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Carbon storage assessment in soil and plant organs: the role of *Prosopis* spp. on mitigate soil degradation

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Abstract Carbon sequestration is a process for stable storage of carbon dioxide. In this process, excess atmospheric carbon dioxide is stored by the aerial and underground organs of rangeland plants to reduce global warming. The aim of this study was to identify the relationship between some chemical properties of soil and ability of carbon storage in two plants, namely *Prosopis cineraria* and *Prosopis juliflora* in soil depth ranging between 0–15 and 15–30 cm. This research was carried out in Anbarabad region which is located at 258 km in the southeast of Kerman during 2016–2018. The present research was performed as a factorial experiment so that the first factor was the plant species and the control treatment and the second component was soil depth. Sampling was done from the shady soil of plants and the control area. Soil properties including organic carbon, bulk density, acidity, electrical conductivity and organic matter were analysed. The results indicated that the carbon stored at depths of 0–15 cm and 15–30 cm in the shade soil of *P. cineraria* was 21.39 and 24.36 t/ha, and in *P. juliflora* was 23.70 and 24.85 t/ha, and in control area is 19.83 and 21.31 t/ha. Also, the results of stepwise regression study showed that organic carbon percentage and bulk density are the most important factors affecting soil carbon sequestration.

Keywords Organic carbon · Dryland species · Bulk density · Stepwise regression · Soil degradation

Highlights
- Higher electrical conductivity reduces the accumulation of humus
- *Prosopis cineraria* and *Prosopis juliflora* have a great role on mitigate soil degradation
- Bulk density and soil electrical conductivity are the most important factors in soil organic carbon storage

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Introduction

Many scientific studies at the international level indicate the emergence of climate change (IPCC, 2007). Climate change is one of the most important challenges of sustainable development that can have a negative impact on the sustainability of aquatic and terrestrial ecosystems (UNDP, 2000). This phenomenon can greatly affect deforestation and desertification (Iranmanesh & Sadeghi, 2019a, b).

In order to assess the potential effects of climate change on soil characteristics and processes, it is necessary to pay attention to the main factors caused by climate change that directly or indirectly affect soil development and characteristics (Gelybo et al., 2018). Climate change and global warming are believed by many researchers to be due to rising greenhouse gas concentrations in the atmosphere (Brooks, 1998).

Human activities are now a major factor in changing the composition of the Earth's atmosphere, resulting in more climate change in the future (Archer, 2005).

Greenhouse gases are a complex set of gases that disturb the temperature balance of the climate and other important and influential factors that affect the totality of each climate (Lal, 2004). Increasing the concentration of greenhouse gases has caused a greenhouse effect on the earth (Su, 2007).

Carbon is the major component of greenhouse gases (Petit et al., 1999; Scott, 2002). So that it has a great role in absorbing the reflections coming out of the ground and includes almost half of the greenhouse effect (Pandey, 2002). Also, by doubling the CO_2 concentration, the average temperature will increase between 2 °C and 4 °C (Quay et al., 2003). Therefore, in order to reduce atmospheric carbon dioxide and balance the greenhouse gas content, atmospheric carbon must be absorbed and deposited in various forms (Ansari & Sadeghi, 2021; Noel & Bloodworth, 2000). Thus, the goal of any carbon sequestration strategy is to increase carbon stocks in vegetation and soils under vegetation and maintain it for a longer period of time and to increase and protect soil organic carbon (Surya Prabha et al., 2019).

Soil is an important and valuable natural renewable source and terrestrial resource in the storage of organic carbon, which plays a significant role in the process of the global atmospheric carbon cycle by storing about 1500 billion tons of carbon (Lal, 2002). In other words, soils are the largest pool of terrestrial carbon and the dynamics of soil organic matter is an important part of the global carbon cycle (Cervantes & Rojas, 2018). Soil has more than three times more carbon than the Earth's atmosphere and terrestrial vegetation, so it plays an important role in global climate change and agricultural production (Li et al., 2017).

