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ORIGINAL PAPER

Capability investigation of carbon sequestration in *Artemisia aucheri* Bioss

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Abstract *Artemisia* spp. is widespread Iranian rangelands, covering more than 50 % of land cover. The present study was conducted to estimate the amount of carbon sequestration in soil containing *Artemisia aucheri* at different soil depths (0–15 and 15–30 cm), as well as its organs (root, shoot and leaves) and some soil chemical and physical characteristics in the SalehAbad region, 41 km north of HajiAbad, Hormozgan, Iran. The results showed that soil with 0–15 cm depth had higher soil pH and moisture percentage, as well as lower nitrogen percentage and organic carbon percentage than soil at deeper depths. Soil samples from 0 to 15 cm depth had higher clay percentage. Multiple regression showed that nitrogen percentage and moisture percentage were the most effective traits contributing to carbon sequestration. Root and leaf plant tissues had higher and lower stored organic carbon, respectively. Overall, the results of this study indicated that the highest carbon sequestration was obtained at a soil depth of 0–15 cm and in the roots of *A. aucheri* in the SalehAbad region. Therefore, by recognizing the species that have more potential for carbon sequestration, as well as more resistance to environmental limits such as salinity and drought, and also to investigate the management factors affecting the sequestration process, regeneration and rehabilitation of rangeland can be followed in terms of carbon sequestration.

Keywords Carbon sequestration · Greenhouse gases · *Artemisia aucheri* Bioss · Soil texture

Introduction

Climate change is one of the most important challenges in sustainable development that bears many negative effects on aquatic and terrestrial ecosystems. The lead factor of climate change is CO_2 accumulation in the atmosphere (Petit et al. 1999). Like other such gases, atmospheric CO_2 absorbs heat that is re-radiated from the Earth's surface, thus producing a greenhouse effect. The present atmospheric concentration of CO_2 is about 385 parts per million (ppm) by volume, but this level is expected to increase significantly over the next few decades due to the burning of fossil fuels and land use changes. The rate of this increase will depend on uncertain economic, sociological, technological and natural developments, but may ultimately be limited by the reduced availability of fossil fuels (Nakicenovic et al. 2000) or CO_2 reduction strategies. A critical feedback that influences the accumulation of atmospheric CO_2 involves the capacities of the oceans and lands that behave as natural sequestration reservoirs, to capture and store carbon dioxide. These ocean and land uptakes depend upon complex relationships, since increasing levels of CO_2 in the atmosphere induce global warming, which in turn influences the ocean and land carbon cycles by reducing their natural capacities to store CO_2 (Cramer et al. 2001; Ghommem et al. 2012). Many technical solutions have been suggested to reduce CO_2 emissions and stabilize the atmospheric CO_2 concentration

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(Yamasaki 2003). One of those solutions is natural carbon sequestration by enhancing the natural sinks for CO_2. For example, forests, rangelands, shrub-lands, farmlands and soils can reduce atmospheric CO_2 by increasing their uptake and storage of that gas (Trabuccoa et al. 2008). As a result, rangelands and shrub-lands are large carbon pools that play important roles in global carbon cycles as natural carbon sinks (Alizadeh et al. 2010). Shrubs, and especially their woody organs, have a high potential for carbon sequestration (Bruce et al. 1999; Gao et al. 2007; Alizadeh et al. 2010). Many arid and semi-arid rangelands of Iran are vegetated from between 5 and 50 %. The annual rainfalls of these areas are between 50 and 300 mm and have the potential to facilitate carbon sequestration by compatible species, which primarily includes woody plants with resistance to low rainfall and soil salinization. If corrective action is implemented in these areas, they are capable to sequester one billion tons of organic carbon. The value of such a huge amount of carbon is equivalent to 20 million tons of oil (UNDP 2000). Moreover, carbon sequestration can be transformed into a global standard and guaranteed business. The transport cost of CO_2 (from atmosphere to soil), due to the increased negative effects of CO_2 on the climate, has been rising. The value of carbon sequestration in rangeland is \$200 for each ton per hectare (Luciuk et al. 2000).

