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RESEARCH ARTICLE

Above and belowground carbon pools are affected by dominant floral species in hyper-arid environments

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Abstract

Introduction: Carbon (C) pools in desert ecosystems have not been well investigated, especially in relation to quantitative assessment for different compartments. In many ecosystems C uptake may increase, which leads to accelerated C cycling belowground.

Methods: Therefore there is a strong need for C storage in compartments such as phytomass and/or within soils. In the present study we assessed C pools of different soil/vegetation associations as affected by the dominant tree and shrub species.

Results: Mountain valleys had the highest C pool in the phytomass compartment with an average of 3.6 tons per hectare, of which 1.32 tons per hectare were contained aboveground. The introduced *Prosopis juliflora* had by far the highest average contribution of 3.47 tons of C per hectare. Most of which is in the above ground parts (83.3%) and the remaining is sequestered below ground. *Halopeplis perfoliata*, however, contributed the least C to the desert systems of the UAE. Some land forms, such as mountain valleys, were shown to sequester more C than others, which constitute a good reason to improve their conditions.

Conclusions: Few shrub/tree species, such as *P. juliflora*, were also reported to have high potentials as a C pool in the hyper-arid environment of the UAE.

Keywords

Carbon Pool, Climate Change, Climate Ecology, Tree Carbon Storage

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Introduction

The potential for desert plant species to capture carbon (C) has not been well investigated, especially with the potential impact of enhanced greenhouse gas emissions. This was supported by leading investigators such as Lal and colleagues¹, who stated that the contributions of soil organic C dynamics on CO₂ as a greenhouse gas, and its strategic importance in mitigating enhanced atmospheric CO₂ are not well accepted. Moreover, estimates of net ecosystem production in deserts are incompatible with recent net primary production and C pools in deserts². The potential for desertified ecosystems to sequester C are still considerable³. But a significant part of C can be sequestered within a reasonable time frame³. Especially that estimates of soil organic carbon (SOC) pool in desert and semi-desert ecosystems, for instance, are in the order of 159-191 billion tons C. But the role of SOC on historic increase in atmospheric CO₂ are not widely recognized³.

Li *et al.*⁴ studied soil carbon sequestration potential in semi-arid grasslands with significant offsets to increasing atmospheric CO₂ levels may be achieved in addition to erosion control and improved wildlife habitat. Atmospheric CO₂ concentrations continue to rise due to human activities. CO₂ is a leading greenhouse gas, the levels of which are directly affected by anthropogenic activities. In forested ecosystems there is a ubiquitous initial increase in net primary productivity⁵, however, as these systems shunt more C belowground heterotrophic communities may increase activity, resulting in net soil C losses. Similarly, in grassland ecosystems C uptake may increase, which in turns leads to increased rates of C cycling belowground and speeds up the loss of C from the slowest cycling C pool⁶. There is a need for C storage in different pools, with long residence times or which transfer C from organic to inorganic forms. Arid and semi-arid regions, for instance, account for about 30% of the earth terrestrial surface⁷ and these important areas are expanding due to anthropogenic impact. However, these arid environments have been understudied, despite recent studies that have shown these environments may be sinks for atmospheric CO₂⁸. The stability of soil C is also affected by desertification processes⁹.

There is a strong need to study semi-arid shrublands and deserts, since studies have shown that they remove similar amounts of CO₂ from the air as forests and grasslands¹⁰⁻¹³. These semi-arid lands have high CO₂ uptake due to three main factors: 1) the expansion of shrubland vegetation, 2) the cryptobiotic crust communities and 3) the accumulation of C in soil carbonates. These mechanisms may increase C in both above and belowground C pools which may sequester C and retain it in pools with various mean residence times. It has been estimated that arid and semi-arid soils may remove as much as 5.1 g C/m²/year from the atmosphere¹⁴. Stanbery *et al.*¹⁵ examined variability in soil carbonate storage at the pedon-scale, quantified analytical and measurement error in soil carbonate measurements and defined the amount of carbonate stored in gravelly vs. non-gravelly soils.

