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Carbon Sequestration by the Terrestrial Soil-Plant System in a Heavily Polluted Area of Riyadh City, Saudi Arabia

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Abstract

With the increase of atmospheric carbon dioxide, there is a growing public and scientific concern over the carbon sequestration potential of soil/plant system. The objectives of the present study are: to assess the effect of carbon emission from industrial area, Riyadh City, on the Soil Organic Carbon (SOC) concentration and carbon stored by two plant species Calotropisprocera and Phragmitesaustralis to provide specific information for estimating the carbon sequestration potential of Soil/Plant system of selected polluted area. In the present study, soil organic carbon content ranged from 0.025 g C kg^{-1} at location I associated with Phragmitesaustralis to 0.097 g C kg^{-1} at location III associated with Calotropisprocera. Results showed that leaves of the studied species sequestered more TOC than the corresponding roots . The present study concluded that, both studied plants could be instrumental in formulating efficient strategies related to carbon sequestration and reduction of greenhouse gas emissions in the studied area.

1. Introduction

Carbon is an essential element for sustaining life. It enters the atmosphere from a variety of sources, both natural and anthropogenic. Natural sources include decay of animal and plant life, volcanoes, natural brush and forest fires, respiration of plants and animals. Anthropogenic sources include vehicles (cars, trucks, trains, and planes), home heating, power plants, cement plants, ethanol plants, steel mills, and other industrial plants. By the end of the 19th century, the concentration of carbon dioxide (CO_2) in the atmosphere increased from 285 ppm, before the industrial revolution, to about 366 ppm in 1998 (equivalent to 28 % increase), to 396.8 ppm in 2012 [1-5].
There is growing concern that increasing levels of greenhouse gases (GHGs) in the atmosphere, particularly CO_2, are contributing to global climate change [2]. This concern has led to the 1997 international agreement in Kyoto (called Kyoto Protocol), whereby most countries are committed to reducing their GHG emissions to the atmosphere. Carbon sequestration has been highlighted recently as an important approach for mitigating the greenhouse effect by converting the atmospheric CO_2 into biotic or abiotic carbon sequestered in terrestrial ecosystems, underground reservoirs, oceans, as mineral carbonates and in vegetation and soil for a specific time period [6-7]**.** Terrestrial carbon sequestration has a potential role in reducing the recent increase in atmospheric carbon dioxide (CO_2). Soils capabilities to sequester carbon seem to be larger than the aboveground woody pool but this largely depends on spatial location and vegetation availability [8].Terrestrial carbon sequestration occurs when the uptake of carbon by plants exceeds carbon losses through soil respiration, plant respiration, and biomass removal[9].

Soils are the largest carbon reservoir of the terrestrial carbon cycle and play a pivotal role in global carbon budget because they store over 1550 Pg of soil organic carbon (SOC) in the terrestrial ecosystem, which is 2–3 times larger than that in the atmospheric pool with 750 Pg and biotic pool with 500–600 Pg [10-11]. Then, soil organic carbon (SOC) is a significant component of the global carbon stocks [12].
The objective of this research was to assess the effect of carbon emission from industrial area, Riyadh City, on the (SOC) concentration and carbon stored by two plant species *Calotropisprocera*and*Phragmitesaustralis* to provide specific information for estimating the carbon sequestration potential of Soil- Plant system of selected polluted area.

2. Material and Methods

2.1.Site Description

The second industrial city that located 12 km south of Riyadh city, capital of Saudi Arabia, was established in 1976 (Fig.1). It has been developed on four stages of a total area more than 18 million square meters. It houses more than 1050 of different industrial units with 120 thousand workers. The most important industries in this area are; food industries, metal industries, electrical and control equipment industries and chemical industries.

Figure 1 : Map of Southern area of Riyadh City showing second industrial area.

Plants growing in the nearby zone of industrial areas along varies industrial units are subjected to carbon emission from different industries and heavily traffic high way. The area of collected plants and soils extended about 3 km around metal and chemical industries. The climate in this area is continental with extremes of heat in summer and markedly cold in winter with low rainfall distributed mainly from December to March. Plant species collected were the most common/dominant species at area under investigation. Two plants and soils (at 0-10 cm depth from rhizosphere of each plant were taken from each location from were plant sample was rooted) were collected in September 2016 and their scientific names and characteristics were determined.

