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Comparison of carbon pool in habitats of *Zygophyllum atriplicoides Fisch. & C.A.Mey*. and *Artemisia sieberi Besser*. in Luchunasi rangelands (Southeastern Iran)

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ABSTRACT

Arid ecosystems have a high capacity for carbon pool since they involve 41% of the world's land surface. It is important to make reliable estimations of the amount of carbon stored in the soil and plat of rangelands. The present study was conducted to compare the ability of two native plant species, namely *Artemisia sieberi* Besser. and *Zygophyllum atriplicoides* Fisch. & C.A.Mey., concerning carbon pool in arid rangelands of Luchunasi, Sistan and Baluchestan province, Iran. The data were collected in 2020 through a randomized complete block design. We measured soil bulk density, organic carbon, pH, EC, and soil carbon pool from three soil layers (0–30, 30–60, and 60–90 cm), as well as carbon pool of aboveground and belowground biomass. The data were analyzed via analysis of variance and paired T-test. The obtained results indicated that in both habitats, the maximum levels of soil carbon pool, bulk density, and organic carbon were observed in the 0-30-cm soil layer. In *Z. atriplicoides* habitat, Cp in the depth of 0-30 cm was higher than that in *A. sieberi* habitat. In both plants, Cp in the belowground biomass was significantly higher than the aboveground parts ($P<0.01$). Moreover, our study showed that *Z. atriplicoides* (shrub form) has further potential to store carbon compared with *A. sieberi.* (bush form). The use of plants with shrub form in biological practices can increase the carbon pool in arid lands, but the efficiency of more plant species needs to be assessed.

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Introduction

Carbon (C) is a key nutrient in natural ecosystems around the world. It plays an essential role in regulating the structure and performance of rangelands (Wang *et al.*, 2014; Hu *et al.*, 2020; Yang *et al.*, 2020). Rangeland ecosystems have a high capacity for carbon pool (Cp) that provides plant nutrients, reduces soil erosion, and increases the cation exchange and water holding capacities (Conant *et al.*, 2017; Tessema *et al.*, 2020). Rangelands account for about 41% of the world's land surface (Reynolds *et al.*, 2007; Chillo *et al.*, 2015; Khosravi *et al.*, 2017). Two billion people live in arid rangeland, who depend on the natural ecosystems (Khosravi *et al.*, 2017; Hashemi Rad *et al.*, 2018; Ebrahimi *et al.*, 2019). A small change in

Cp in rangelands has irreversible effects on atmospheric carbon dioxide (CO_2) concentrations since the amount of Cp in the soil is much greater than that in the atmosphere (Yang *et al*., 2020). Thus, Cp is considered as a tool for reducing climate changes through decreasing CO_2 concentration in the atmosphere (Conant *et al*., 2017; Tessema *et al*., 2020).

High Cp in rangelands is owing to their perennial nature which results in constant carbon inputs from aboveground vegetation and the large quantities of carbon to the subsoil via root exudates and decomposing deep roots (Zimmermann *et al*., 2012; Tessema *et al*., 2020). Thus, rangeland management practices have significant effects on Cp and soil nutrients, resulting in various effects on the soil organic carbon (SOC) (Dlamini *et al*., 2016; Jafarian and Ahmadi, 2017). In Iran, rangelands are important natural resources with great ecological, economic, and social importance, thanks to their crucial role in the development of rural areas. Management-related measures to restore rangelands in Iran include techniques to increase soil fertility and vegetation cover, which have been highly suitable approaches for conservation objectives (Ebrahimi *et al*., 2019; Zand, 2019). In this regard, biological restoration in arid rangeland ecosystems is a common practice that aims to increase soil C contents, which has been highly effective as a potential strategy for Cp (Ghasemi Nejad Raeeni and Sadeghi, 2018). Tree and shrub planting helps to satisfy environmental, social, and industrial needs and, where applicable, is suitable for the prevention of erosion caused by wind and water (Ebrahimi *et al*., 2019). In Iran, some studies have considered the importance of biological practices as a simple management tool for increasing soil Cp and restoring degraded lands. In the three basins of Rimele, flood spreading Romeshkan and Abkandari Kohdasht, for instance, mechanical operations and watershed management have resulted in a notable soil carbon enrichment (Zand, 2019). In total, the amount of soil Cp resulting from mechanical operations was 45.7, 78.4, and 54.8ton ha^{-1} for the three basins of Rimele, Romeshkan, and Abkandari Kohdasht, respectively. An assessment of content and distribution of soil carbon sequestration in 1) native rangelands and cultivated rangelands (seeded with non-native perennial grasses (*Agropyron elongatum* and *Agropyron desertorum*)), 2) seeded with non-native shrub (*Kochia prostrata*), or 3) cropped annually with *Triticum aestivum*) in semiarid rangelands of North Khorasan province of Iran showed that the total carbon sequestration in native rangelands and soils under *K. prostrata*, *A. elongatum*, *A. desertorum*, and *T. aestivum* was 38.71, 23.66, 14.47, 18.32, and 13.57ton ha^{-1}, respectively. The maximum Cp belonged to the native rangeland (Naghipour Borj et al., 2012).