Global climate conditions have led to the use of soils as a resource for mitigation and adaptation to climate change due to human activities. Soil organic carbon has long been recognized as a factor in soil fertility as well as the environment due to its high potential for carbon sequestration (Surya Prabha et al., 2019). It is widely acknowledged that soil reduces climate change by absorbing atmospheric carbon dioxide and converting it to soil carbon using total organic carbon storage (Minasny et al., 2017). On the other hand, soil organic carbon is one of the important parameters determining soil fertility, production capacity, cation exchange capacity, water retention and an important indicator in showing the quality of soils in arid and semi-arid regions where carbon input is low, and it can have positive effects on soil fertility (Chen et al., 2010; Zornoza et al., 2007; Okoy et al., 2010; De Blécourt et al., 2019; Liu et al., 2019). In other words, in tropical, hot and humid regions, vegetation and mineralogy are the most important factors controlling the amount of soil organic matter, while in semi-arid regions, due to low return of plant litter and high temperature, mostly is controlled by physical and chemical properties of soil (Bernoux et al., 2002).

Soil organic carbon is not a static carbon reservoir, but also affects the physical, chemical and biological properties of the soil, which is of great importance in sustainable agriculture. Therefore, soil organic carbon is an indicator of soil quality as well as environmental stability (Surya Prabha et al., 2019). The three most important components controlling soil organic carbon content are temperature and moisture content (biological factors, plant composition and addition of plant debris) and physicochemical properties of soil such as structure, texture, clay content, mineralogy and acidity (Paustian et al., 1997).

Various studies have pointed to various factors affecting the amount of carbon storage, including bulk density, management activities, return of plant debris and organic matter to soil, microbial activity and soil structure, percentage of clay, calcium ion, organic carbon, pattern Return of organic matter to soil, soil turbulence, soil depth and amount of organic matter (Brar et al., 2013; Corsi et al., 2012; Nguyen & Marschner, 2014; Yan et al., 2013). Soil characteristics are affected by the activities of roots and litter accumulated under the canopy of perennial plants (Sadeghi et al., 2016b). Substrate nutrients have a significant effect on plant productivity and ecosystem stability (Parsamanesh & Sadeghi, 2019). Soil pH also significantly affects organic carbon content, as it regulates access to soil nutrients, organic matter circulation, and a range of soil processes. Soil texture, which is used to describe the size distribution of mineral particles, has been reported as another important factor affecting soil organic matter accumulation (Zhou et al., 2019). The amount of soil organic carbon (SOC), soil organic matter content (SOM) and soil pH are very important to understand the change in soil quality and the impact of its components on the environment, especially the effect of greenhouse gas (GHG) emissions (Dinka & Dawit, 2019).

The present study, considering that Kerman province is located in an area with hot and dry climate and on the other hand, the *Prosopis* spp. have been significantly distributed in this area, with the aim of evaluating and recognizing the relationship between physical and chemical parameters of soil at two species of *Prosopis cineraria* and *Prosopis juliflora* were stored with carbon. In this study, it is hypothesized that carbon sequestration in soil is related to other soil properties. Accordingly, correlations are also examined. It should be noted that in order to obtain a large set of soil information vegetation, elevation and climate should also be considered during sampling, because these factors are influential in soil formation and evolution. Therefore, with this explanation, it is stated that although these factors have not been directly considered in the study, but they have been indirectly considered.

Materials and methods

Area of study

Anbarabad is one of the cities of Kerman province located in Iran, which has an area of about 4656.72 km^2. The sampling site is approximately 50 km from the centre of Anbarabad towards the Ismaili section of the city (28° 31′ 5″- 28° 52′ 16″ N and 57° 39′ 50″- 57° 38′ 43″ E) with an area of 284 acres. The temperature varies from − 10 to 50 °C. The average rainfall in the city varies from 45 to 200 mm. The average elevation is 577 m above sea level (Fig. 1). The *P. cineraria* and *P. juliflora* species were planted with the same age (45 years old). This research was done during 2016–2018.

One of the unique vegetation of this region is *Prosopis* spp, which is one of the most important genera under the genus Mimosoideae of the extended family Fabaceae. These plants are highly resistant to drought and can withstand less than 100 mm of rainfall and soil salinity up to 16 mm/cm or dS/m (Birhane et al., 2017; Catalano et al., 2008).