Artemisia spp. is widespread Iranian rangelands accounting for more than 50 % of land cover. The severity of the harsh environment in most places and competitiveness of this species does not allow other species to grow (Mirhaji 2000). Hence, calculating their capability of carbon sequestration would be useful in calculating the carbon sequestration capability of the rangeland. In SalehAbad rangeland (study area), there were two *Artemisia* spp. which were dominant, *Artemisia sieberi* and *Artemisia aucheri*. As the carbon sequestration capability of *A. sieberi* is well documented (Alizadeh et al. 2010), we have decided to conduct research on *A. aucheri*. *Artemisia* is the largest genus of the family Asteraceae and a small herb and shrub. It comprises around 500 species and grows in various areas of Iran (Babaahmadi et al. 2013). *A. aucheri* is an aromatic plant that is used in traditional medicine for treatment of various diseases in various forms, such as astringents, antipoisonings, antiseptics, antiparasitics, stimulants and appetizers, and reduces the rheumatic pains (Pellicer et al. 2011). Moreover, it contains santonian, coumarin and flavonoid, all compounds which undertake antioxidant activity (Farzaneh et al. 2006; Bahrami Karcondi et al. 2010; Dinani et al. 2010). Professionals recommend antioxidants as very beneficial to human health (Siahpoosh and Amraee 2011). Since the debate on climate change and greenhouse gases is a global concern and any action in any part of the world will impact on it, mitigating the effects of climate change and reducing greenhouse gases requires an international will. Countries with limited resources should take necessary steps in this regard. Therefore, the aim of this study was to estimate the amount of carbon sequestration capability in the soil containing *A. aucheri,* as well as its organs (root, shoot and leaves) and some soil characteristics in the SalehAbad region, 41 km north of HajiAbad, Hormozgan, Iran, during 2012.

Materials and methods

Study site

The study site (SalehAbad rangeland) is located near (41 km) the town of HajiAbad, Hormozgan Province, in the south of Iran (Fig. 1). The study area is located on 28°35′–28°38′17″N and 52°48′–55°44′E, which is one of the most important winter quarter rangelands in the Hormozgan Province. This area comprises three parts including: plain, foothills and almost mountainous areas, with altitude ranges from 1464 m in plain areas to 1918 m in mountainous areas above sea level. Its climate is characterized by hot and dry summers and mild winters. The mean annual temperature is 19.8 °C (minimum and maximum temperatures are 8.9 °C in February and 30.2 °C in July, respectively). The mean annual rainfall is approximately 250 mm. The average rainfalls of different months during 2002–2012 are shown in Table 1. The SalehAbad rangeland covers 2254 ha, and the main shrub species in the area is *Artemisia aucheri*. To reduce the effects of other plant species, sampling areas were chosen based on the lower existence of other companion plant species and that were dominated *A. aucheri*.

Plant and soil sampling

Separate sampling of plant leaves, stems and roots was carried out. We randomly established plots in each *A. aucheri* community to measure above-ground biomass and root biomass (0–30 cm depth). Plot dimensions were considered as 1 × 1 m. For above-ground biomass (leaves and stems), 30 plants (for each tested species) were randomly selected and then leaves and stems were cut separately by saw. After weighing and packaging in plastic bags, these samples were sent to the laboratory. For underground biomass (roots), due to the necessity of reducing loss, just five plant samples were selected and cut. Sampling from the roots was carried out by digging around the root area; roots with a thickness >2 mm were selected, cut to the end of the penetration depth and, after weighing for the