The arid region of Luchunasi is one of the arid rangelands in Sistan and Balouchestan province, Iran. Since 2000, large parts of the area have been planted with perennial plants to combat wind erosion. However, there is little research on the effects of biological restoration on soil Cp in the arid desert steppes of Iran. This study was conducted to determine the effects of biological restoration using two native plant species, namely *Artemisia sieberi* Besser. and *Zygophyllum atriplicoides* Fisch. & C.A.Mey. on Cp of the plant-soil. We considered the following hypotheses: (1) Cp at the belowground parts of both plants is greater than that at the aboveground parts; (2) soil Cp in *Z. atriplicoides* habitat is higher than that in *A. sieberi* habitat.

Material and methods

Area description

Leuchonassi rangeland is located in Sistan and Balouchestan province, Iran, between latitude 29° 15′ 10″to 29° 17′ 32″ N and between longitude 60° 44′ 15″ to 60° 46′ 10″E (Figure 1). The experimental area (10994 ha) is characterized by dry summers and cool winter climate.

According to the data available for the period from 2011 to 2020 at the study site from the National Meteorological Information Center of Iran, the mean annual rainfall level reaches 101 mm. The mean elevation is 1650 m a.s.l. The mean maximum temperature is 25°C in May and June. The mean minimum temperature is 11°C in December and January. The soil with a loam-sandy texture in the study area is taxonomically characterized as a moderate, loamy, and mixed soil with aridic moisture and thermic temperature regimes. The soil was classified as Aridsols or Entisols according to the US soil taxonomy classification. The site was within an area where its characteristic topography was plateau and upper terraces, piedmont plains, and mountains. The vegetation types are dominated by arid land vegetation (for example, *Hammada salicornia*, *Z. atriplicoidesa*, *A. sieberi*, and *Salsola* spp) (Report of Rangeland Improvement, Luchunasi, Sistan and Baluchestan, 2015).