Laboratory analysis

At first, a pit was dug with a depth of 30 cm and samples of litter-free soils were collected from a depth of 0–15 and 15–30 cm from the base of the plant and between the plants (Woomer et al., 2004). Then, a composite sample of each plant was prepared. In this way, three pits were dug at each point of the sample and the samples were combined with similar depths to form a composite sample (this was done to reduce the error). After which, 18 composite soil samples were prepared, 12 of which were related to plant species and 6 were related to control areas. The items measured in this study include soil acidity, soil electrical conductivity, bulk and soil organic carbon content and soil organic matter content. Bulk was measured by using special cylinders (Klute & Dirksen, 1986, soil acidity (pH) was also calculated by potentiometric method in saturated extract (Pauwels et al., 1992), electrical conductivity (EC) was measured through using a saturated extract solution, and the (Walkley & Black, 1934) was used to measure the percentage of organic carbon in the soil.

Statistical analyses

The present research was conducted as a factorial experiment based on a completely randomized design with three replications. In this experiment, the first factor was different soil depths and the second factor was plant type. The factors studied were the effect of different soil depths of the studied species and the soil foot of the plants on carbon sequestration and some different chemical and physical properties of the soil. The results were analysed using Excel and SAS software. Statistical analysis was conducted at 5% level. The correlation coefficient and assessment of the stepwise regression model was measured by SAS software.

Results

The effect of electrical conductivity and acidity

Soil type was significantly effects on electrical conductivity ($P \leq 0.01$). While the effect of different soil depths on electrical conductivity was not significant