2.2. Study Species

*Calotropisprocera*and*Phragmitesaustralis*were selected for this study. They are widely spread throughout the area under investigation.***Calotropisprocera*** *(Aiton)* is a spreading shrub reaching 2.5 to 6 m in height, with a deep taproot, 3-4 m deep. It has grey-green leaves (15-30 cm long and 2.5-10 cm broad) with a succulent and waxy appearance [13]. It originated from the Afro-Asian monsoonal regions, spreads on an arc expanding from north western Africa (Mauritania, Senegal), through the Arabian Peninsula and Middle-East to the Indian subcontinent. It also acts as a soil binder and as a nurse crop for more valuable species in afforestation programs [14].***Phragmitesaustralis***is a robust erect perennial grass in aquatic or subaquatic,growing to 4 m high, strongly tufted, with an extensive rhizome system. It is most often seen in large colonies. The stems and leaves are smooth and glabrous. The gray-green leaves are acuminate in shape, 25-50 cm long and 2-3 cm wide [15].

2.3. Sampling

Sampling was carried out in three locations to represent the studied area. The selection of the sampling location relied on the random sampling techniques. The field work of this study was conducted in September 2016. Triplicate soil samples were collected from each location with using trowel. Top soil samples were collected (0-10 cm) and sealed in plastic bags. For plant sampling, at least three whole plants from each species were collected. The species collected from each sampling stations were identified according to Alfarhan and Thomas [16]. Then it was washed with distilled water and dried then divided into leaves and roots, finally was grinded and preserved until use.

2.4.Analytical Techniques

2.4.1. Estimation of grain size analysis for selected soil

Soil samples (a composite mixture) were –sieved through a 63-mm sieve, washed with de-ionized water, dried at 105 ^{o}C and homogenized. A representative portion of the sample (about 20 g) was used for grain size analysis using the standard dry sieving and sedimentation techniques [17].

2.4.2. Estimation of total organic Carbon in the soil and vegetation samples (weight/weight)

Total organic carbon in the soil and vegetation samples was determined using the method carried out by Ravindranath and Ostwald [18]. In soils and sediments:

$$\text{Total Carbon} = \text{Inorganic Carbon} + \text{Organic Carbon} \qquad (1)$$

Total organic carbon content can be measured directly or can be determined by difference if the total carbon content and inorganic carbon contents are measured. For soils and sediments where no inorganic carbon forms are present, Equation (1) becomes:

$$\text{Total Carbon} = \text{Organic Carbon} \qquad (2)$$

This method is modified from the traditional Walkley-Black method [19]. A soil sample (0.5 g) is treated with 5 ml concentrated H_2SO_4 for 4 hours, then mixed with 5 ml 1 N $K_2Cr_2O_7$. The mixture is heated at 150–160^{0}C for 5 minutes, and then cooled at room temperature. The solution is transferred into a triangular flask with 100 ml deionized water. Unreacted $K_2Cr_2O_7$ is determined by titrating with 0.25 M $FeSO_4$. Soil organic carbon content is calculated, without a recovery factor, from the difference in $FeSO_4$ used between a blank and a soil solution.

The total organic carbon(TOC) was calculated by the following equation:

$$\text{Total organic carbon (TOC) (g\textbackslash g)} = \frac{\left[\frac{X-Y}{2} \times 0.003\right]}{S} \qquad (3)$$

Where:

S= Weight of the dry sample (g)

X= Volume of ferrous sulfate used in blank (ml)

Y= Volume of ferrous sulfate used to oxidize SOC (ml)

2.4.3. Estimation of soil organic Carbon (weight/area)

The soil organic carbon was calculated using the following equation[20]:

$$\text{SOC in weight per area} = \text{SOC } (g.g^{-1}) \times \rho \ (g.cm^{-3}) \times H \text{ (cm)} \qquad (4)$$

Where: H = soil depth (1-10) cm.

