Open Journal of Soil Science, 2012, 2, 116-122
http://dx.doi.org/10.4236/ojss.2012.22017 Published Online June 2012 (http://www.SciRP.org/journal/ojss)

Acacia trotilis and *Calotropis procera*: Do They Substantially Promote Soil Carbon Sequestration?

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Received October 23rd, 2011; revised November 30th, 2011; accepted December 18, 2011

ABSTRACT

Very little is known about the type and mix of desert plant species and their management to optimize carbon sequestration in desert ecosystems. Overgrazing is one important practice that affects soil carbon cycling and therefore sequestration. Improving soil carbon in desert ecosystems may be best through the use of native trees and shrubs. Acacia tortilis and calotropis procera are two important species in the United Arab Emirates (UAE). The former is a native species that improves biodiversity and the latter is not native and has been reported to be an indicator of overgrazing. The average soil organic matter (SOM) content was higher in soils dominated by *A. tortilis* when compared to those dominated by *C. procera*; 2.98 and 1.34; respectively ($P < 0.05$). Moreover, *A. tortilis* leaves had a higher OM content than *C. procera* leaves (94.1% and 90.6%; respectively). The higher OM content of *A. tortilis* leaves explains the higher contribution of this species to the overall soil organic matter inputs. There was also a significant effect of shrub species on total SOC ($P < 0.05$). A total of about 14.7 tons of SOC were added per hectare in the areas dominated by *A. tortilis*. While only about 6.6 tons of SOC were added to the areas dominated by *C. procera*. In short, it is believed that both species substantially promote soil carbon sequestration. Some significant superiority of the native *A. tortilis* has been shown. But much has to be done to investigate the mix of plant species that promote the best soil carbon sequestration in the desert areas. Further studies are required in order to assess temporal as well as spatial variations in soil carbon sequestration in the UAE deserts. This will certainly help, in addition to other practices, in mitigating CO_2 emission.

Keywords: Desert Soils; Nutrient Cycling; Soil Carbon

1. Introduction

Soil restoration and woodland regeneration are sound strategies to increase soil carbon pool [1]. Increasing soil carbon improves soil quality, productivity and long-term sustainability. Equally important are the growing concerns about global greenhouse gas emission issues, which call for proper management of the terrestrial carbon pool. Specifically, this calls for a better understanding of carbon sequestration and ways to optimize it. Especially that desert lands are believed to contain small amounts of soil carbon. In general terms, carbon sequestration in terrestrial ecosystems can be defined as the net removal of carbon dioxide from the atmosphere into long-lived pools of carbon. These pools can be living above-ground biomass, wood products, living biomass in soils such as roots and micro-organisms or recalcitrant organic and inorganic carbon in soils [2]. In the UAE, for example, soil carbon pools become more important and relevant if we consider the vast areas covered by desert ecosystems, which occupy at least two-third of the country's land area.

Fortunately, terrestrial carbon pools could be significantly enhanced by adopting sound management practices in desert ecosystems. As in other agricultural systems, the potential of desert ecosystems to store carbon is dependent on how adequately the soil-plant resources are managed. For instance, promoting healthy perennial plant species is a management option that could improve the terrestrial carbon pool, through increased rooting depth. This will be even more pertinent if native shrub and tree species were used.

Unfortunately, very little is known about the type and mix of desert plant species that optimize carbon stocks in desert ecosystems. Additionally management principles and practices which can maintain carbon stocks through time are not well defined and adopted. *Panicum*, for instance, offers an excellent carbon sequestration option because of its deep rooting system and perenniality [3]. Understandably, plant species differ markedly in their impact on soil carbon concentration and distribution, mainly because of differences in their root systems. For example, the mean carbon concentration in the top 10 cm of soil in areas dominated by *Panicum maximum* was 3.31% compared to 1.89% and 0.74% in areas dominated by *Themeda triandra* and *Aristida jerichoensis*, respectively [4]. Furthermore, the restoration of some types of soils with *Astrebla* species has been attributed to a substantial increase in organic carbon concentration in the top 5 cm of soil [5]. Such differences in soil carbon under different species can be attributed to root systems' characteristics, specifically root turnover, which is a central component of ecosystem carbon and nutrient cycling [6]. In areas where *Prosopis* and Acacia are adapted, 6.2 × 109 Mg of carbon would be sequestered [7]. These types of carbon sequestration could offset CO_2 emission due to fossil fuel burning.