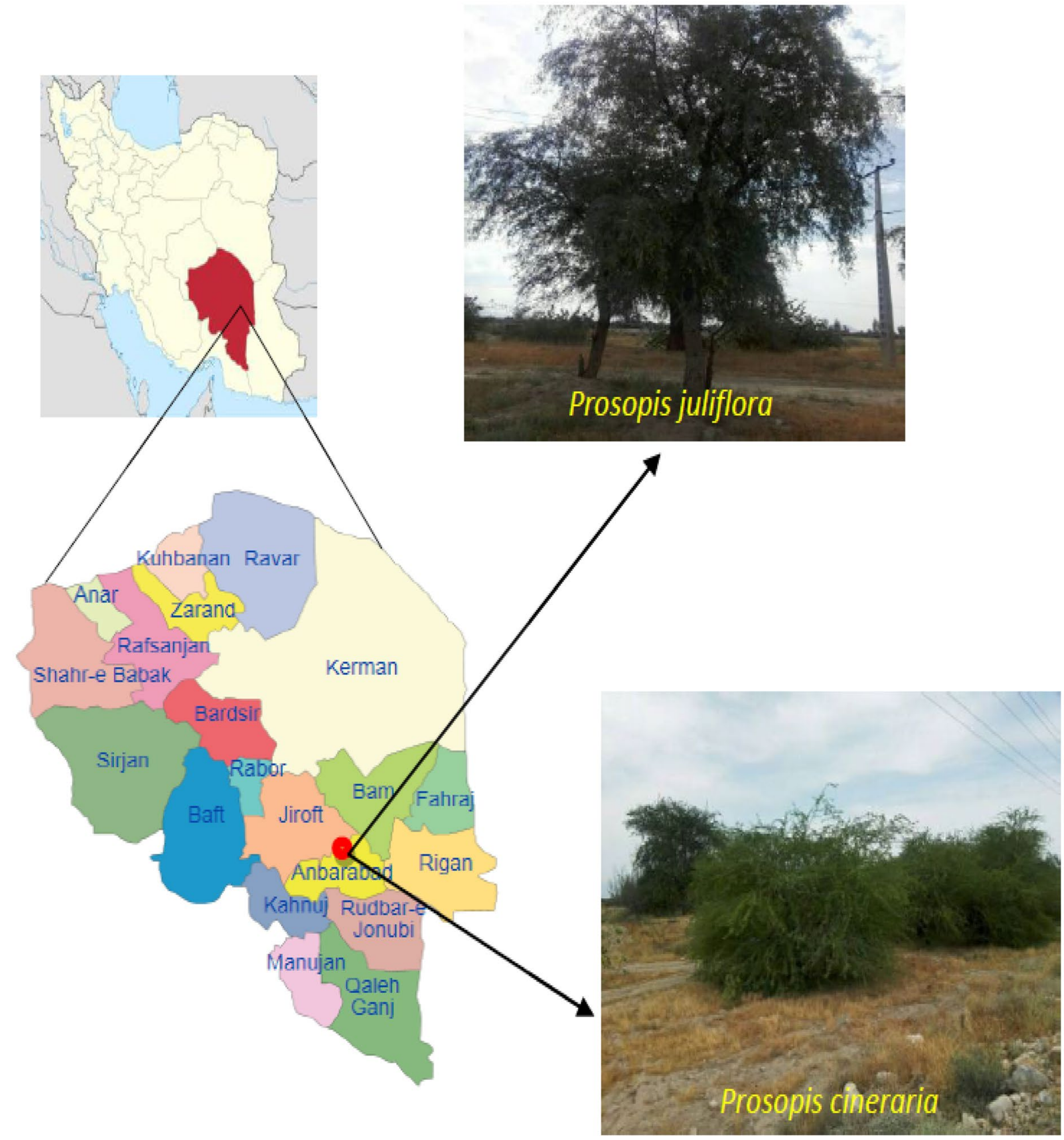

Fig. 1 The site study

(Table 1). The highest electrical conductivity observed in control; it was equal to 2.89a ± 0.634 which was significantly higher than the soil of *P. cineraria* and *P. juliflora* (Table 2). The interaction analysis showed that the highest electrical conductivity was related to the depth of 0–15 cm and 15–30 cm of the soil in the control treatment (2.41a ± 0.66 and 2.36ab ± 1.125, respectively), and no significant differences were observed at different depths of *P. juliflora* and *P. cineraria* (Table 4).

The soil containing *P. juliflora* and *P. cineraria* had a significant effect on acidity ($P \leq 0.05$), whereas

Table 1 Analysis of variance of soil characteristics at two depths of 0–15 and 15–30 cm in soils (*P. cineraria*, *P. juliflora* and control)

Source of variance	Degree of freedom	EC (mscm^{-1})	pH	BD (g/cm^3)	OM (%)	OC (%)	Cs (t ha^{-1})
Plants + control	2	1.111**	0.1274*	0.022*	0.00002^{ns}	0.000006^{ns}	15.7723*
Depth	1	0.049^{ns}	0.0008^{ns}	0.029^{ns}	0.00004*	0.00001*	20.7338*
(Plants + control) × Depth	2	0.7017^{ns}	0.9389^{ns}	0.9020^{ns}	0.5425^{ns}	0.5425^{ns}	0.4063^{ns}
Error	12	0.081	0.0296	0.006	0.000008	0.000002	4.5539
Coefficient variance (%)	-	23.88	1.9613	9.326	0.0986	0.02909	9.4161

BD, bulk density; *OC*, organic carbon; *OM*, organic matter; *Cs*, carbon sequestration; *ns*, non-significant

* Significant at ($P \leq 0.05$)

** Significant at ($P \leq 0.01$)

soil depth did not significantly effect on soil acidity (Table 1). The highest acidity was related to the soil of the control treatment, and the lowest was observed in the soil sample surrounding the *P. juliflora* (Table 2). Analysis of the interaction of plant type and soil depth showed that there was no significant difference between the soil around the roots of *P. juliflora* and *P. cineraria* and the soil of the control sample (Table 4).

Effect of bulk density and soil's organic carbon

Bulk density was significantly affected by the type of soil around the plant ($P \leq 0.05$) (Table 1). So that the highest bulk density was related to the control soil sample and the lowest was related to *P. juliflora* which was equal to 0.9197a ± 0.007 and 0.7997b ± 0.028, respectively (Table 2). The results of the interaction between plant type and soil depth showed a significant difference between the bulk density at different depths and the soil around the plants and the control sample, so that the lowest amount at a depth 15–30 cm of the *P. juliflora* and the highest at a depth 0–15 cm and 15–30 cm of control soil sample were observed without significant differences (Table 4).

The effect of soil depth on percentage of organic matter was significant at the 5% level, while plant type did not show a significant effect on the percentage of organic matter (Table 1). The organic matter percentage in depth 15–30 cm was higher than the depth of 0–15 cm (Table 3). The overall analysis showed that the highest percentage of organic matter was observed in the second depth of *Prosopis juliflora* and *Prosopis cineraria*, and the lowest was observed in the first depth of control treatment (Table 4).

