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Comparative Assessment of Carbon Sequestration Capability in Plant and Soil of Three Dominant Halophytic Species, Including Aeluropus littoralis, Halocnemum strobilaceum, and Seidlitzia rosmarinus in Fars Province

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ABSTRACT

Aims In the present work, carbon sequestration in different organs of 3 dominant halophytes of saltlands (A. littoralis, H. strobilaceum, and S. rosmarinus) as well as soil carbon sequestration of the corresponding habitats were examined.

Materials & Methods The aboveground and belowground organs of 3 halophyte species were randomly sampled and oven dried. Three soil samples were taken from 0-0.15 and 0.15-0.3 m soil depths (SD). From these, soil organic carbon (SOC), soil texture (sand, silt, and clay), bulk density (BD), moisture content (MC), electrical conductivity (EC), and soil acidity (pH) were measured.

Findings All of the tested halophytes had more carbon sequestration in the aboveground rather than belowground organs. The highest value of carbon sequestration was observed in S. rosmarinus, which was about 18% and 90% more than the reported values of H. strobilaceum and A. littoralis, respectively. Soil with S. rosmarinus presented significantly greater content of organic carbon (1.5%) compared with H. strobilaceum (0.64%) and A. littoralis (0.63%), respectively. The results confirmed that soil top layer (0-0.15m) of patch area had more capability to sequester carbon (1.81%) in S. rosmarinus habitat compared with the other species.

Conclusion All the tested plants had higher carbon sequestration in the aboveground organs compared with the belowground parts. The leaves had presented the lowest value compared with shoots and roots. The soil organic carbon of the species habitat varied from 0.63 (A. Littoralis) to 1.5% (H. strobilaceum). Moreover, with increasing the soil depth, carbon sequestration of the underlying soil layers decreased.

Keywords Saltland; Halophyte Plants; Carbon Sequestration; Soil Organic Carbon; Halocnemum Strobilaceum; Seidlitzia Rosmarinus; Aeluropus Littoralis

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Introduction

There are rising concerns about the impacts of climate change on human societies and natural ecosystems [1-4]. Industrial activities and combustion of fossil fuels have contributed to emission of 78% of total greenhouse gasses (GHGs) in the world. It is expected that growth of GHG emissions will persist, driven by growth in economic activities and global population [4].

Different policies have been suggested to reduce the emission of GHGs and decrease the negative impacts of climate change [5, 6]. Movement of CO_2 from the atmosphere and storing it in soil and vegetation can be regarded as a sustainable simple procedure in various ecosystems, particularly in the widespread arid and semi-arid lands of Iran [7, 8].

It is estimated that salt-afflicted lands cover about 25 million ha (15%) of the areas in Iran, of which 8.5 million ha is severely affected and classified as saline or saline-alkali soil [9, 10]. Saltlands have much potentials for productive use and saline lands can be rehabilitate for uses such as grazing of livestock, harvesting of salts and minerals, production of salt-tolerant crops, and recreational activities [11-13]. Due to the high restrictions exerted by prevalent agricultural activities, the mentioned saltlands are mainly used as a source for livestock feeding or a place for performing recreational activities in the arid regions of southern Iran [14]. Implementation of carbon sequestration projects in arid lands, which is in line with sustainable ecosystem management, can be considered one of the most significant issues worldwide, which aimed at improving the local economy, reducing the environmentally-induced migration, and reducing the negative impacts of climate change on local populations [15-17].

Indigenous halophyte species are the main vegetation communities through saltlands and Salt Lake shores of arid ecosystems in Iran. It is estimated that more than 50 plant species are grown in the saltlands of Fars Province, Iran. A good number of the mentioned species are prevailing perennial halophytes that are currently used for livestock feeding during the cold seasons and they have high potential for reclamation of rangelands and salt-induced arid lands [13, 18]. *Aeluropus littoralis* Trin., *Halocnemum strobilaceum* M.B., and *Seidlitzia rosmarinus* Bge. can be found in most salt-induced regions (260000 ha) of Fars, Iran. *A. littoralis* is a rhizomatous perennial grass of the Poaceae family that grows wildly in tropical and temperate parts of Asia, North Africa, and South Europe (Figure 1a). It is widely distributed in the salt deserts of Iran [19]. *S. rosmarinus* and *H. strobilaceum* are the other two dominant halophytes belonging to the Chenopodiaceae family with shrubby life form that occur in the saline soils of arid lands in Southern Fars (Figures 1b and 1c). *H. strobilaceum* mainly occurs in saline soils of Northern Africa, Western Asia, and as far as Eastern Mongolia and China [20, 21].