Other studies have shown that this accumulation of C in soils as carbonates can occur over a very short period of time¹⁶ and

that the conditions that lead to increased soil carbonates may be controlled by vegetation and the availability of calcium and bicarbonate¹⁷. The use of native plant species has also been suggested to improve soil C sequestration¹⁸. Land management may affect future amounts of SOC in semi-arid areas thereby turning them from sources into sinks of C¹⁹. Encouraging sustainable land management practices can contribute to restoring soil organic C stocks and to creating new C sinks, leading to improved C sequestration potentials²⁰. Additionally, land management may turn sources of SOC into sinks of C in semi-arid areas¹⁹.

The present work was intended to consequently contribute to assessing C pools in the hyper-arid ecosystems of the UAE, using biomass that affects C allocation in the belowground compartment. Of great interest was to determine which species present the greatest increases in belowground organic and inorganic C pools. Globally, soils store more than twice the amount of C than is present in the atmosphere and terrestrial biomass C pools, combined²¹. Soil organic C may also have a longer mean residence time than atmospheric CO₂ (5 years) or terrestrial biomass C pools (9 years, globally averaged)^{22,23}. Even more exciting is the ability of some arid ecosystems to take atmospheric C, fix it via photosynthesis, move that organic C belowground and eventually transform that organic C into inorganic C under relatively short time scales⁸. These arid ecosystems have not been well investigated and it is unclear which plant species possess the greatest ability to sequester C both below as well as above-ground. In the present study we measured C sequestration potentials of different soil/vegetation associations as affected by the dominant tree and shrub species. It is therefore aimed to accurately quantify the amount of C removed from the atmosphere and stored in above and belowground C pools of plants that are native to this hyperarid environment.

Methods

Study site

This study site covered various land forms covering various areas across the United Arab Emirates (UAE). Table 1 list the location of the study plots, including geographical coordinates. The soil/vegetation features of each plot is also indicated. Figure 1 also overlays the location of the study sites.

A total of 30 sites were visited in this study between May and September 2015. Sites represented different land forms as described in Table 1. A site consisted of 10 × 10 m plots. Tree, shrub and herbaceous (if present) dimensions were assessed.

Aboveground biomass sampling

Aboveground plant samples were collected from leaves and stems. Samples were dried to estimate C content following the method reported previously²⁴.

The amount of litter collected within three separate quadrats (10 × 10 cm), from underneath each plant, was weighed to estimate litter fall per unit area. The samples were then air dried, ground to 20 mesh in a Wiley mill, and oven-dried at 50°C for 48 h. Subsamples were used to determine moisture content (at about 105°C for 48 h), ash content (500°C for 12 h) and total C fraction composition.

Table 1. List of land forms and respective sampling sites with their geographic coordinates. Site IDs are extracted from the United Arab Emirates Soil Information System²⁵.

Land Form	Site ID	Lat	Long
Sand Dunes	AD1	55.09	24.25
-	NE1	55.62	25.51
-	NE2	55.73	25.14
-	NE3	55.73	25.17
-	AD2	54.83	23.86
Gravel Plains	D10	53.28	24.02
-	D11	53.39	24.00
-	D12	53.59	23.08
-	D13	55.96	24.12
-	D14	55.86	24.06
-	D15	54.26	22.94
-	D16	54.87	24.25
-	AD8	55.44	23.49
-	AD9	52.68	24.08
-	E10	55.93	25.27

Land Form	Site ID	Lat	Long
-	E11	55.76	24.91
Plains	E12	55.85	25.21
-	E13	55.96	25.65
-	E14	55.75	24.93
-	E15	55.93	25.48
Sabkhas	AD3	51.81	23.98
-	AD4	52.71	23.86
-	AD5	54.19	23.90
-	NE4	55.65	25.58
-	NE5	55.61	25.51
-	NE6	55.64	25.57
-	NE7	55.79	25.64
Sand Plains	D17	52.88	24.01
-	D18	54.84	24.34
-	D19	55.44	23.49
Mountain Valleys	AD6	55.74	24.09
-	AD7	55.77	24.06
-	NE8	56.10	25.83
-	NE9	56.06	25.78