In the UAE, desired and undesired species are becoming part of the desert ecosystems. An undesired species that is prevalent in many parts of the UAE deserts is *colotropis procera* (Aiton) W.T. Aiton. It is common in many parts of the UAE desert as it is an indicator of overgrazing [8]. Desired species—such as *acacia toritillis*—are also an integral part of the UAE deserts. *Acacia toritillis* promotes floral diversity as well as provides feed sources for the majority of wildlife as well as livestock species in the country [9]. But do *C. procera* and *A. toritillis* have a potential to substantially improve soil carbon sequestration? What is the extent of such sequestration in the UAE soils? Those are some of the questions that the present endeavor will try to address.

2. Materials and Methods

2.1. Study Site

The study was conducted in the surrounding area of Al-Ain city in the (UAE). The average minimum temperature in Al-Ain is 22˚C while the average maximum is 35.8˚C (**Table 1**). The annual average long term rainfall is 119.7 mm (**Table 2**) and the humidity is 58% (**Table 3**). Three locations were selected where the two plant species grow. The aim was to collect pair samples with similar soil characteristics. The soils were characterized as sandy to sandy loam.

2.2. Sample Collection

Soil samples—about 150 grams—were collected from the various locations from the top soil layer (5 cm) and at 10 cm deep. A total of 72 samples (2 Species × 2 Positions × 2 Depths × 9 Replicates) were collected during Spring and during Winter of 2009-2010. Samples were collected from underneath the shrub canopy and away from the shrub canopy; referred to as in and out; respectively. Leaf samples were collected from each tree to assess percent OM and OC. Percent dry matter loss and percent moisture losses were also assessed. All samples were then transported to the UAE University labs for analyses.

2.3. Sample Analyses

Soil and leaf samples were first air dried for 48 hours. Soil samples were sieved to remove coarse material. Crucibles were then used to oven-dry each sample at 105 degrees C for 72 hours. Moisture content was calculated for the soils samples following this step (formula a). Combustion was performed for 3 hours on the soil and leaf samples to estimate organic matter (formula b). Percent organic carbon was calculated as a fraction of OM (formula c).

a) Moisture content: Sample loss/Dry Weight of Sample.

b) Percent Soil Organic Matter (SOM): Sample loss in combustion/Dry Weight of Sample.

c) Percent Soil Organic Carbon (SOC): Organic matter × 0.58.

In order to assess the total bulk SOC that the two spe-

Table 1. Monthly variation in the air temperature (˚C) (1965-2001) of ten meteorological stations in Al-Ain UAE. Minimum (top row) and maximum (bottom row) (Ministry of Agriculture and fisheries UAE, 1965-2001).

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Al-Ain	14.8	14.9	18.5	20.4	23.9	27.1	30	30.2	26.6	23	18.9	15.8	22.0
	23.3	26.9	30.8	35.4	40.4	43.5	43.5	44.9	42.0	37.6	32.4	28.8	35.8

Table 2. Monthly variation in the annual rainfall (mm) during (1965-2001) of ten meteorological stations in Al-Ain UAE (Ministry of Agriculture and fisheries UAE, 1965-2001).

Station	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Al-Ain	68.1	45.7	2.7	Trace	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	119.7

Table 3. Monthly variation in the relative humidity (%) during (1965-2001) of ten meteorological stations in Al-Ain UAE (Ministry of Agriculture and fisheries UAE, 1965-2001).

Station	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Al-Ain	66	64	59	53	50	53	53	54	56	58	63	66	58

cies add to the soils, it has been decided to estimate bulk SOC based on an approximate number of shrubs growing in the study sites. It has been assumed that an average 20 shrubs and *A. tortilis* and 5 shrubs of *C. procera* were growing in the site. It was also estimated that the age of shrubs was 15 and 10 years for *A. tortilis* and *C. procera*; respectively. The total amount of SOC per square meter was calculated following the method (formula d) reported by [10].

d) Soil C ($g \cdot m^{-2}$) = $z \times p_b \times c \times 10$.

where z = thickness of each sample depth (cm), p_b = bulk density ($1.7\ g \cdot cm^{-3}$) of each sample depth and c = carbon concentration ($g \cdot C \cdot kg^{-1}$ soil) of each sample depth. The results will be reported in tons per hectare ($tons \cdot Ha^{-1}$).

2.4. Statistical Analyses

ANOVA analyses were performed to compare main effects (season, shrub species, soil depth and position in relation to shrub canopy) and all interactions. SYSTAT11 was used to perform all analyses [11].