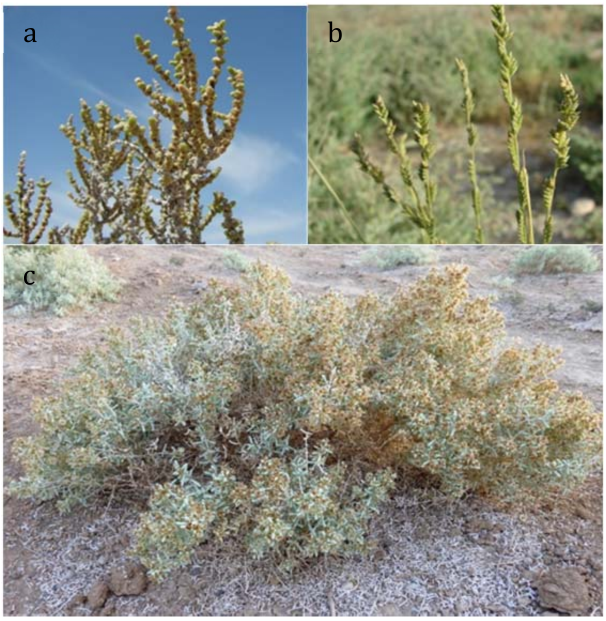

Figure 1) Three studied plants a: *Halocnemum strobilaceum,* b: *Aeluropus littoralis*, and c: *Seidlitzia rosmarinus*

Moreover, it is a dominant species in salt desert of Southern Fars, Iran. Although some ecological, morphological, and physiological aspects of the mentioned species were addressed in several studies [22-28], the capability of these halophytic plants and their habitats to sequester carbon is not well documented in the arid ecosystems of Southern Iran. Then, the questions of the current study were:

1-Which plant species has more carbon sequestration potential?

2-Which plant organ could reserve more carbon?

3-What is the relationship between soil properties and sequestrated carbon?

In this research, carbon sequestration in different organs of 3 different halophytes, including *A. littoralis, H. strobilaceum*, and *S. rosmarinus* as well as soil carbon sequestrations of the related habitats was examined and compared. Also, the relationship between soil factors and sequestrated carbons was addressed.

Materials and Methods

Study area: The study area is located in 70 km north-west of Lar, Fars province, Iran at 53° 47′ 04″ N to 53° 48′ 26″ N of latitude and 27° 56′ 18″ N to 27° 58′ 01″ of longitude with mean elevation of about 760 m above sea level (Figure 2).

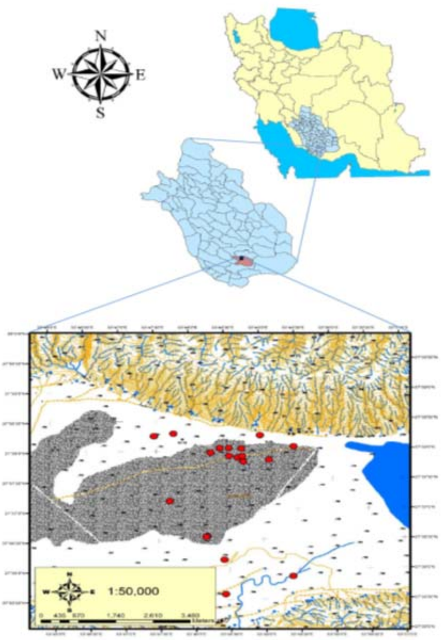

Figure 2) Location map of the study area

Geologically, the study area presents a salt pan with original alluvial deposited materials and annual wet (from December to April) and dry (from May to November) periods with clay-loam and sandy-clay- loam soil texture. The climate is classified as BWh according to the Köppen-Geiger system [29]. Mean precipitation and average annual temperature are 198.8 mm and 23.6°C, respectively. The study area is employed for local livestock grazing during dry seasons.

Plant and soil sampling procedure: Three relatively uniform stands of each tested plant (*A. littoralis, S. rosmarinus*, and *H. strobilaceum*) were randomly selected (representative stand), and aboveground (shoots and leaves) and belowground (roots thicker than 1mm) parts of each selected plant were separately collected, weighted, and stored in paper bags to determine their biomass and carbon content. Soil samples were taken from underneath of each plant (patch) from 0-0.15 and .015-0.3m depths, using a 10-cm diameter core sampler and, then, they were immediately weighted. Simultaneously, 3 soil samples were selected from the existing spaces between the plants (inter-patch) to be compared with samples of patch area. Soil bulk density (BD) was determined in each plant patch and inter-patch area, using 8-cm diameter core samplers.

Laboratory analysis: Plant samples (shoots, leaves, and roots) were separately oven-dried at 105°C for 48 h and subsequently reweighted. Then, samples of each plant parts were hammer-milled to pass through 0.5 mm sieve and prepared to conduct carbon content measurements based on standard method of combustion in an electrical oven. According to Schlesinger *et al*. and Food and Agriculture Organization (FAO), the carbon content of vegetation may be estimated by taking a fraction of biomass, using the following factor [30, 31]:

$C=0.475\times B$ (Equation 1)

, where C is carbon content and B is the oven-dry biomass. Subsequently, carbon content of various parts of plants was determined and the mean values were utilized in the statistical analyses.