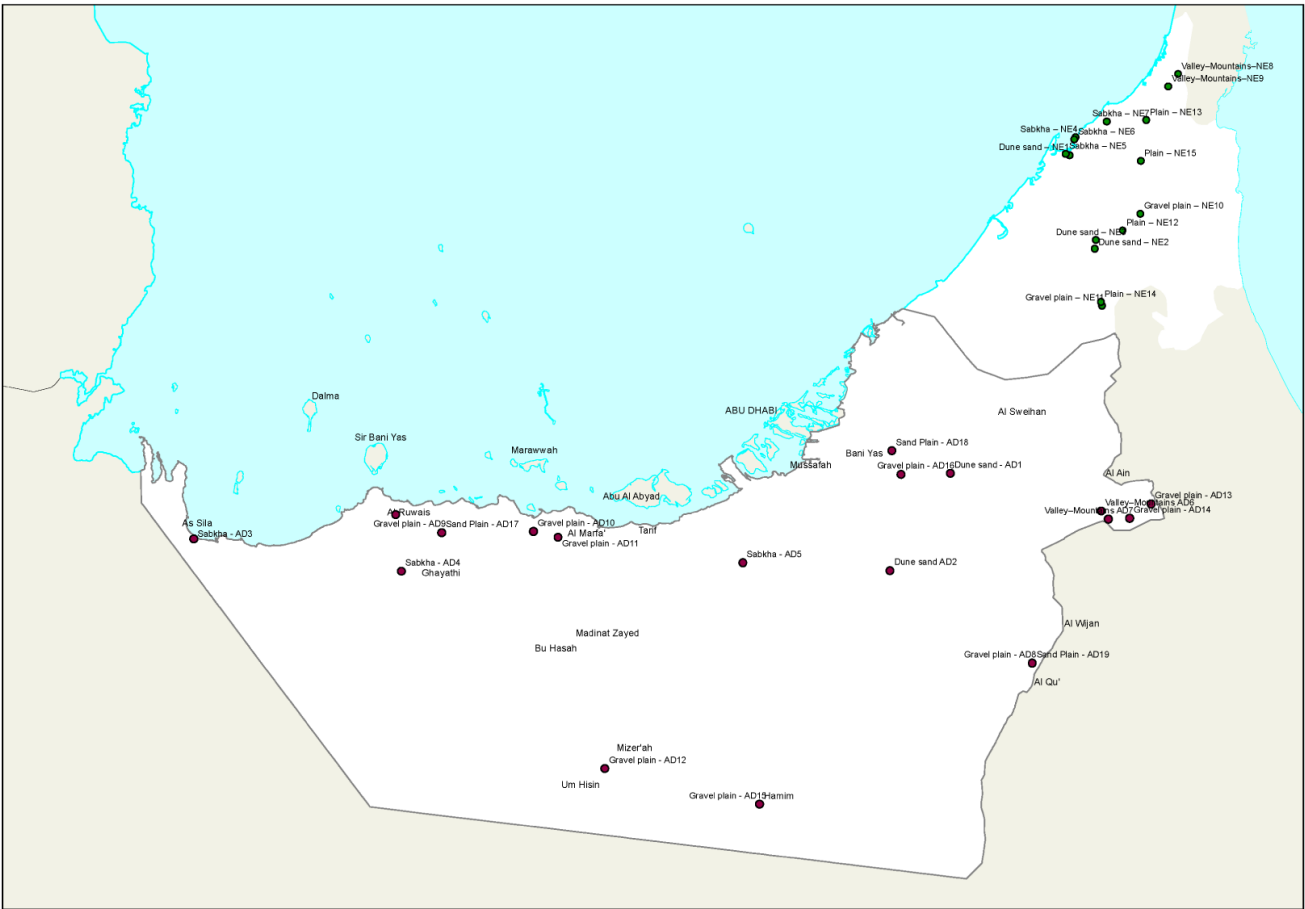


Figure 1. A map overlaying the location of the study sites across the UAE.

Soil sampling and analyses

Soil cores were taken from each plant, within 0.5m of the plant main stem/trunk. Soil samples were dried for total C. Analyses were done using a Thermo Scientific Flash 2000 Combustion CHNS/O Analyzer. The amount of soil organic C (SOC) was determined.