Furthermore, the effect of soil depth organic carbon was significant at the 5% level, while there was not a significant effect on organic carbon (Table 1). Analysis of the interaction of plant type and soil depth on the percentage of organic carbon indicated the highest percentage of organic carbon was observed at a depth of 15–30 cm *P. juliflora* and the lowest at a depth of 0–15 cm in the control soil sample whereas, no significant differences were observed for the other treatments (Table 4).

The effects of both plant type and soil depth on carbon sequestration were reported with significant

Table 2 Comparison of mean soil characteristics in soils (*P. cineraria*, *P. juliflora* and control)

Plants	EC (ms cm^{-1})	pH	BD (g/cm^3)	OM (%)	OC (%)	Cs (t ha^{-1})
P. cineraria	1.27b ± 0.171	8.81ab ± 0.086	0.8835ab ± 0.042	2.9995a ± 0.001	1.7398a ± 0.0006	23.08 ab ± 0.752
P. juliflora	0.64b ± 0.09	8.61b ± 0.076	0.7997b ± 0.028	3.0025a ± 0.001	1.7416a ± 0.0007	24.03a ± 1.113
Control	2.89a ± 0.634	8.89a ± 0.031	0.9197a ± 0.007	3.0029a ± 0.0005	1.7418a ± 0.0003	20.87b ± 0.203

Means with the same letter in each column are not significantly different using Duncan multiple range test ($P \leq 0.05$). *BD*, bulk density; *OC*, organic carbon; *OM*, organic matter; *Cs*, carbon sequestration

Table 3 Comparison of mean soil characteristics at depths of 0-–15- and 15—30 cm soil

Depth (cm)	EC (ms cm^{-1})	pH	BD (g/cm^3)	OM (%)	OC (%)	Cs (t ha^{-1})
0–15	1.7768a ± 0.272	8.7811a ± 0.061	0.8270a ± 0.016	3.0008b ± 0.0008	1.7401b ± 0.0004	21.58b ± 0.451
15–30	1.4320a ± 0.172	8.7672a ± 0.034	0.9082a ± 0.025	3.00320a ± 0.0008	1.7420a ± 0.001	23.73a ± 0.674

Means with the same letter in each column are not significantly different using Duncan multiple range test (P ≤ 0.05). *BD*, bulk density; *OC*, organic carbon; *OM*, organic matter; *Cs*, carbon sequestration

differences (P ≤ 0.05) (Table 1). The highest carbon sequestration was related to *P. juliflora* treatment (24.03a ± 1.113 t/ha) and the lowest carbon sequestration was to control treatment (20.87b ± 0.203 t/ha) (Table 2). Also, the second depth had higher ability than the former depth in carbon sequestration (Table 3). The overall analysis revealed that the highest carbon sequestration was reported at the second depth of *P. cineraria* treatment and two depths of *P. juliflora* without a significant difference and the lowest was observed in the first depth of control treatment (Table 4).

Stepwise regression and correlations between the soil's chemical properties

Chemical analysis showed that there was an effective and first-rate relationship between carbon sequestration and bulk density and percentage of soil organic matter. Moreover, according to the regression model, the percentage of organic matter (0.575) had a greater effect on carbon sequestration than bulk density (− 0.889) (Table 5).

The results of analysis of correlation coefficients between soil properties around *P. juliflora* and *P. cineraria* indicated that soil's acidity and electrical conductivity had a negative correlation at 1% level, electrical conductivity had a negative relation with bulk density at level 5%. As well as, bulk density had a negative relation with organic matter, organic carbon and carbon sequestration at 1%. Carbon sequestration was also positively correlated with organic matter and organic carbon at 1% (Table 6).

Discussion

Due to climate change and the development of arid regions, green policies such as forestry were implemented by governments to prevent environmental degradation. Nevertheless, efforts that have been done to assess carbon uptake and environmental control capacities related with arid and semi-arid conditions have been inadequate and dependent on historical conditions and technical constraints (Ansari & Sadeghi, 2021). Today, the preservation of organic matter, especially plant residues covering the soil surface, has become one of the most important and challenging issues in the world (Dinakaran & Krishnayya, 2008).