Soil samples of patch and inter-patch areas were air-dried and sieved through a 2-mm screen. Soil organic carbon (SOC) was specified by applying the Walkley-Black method [32]. Soil texture was determined, using hydrometer method. Soil pH was determined, using an electric pH meter and Electrical Conductivity (EC) was determined from a 1:1 soil-water suspension, using an electric conductivity meter. Also, soil bulk density was determined by a core sampler of 8 cm diameter [33, 34].

Statistical analysis: In order to analyze the obtained data, 2 separate factorial experiments with a completely randomized design (CRD) were performed. The first experiment focused on different plant species (PS) and different plant organs (PO), i.e. shoots, leaves, and roots. It examined the interactions between PS and PO with 3 replications of each variable. The second experiment examined the soil properties in different habitats of PSs, various soil depths (SD), and patch/inter-patch (PI) areas of plants. The under-plant area and the open space between plants were labelled as the patch and inter-patch areas, respectively. Moreover, the interaction between all traits (PS×PI, PS×SD, PI×SD, and PS×PI×SD) was analyzed, using a GLM procedure. Duncan's multiple range test ($p \leq 0.01$) was employed for comparing the means. To scrutinize the relationships between SOC and physical and chemical properties of the selected soil, bivariate correlation analyses were carried out. All the statistical analyses were performed, using SPSS 19 software [35].

Findings

Plant carbon sequestration: The amount of carbon sequestration in 3 plant species was significantly different ($p \leq 0.01$). Moreover, PO including leaves, shoots, and roots of the 3 studied halophytes indicated significant differences with respect to the amount of carbon sequestration at $p \leq 0.01$ (Table 1). Furthermore, the interaction of PS and PO had significant effect on carbon sequestration in various plant species (Table 1).

Table 1) The effect of PS, PO, and interaction of PS×PO on reserved carbon of *A. littoralis*, *S. rosmarinus*, and *H. strobilaceum*

Source of variation	Mean square	F	p- value
Plant species (PS)	7401.1[a]	1082.8	0.000
Plant organ (PO)	22751.1[a]	3228.6	0.000
Interaction (PS×PO)	5148.0[a]	753.1	0.000
Error	6.8		

[a] Significant at ($p \leq 0.01$)

Generally, *H. strobilaceum* and *S. rosmarinus* presented significantly higher capability for carbon sequestration than *A. littoralis* (Table 2). Besides, *H. strobilaceum* showed 18.0% more stored carbon than *S. rosmarinus*. In all 3 species, the highest and the lowest values of sequestrated carbon were observed in shoots with a mean value of 95.6 gr and leaves with a mean value of 3.0 g, respectively (Table 2). The roots of *H. strobilaceum* with 144.7 g and leaves of *S. rosmarinus* with 2.1 g presented the highest and lowest values of carbon sequestration among the halophytes studied (Table 2). The stored carbon in roots was 97, 98, and 69% more than the stored carbon in leaves of *H. strobilaceum*, *S. rosmarinus*, and *A. littoralis*, respectively (Table 2). Aboveground parts, i.e. shoots plus leaves, revealed significantly higher capability of carbon sequestration than belowground plant organs (roots >1 mm at 0.3 m soil top layer) in all 3 species (Table 2).

Means followed by the same letter within one column or row do not significantly differ at $p \leq 0.01$, using Duncan's multiple range test.

Table 2) Mean comparison of carbon sequestration (Mean± SD) in 3 studied halophytes and different plant organs

Plant species	Plant organ (g C per individual plant)			Mean
	Leaves	Shoots	Roots	
A. littoralis	2.6^{h}±1.2	8.5^{e}±1.3	5.5^{f}±0.6	5.5 C
S. rosmarinus	2.1^{i}±0.3	133.8^{b}±6.0	10.8^{d}±0.7	48.9 B
H. strobilaceum	4.3^{g}±1.0	144.7^{a}±4.1	30.2^{c}±1.3	59.7 A
Mean	3.0 C	95.6 A	15.5 B	

Soil carbon sequestration: The results of analysis of variance indicated a significant effect of PS, PI, SD, and the interaction between these traits (PS×PI, PS×SD, PI×SD, and PS×PI×SD) on SOC as well as the other soil physical and chemical properties of the studied area (Table 3). All 3 species revealed significant differences ($p \leq 0.01$) in terms of SOC as well as sand, silt, clay, BD, MC, EC, and pH values. Underneath plants (patch), all values of soil properties were significantly different, with the exception of clay and pH values. The results of two different soil depths showed different values of SOC and all the other soil properties, with the exception of sand percentage (Table 3).

Among 3 studied halophytes, soil of *A. littoralis* showed the highest values of sand, BD, and MC. The plant species of *S. rosmarinus* had the highest content of SOC, silt, and EC in comparison to the other 2 studied plants. The SOC value of 3 species habitat varied from 0.63% to 1.5%. Soils of *S. rosmarinus* habitat indicated 57% and 58% more SOC value than *H. strobilaceum* and *A. littoralis* habitats, respectively (Table 4).