Carbon estimation in woody species

Woody species were collected and kept in the herbarium of Biology Department, UAE University. Following the methods described by 26, the diameter at breast height (DBH) was measured for all tree species. While the basal diameter (BD) was measured for all shrubs within the sampling areas. Sampling plots were selected across the 22 sites measuring 10 × 10 m.

Published allometric equations²⁷ were adopted to assess carbon stocks in tree and shrub species. The fresh biomass for trees and shrubs was estimated using the following equations:

- For trees: $Y = 0.1975 \times DBH \times 1.1859$
- For shrubs: $Y = 0.1936 \times BD \times 1.1654$

While the above equations estimate fresh weight, a 0.6 constant was used to estimate dry weight and 0.5 to estimate carbon content²⁸. Root carbon was estimated using 0.2 reduction factor²⁹. Tons per hectare are the units used hereafter.

Results

Variations between land forms

Mountain valleys sequestered the highest C in the phytomass compartment with an average of 3.6 tons per hectare (Table 2), of which 1.32 tons per hectare were as aboveground tree biomass. The soil carbon compartment for this landform was 1.08 tons per hectare. Sand plains, had the smallest average sequestration potentials of 1.61 tons per hectare.

The proportions of carbon sequestration was highest in the soil compartment within sand plains (i.e. 49.1%). Soil carbon sequestration was lowest for plains with an average of 28.3%.

For tree species' contributions to C sequestration, mountain valleys had the highest contributions of 1.32 and 0.26 tons per hectare as shoot and root phytomass; respectively (Figure 2). The lowest contribution from trees was observed in Sabkhas with average of 0.58 and 0.12 tons per hectare in shoots and roots, respectively.

Variations between plant species Trees

Prosopis cineraria, *Acacia tortilis* and *Zyzyphus spinachristi* were the three dominant trees species recorded (Figure 3). The highest contribution was from *Z. spinachristi* with an average of 1.73 tons per hectare of sequestered C. The proportions were 83.2% and 16.7% as contributions from shoots and roots,

Table 2. Carbon stocks in different land forms of the UAE for both shoot and root components.

Land Forms	BG (Shrubs)	AG (Shrubs)	BG (Trees)	AG (Trees)	Soil C	Total C (Kg=Ha)
Sand Dunes	0.13	0.67	0.15	0.74	0.73	2.42
Gravel Plains	0.03	0.15	0.23	1.13	0.97	2.51
Plains	0.23	1.15	0.13	0.64	0.85	3.00
Sabkhas	0.13	0.65	0.12	0.58	1.07	2.55
Sand Plains	0.14	0.68	-	-	0.79	1.61
Mountain Valleys	0.16	0.78	0.26	1.32	1.08	3.60

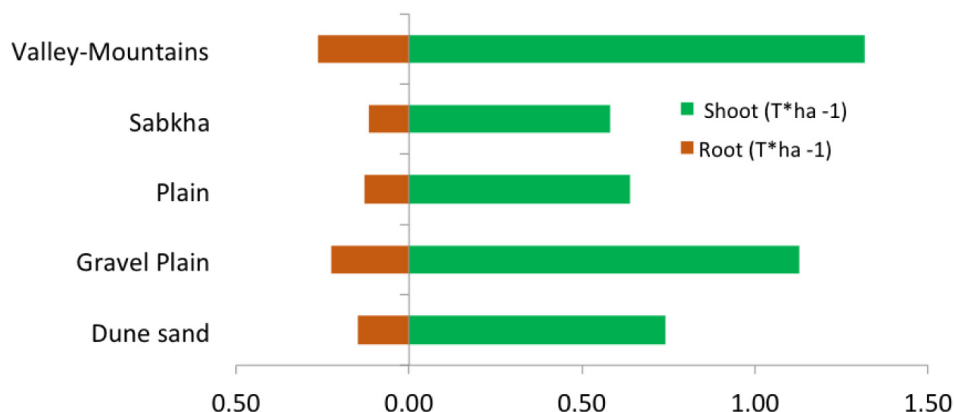


Figure 2. Carbon stocks (shoot and root components) in different land forms of the UAE.