3. Results

3.1. Soil Organic Matter

3.1.1. The Effects of Tree Species

Soil organic matter (SOM) was different in soils dominated with *A. tortilis* than in those dominated with *C. procera* ($P < 0.05$; **Table 4**; **Table 5**). The average SOM content was higher in soils dominated by *A. tortilis* when compared to those dominated by *C. procera*; 2.98 and 1.34; respectively (**Table 4**). When comparing canopy positions (*i.e.* underneath or away from the shrub) in areas dominated by either *A. tortilis* or *C. procera*, no differences were detected ($P > 0.05$). The above findings do not agree with much of what was reported elsewhere. Results from the sonorant desert suggested higher soil fertility underneath live plants, regardless of species and phenology [12]. Except for cactus, which was suggested to use nutrients and remove fertility areas around them. There was an improvement in soil characteristics underneath *A. tortilis* when compared to open grassland area, away from the shrub [13]. Their findings restrict these differences, however, to lightly grazed sites. Additionally, significant differences in soil characteristics, underneath vs away from the tree/shrub canopies, in lightly grazed areas were found [14].

While in our study, the grazing history is unknown but heavy camel grazing has been a wide spread practice in the area. The increase in camel populations within the UAE during the past few decades is also an indicator of the pressure on the desert ecosystems [15]. It is strongly believed, therefore, that while the dominant shrub species contribute to SOM, but a substantial part of this contribution may be the result of the associated species that grow in soils where *A. tortilis* or *C. procera* dominate. The associated species contributed to soil fertility in soils dominated with *A. tortilis* in Ethiopia [14]. Acacia tortilis has also been reported to improve associated species in

Table 4. Summary averages for percent soil organic matter (OM) and soil organic carbon (OC) for the two seasons at two different soil depths under *Acacia tortilis* and *Calotropis procera* species growing in the deserts of the UAE.

			Soil Depths					
			5		10			
	Shrub Species	under/out of Shrub	% OM	% OC	% OM	% OC	Average % OM	Average % OC
Spring			2.13	1.23	2.02	1.17	2.07	1.20
	Acacia		2.77	1.61	2.70	1.56	2.73	1.59
		In	2.94	1.71	2.85	1.65	2.90	1.68
		Out	2.60	1.51	2.54	1.47	2.57	1.49
	Calotropis		1.49	0.86	1.34	0.78	1.41	0.82
		In	1.38	0.80	1.36	0.79	1.37	0.79
		Out	1.60	0.92	1.31	0.76	1.45	0.84
Winter			2.46	1.43	2.04	1.19	2.25	1.31
	Acacia		3.52	2.04	2.93	1.70	3.23	1.87
		In	3.66	2.12	2.90	1.68	3.28	1.90
		Out	3.37	1.96	2.96	1.72	3.17	1.84
	Calotropis		1.40	0.81	1.15	0.67	1.28	0.74
		In	1.34	0.78	1.24	0.72	1.29	0.75
		Out	1.46	0.85	1.06	0.62	1.26	0.73
grand total			2.29	1.33	2.03	1.18	2.16	1.25

Table 5. ANOVA analysis percent soil organic matter (SOM) for the two seasons at two different soil depths under *Acacia tortilis* and *Calotropis procera* species growing in the deserts of the UAE.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Season	1.165	1	1.165	1.747	0.189
Taxa	96.154	1	96.154	144.220	0.000
Depth	2.499	1	2.499	3.748	0.055
Season*Taxa	3.525	1	3.525	5.287	0.023
Season*Depth	0.827	1	0.827	1.240	0.267
Taxa*Depth	0.149	1	0.149	0.223	0.637
Season*Taxa*Depth	0.381	1	0.381	0.572	0.451
Error	90.674	136	0.667		

desert ecosystems [9,13]. Some other desert species were also reported to improve soil characteristics beyond their canopy [16].

3.1.2. The Effects of Season

SOM was highest during winter collection than during spring ($P < 0.05$). The difference between the two shrub species is more pronounced during winter. During which *A. tortilis* had an average SOM of 3.23% while *C. procera* had an average SOM of 1.28%. During spring the average SOM for *A. tortilis* and *C. procera* was 2.73% and 1.41%; respectively.

3.1.3. The Effects of Soil Depth

The average SOM was highest in the top 5 cm ($P = 0.055$). SOM was 2.29% and 2.03% at 5 cm and 10 cm soil depth; respectively. For *A. tortilis*, SOM was 3.14% and 2.81% for 5 cm and 10 cm soil depths; respectively. While for *C. procera* SOM was 1.82% and 1.63% for the two depths, respectively. Marked differences in the top 5 cm of the soil profile were reported by [14].