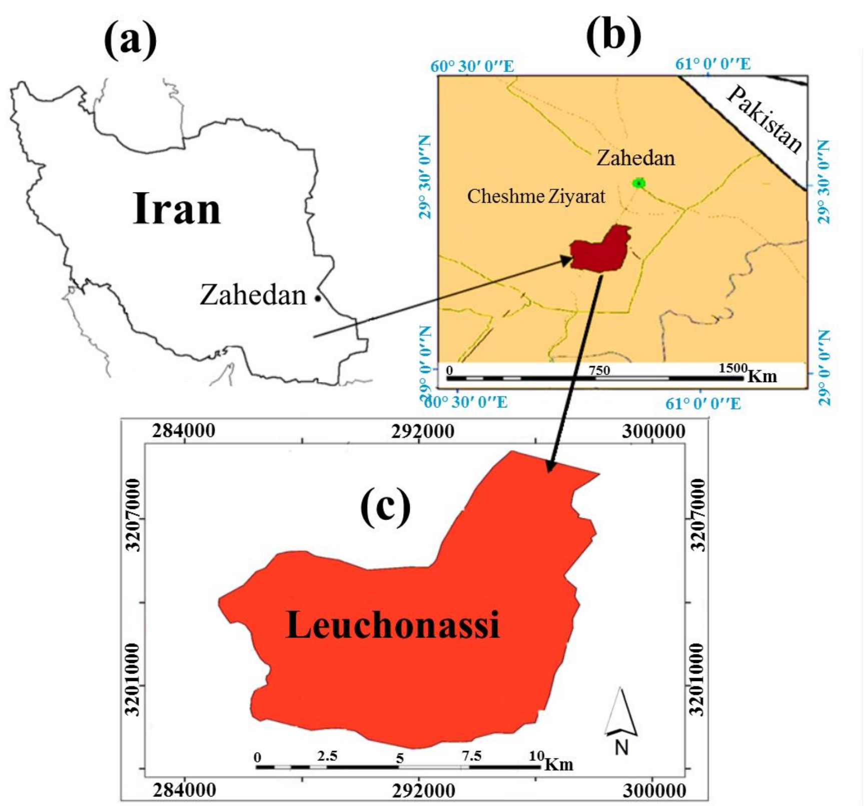

Figure 1. The study area in Sistan and Baluchestan province, southeastern Iran (a-Iran, b- middle part of Sistan and Balouchestan province, and c- Leuchonassi rangeland)

Sampling method

The study was carried out in a randomized complete block design (RCBD). For selecting the study habitats, we conducted a multi-site survey during the growing season from January to April (2020). We selected two habitats (pure stand of *A. sieberi* and *Z. atriplicoides*) that had undergone succession for 25 years. There were no significant differences concerning spatial heterogeneity (topography, soil type, distribution of traits, event, or relationship across the area) among the selected habitats. Data sampling was done using the simple transect line (100 m) method within quadrats ($5m^2$) using a systematically randomized method. In total, six transects were sampled. The distance between the transect lines was 100 m. Along each transect within quadrats (with 25 m intervals), all the aboveground plant parts of each plant species were cut, collected, and put into separate labeled envelops (24 samples). The aboveground parts of the plants were oven dried at 70°C to a constant weight for approximately 48 hours and weighed to determine the dry mass. In order to estimate the belowground Cp of the plant's biomass, root samples were taken at five points along the transects under canopy of each plant species (within quadrats) using a soil auger from the surface layers (0–30 cm) to the depth of 60-90 cm (Mirlashkari, 2016). A total of 30 root samples were selected (15 samples for each plant species). The root samples were washed and dried in oven (70°C for 48 hours). Plant OC was measured via the dry combustion method (MacDicken, 1997).

Soil samples (36 samples) were collected from three soil layers (0–30, 30–60, and 60–90 cm) at the beginning and end of each transect. The soil samples were air-dried and then passed through a 0.14 mm sieve and the roots and other debris were removed. Soil pH was determined for a soil–water ratio of 1:5. Electrical conductivity of saturated soil paste extract (ECe) was measured employing an EC–meter (DDS–307, Shanghai, China) (Rhoades, 1996). The soil BD (g cm^{-3}) of the three soil layers was measured with the soil cores (volume, 100 cm3) through the volumetric ring method (Wu et al., 2010). Soil organic carbon was assayed by dichromate oxidation (Nelson and Sommers, 1982). The soil organic carbon pool for each layer was determined with the following formula: Cp=BD×SOC×D (Deng et al., 2013; Wang et al., 2014). In this formula, Cp is the soil organic carbon pool (kg m^{-2}), BD is the soil bulk density (g cm^{-3}), SOC is the soil organic carbon content (g kg^{-1}), and D is the thickness of the sampled soil layer (m).

Statistical analysis

All the data were analyzed utilizing SPSS 20.0. The data (three replicates) were analyzed through analysis of variance (ANOVA). Distribution was tested for normality by Kolmogorov-Smirnov. Equality of variance among the treatments was tested with Levene's test for homogeneity of variance. Post hoc Duncan test was performed to determine the significant differences among the treatments. When the P-value was lower than 0.05, the difference was considered to be significant. Variations in Cp in the soil and plant parts of both habitats were compared by paired T-test. A probability of 0.05 or lower was considered as significant.