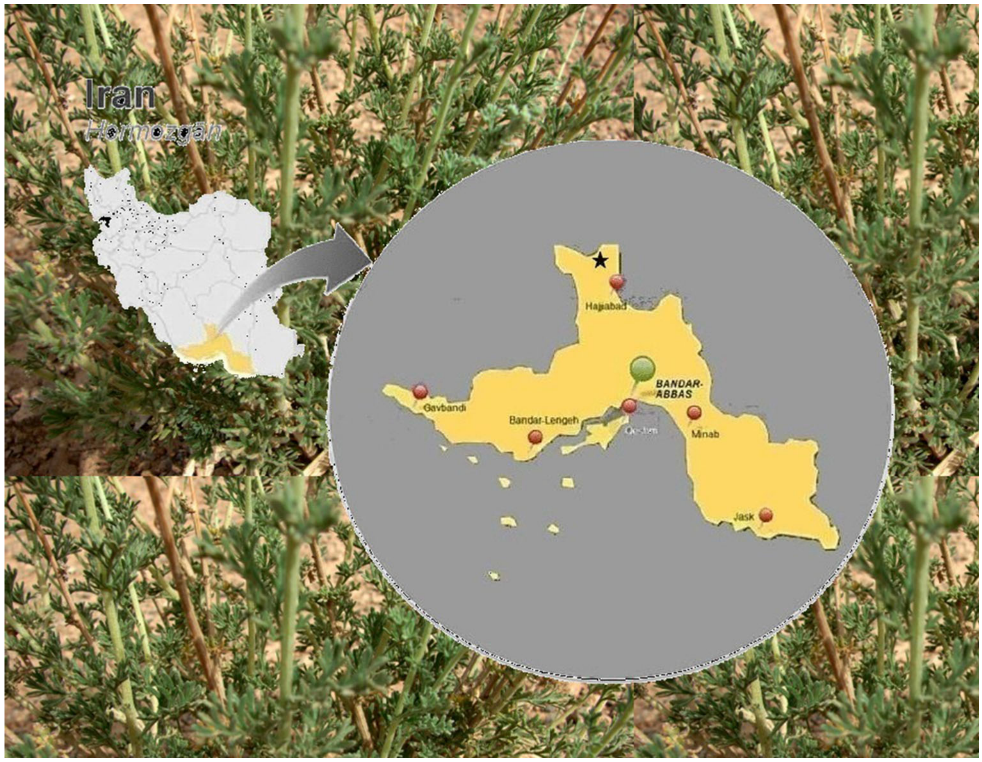

Fig. 1 Study area and experimental sites in the study area (*star*)

Table 1 Average monthly rainfalls (mm) during 2002–2012

Dec	Nov	Oct	Sept	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan
24.8	3.1	2.83	9.03	11.7	10.4	28.2	6.4	19.1	39.3	46.3	52.3

material analysis, sent to the laboratory. Sampling was done in April when the plants had fresh canopies and new leaves and stems were growing.

For the soil sampling, after removing the litter layer, a hole was drilled to a depth of 0–30 cm (Woomer et al. 2004). As the sampling was done on the surface, a shovel and pick were used. Sampling was done at depths of 15 and 30 cm. These depths were chosen because most soil microorganisms and the major part of root development are in the first 30 cm of the soil surface layer. Additionally, soil organic carbon (SOC) changes in depths of more than 30 cm are very low (Gao et al. 2007). To prepare a representative soil sample of each plant, three pits were dug at the base of each plant sample. To reduce errors, a combined sample was made of soils from three pits around the plant base and also from the pit's soil from the space between two plants. Forty soil samples from the studied area (30 soil samples from the basal area of the plants and ten soil samples from the space between two plants) were taken.

Laboratory analysis

Soil samples were air-dried to extract water and were then gently broken. Plant, organic debris and roots in the soil were carefully removed with forceps and passed through 0.25-mm sieves. After thorough mixing, each sample of the sieved soil was air-dried and used to determine SOC, total nitrogen (TN), pH, soil texture (ST), saturation percentage (SP), moisture content (MC) and electrical conductivity (EC). Soil TN was determined using the Kjeldahl method (Bremner and Mulvaney 1982). The soil EC and MC were determined according to the standard methods (Carter and Gregorich 1993). SOC was measured using a SOC analyser (TOC-VCPN Shimadzu, Japan) with a SSM-5000A solid burning device.

Plant's organic carbon content

In order to estimate the carbon content of the different organs (root, stem and leaves) obtained from shrub species, we followed the methodologies outlined by Tue et al. (2011). Samples of different organs from each species were analysed through the dry combustion procedure at 1050 °C using an element analyser (LECO HCN 600, St. Joseph, MI, USA).