3.1.4. Leaf Content

Overall *A. tortilis* leaves had a higher OM content than *C. procera* leaves (94.1% and 90.6%; respectively) at $P < 0.05$ (**Figure 1**). But little fluctuations were observed during the 28-day period (data not shown). The higher OM content of *A. tortilis* leaves explains the higher contribution of this species to the overall soil organic matter inputs. This is another reason to encourage the plantations of such native species in the UAE deserts.

As for the leaf moisture content, *A. tortilis* contained a slightly lower level (52.2% and 84.6%; respectively) and lost moisture at a relatively faster rate than *C. procera* (**Figure 2**). But toward the end of the 28-day period, both species had comparable moisture contents (9.7% and 11.3%; respectively).

3.2. Soil Organic Carbon

Percent SOC was transformed into bulk tons of SOC per hectare. Please see the methodology section for more details. There was significant effect of shrub species on SOC ($P < 0.05$). An estimated total of about 14.7 tons of SOC were added per hectare in the areas dominated by *A. tortilis* (**Table 6**). While about 6.6 tons of SOC were added to the areas dominated by *C. procera*.

Variations between soil depths was also detected ($P < 0.05$). The average SOC at 5 and 10 cm depths was 15.5 tons·Ha^{-1} and 13.9 tons·Ha^{-1} for *A. tortilis*; while SOC was 7.1 tons·Ha^{-1} and 6.1 tons·Ha^{-1} for *C. procera*; respectively.

Many other studies also report positive SOC sequestration but many disagree on the estimated amount per hectare; mainly because of ecosystem differences and variations in the adopted experimental protocols. An average of about 26 tons·Ha^{-1} of SOC in the grazing lands of Ethiopia was reported [17]. While others [10] reported about 14.7 tons·Ha^{-1} of SOC in the top 10 cm of the soil profile semiarid acacia woodland. The accumulation of SOC at 0 - 10 cm depth was estimated to be a staggering 61.2 tons·Ha^{-1} [18]. Some of the changes to SOC were attributed, and rightly so, to land management practices [19] such as overgrazing [20]. In the UAE, and across much of the region, overgrazing has been reported as one of the main threats facing desert environments [21].

For *A. tortilis*, we can estimate an annual SOC addition of about 0.98 tons·Ha^{-1} would be added to the desert soils of the UAE. While an estimated annual addition of 0.66 tons·Ha^{-1} of SOC in soils dominated by *C. procera*. Restoring grasslands to woody grasslands, where *A. tortilis* was growing in the sahel, would add about 0.8 tons·Ha^{-1} of SOC annually [22]. The huge differences between the estimates in our study and those in many other studies may be attributed to floral understory. In the UAE, the understory of grass species is much less when compared to the Ethiopian grasslands, for instance.

4. Discussion

Acacia tortilis is an important native species to the UAE and needs to be grown in large areas as part of the current attempts to re-vegetate the desert. Assuming an average success rate of 20 individuals per hectare, we can

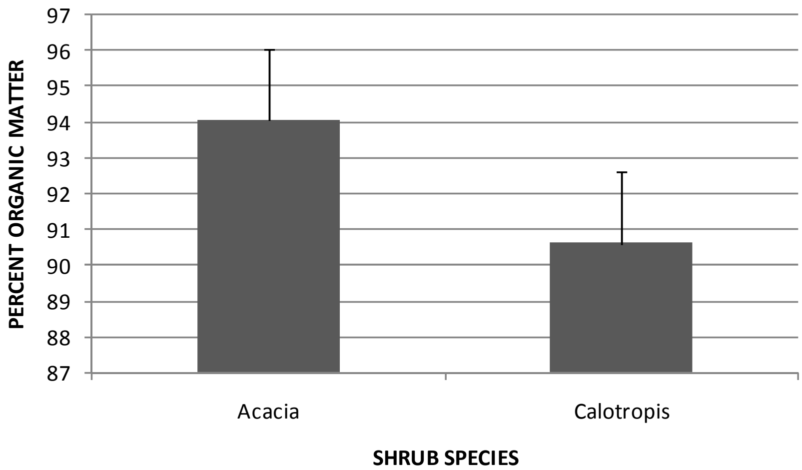

Figure 1. Percent leaf organic matter content (%OM) for both *Acacia tortilis* and *Calotropis procera* species growing in the deserts of the UAE.