The results of mean comparison indicated 22% more SOC value in patch area compared with inter-patch area. Moreover, silt and MC had values of 11% and 41% in patch area, which were higher in comparison to the values of inter-patch area. The bulk density, EC, and sand had significantly greater values, i.e. 2.1%, 7.4%, and 10.9%, respectively, in the inter-patch or open space area compared with the patch area or underneath plants (Table 4).

Soil depth had a significant effect on both SOC content and all the other soil characteristics (Table 3). In comparison with lower layers (15-30 cm), the top 0-15 cm soil layer indicated 20% more stored carbon with more significant contents of BD and pH (Table 4). As the soil depth increased, the bulk density increased as well by about 6.5 %; however, soil organic carbon decreased by 20%. On the other hand, various soil depths showed different amounts of soil water content as increasing the soil depth was associated with 22% increase of soil water content (Tables 4 and 5). On the other hand, the results of the present study showed that the highest (1.81%) and the lowest (0.19%) values of SOC were related to *S. rosmarinus* (SD: 0-15 cm, patch) and *A. littoralis* (SD: 0.15-0.3m, inter-patch) habitats, respectively (Table 5).

The correlation coefficient analysis of soil properties indicated that SOC demonstrated a significant positive correlation (p≤0.01) with clay and a significant negative correlation with sand and BD (p≤0.01). Furthermore, sand showed a significant negative correlation with silt and BD. Moreover, the clay was negatively correlated with BD of the considered habitats (Table 6).

Table 3) ANOVA results of the effect of PS, PI, SD and their interactions on SOC and soil properties

Source of variation	Mean Square							
	Sand(%)	Silt (%)	Clay (%)	BD (g cm^{-3})	MC (%)	EC (ds m^{-1})	pH	SOC (%)
Plant species (PS)	4328.3^{a}	3706.7^{a}	124.0^{a}	0.07^{a}	502.1^{a}	37.3^{a}	0.02^{ns}	3.53^{a}
Patch/Inter-patch (PI)	142.0^{a}	245.4^{a}	14.0^{ns}	0.005^{b}	583.7^{a}	5.4^{a}	0.03^{ns}	0.58^{a}
Soil depth (SD)	0.8^{ns}	38.0^{a}	27.5^{b}	0.09^{a}	142.6^{a}	4.78^{a}	0.3^{a}	0.42^{a}
PS×PI	165.9^{a}	256.7^{a}	10.6^{ns}	0.008^{a}	70.7^{a}	23.8^{a}	0.001^{ns}	0.09^{a}
PS×SD	41.7^{a}	130.3^{a}	119.7^{a}	0.005^{a}	14.8^{a}	6.6^{a}	0.1^{b}	0.04^{b}
PI×SD	37.0^{a}	5.4^{ns}	14.0^{ns}	0.00002^{ns}	42.3^{a}	21.9^{a}	0.5^{a}	0.11^{a}
PS×PI×SD	32.1^{a}	188.1^{a}	289.9^{a}	0.002^{ns}	2.3^{ns}	1.95^{b}	0.01^{ns}	0.04^{b}
Error	3.8	3.6	4.6	0.001	0.7	0.4	0.3	0.008
±SE	0.32	0.31	0.36	0.005	0.15	0.11	0.03	0.01

ns: non-significant; a: Significant at (p≤0.01); b: Significant at (p≤0.05); SE: Standard error

Table 4) Mean comparison of the main effect of plant species, patch/Inter-patch area and soil depths on the soil properties and SOC sequestration

Plant species	Mean± SD							
	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	MC (%)	EC (ds m^{-1})	pH	SOC (%)
A. Littoralis	56.4^{a}±6.2	22.3^{c}±7.8	21.2^{b}±4.4	1.56^{a}±0.08	21.0^{a}±4.0	8.5^{b}±1.2	7.2^{a}±0.2	0.63^{b}±0.17
H. strobilaceum	24.2^{b}±3.6	48.0^{b}±4.7	26.9^{a}±2.8	1.46^{b}±0.04	17.9^{b}±3.7	7.6^{c}±2.1	7.3^{a}±0.2	0.64^{b}±0.09
S. rosmarinus	22.9^{b}±3.9	55.5^{a}±7.3	21.5^{b}±3.1	1.41^{c}±0.06	8.4^{c}±2.8	11.0^{a}±1.8	7.3^{a}±0.1	1.50^{a}±0.25
Patch/Inter-patch								
Patch	32.5^{b}±7.0	44.8^{a}±6.3	22.5^{a}±4.0	1.46^{b}±0.07	19.6^{a}±7.3	8.7^{b}±2.7	7.3^{a}±0.2	1.07^{a}±0.56
Inter-patch	36.5^{a}±8.4	39.6^{b}±9.3	23.8^{a}±7.5	1.49^{a}±0.15	11.5^{b}±5.2	9.4^{a}±1.7	7.3^{a}±0.2	0.83^{b}±0.36
Soil depth (m)								
0-0.15	34.3^{a}±7.5	43.2^{a}±8.3	22.3^{b}±6.5	1.43^{b}±0.06	13.6^{b}±7.5	9.4^{a}±2.5	7.2^{b}±0.2	1.05^{a}±0.47
0.15-0.3	34.6^{a}±8.9	41.2^{b}±7.8	24.0^{a}±5.3	1.53^{a}±0.08	17.6^{a}±7.1	8.7^{b}±1.9	7.4^{a}±0.2	0.84^{b}±0.56
Mean± SE	34.5±0.32	42.25±0.31	23.2±0.36	1.48±0.005	15.6±0.1	9.1±0.1	7.3±0.03	0.95±0.01