2.4.4. Estimation of bulk density for soil samples (ρ) :

The main purpose of determining the bulk density for soil is to convert the units of the concentration of organic carbon from weight per weight values to weight per area [21]. Each soil sample was oven-dried at 105 °C for three days, cooled down to room temperature in a desiccator, and weighed to determine the soil bulk density (g. cm^{-3}) as follows[22]:

Dry bulk density (ρ) (g.cm^{-3}) = Soil dry sample (W_d)/ Total sample volume (V_t) (5)

2.4.5. Estimation of Biological concentration factor (BCF) and translocation factor (TF):

The Biological Concentration Factor (BCF) was calculated, as metal concentration ratio of plant roots to soil [23], while Translocation Factor (TF) was described as ratio of heavy metals in plant shoot to that in plant root [24] :

BCF = [Metals] root/[Metals]soil (6)

TF = [Metals] shoot/ [Metals] root (7)

3. Results and discussion

3.1. Soil Properties

The top soil from the different sampling sites, in the area under investigation, had small differences in texture (Table 1). Results revealed that all sites are characterized by sandy texture (88.6%-92.8%) The uniform grain size distribution obtained along the area indicated a stable depositional environment for a long period of time.

Table1: Fatty acid (%) compositions of *CitrullusColocynthis*seed oils and retention indices (min).

Soil properties	Soil Locations		
	I	II	III
Sand %	92.8	91.5	88.6
Mud%	7.2	8.5	11.4

3.2.Plant and SOC composition

Our capacity to predict and ameliorate the consequences of climate and land cover changes depends, in part, on a clear description of plant and (SOC) distribution [25]. In this approach, plant capable of accumulating high levels of organic carbon in its shoot and root. In addition, the study of the distribution of SOC content is important for the studying of the global carbon cycle and the greenhouse effect [3]. Also, the potential of plant and soil to sequester the carbon can be assessed by the estimation of their stock [26].

A quick dip in the results demonstrates that the average concentrations of total organic carbon (TOC) in different locations for both plants and soil , showed small variation in their concentrations with the sequence of location III > location II > location I as shown in (Figs 2 & 3). Moreover, the investigated soil and native plants exhibited different TOC concentrations depending on plant organs and sampling locations where shoot> root > soil.

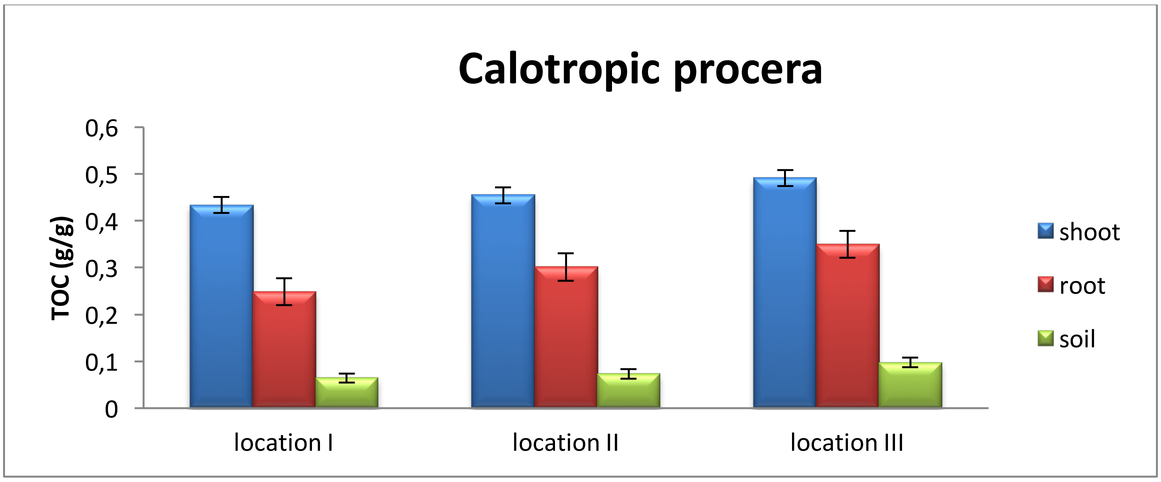

Figure 2: Total organic carbon content (TOC, g/g) of *Calotropisprocera*(shoots and roots) and its soils collected from the study area (±Standerd deviation).