Results

Soil characteristics and Cp in Z. atriplicoides habitat

The results of data variance analysis (Table 1) revealed that organic carbon (P<0.01), C pool (P<0.01), and bulk density (P<0.05) among different soil layers of *Z. atriplicoides* habitat were significantly different while soil pH and EC were not found to have any significant differences among the soil layers.

Table 1. Analysis variance of soil characteristics sampled at *Z. atriplicoides* habitat

Soil properties	SOV	df	Mean square	F	Sig
Organic carbon(%)	Between group	2	0.020	14.62	0.00^{**}
	Among group	15	0.001		
Cp (ton ha^{-1})	Between group	2	44.590	10.003	0.00^{**}
	Among group	15	4.450		
EC (dSm^{-1})	Between group	2	0.036	0.39	$0.00^{n.s}$
	Among group	15	0.910		
pH	Between group	2	0.140	0.65	$0.02^{n.s}$
	Among group	15	0.220		
Bulk density (g cm^{-3})	Between group	2	0.010	3.94	0.05^{*}
	Among group	15	0.003		

S.O.V = Source of variations
** $P < 0.01$, * $P \leq 0.05$, $^{n.s}$ $P > 0.05$

The results of mean comparison (Table 2) proved that the depth of 0-30 cm had a significantly higher organic carbon value (P< 0.01) when compared with the other two depths; however, there were no significant differences between the depths of 30-60 and 60-90 cm in this regard. Bulk density followed the same pattern. The pH and EC did not significantly change among different soil layers. The Cp value was the highest in the depth of 0-30 cm; meanwhile, concerning the Cp value, no significant differences were observed between the 30-60 and 60-90 cm depths.

Table 2. Soil characteristics and Cp at *Z. atriplicoides* habitat

Soil depth (cm)	OC (%)	Cp (ton ha^{-1})	EC (dSm^{-1})	Ph	Bulk density (g cm^{-3})	Soil texture
0-30	0.27±0.022^{a}	14.01±1.46^{a}	0.99±0.23^{a}	7.57±0.12^{a}	1.90±0.57^{a}	Sandy loam
30-60	0.17±0.045^{b}	9.07±2.21^{b}	1.08±0.20^{a}	7.59±0.20^{a}	1.82±0.38^{b}	Sandy loam
60-90	0.16±0.40^{b}	9.54±2.50^{b}	1.15±0.42^{a}	7.66±0.09^{a}	1.88±0.054^{ab}	Sandy loam

Values shown are the means ± SE. Values within a column followed by different letters are significantly different (P < 0.05, post hoc Duncan test).

Soil Cp in A. sieberi habitat

The results of data variance analysis in *A. sieberi* habitat are represented in Table 3. A similar trend was observed for the soil under cover of *A. sieberi*. The results indicated that the soil properties had significant differences (P<0.01), except for EC and pH.

Table 3. Analysis variance of soil characteristics sampled in *A. sieberi* habitat

Soil properties	SOV	df	Mean square	F	Sig
Organic carbon (%)	Between group	2	0.02	18.55	0.00**
	Among group	15	0.001		
Cp (ton ha^{-1})	Between group	2	24.04	9.80	0.00**
	Among group	15	2.45		
EC (dSm^{-1})	Between group	2	0.134	0.54	0.59$^{n.s}$
	Among group	15	0.246		
pH	Between group	2	0.044	1.63	0.22$^{n.s}$
	Among group	15	0.027		
Bulk density (g cm^{-3})	Between group	2	0.75	14.89	0.00**
	Among group	15	0.05		

S.O.V = Source of variations
** $P < 0.01$, $^{n.s}$ $P > 0.05$

The results of mean comparison (Table 4) showed that organic carbon and Cp were greater in 0-30 cm depth compared with the 30-60 and 60-90 cm depths. The results proved that bulk density had significantly more value in the depth of 0–30 cm (P<0.01) when compared with the other two depths. The soil layers were not significantly different concerning the EC and pH (Table 4). The results indicated more bulk density in the depth of 0-30 cm compared with the other two depths.