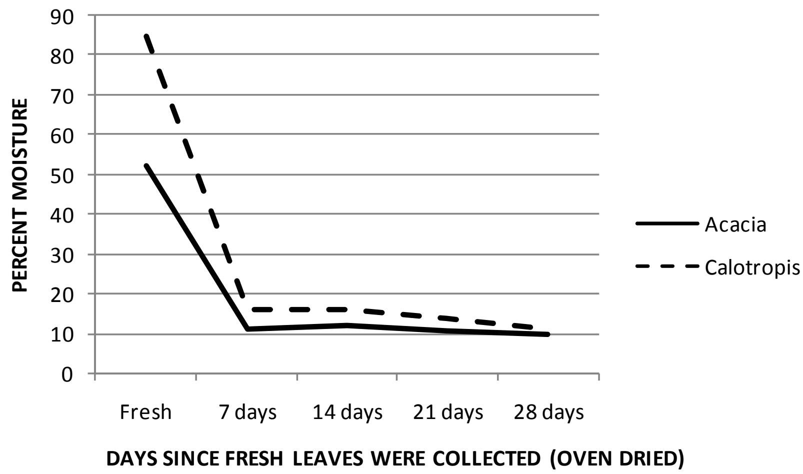

Figure 2. Percent moisture loss for both *Acacia tortilis* and *Calotropis procera* species growing in the deserts of the UAE.

Table 6. Average soil organic carbon (SOC) at two different soil depths under and away from the canopies of *Acacia tortilis* and *Calotropis procera* species growing in the deserts of the UAE.

Soil Organic Carbon		Canopy Position		
Taxa	Soil Depth	Under	Away	Average
Acacia	5	16282.22	14728.61	15505.42
	10	14180.83	13571.67	13876.25
Acacia Average		15231.53	14150.14	14690.83
Calotropis	5	6696.11	7536.67	7116.39
	10	6417.50	5855.55	6136.53
Calotropis Average		6556.80	6696.11	6626.46
Grand Average		10894.17	10423.12	10658.64

sequester 19.6 Mt in the next 10 years if we plant 2000 hectares of *A. tortilis*. The other equally important benefits of improved species diversity and soil improvement are to be taken into consideration.

For *A. tortilis*, based on the above numbers, we can estimate an annual SOC addition of about 0.98 tons·Ha^{-1} to be added to the UAE desert ecosystem. While an estimated annual addition of 0.66 tons·Ha^{-1} of SOC in soils dominated by *C. procera*. This highlights the importance of re-vegetating our desert ecosystems using species that promote carbon sequestration. The direct benefits are the greening of these ecosystems, while indirect benefits may include the creation of islands of fertility underneath these shrubs and the improvement of the vegetative cover in the floral understory. Islands of fertility in the Sonoran Desert underneath mesquite canopies played important ecosystem functions [22].

Furthermore, SOC inputs enrich soil characteristics. An increase of 1 ton of soil carbon of degraded cropland soils may increase crop yield by 20 to 40 $kg\cdot Ha^{-1}$ for wheat, 10 to 20 $kg\cdot Ha^{-1}$ for maize, and 0.5 to 1 $kg\cdot Ha^{-1}$ for cowpeas. In addition to enhancing food security, carbon sequestration has may possibly offset fossil fuel emissions by 0.4 to 1.2 gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions [1].

Finally and to address the question stated in the project title, it is believed that both species substantially promote soil carbon sequestration. It is important to note that one species is a native wanted species (*A. tortilis*) and the other is an introduced unwanted plant species (*C. procera*). Some significant superiority of the native *A. tortilis* has been shown. As for the extent of soil carbon sequestration, some evidence of vertical as well as horizontal variability was shown. Much has to be done, however, to investigate the mix of plant species that promote the best soil carbon sequestration in desert areas. Besides enhancing food security, soil carbon sequestration offsets global fossil fuel emission by up to 15% [1]. The extent of such quantitative estimates within the region and more specifically within the UAE is unknown. More detailed studies are to be initiated in order to assess temporal as well as spatial variations in soil carbon sequestration in the UAE deserts.

5. Acknowledgements

The investigator would like to express his sincere appreciation to the Research Affairs at the United Arab Emirates University for the financial support of this project under fund Grant # 01-04-2-11/09. The support from the Biology Department and the Faculty of Science is also much appreciated. The investigator would also like to express his gratitude to Drs Mohamed T. Moussa and Nael Fawzi for their assistance in data collection.

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