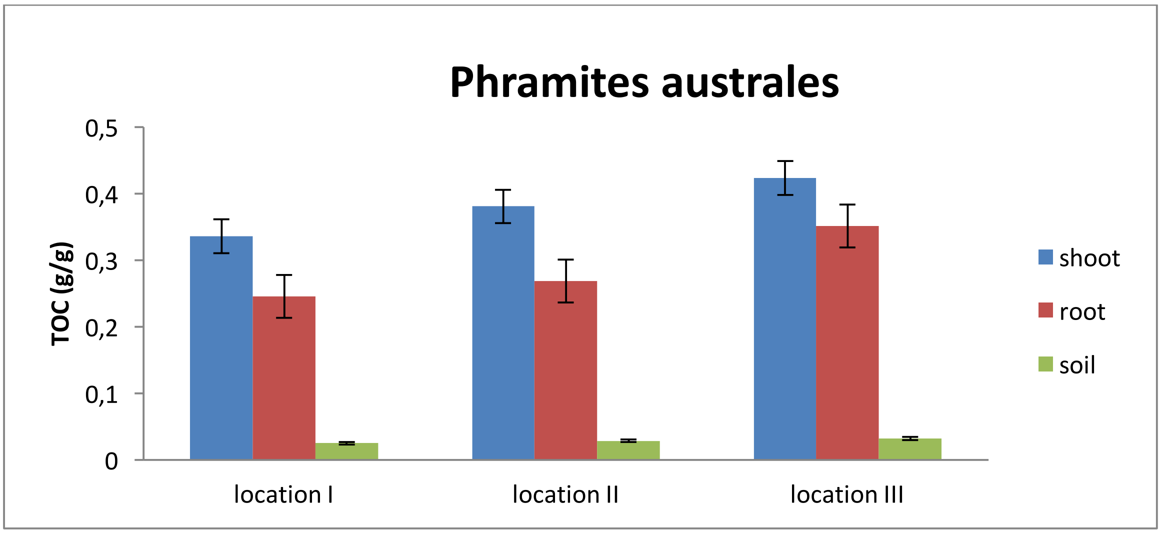

Figure 3: Total organic carbon content (TOC, g/g) of *phragmitesaustrales* (shoots and roots) and its soils collected from the study area (±Standerd deviation).

As shown from figures, differences in TOC concentrations between shoots and roots of both plant species are less detected. It is worth noting that shoots accumulate higher TOC values than roots with the highest value of 0.492 $g.g^{-1}$ attained by *Calotropisprocera* (Fig. 2). Generally, green parts (shoots) acquired higher TOC content than root due to photosynthesis processes which is occurred in these parts [27-32].
The soil bulk density plays an important role in the assessment of SOC contents [33]. Regionally, as shown from (Tables 2 and 3), the soil bulk density of location III was lower than that of the other two with an inverse relation with SOC contents. The total mean distribution of soil bulk density increased significantly from 0.991 g cm^{-3} at location III up to 1.666 g cm^{-3} at location I (Table 2). However, SOC content decreased from 0.097633 g C kg^{-1} at location III reaching a minimum of 0.025383 g C kg^{-1} at location I. Comparing the results obtained for the two plants under investigation, the soil bulk density and SOC of surface layer under *Phragmitesaustrales* was lower than the other plant. This could be attributed to the dense growth of its roots which can evidently reduce their values [34]. Results obtained by Eid and Shaltout [35] for the evaluation of carbon sequestration potentiality of Lake Burullus, Egypt, indicated that the soil bulk density of the vegetated sites was lower than that of the un-vegetated sites due to roots effect. Moreover, Jobbagy and Jackson [25] indicated that the abundance of SOC affects and is affected by plant production.
However, the results obtained for the soil associated with *Calotropisprocera* had higher soil bulk density and SOC content compared with the other one. This is due to higher shoot biomasses than *Phragmitesaustralis*. According to Bolinder et al., [27-28], shoot biomasses act as a sink for greenhouse gases by photosynthetic assimilation of carbon dioxide (CO_2) from the atmosphere.
As far as we know, no data existed about the relationship between soil bulk density (g. cm^{-3}) and SOC content (g C kg^{-1}) for soils of area under investigation, thus we calculated this relationship using non-linear regression equation:

$$\text{Soil bulk density} = 1.683 - 0.009 \times \text{SOC}^{1.0131} \quad (8)$$

Generally, soils of all selected locations in area under investigation acquired low SOC concentrations compared with plant organs. This indicates that little of carbon that being introduced in the soil is stored there and rapidly decomposed by biotic systems [36].Moreover, according to Schlesinger [37], there is a strong relation between climate and soil organic carbon contents where organic carbon content decreases with increasing temperatures because decomposition rate doubles with every 10 increase in temperature. Thus, it is clear that the climate in the studied area is continental with extreme high temperature (> 45 ^oC) from May to October, that make this region is a lower net sink for the terrestrial carbon cycle than in temperate regions.