According to studies on carbon sequestration, the process of decomposition of plant litter is very time consuming and is done from the surface to the depth of the soil. This indicates an inverse relationship between carbon storage and soil depths (Vural, 2015;

Table 4 Comparison of mean interactions between soil characteristics at depths of 0–15 and 15–30 cm in soils (*P. cineraria*, *P. juliflora* and control)

Plants	Depth	EC (ms cm^{-1})	pH	BD (g/cm^3)	OM (%)	OC (%)	Cs (t ha^{-1})
P. cineraria	0–15	1.08b ± 0.267	8.640a ± 0.125	0.87ab ± 0.017	3.0025ab ± 0.0007	1.74ab ± 0.001	21.39ab ± 0.67
	15–30	1.07b ± 0.22	8.586a ± 0.09	0.84ab ± 0.035	3.0033a ± 0.0007	1.74ab ± 0.0003	24.36a ± 0.92
P. juliflora	0–15	0.68b ± 0.019	8.813a ± 0.17	0.85ab ± 0.025	3.0007ab ± 0.0009	1.74ab ± 0.0005	23.70a ± 1.201
	15–30	0.60b ± 0.004	8.810a ± 0.073	0.75b ± 0.045	3.0042a ± 0.002	1.74a ± 0.0016	24.85a ± 2.47
Control	0–15	2.41a ± 0.66	8.890a ± 0.023	0.91a ± 0.093	2.9990b ± 0.002	1.73b ± 0.0004	19.83b ± 0.46
	15–30	2.36ab ± 1.125	8.905a ± 0.014	0.96a ± 0.003	2.9998ab ± 0.0006	1.74ab ± 0.0004	21.31ab ± 0.1

Means with the same letter in each column are not significantly different using Duncan multiple range test (P ≤ 0.05). *BD*, bulk density; *OC*, organic carbon; *OM*, organic matter; *Cs*, carbon sequestration

Table 5 Multiple regression analysis to identify the traits affecting the organic carbon percentage of soil

Variables	Degree of freedom	Regression coefficients	Standard error	t value	Pr > | t |
Bd	1	− 0.889	0.0192	− 137.72	< .0001
% OM	1	0.575	0.4893	15.44	< .0001

Intercept -22.64

The proposed model for organic carbon percentage OC = -22.64 -0.889 Bd + 0.575 OM

Sadeghi et al., 2016a; Vural, 2018). While in the present study, the highest and the lowest amount of carbon sequestration was observed in the depth containing the roots of the two species and the initial depth of the control treatment, respectively. Regarding the result obtained, it is acknowledged that the higher rate of decomposition in the substrate and the accumulation of roots at 15–30 cm depths were probably the main reasons for this result. It should be noted that in the secondary depth of the control treatment, due to the lack of canopy and litter, carbon storage is less than under the canopy.

The rate of decomposition of organic matter can be controlled and reduced to an acceptable level (Sadeghi et al., 2016a). On the other hand, Su et al. (2010) states that the biological remediation of dry lands contributes significantly to the ability of soil carbon sequestration.

The amount of organic carbon in soil reserves is related to physical and chemical parameters such as bulk density, sand, silt, clay and acidity, and differences in soil type can explain the difference in the amount and manner of these properties (Brahim et al., 2011). The effect of plant on acidity was reported with a significant difference, and that the highest amount was related to the soil of the control area, while the effect of depth and interaction on this factor was not significantly different. The effect of plant on the amount of organic matter as well as organic carbon was reported to be insignificant, whereas the effect of soil depth and the interaction of depth and plant on these two factors were reported with significant differences. The highest amount was observed at a depth of 15–30 cm of *P. juliflora.* Approximately 50% of the soil organic carbon deposited to a depth of 100 cm is stored in the first 30 cm of the soil (Ansari & Sadeghi, 2021). The highest amount of organic carbon and carbon sequestration was at a depth of 0–30 cm. The type of vegetation can significantly affect soil properties (Dinakaran & Krishnayya, 2008).