Table 4. Soil characteristics and Cp in *A. sieberi* habitat

Soil depth (cm)	OC (%)	Cp (ton ha^{-1})	EC (dSm^{-1})	pH	Bulk density (g cm^{-3})	Soil texture
0-30	0.24±0.02^{a}	12.17±1.64^{a}	1.05±0.34^{a}	7.70±0.12^{a}	1.49±0.28^{a}	Sandy loam

30-60	0.17±0.02^{b}	9.17±1.53^{b}	0.97±0.47^{a}	7.50±0.12^{a}	0.86±0.21^{b}	Sandy loam
60-90	0.15±0.02^{b}	8.37±1.51^{b}	1.26±0.62^{a}	7.62±0.22^{a}	0.90±0.14^{b}	Sandy loam

Values shown are the means ± SE. Values within a column followed by different letters are significantly different (P < 0.05, post hoc Duncan test).

C pool in plants biomass

Carbon pool in the plants' parts is depicted in Table 5. It was found that *Z. atriplicoides* had a belowground content of carbon significantly greater than Cp in the aboveground parts (P<0.01). In general, the Cp in organs of *Z. atriplicoides* decreased in the order of belowground >aboveground. The same pattern was found in *A. sieberi*. This finding supported our first hypothesis. The results demonstrated, however, that Cp in the aboveground biomass of *A. sieberi* was higher than that of *Z. atriplicoides* and there were no significant differences between Cp of the aboveground biomass (P>0.05). Belowground biomass of *Z. atriplicoides* showed the highest Cp (P<0.01). The Cp ratio in *Z. atriplicoides* was 0.58, which was more than that of *A. sieberi* (0.34).

Table 5. Carbon pool (ton ha^{-1}) in the aboveground and belowground parts of the plant species

Habitat	Cp of aboveground biomass (ton ha^{-1})	Cp of belowground biomass (ton ha^{-1})
Z. atriplicoides	1.38±0.64^{B-b}	4.05±0.70^{A-a}
A. sieberi	1.47±0.20^{B-b}	2.54±0.53^{B-a}

*Values shown are the means±SE. Different lower-case letters in each row indicate significant differences among Cp of the aboveground and belowground biomass (P < 0.01, T Test). Different upper-case letters in each column indicate significant differences between Cp of the plant species in the similar biomass (P < 0.01, T Test).

Comparison of Cp in the soil of the two habitats

Figure 2 summarizes the comparison of soil Cp of the plant habitats. The amount of Cp was found to be significantly more in the depth of 0-30 cm of *Z. atriplicoides* habitat (P <0.05) compared to that in the *A. sieberi* habitat; meanwhile, it was not significantly different between the 30-60 and 60-90 cm depths of both habitats. In general, the soil under cover of *Z. atriplicoides* had further Cp than the soil of *A. sieberi* habitat, which supported the second hypothesis of the study presented in the Introduction section.

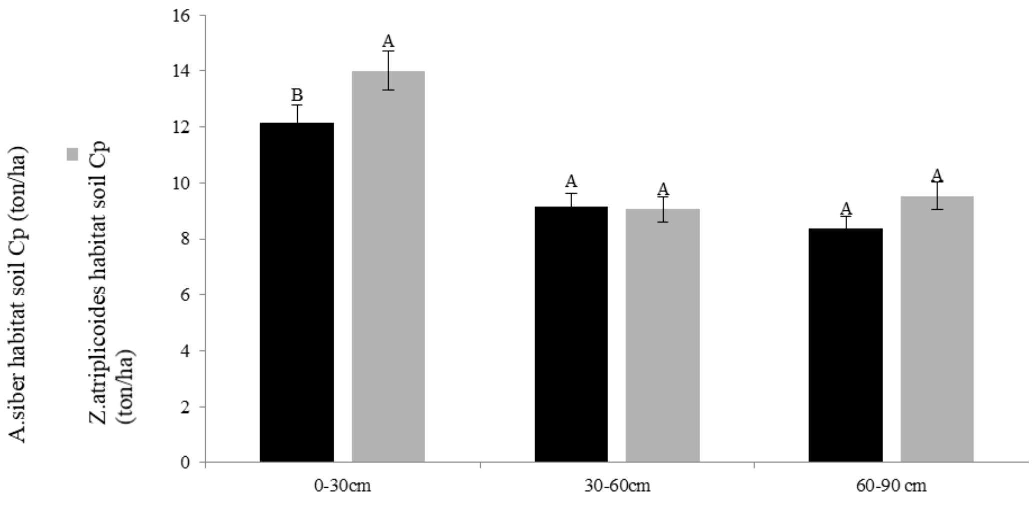

Figure 2. Soil Cp (ton ha^{-1}). Different upper-case letters indicate significant differences between the soil depth. The bars mean+SE.