Table 2: Average total organic carbon content (g/g) of plant parts and soils organic carbon (SOC), Bulk density (g/cm^3), BCF and TF among the studied locations for *Calotropisprocera.*

Items	Calotropisprocera		
	Location I	**Location II**	**Location III**
Shoot	0.436 0.4587 0.4056	0.4587 0.4932 0.4120	0.5019 0.4598 0.5134
Average	**0.433433**	**0.454633**	**0.4917**
Root	0.2595 0.2345 0.2523	0.3171 0.3211 0.3020	0.3276 0.3651 0.3567
Average	**0.248767**	**0.3134**	**0.3498**
Soil	0.06375 0.05956 0.06973	0.0716 0.0701 0.0726	0.0967 0.1099 0.0863
Average	**0.064347**	**0.07143**	**0.097633**
Soil Bulk Density (g/cm^3)	**1.666**	**1.022**	**0.991**
BCF	**3.866023**	**1.07339**	**3.582805**
TF	**1.742325**	**1.593**	**1.40566**

Table 3: Average total organic carbon content (g/g) of plant parts and the soils organic carbon (SOC), Bulk density (g/cm^3), BCF and TF among the studied locations for *Phragmitesaustralis.*

Items	Phragmitesaustrales		
	Location I	Location II	Location III
Shoot	0.3315 0.356 0.321	0.3967 0.3501 0.3967	0.4012 0.4236 0.4467
Average	**0.336167**	**0.381167**	**0.423833**
Root	0.2445 0.2595 0.2345	0.2613 0.2785 0.2675	0.3097 0.3478 0.3980
Average	**0.246167**	**0.2691**	**0.351833**
Soil	0.02925 0.02234 0.02456	0.02768 0.02989 0.0298	0.03124 0.03451 0.03234
Average	**0.025383**	**0.029123**	**0.032697**
Soil Bulk Density(g/cm^3)	**1.234**	**1.145**	**0.956**
BCF	**9.698105**	**9.240119**	**10.76041**
TF	**1.365605**	**1.416451**	**1.204643**

3.3.Bioaccumulation and Translocation in Plants:

Accumulation of TOC varied greatly among plants species and uptake of it by a plant is primarily dependent on the plant species, its inherent controls and the soil quality [38]. Large number of factors control TOC accumulation and bioavailability associated with soil and climatic conditions, plant genotype and agronomic management, including : active/ passive transfer processes, sequestration potential and the type of plant root system [39]. Both plants under investigation had BCF >1. *Phragmiteaustralis* had higher BCF than *Calotropisprocera.* This means that *P. australis* retains TOC in their root and limits mobility from roots to soil [40].

The translocation factor (TF) generally showed the movement of TOC from soil to root to shoot. It gives an idea whether the native plant is an accumulator, excluder or indicator[40]. Results indicated that *Calotropisprocera* was efficient in translocation of TOC from roots to shoots with higher TF average values of (1.74) recorded at location I. It is easy for plants species with TF > 1 to translocate TOC from roots to shoots than those which restrict it in their roots. Those plant species were considered suitable for phytoexctraction [41].

Conclusion

The present study has provided basic data for carbon sequestration by soil/plant system which in turn will offer scientific guidance for policy making efforts to control CO_2 emission in polluted area of Riyadh City. In the course of this study it can be concluded that the native plants exhibited more TOC concentrations than soil with a sequence of shoot > root > soil.

Comparing the results obtained for the two plants under investigation, the soil bulk density and SOC of surface layer under *Phragmitesaustrales* was lower than *Calotropisprocera* due to the dense growth of its roots. The present study indicated that the soil in hot regions (Riyadh City) is a lower net sink for the terrestrial carbon cycle where both plants proved to be more effective in carbon sequestration process. The present study could be instrumental in formulating strategies related to carbon sequestration by plants and reduction of CO_2 emission in the polluted areas. More research is needed to better understand the impacts of other environmental factors such as wind, temperature and emission of other greenhouse gases. Such an approach would potentially enhance our understanding of climate change.

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