Means with the same letter within each column are not significantly different, using Duncan's multiple range test (p≤0.01)

Table 5) Mean comparison of the interaction effects of different plant species, patch/Inter-patch area and soil depths on the soil properties and SOC sequestration

Plant species	Soildepth (m)	Mean± SD							
		Sand(%)	Silt (%)	Clay (%)	BD(gcm^{-3})	MC (%)	EC (ds m^{-1})	pH	SOC (%)
A. littralis									
Patch	0-0.15	50.0±1.0	32.3±2.5	17.6±2.0	1.4±0.01	26.1±1.6	8.3±0.8	7.4±0.3	0.86±0.09
	0.15-0.3	52.5±2.1	26.6±2.2	21.5±1.3	1.5±0.01	29.6±1.0	8.9±0.7	7.0±0.1	0.77±0.07
Inter-patch	0-0.15	58.6±2.8	14.0±1.0	27.3±1.7	1.5±0.01	9.4±0.4	10.0±0.3	7.1±0.1	0.72±0.04
	0.15-0.3	64.6±2.8	17.0±3.1	18.3±1.5	1.6±0.05	19.1±0.7	7.0±0.6	7.4±0.2	0.19±0.01
H. strobilaceum									
Patch	0-0.15	26.0±2.0	47.3±1.5	26.6±2.0	1.4±0.02	19.9±1.0	4.9±0.8	7.2±0.04	0.71±0.06
	0.15-0.3	26.6±1.5	45.6±1.1	27.6±0.5	1.4±0.01	20.7±0.4	6.5±0.3	7.4±0.05	0.61±0.06
Inter-patch	0-0.15	25.6±1.1	46.0±1.0	28.3±0.5	1.4±0.03	11.8±0.5	9.5±0.4	7.0±0.2	0.65±0.12
	0.15-0.3	18.6±1.5	56.3±2.0	25.0±1.4	1.5±0.03	16.7±1.5	9.7±0.1	7.7±0.05	0.57±0.06
S. rosmarinus									
Patch	0-0.15	18.1±1.7	59.1±1.0	22.6±2.3	1.3±0.03	10.1±0.3	11.6±0.8	7.2±0.2	1.81±0.04
	0.15-0.3	21.0±2.0	58.6±0.5	19.3±2.0	1.4±0.02	11.3±0.6	11.9±1.1	7.2±0.1	1.69±0.21
Inter-patch	0-0.15	27.8±2.2	60.8±3.2	11.3±2.3	1.3±0.01	4.2±0.7	12.4±0.1	7.2±0.1	1.58±0.11
	0.15-0.3	23.6±1.4	43.6±0.2	32.6a±1.1	1.4±0.01	8.1±0.3	8.2±0.4	7.5±0.08	1.21±0.06

Table 6) Correlation coefficient among different soil properties and SOC

Variables	Sand (%)	Silt (%)	Clay (%)	BD (gcm^{-3})	EC (dsm^{-1})	pH	SOC (%)
Sand (%)	1						
Silt (%)	-0.93[a]	1					
Clay (%)	-0.25[ns]	-0.11[ns]	1				
BD (gcm^{-3})	0.69[a]	-0.74[a]	0.12[ns]	1			
EC (dsm^{-1})	-0.25[ns]	0.41[ns]	-0.43[ns]	-0.39[ns]	1		
pH	-0.21[ns]	0.16[ns]	0.11[ns]	0.18[ns]	0.22[ns]	1	
SOC (%)	-0.54[ns]	0.65[b]	0.68[a]	-0.78[a]	0.72[a]	0.19[ns]	1

ns: non-significant; a: Significant at ($p \leq 0.01$); b: Significant at ($p \leq 0.05$)

Discussion

A significantly higher total carbon sequestration was observed in plant parts of *H. strobilaceum* and *S. rosmarinus* compared with *A. littoralis*. The finding can be attributed to more woody biomass and more lignocelluloses content in woody shrubs, which are absent from grasses [36, 8]. As expected, total carbon sequestration value of woody and shrubby species of *H. strobilaceum* and *S. rosmarinus* was 90% and 88% more than that of *A. littoralis* per individual plant. The findings of the present study are supported by the justification provided by Gao *et al*. and Roy *et al*. [37, 38]. Their studies have reported that shrubs such as *Amygdalus scoparia* and other tree/shrub life forms had more carbon content in comparison with non-woody forb and grass life forms. Accordingly, as shown in Table 2, woody organs of plants such as roots and shoots of *S. rosmarinus* and *H. strobilaceum* indicated more capability to store the carbon compared with organs of *A. littoralis* [24, 25, 9].