Discussion

The study of soil and plant Cp and its controlling factors in rangeland ecosystems contributes to understanding and evaluating the global carbon cycle and global climate changes. Whether rangelands act as sources of atmospheric carbon dioxide depends on the type of use, climate, vegetation, and grazing intensity (Jia et al., 2007). In the current work, no significant differences were observed between the pH and EC values of the soils at different depths in both habitats. One of the effects of salinity on plants is the reduction in photosynthetic activity, which reduces the amount of chlorophyll and absorption of CO_2 and photosynthetic capacity. It ultimately reduces the volume of litter entering to the soil. It seems as though the amount of EC has a negative effect on the plant production and litter input to the soil, which ultimately leads to reduction in soil organic matter and Cp (Yibing, 2008; Zare Chahouki *et al*., 2010). Fortunately, in the present study, the soil EC was not high (0.97 -1.26 dSm^{-1}) in the two habitats; this could have a positive effect on the soil and plant Cp of both habitats.

The results implied that the percentage of carbon as well as the bulk density were significantly different between the habitats. The amount of Cp in the plants and soil of both habitats varied according to the type of plant species and soil depth. Most of the Cp belonged to the surface layer of the soil (0-30 cm) and with the increased soil depth, the amount of Cp decreased significantly. Ghasemi Nejad Raeeni and Sadeghi (2018), in a study on Cp in the soil of *Z. atriplicoides* and *Gymnocarpus decander* habitats, found that the highest Cp was observed in the depth of 0-15 cm. The high amount of Cp at a depth of 0-30 cm may be on account of the fact that most of the organic matters in the soil are related to the decomposition of dead roots as well as the conversion of microbial biomass to organic matter located at this depth (Dianati Tilaki *et al*., 2009). Dong *et al*. (2014) reported that large amounts of plant's litters in the topsoil increase the carbon stored in this layer of soil compared to deep soil. Woomer et al. (2004) showed that approximately 60% of organic carbon is stored at a soil depth of 20 cm.

Soil Cp is positively correlated with bulk density and organic matter (Garten and Charles, 2002). Mckenzie *et al*. (2000) stated that soil bulk density is one of the important factors in estimating soil Cp capacity. In the present study, the bulk density at the depth of 0-30 cm was greater than that at depths of 30-60 and 60-90 cm. The bulk density of the soil is a relative characteristic that plays an important role in estimating the amount of soil carbon storage (Hill *et al*., 2003). Accordingly, the soil with a higher bulk density has a higher carbon content; in fact, the bulk density consists of the weight of solid particles and solutes in the pores of the soil (Ponce Hernandez *et al*., 2004).

The results revealed that in both plants, the amounts of Cp in the belowground biomass were higher than that in the aboveground biomass. This could be attributed to the high amount of woody tissue of the roots compared to the aboveground parts of the plants (Foroozeh *et al*., 2008; Capuana, 2020; Rigi Pardad, 2021). In arid rangelands, the belowground biomass of the plants has the largest proportion of the total biomass while the aboveground biomass comprises a small proportion of the total plant biomass (Joneidi Jafari *et al*., 2013). The roots system in A. sieberi and Z. atriplicoides is thick with woody tissues (Ghasemi Nejad Raeeni and Sadeghi, 2018; Souri *et al*., 2020). Plant organs with woody tissue have a greater ability to store carbon (Nejadi and Rahbar, 2012; Lashani Zand *et al*., 2016; Motamedi *et al*., 2020). In this regard, other studies have acknowledged that the more woody tissues in the plant, the greater the plant's ability to uptake carbon (Motamedi *et al*., 2020; Tessema *et al*., 2020). The increase in the share of the root increases carbon entrance into the soil (Moghbeli, 2016). Souri *et al*. (2020), in Kalat Sadat Abad, Sabzevar rangeland, Iran, reported that the root of *A.*