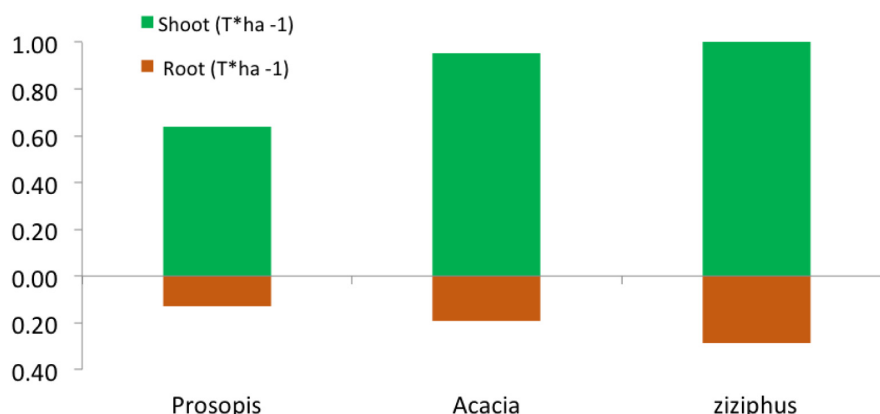


Figure 3. Carbon stocks (shoot and root components) in the three most important tree species in the UAE.

respectively. *Prosopis cineraria* contributed the least in C sequestration with averages of 0.64 ton per hectare and 0.13 ton/ha as shoot and root components; respectively. Raw results are available as *Underlying data*³⁰.

Shrubs

Shrubs species contributions to C sequestration is summarized in Figure 4. The introduced *Prosopis juliflora* had by far the highest average contribution of 3.47 tons of C per hectare. Most of which is in the above ground parts (83.3%) with the remaining C allocated belowground (i.e. 0.58 tons per hectare). An average C sequestration of 0.89 tons per hectare was estimated for *Arthrocnemum macrostachyum* and 0.76 tons per hectare for *Haloxylon salicornicum*. Both species are important in the saline soils of the UAE; about 83% and 84% of the Carbon is in the shoot system of each shrub, respectively. *Haloepelis perfoliata*, however, contributed the least C to the desert systems of the UAE. An average C sequestration of about 0.04 tons per hectare was estimated for this halophyte species common in salt marshes.

Variations in litter C content

The percent litter content from various plant sources is summarized in Table 3. The average C content of litter from *A. tortilis* was the highest at about 49%. Litter from *S. imbricata* and *A. macrostachyum* had average C content of 48.8% and 47.7%, respectively. The lowest C levels were measured in *P. juliflora* litter, at about 36.5%.

Discussion

Here we measured the potentials of C pools in different land forms (soil/vegetation associations) as affected by the dominant tree and shrub species. Plant characteristics regulate soil carbon storage through the outcomes of C assimilation and its storage belowground³¹. Changes in ecosystem soil C may be in response to a variety of management as well as environmental factors³². It therefore aimed to accurately quantify the

amount of C removed from the atmosphere and stored in above and belowground C pools of plants that are native to the UAE arid environment. The C stored in aboveground components constitutes one-third of that in soils³³. However, this differs from ecosystem to ecosystem as a relationship between soil C and climate have been reported, especially the positive impact of precipitation³⁴. Mountain valleys sequestered the highest C in the phytomass compartment, with an average of 3.6 tons per hectare. It may be because of the limited anthropogenic impact on such ecosystems in the UAE. Human intrusions, such as that in relation to degradation, added to the further depletion of soil C³.

Desertification, degradation of soil and vegetation because of anthropogenic factors, among others, affect close to 4 billion ha globally³⁵. The rate of desertification is estimated at 5.8 million ha per year³⁵. Here it was the case for gravel plains, which was the most affected soil/vegetation association in the UAE. Unwanted plant species, which were indicators of overgrazing, were most abundant in such plains³⁶. The proportions of carbon sequestration was highest in the soil compartment within sand plains (i.e. 49.1%). Soil carbon sequestration was lowest for gravel plains, with an average of 28.3%. At the species level, the highest contribution was from *Z. spina christi*, with an average of 1.73 tons per hectare of sequestered C. A different *Ziziphus* was reported to sequester 24 Mg/Ha³⁷. For the introduced *P. juliflora*, we reported by far the highest average contribution of tons of C per hectare, most of which is in the aboveground part. It is important to note that such introduced species are widespread and still occupying more areas in the UAE. In semi-arid areas to which *Prosopis* and *Acacia* are adapted, 6,210⁹ Mg of carbon would be sequestered. Litter is an important aspect in the dynamics of soil C pools. Biological and physical processes play critical functions in litter decomposition³⁸. In this study, we report that the average C content of litter from *A. tortilis* was the highest at about 49%. A large accumulation of C in the litter layer was reported in a forest