Globally, measured SOC is strongly and positively correlated with modelled woody litter stocks [39], and the plant biomass is correlated with SOC [40].

In general, carbon sequestration of the aboveground organs (leaves and shoots) of the studied species was significantly higher than that of the belowground (root>1mm in 0.3m soil top layer) organ. The leaves had presented the lowest value compared with shoots and roots in all 3 halophyte species. The observed finding might be due to the fact that plants in arid ecosystems adapt smaller leaf size and fewer branches in terms of morphology, develop root system to reduce water loss, and can tolerate the harsh environment [41]. The findings of the current study are in line with those of previous studies, which indicated that aboveground plant organs such as shoots and leaves had more potential to sequester carbon [42, 8, 7].

The present study revealed that soil in *A. littoralis* habitat had more sand, less clay, and lower SOC compared with the other 2 species. Furthermore, a good number of studies had indicated that soil properties such as soil texture and bulk density could affect sequestration of soil organic carbon [43, 44]. As already presented, in *S. rosmarinus* habitat with lower values of bulk density and sand, the organic carbon sequestration of soil was more than that of *A. littoralis* species. The results of the present study are in accordance with those of previous studies reporting the significant effect of BD and sand content on soil carbon sequestration [45].

On the other hand, patch or underneath area of the considered species indicated higher concentration of carbon in the soil profile (Tables 4 and 5). The effect of accumulation of plant litter and residuals of vegetation on soil quality, and carbon sequestration has been indicated in other studies. For instance, Bikila *et al*. revealed that more aboveground carbon was observed in dense vegetation of the experimental area compared with open spaces in sparse vegetation stands [46].

Furthermore, the findings of the present study indicated that as soil depth increased, BD and MC values of the soil increased, as well. However, with increasing soil depth, carbon sequestration in soil layers was decreased. This might be due to the negative relationship between soil depth and some physical properties of soil such as BD. Ghanbarian *et al*. [8] indicated that the top layer of the studied area in Iran had less BD value and more carbon sequestration value in comparison with lower layers of soil.

Similar to the observations reported by Jobbagy and Jackson [47], the top layer of soil had the highest amount of carbon sequestration. Similarly, Schuman *et al*. [48] and Li *et al*. [49] reported that carbon sequestration is influenced by soil depth, texture, and BD.

Generally, the maximum value of sequestrated carbon was observed in *S. rosmarinus* (SD: 0-15 cm, patch zone) and the minimum carbon sequestration was measured in *A. littoralis* (SD: 15-30 cm, inter-patch zone; Table 5). Accordingly, the results indicated the significant positive effect of patch area on carbon accumulation and moisture content. In addition, higher infiltration rate and enhancement of soil fertility were observed, as explained in earlier studies [50, 51, 44].

The results of the correlation analysis of the soil properties indicated that soil BD had a significantly positive correlation with sand content (Table 6). However, soil BD was negatively correlated with silt. On the other hand, SOC value indicated positive correlation with silt and clay, while it revealed a significant negative correlation with BD. Although the correlation of sand and SOC was not significant ($p \leq 0.05$), they indicated a negative relationship. Given the positive relationship of SOC with clay and silt and its negative correlation with BD and sand, the results of the present study are in line with name of authors' (date) research, which explained that increased values of soil BD and sand or decreased values of clay or silt content relates to a reduction of soil organic carbon of various natural ecosystems [52, 48, 35, 8, 7].

Conclusion

Soil and vegetation are two important carbon pools in arid ecosystems globally. In the present work, carbon sequestration potential of above- and belowground parts of 3 dominant halophytes (*A. littoralis, S. rosmarinus*, and *H. strobilaceum*) as well as soil organic carbon of the related habitats in southern saltlands of Fars, Iran were examined. The results indicated that carbon sequestration capability can vary based on plant species, parts of the plant organs, and soil characteristics of different habitats. All the studied plants had more carbon storage in the aboveground organs (shoots and leaves) compared with the belowground parts (roots). Moreover, the obtained findings indicated dissimilar values of sequestrated carbon in different plant organs of the mentioned species.

Furthermore, the results shed light on the effect of soil habitat properties such as BD and soil texture on the total soil carbon sequestration in the studied saltlands. The present study revealed that soil and vegetation of saltlands can be considered important carbon pools in the arid ecosystems. Most importantly, several sustainable management practices, including optimum grazing and vegetation restoration should be conducted to improve carbon sequestration in soil and vegetation, reduce the risk of desertification, and, consequently, mitigate the negative effects of global warming in the arid ecosystems of southern Iran.

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References

1- Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJ, et al. Ecological responses to recent climate change. Nature. 2002;416(6879):389-95.

2- Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. Impact of regional climate change on human health. Nature. 2005;438(7066):310-7.

3- Lindner M, Maroschek M, Netherer S, Kremer A, Barbati A, Garcia-Gonzalo J, et al. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For Ecol Manag. 2010;259(4):698-709.