sieberi had a bigger proportion of Cp compared to the stems and leaves. In studying the effects of grazing on the above and belowground Cp in arid rangeland of Jiroft (Iran), Moghbeli (2016) cited that Cp in *Z. eurypterum* was higher in the roots than the shoots. The type of plant species and even different organs of a plant have different potentials for Cp. In fact, the performance of plants to store carbon is a function of various factors, such as morphological traits (including plant root height, canopy cover, plant density, plant distribution pattern, topographic characteristics, and physical and chemical properties of the soil) and management factors (such as livestock grazing and rangeland exclusion) (Post and Kwon, 2000; Conti and Diaz, 2013; Moghbeli, 2016; Mirlashkari, 2016). Expansion of vegetation cover will result in reduction in and modification of the amount of CO_2 in the atmosphere by increasing photosynthetic levels and eventually increasing the level of carbon uptake (Souri *et al*., 2020). Mirlashkari (2016), in the investigation of the impacts of exclusion on the soil Cp in Jonabad rangeland of Zahedan, Iran, reported that Cp was higher in the site with higher plant biomass than the grazed area.

Our results indicated that Cp ratio in *Z. atriplicoides* was more than the Cp ratio in *A. sieberi.* The potential of different plant species for carbon uptake also depends on the growth form (Wardle *et al*., 2012; Capuana, 2020). Z. atriplicoides grows in the form of shrub (Rechinger, 1972) while A. sieberi has a bush form (Azarnivand, 2003). Shrub species have a greater ability to absorb and store carbon than herbaceous and bush species, owing to their long and deep roots, high wood density, high viability, and slower decomposition (Post and Kwon, 2000; Conti and Diaz, 2013; Azizi, 2013; Mirlashkari, 2016; Motamedi *et al*., 2020).
The obtained findings also showed that *Z. atriplicoides* has further organic carbon storage capacity in the soil of the studied area than *A. sieberi*. One of the reasons of the high soil Cp in the habitat of *Z. atriplicoides* could be the high volume of the root of this plant species compared to *A. sieberi* (Azizi, 2013). Total Cp has a positive and significant relationship with total aerial biomass, total underground biomass, plant litter amount, and SOC (Honda *et al*., 2000). The results of Zimming *et al*. (2012), on rangeland carbon assessment, showed that Cp in soil could be strongly influenced by management, climate changes, and physical and chemical properties of the soil. It is noteworthy that the production and decomposition of plant biomass can affect ecosystem processes (Windham, 2001). Therefore, plant biomass production and decomposition can determine carbon inputs to the soil profile (Tessema *et al*., 2020). The high carbon input derived from high root biomass in rangelands can increase soil organic matter content, which is an important factor for increased SOC (Farage *et al*., 2004). Therefore, maximizing productivity and root inputs in rangelands is crucial for increasing their Cp (Tessema *et al*., 2020). Kuzyakov (2002) noted that a large root biomass supports substantial soil microorganism populations and their metabolic processes, thereby contributing significantly to the soil organic matter decomposition and carbon turnover.

Conclusion

The results demonstrated that restoration practices using *Z. atriplicoides* greatly enhanced the habitat organic carbon compared with *A. sieberi* and resulted in Cp enrichment in the steppe rangeland of Luchunasi. Carbon storage capacity varies according to the plant species, plant’s organs, and soil depth. According to our findings, the Cp in the roots of both plants was more than that in the aboveground parts. The results indicated that *Z. atriplicoides* has more Cp capacity in the soil of the studied area than *A. sieberi*. Proper management of rangelands in order to increase Cp and restore rangeland requires sufficient information on the rangeland ecosystems. Evaluation of the effects of restoration practices in order to discover the most efficient management strategy is essential in degraded rangelands. Overall, we could suggest further investigation on the plants’ Cp and SOC sequestration potential of arid rangelands when taking management-related measures. The effects of plant type and management practices on SOC storage potential need to be fully quantified (including greater soil depths). Furthermore, to improve decision making on prioritizing Cp-enhancing measures, carbon sequestration potential in rangelands should be compared to other land use.

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