Different plant species have different abilities to restore soil properties in different ecosystems. The rate of carbon sequestration at a depth of 15–50 cm was greater than 0–15 cm, which, of course, was due to perturbations in the amount of bulk density at the second depth compared to the first depth. The results of various studies have shown that changes in soil organic carbon are associated with changes in soil structure or its stability (Bicheldey & Latushkina, 2010). Soil physical properties, such as bulk density, affect soil carbon storage. There is a correlation between bulk density and organic carbon content, as increasing the amount of organic carbon reduces bulk density (Iranmanesh & Sadeghi, 2019a, b). The bulk density has a direct role in the amount of carbon sequestration in each area (Derner & Schuman, 2007). The results showed that no significant relationship was observed between carbon and soil pH (Sadeghi et al., 2016b). The effect of depth on electrical conductivity and bulk density was not significantly different, while the effect of plant type and interaction on electrical conductivity and bulk density were reported with significant differences. Therefore, the highest amount of

Table 6 Correlation coefficients between soil characteristics

	pH	EC (ms cm^{-1})	BD (g/cm^3)	OM (%)	OC (%)	Cs (tha^{-1})
pH	1.000					
EC(mscm^{-1})	− 0.7400**	1.000				
BD (g/cm^3)	0.4049^{ns}	− 0.5629*	1.000			
OM (%)	0.3584^{ns}	− 0.4444^{ns}	− 0.8630**	1.000		
OC (%)	0.3571^{ns}	− 0.4449^{ns}	− 0.8430**	0.9795**	1.000	
Cs (tha^{-1})	0.4041^{ns}	− 0.5577^{ns}	− 0.9930**	0.8630**	0.8630**	1.000

BD, bulk density; *OM*, organic matter; *OC*, organic carbon

* Significant at ($P \leq 0.05$)

** Significant at ($P \leq 0.01$)

electrical conductivity and bulk density at a depth of 15–30 was related to the soil of the control area.

In general, afforestation on the sandy areas improves some chemical and physical soil properties (Pazhavand & Sadeghi, 2020). Aforestation has led to a change in the size distribution of soil particles and a significant increase in the percentage of sand. In other words, the results reported that afforestation has improved some chemical and physical properties of the soil. Parameters such as bulk density, acidity and electrical conductivity have a direct effect on the amount of organic carbon stored in the soil (Iranmanesh & Sadeghi, 2019a, 2019b).

Lowering the pH increases the uptake of nitrogen and the uptake of more nutrients by trees. Finally, it increases the amount of soil carbon (Augusto et al., 2002). The bulk density and the percentage of saturated moisture soil affect the amount of soil carbon storage (Derner & Schuman, 2007). Higher electrical conductivity reduces the accumulation of humus (Setia et al., 2013). Salt is an influential factor in soil organic carbon. Saline soils can host halophyte plants that are more tolerant to salinity, so they are highly resistant to the side effects of high electrical conductivity (Chowdhury et al., 2011). Generally, the results indicate that the bulk density, and electrical conductivity of the soil are among the effective factors in soil organic carbon storage and vegetation is an important and effective component in soil organic carbon storage.

Conclusion

The results indicated that soil carbon storage was higher in soils containing *Prosopis juliflora* compared to *Prosopis cineraria* and control soils samples. Also in deeper soils, more soil carbon sequestration was reported than at shallower depths. The effect of plant, soil depth and interaction on carbon sequestration showed a significant difference, so that the highest amount was related to the depth of 15–30 cm in *P. juliflora*. Stepwise regression showed that organic matter percentage and soil bulk density were effectively related to carbon sequestration. Carbon sequestration has a direct and significant relationship with the percentage of organic matter and a significant negative relationship with bulk density. Also, the results of the correlation between soil traits around *P. cineraria* and *P. juliflora* showed a significant negative relationship between electrical conductivity and acidity. Bulk density also had a significant negative correlation with the percentage of electrical conductivity, organic carbon, organic matter percentage and carbon storage. Finally, organic matter, organic carbon and organic carbon were reported with significant positive correlations. Generally, by maintaining plant residues on the surface. Carbon sequestration was the highest in the depth containing the roots of both species and the lowest in the first depth of the control treatment.

Author contribution Hossein Sadeghi designed the experiment. Sara Ansari assembled input data, and analysed output data. H. Sadeghi administered the experiment and S.Ansari wrote the manuscript.

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Declarations

Ethics approval Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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