4- Intergovernmental Panel on Climate Change. Climate change 2014: Mitigation of climate change. New York: Cambridge University Press; 2015.

5- Sinn HW. Public policies against global warming: A supply side approach. Int Tax Public Financ. 2008;15(4):360-94.

6- Meinshausen M, Meinshausen N, Hare W, Raper SC, Frieler K, Knutti R, et al. Greenhouse-gas emission targets for limiting global warming to 2 degrees C. Nature. 2009;458(7242):1158-62.

7- Sadeghi H, Ghasemi Nejad Raeini M. Estimation and comparison of carbon sequestration by Zygophyllum atriplicoides and Gymnocarpus decander. Clean Soil Air Water. 2016;44(3):284-90.

8- Ghanbarian GA, Hassanli AM, Rajabi Noghab V. Comparing potential carbon sequestration of different parts of mountain almond and grape plants and soil in Fars province. J Nat Environ. 2015;68(2):257-65. [Persian]
9- Hadi MR. Biotechnological potentials of Seidlitzia rosmarinus: A mini review. Afr J Biotechnol. 2009;8(11):2429-31.
10- Roozitalab MH, Siadat H, Farshad, A. The soils of Iran. 1st Edition. New York: Springer; 2018.
11- Barrett-Lennard EG. Restoration of saline land through revegetation. Agric Water Manag. 2002;53(1-3):213-26.
12- Barrett-Lennard EG, Bathgate AD, Malcolm CV. Saltland pastures in Australia, a practical guide. 2nd Edition. Kensington: WA Government Dept of Agriculture and Food; 2003.
13- Richter GM, Agostini F, Redmile-Gordon M, White R, Goulding KWT. Sequestration of C in soils under Miscanthus can be marginal and is affected by genotype-specific root distribution. Agric Ecosyst Environ. 2015;200:169-77.
14- Khodahami G, Kowsar SA, Habibian SH, Tayebi M. Study of saltlands, halophyte plants and mechanisms for salt tolerance in Fars province, 3rd National Congress of Rangeland and Range Management, Karaj, Iran. 2004. p. 34-49. [Persian]
15- Forest, Rangeland and Watershed Organization (FRWO). Carbon sequestration project implementation report 2011. Tehran: Ministry of Jihad Agriculture; 2012. p. 28. [English]
16- Falsolaiman M, Sadeghi H, Chakoshi B. Carbon sequestration international project, successful sample in creating people and participation organizations in village development (Hossein Abad plain, South Khorasan province, East of Iran). Span J Rural Dev. 2013;4(1):9-23.
17- Sharifi Rad M, Sharifi Rad J, Teixeira Da Silva JA, Mohsenzadeh S. Forage quality of two halophytic species, Aeluropus lagopoides and Aeluropus littoralis, in two phenological stages. Int J Agron Plant Prod. 2013;4(5):998-1005.
18- Bor NL. Flora Iranica. Rechinger KH, editor. Vienna: Akademische Druk-u. Verlagsastalt; 1970. pp. 419-23. [Latin]
19- Qu XX, Huang ZY, Baskin JM, Baskin CC. Effect of temperature, light and salinity on seed germination and radicle growth of the geographically widespread halophyte shrub Halocnemum strobilaceum. Ann Bot. 2008;101(2):293-9.
20- Khan MA, Böer B, Kust GS, Barth HJ. Sabkha ecosystems, West and central Asia. 2nd Volume. Dordrecht: Springer Science and Business Media; 2008. [English]
21- Abbadi GA, El-Sheikh MA. Vegetation analysis of Failaka Island (Kuwait). J Arid Environ. 2002;50(1):153-65.
22- Nilhan TG, Emre YA, Osman K. Soil determinants for distribution of Halocnemum strobilaceum Bieb.(Chenopodiaceae) around lake Tuz, Turkey. Pak J Biol Sci. 2008;11(4):565-70.
23- Baghestani Maybodi N, Zare MT. Some ecological requirements and exploitation of Seidlitzia rosmarinus in the desert region of Yazd province. Environ Sci. 2009;6(3):31-42. [Persian]
24- Assadi M. Flora of Iran: Chenopodiaceae. 38th Volume. Tehran: Research Institute of Forests and Rangelands; 2001. [Persian]
25- Kurkova EB, Kalinkina LG, Baburina OK, Myasoedov NA, Naumova TG. Responses of Seidlitzia rosmarinus to salt stress. Biol Bull Russ Acad Sci. 2002;29(3):221-9.
26- Song J, Feng G, Zhang F. Salinity and temperature effects on germination for three salt-resistant euhalophytes, Halostachys caspica, Kalidium foliatum and Halocnemum strobilaceum. Plant Soil. 2006;279(1-2):201-7.
27- Barhoumi Z, Djebali W, Smaoui A, Chaïbi W, Abdelly C. Contribution of NaCl excretion to salt resistance of Aeluropus littoralis (Willd) Parl. J Plant Physiol. 2007;164(7):842-50.
28- Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift. 2006;15(3):259-63.
29- Schlesinger WH, Bernhardt ES. Biogeochemistry: An analysis of global change. Waltham: Academic Press; 2013.
30- FAO. Carbon content estimation: Carbon content of vegetation [Internet]. Rome: FAO; 2016 [cited 2017 Oct 13]. Available from: http://www.fao.org/forestry/17111/en/.
31- Nosetto MD, Jobbágy EG, Paruelo JM. Carbon sequestration in semi-arid rangelands: Comparison of Pinus ponderosa plantations and grazing exclusion in NW Patagonia. J Arid Environ. 2006;67(1):142-56.
32- Page AL, Miller RH, Keeney DR, editors. Methods of soil analysis, part 2: Chemical and microbiological properties. Madison WI: American Society of Agronomy/Soil Science Society of America; 1982. pp. 595-624.
33- Carter MR. Soil sampling and methods of analysis. Boca Raton FL: CRC Press; 2008.
34- IBM Corp. IBM SPSS statistics for windows, Ver. 19.0. Armonk NY; 2010.
35- Asner GP, Archer S, Flint Hughes R, James Ansley R, Wessman CA. Net changes in regional woody vegetation cover and carbon storage in Texas Drylands, 1937-1999. Glob Change Biol. 2003;9(3):316-35.
36- Coomes DA, Holdaway RJ, Kobe RK, Lines ER, Allen RB. A general integrative framework for modelling woody biomass production and carbon sequestration rates in forests. J Ecol. 2012;100(1):42-64.
37- Gao YH, Luo P, Wu N, Chen H, Wang GX. Grazing intensity impacts on carbon sequestration in an Alpine meadow on the Eastern Tibetan Plateau. Res J Agric Biol Sci. 2007;3(6):642-7.
38- Roy PK, Samal NR, Roy MB, Mazumdar A. Soil carbon and nutrient accumulation under forest plantations in Jharkhand state of India. Clean Soil Air Water. 2010;38(8):706-12.
39- Potter CS, Randerson JT, Field CB, Matson PA, Vitousek PM, Mooney HA, et al. Terrestrial ecosystem production: A process model based on global satellite and surface data. Glob Biogeochem Cycles. 1993;7(4):811-41.
40- Dean C, Kirkpatrick JB, Friedland AJ. Conventional intensive logging promotes loss of organic carbon from the mineral soil. Glob Change Biol. 2017;23(1):1-11.
41- Brown GW, editor. Desert biology: special topics on the physical and biological aspects of arid regions. New York: Elsevier; 2013.
42- Perera KA, Amarasinghe MD. Carbon partitioning and allometric relationships between stem diameter and total organic carbon (TOC) in plant components of Bruguiera gymnorrhiza (L.) Lamk. and Lumnitzera racemosa Willd. in a microtidal masin Estuary in Sri Lanka. Int J Mar Sci. 2013;3(9):72-8.
43- Suman A, Singh KP, Singh P, Yadav RL. Carbon input, loss and storage in sub-tropical Indian Inceptisol under