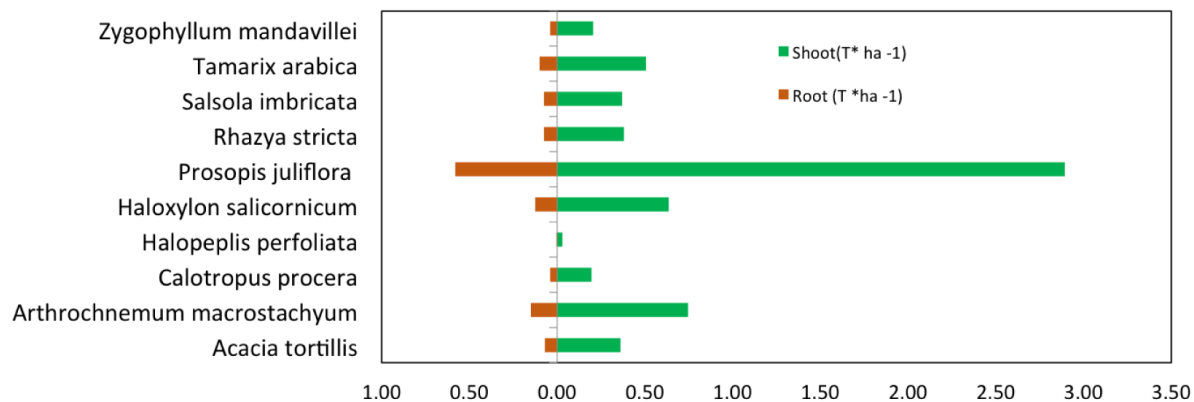


Figure 4. Carbon stocks (shoot and root components) in the most important shrub species in the UAE.

Table 3. Carbon content of litter from various plant sources in the study plots.

Litter Source	% C
<i>A. tortilis</i>	49.2
<i>P. juliflora</i>	36.5
<i>S. imbricata</i>	48.8
<i>A. macrostachyum</i>	47.7
<i>Z. mandavillei</i>	36.9

ecosystem³⁹. Land management also plays important roles in litter accumulation. Higher litter accumulation was reported when the land management was appropriate⁴⁰.

Conclusions

In short, some land forms, such as mountain valleys, were shown to sequester more C than others, which constitutes a good reason to improve their conditions and minimise anthropogenic impacts. Focusing future identification of protected areas can be a practical option to improve these types of soil associations. Few shrub/tree species were also reported to have high potentials for C sequestration in the hyper-arid environment of the UAE. Species such *P. juliflora* are an example of floral species that accumulate large amounts of soil C. Such species, despite its negative invasive features, may be a good candidate to re-vegetate many of the marginal lands in the UAE.

Data availability

Underlying data

Figshare: Soil Carbon. <https://doi.org/10.6084/m9.figshare.8281430>³⁰.

This project contains SOILCarbon.zip, which contains the following underlying data:

- PlantC.csv (detailing the plant carbon weight, where 'Before + C' represents the weight of the plant and crucible before heating and 'After + C' represents the weight of the plant and crucible after heating).
- PlantSamples.csv (detailing the weight of plant samples before and after heating).
- ShrubDim.csv (detailing the dimension of the assessed shrubs, where 'basal' refers to the length of the stem, the lefthand 'crown' refers to the length of the crown of the shrub and the righthand 'crown' refers to the width of the crown).
- SoilC.csv (detailing the soil carbon weight; for 'kind of sample', 'in' refers to soil taken from next to the plant and 'out' refers to soil taken from the same site but away from the plant).
- TreeDim.csv (Detailing the dimensions of the tree).

Data are available under the terms of the [Creative Commons Attribution 4.0 International license](#) (CC-BY 4.0).

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