Statistical analysis

This study was carried out in two separate experiments arranged in a completely randomized design (CRD). The first experiment included two different soil depths which were compared with the *t* test. This test was selected due to few numbers of treatments for comparison (two treatments) and prevents coming down the degree of freedom. The second experiment included different plant organs (root, stem and leaves) which were analysed by analysis of variance (ANOVA), and the least significant difference (LSD) was performed by using the statistical software SAS program version 9.1.3 (2003) (SAS Institute Inc., Cary, NC, USA). Both of the experiments had four replications, in which each replication was average of five samplings.

Results and discussion

Data analysis of the *t* test showed that the soil depth had a significant effect on all soil chemical characteristics, except for EC and SP (Table 2). With an increasing soil depth, pH and MC increased significantly, so that the soil pH and MC at a depth of 15–30 cm were 19.44 and 44.39 % higher than at the depth of 0–15 cm, respectively, whereas with increasing soil depth, nitrogen percentage (N %) and organic carbon percentage (OC %) decreased significantly, so that N % and OC % at depth of 15–30 cm were 49.15 and 61.41 % lower than at the depth of 0–15 cm, respectively. However, the results of the *t*-test revealed that two different soil depths containing *A. aucheri* showed no significant difference in terms of EC and SP %. The effect of soil depth on clay percentage was significant at 5 % probability level, however, the effect of soil depth on silt and sand percentage was not significant (Table 3).

The effect of plant organs on stored carbon in plant tissues was significant at 1 % probability level (Table 4). As can be inferred from Table 5, there is a significant difference between plant organs in terms of the amount of stored carbon. The highest and lowest amounts of stored carbon were observed in the root and leaves, respectively. Compared to the stem and leaves, 7.18 and 12.05 % more carbon was stored in the root, respectively (Table 5).

In general, with increasing soil depth, N % and OC % decreased, while soil MC and pH increased, and there was no significant difference between the two different soil depths in the case of EC and SP %. These results are in agreement with the results of Rossi et al. (2009), Qing-Biao et al. (2009) and Hopmans and Elms (2009), who concluded that with increasing soil depth, bulk density and pH increased, while the amount of N %, organic matter and OC decreased. Previous studies also have revealed that there is an inverse relationship between soil carbon sequestration and soil depth in arid and semi-arid regions (Rice 2000). This can be due to the gradual process of litter decomposition and its conversion to humus, which is started from the surface soil layers (Schuman et al. 2002).

Soil texture, especially clay percentage, is one of the most important factors influencing soil carbon sequestration (Schuman et al. 2002). In this study, the soil sample at the depth of 0–15 cm contains more clay and also has a higher organic carbon sequestration capability than at the depth of 15–30 cm. These results are aligned with those of

Table 2 Results of *t* test analysis for soil chemical characteristics at two different soil depths

Depth	EC	PH	SP %	MC %	N %	OC %
0–15 cm	0.625	7.278	20.667	0.606	0.059	0.780
15–30 cm	0.546	8.873	20.667	0.875	0.030	0.301
t value	1.12^{ns}	8.64*	0^{ns}	12.06**	9.79*	11.05*

Each mean was average of 20 data including four replications and five samplings

Degree of freedom 3

* Significant at 5 % probability levels, ** significant at 1 % probability levels, ns, non-significant

Table 3 Results of *t* test analysis for soil texture parameters at two different soil depths

Depth (cm)	Clay (%)	Silt (%)	Sand (%)
0–15	5.3a	15a	79.7a
15–30	4.1b	15.7a	80.2a
t value	0.55*	2.09^{ns}	3.8^{ns}

Each mean was average of 20 data including four replications and five samplings

Degree of freedom 3

* Significant at 5 % probability levels, ** significant at 1 % probability levels, ns, non-significant

Table 4 Results of ANOVA of the effects of plant on stored carbon

Source of variance	Degree of freedom	Mean squares
Plant's organ	2	26.4**
Error	9	2.69^{ns}
Coefficient variance		3.68^{ns}

* Significant at 5 % probability levels, ** significant at 1 % probability levels, ns, non-significant

Table 5 Results of mean comparison of the interaction between plant's organs

Plant's organ	OC %
Leaves	42.24c
Stem	44.16b
Root	47.33a

Means with same letter in each column are not significantly different using LSD ($P < 0.01$)