multi-ratooning sugarcane. Soil Tillage Res. 2009;104(2):221-6.
44- Li XJ, Li XR, Wang XP, Yang HT. Changes in soil organic carbon fractions after afforestation with xerophytic shrubs in the Tengger desert, Northern China. Eur J Soil Sci. 2016;67(2):184-95.
45- Li YL, Wang L, Zhang WQ, Zhang SP, Wang HL, Fu XH, et al. Variability of soil carbon sequestration capability and microbial activity of different types of salt marsh soils at Chongming Dongtan. Ecol Eng. 2010;36(12):1754-60.
46- Bikila NG, Tessema ZK, Abule EG. Carbon sequestration potentials of semi-arid rangelands under traditional management practices in Borana, Southern Ethiopia. Agric Ecosyst Environ. 2016;223:108-14.
47- Jobbágy EG, Jackson RB. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecol Appl. 2000;10(2):423-36.
48- E Schuman G, H Janzen H, E Herrick J. Soil carbon dynamics and potential carbon sequestration by rangelands. Environ Pollut. 2002;116(3):391-6.
49- Li J, Zhao C, Zhu H, Li Y, Wang F. Effect of plant species on shrub fertile island at an oasis-desert ecotone in the South Junggar basin, China. J Arid Environ. 2007;71(4):350-61.
50- Walker LR, Thompson DB, Landau FH. Experimental manipulations of fertile islands and nurse plant effects in the Mojave desert, USA. West N Am Nat. 2001;61(1):25-35.
51- Perez-Quezada JF, Delpiano CA, Snyder KA, Johnson DA, Franck N. Carbon pools in an arid shrubland in Chile under natural and afforested conditions. J Arid Environ. 2011;75(1):29-37.
52- Dabasso BH, Taddese Z, Hoag D. Carbon stocks in semi-arid pastoral ecosystems of Northern Kenya. Pastoralism. 2014;4:5.