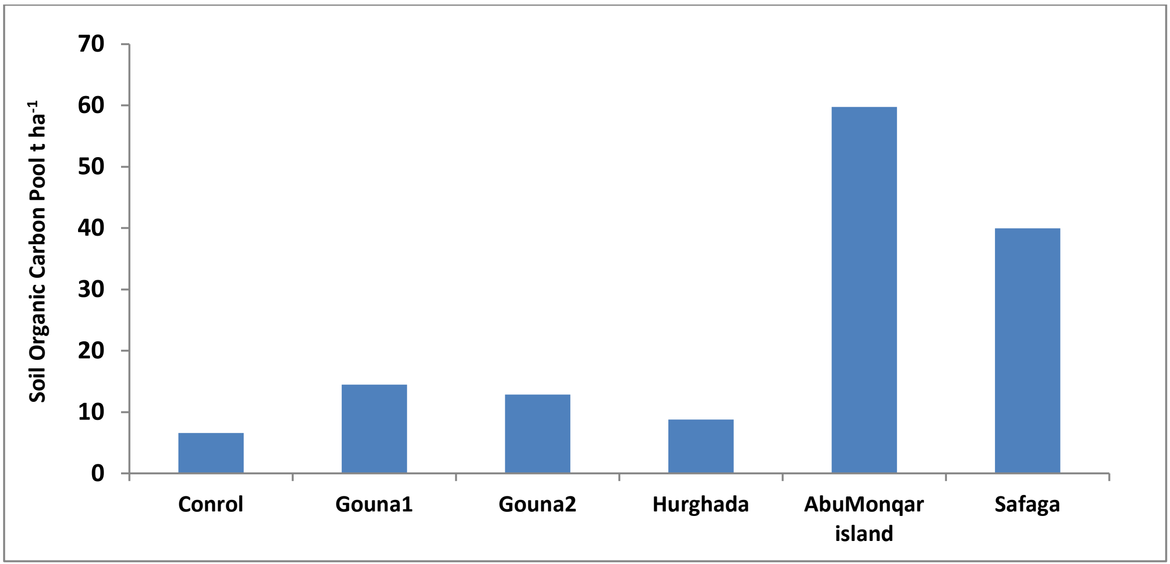

Figure 3. Impact of Mangrove growing in different sites on soil organic carbon pool

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تأثير بيئة المانجروف على حجز كربون التربة والإحتباس الحرارى بمنطقة غرب البحر الأحمر، مصر

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يُعد عزل الكربون في التربة استراتيجية طويلة الأجل للتخفيف من حدة تغير المناخ كإستراتيجية أفضل من تقليل الإنبعاثات المباشرة للغازات حيث يمثل دورًا رئيسيًا في سد فجوات انبعاث الكربون. النظام البيئي للمانجروف هو أرض رطبة طبيعية تقع في البحر الأحمر وتمتد لمسافة 500 كيلومتر على الساحل الغربي المصري. تم فحص خمسة مواقع لأخذ العينات في الشمال بالقرب من مدينة الغردقة بداية من جزيرة أبو منقار (27درجة شمالا 12 دقيقة 85 ثانية و33درجة شرقا 52 دقيقة 34 ثانية) و ذلك لدراسة تأثير البيئات الطبيعية لغابات المانجروف لنوع Avicennia marina على حجز الكربون في التربة. اظهرت متوسط النتائج المتحصل عليها لقيم الكثافة الظاهرية للتربة (SBD) لسطح التربة (0-30 سم) أن أدنى قيم لـ SBD كانت في جزيرة أبو منقار بمتوسط 1.31± 0.02، جم/سم^3 وفي سفاجا بمتوسط 1.53± 0.05 جم/سم^3. بينما في منطقة الجونة 1 و 2 وفي مدينة الغردقة تفاوتت قيم SBD من 1.63 إلى 1.75 جم/سم^3. بالإضافة إلى ذلك، كانت كثافة التربة الجافة في موقع التحكم (شاطئ بدون نباتات) 1.75 ± 0.05 جم/سم^3. من ناحية أخرى ، تم الحصول على أعلى قيم لكربونات الكالسيوم في جزيرة أبو منقار بنسبة 168.82جم/ كجم بينما كانت قيم كربونات الكالسيوم 26.60 جم/ كجم و 69.30 جم/ كجم و 58.50 جم/ كجم و91.90 جم/ كجم و26.90 جم/ كجم في الجونة 1، الجونة 2، الغردقة، سفاجا، والكنترول، على التوالي. أظهرت القيم المتوسطة لمخزون الكربون العضوي في التربة (SOCP) لقطاع التربة (0-90 سم) أن أدنى قيم لـ SOCP كانت في الغردقة 8.81 ± 0.12 طن/هكتار وأعلى القيم في جزيرة أبو منقار مع 59.75 ± 0.15 طن/هكتار. بينما كانت قيم SOCP في الجونة 1 و 2 وسفاجا 14.48 و 12.86 و 39.98 طن/هكتار على التوالي. بالإضافة إلى ذلك، كان SOCP في موقع الكنترول (شاطئ بدون نباتات) 6.62 ± 0.25 طن/هكتار. وأوضحت النتائج أن النظام البيئي لأشجار المانجروف أظهرت إمكانات كبيرة لعزل الكربون العضوي في التربة وبالتالى تقليل إنبعاث ثاني أكسيد الكربون في الغلاف الجوي.

الكلمات الإسترشادية: النظام البيئي للمانجروف ، الكربون العضوي للتربة ، عزل الكربون ، الجزيرة، البحر الأحمر.

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