Each mean was average of 20 data including four replications and five samplings

Table 6 Stepwise regression of nitrogen percentage (N %) and moisture content percentage (MC %)

Variables	Coefficient regression (b)	Partial $R2$	Model $R2$	F value	Pr > F
N % ($X1$)	6.31	0.82	0.82	48.17	<0.0001
MC % ($X2$)	6.25	0.09	0.92	11.15	<0.087
$y = -0.13$					
$Y = -0.13 + 6.31\ X1 + 0.25\ X2$					

Seventy-two data points were used for stepwise regression analysis

other studies; Li et al. (2010) revealed that soil carbon sequestration is associated with the silt–clay percentage of the soil. Soil organic carbon is also affected by soil cation exchange capacity, texture and bulk density (Bruce et al. 1999). On the other hand, at the depth of 0–15 cm with higher clay, carbon sequestration was also more than at the depth of 15–30 cm. Powers and Schlesinger (2002) conducted research in Costa Rica and observed that the concentration of soil OC at various soil depths has a close relationship with ST, especially the clay percentage.

The highest and lowest amounts of stored carbon were observed in the root and leaves, respectively. These results are in agreement with those of Alizadeh et al. (2010) who conducted research on the capability of carbon sequestration of *A. sieberi*. However, this result is opposite to those found by Gao et al. (2007) who expressed that the woody organs of plants have a higher potential to sequester carbon. It is also in contrast to the observations documented by Perera and Amarasinghe (2013) who found that the above-ground carbon accumulation of two mangrove species is three times greater than that of the roots.

The results of stepwise regression of the chemical properties and ST (Table 6) showed that nitrogen percentage and soil MC were the most effective traits of organic carbon percentage and, consequently, soil carbon sequestration as following equation:

$$\mathrm{Y} = -0.13 + (6.31\ \text{nitrogen percentage}) + (0.25\ \text{soil moisture content})$$

According to the regression coefficient, nitrogen percentage (6.31) was more effective than soil MC (0.25) as an indicator of carbon sequestration. The decomposition rate of soil organic matter is influenced by moisture, temperature, oxygen availability, the location of organic matter in the soil profile and intensity of aggregate physical protection (Bruce et al. 1999). Derner and Schuman (2007) argue that the amount of sequestrated carbon in the soil per area is dependent on various factors, such as soil bulk density and MC.

Varamesh et al. (2010) evaluated the effect of afforestation on increased carbon sequestration and improved soil properties, as suggested in the model below:

$$\mathrm{Y} = (3.5 \times 8\ \text{nitrogen}) + (0.89\ \text{clay percentage})$$

They determined nitrogen percentage (similar to our finding) and clay percentage as the most effective traits. In the present study, nitrogen percentage and soil MC were considered as the most effective traits.

Lal (2004) found that the rate of storage and carbon sequestration varied widely among different plant species with different ages. It has been reported that vegetation type can significantly affect soil characteristics; for example, changes in soil carbon sequestration is directly related to carbon input from plant residue and carbon output by soil carbon dioxide emissions (Dinakaran and Krishnayya 2008). A study which was conducted in the Gomishan rangeland, Iran, found that carbon sequestration differed significantly between two different species (Forouzeh 2009).

In general, due to the complexity of natural ecosystems and associated issues, such as mineralization of organic matter and the impact of climatic and other factors on the deposition of carbon dioxide in the shrubs, the need for more research in this area is clear. Thus, given the potential of the country, our results recommend the use of *Artemisia* spp. for restoring vegetation in arid areas due to its ability to sequester carbon.

Conclusion

This study found that the soil sample at the depth of 0–15 cm showed higher carbon sequestration due to the higher clay content. The highest and lowest amounts of stored carbon were found in roots and leaf tissues, respectively. The potential for carbon sequestration can be varied based on the plant species, location and management style. Therefore, by recognizing the species that have more potential for carbon sequestration and also investigating the management factors affecting the sequestration process, regeneration and rehabilitation of rangeland can be followed in terms of carbon sequestration.

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