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Effects of forest plantations on soil carbon sequestration in Chah Nimeh region of Sistan, Iran

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Plantation forests are the most effective and ecologically friendly way of absorbing CO2 and increasing carbon sinks in terrestrial ecosystems; mitigating global warming and beginning ecological restoration. This study was done in Chah Nimeh region located in Sistan and Baluchistan province, the southeastern part of Iran, near the Afghanistan border. In this study, soil samples were collected at depths of 0-15 cm and 16-30 cm in 10 replications. This study was done based on a completely randomized design in a factorial experiment in planted forests stands with bare lands surrounding (control areas). The obtained data were entered to SPSS software and were analyzed using One-way ANOVA and the effectiveness of species of *Eucalyptus camaldulensis*, *Tamarix aphylla*, *Olea europaea* and *Pinus eldarica* on soil carbon sequestration rate was calculated. The results showed that the carbon sequestration in soils under different species of afforestations in this area has significant difference at the 5% level in both depths. As, in the upper soil depth, carbon sequestration in Pine species (12.66 tons per hectare) is higher than Tamarisk (9.22 t/ha), Eucalyptus (8.18 t/ha), Olive (5.70 t/ha) species and the control area (6.30 t/ha). Also in the second depth of soil, carbon sequestration in Pine (11.61 t/ha) is higher than Olive (6.27 t/ha) species. There are no significant differences among Eucalyptus (10.41 t/ha), Tamarisk (9.77 t/ha) plantations and bare land (7.05 t/ha) in this soil depth. In this arid region, afforestation of Eucalyptus, Tamarisk and Pine species has increased the amount of carbon sequestration in soil.

Keywords: Afforestation, Arid Land, Soil Carbon Stock, Sistan Plain.

INTRODUCTION

Anthropogenic release of CO2 into the atmosphere through the combustion of fossil fuels represents a growing threat to the global environment. Although, a permanent solution to this problem can only come through the development of technologies that do not depend on previously stored carbon, in the short-term, offsetting emissions of greenhouse gases together with other CO2 abatement policies may provide some respite. The atmospheric carbon pool at 750 Pg [1] is considerably smaller than the quantity of carbon stored within soil (2200 Pg in top 1 m) of which approximately 1500 Pg is organic carbon [2]. Carbon is readily exchanged between these two pools [3].

The Kyoto Protocol to the Framework Convention on Climate Change, adopted by a majority of the world's nations in December, 1997, sets specific targets and timetables for the reduction of greenhouse gas emissions by Annex I (industrialized) countries. There is currently a great deal of interest in converting non-forest to forest land (afforestation) to offset carbon dioxide (CO2) emissions. Trees and other forest vegetation photosynthesize CO2 to yield carbon, and since forests generally store more carbon than land in other uses (e.g. agriculture), afforestation can achieve a reduction in net greenhouse gas emissions [4,5].

The role of forests (or trees) in carbon cycles is well recognized and forests are a large sink of carbon [6]. There is considerable interest to increase the carbon storage capacity of terrestrial vegetation through land-use practices such as afforestation [7]. Gaining new carbon through forestation has become the most effective, hopeful, and ecologically friendly measure to enhance carbon sequestration in terrestrial ecosystems and mitigate increasing CO2 concentrations in the atmosphere. Large scale forestation will establish large areas of new vegetation to enhance carbon

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sinks, conserve soils, and improve water quality [8,9]. Forestation is also the primary driving force for transformation between carbon sinks and sources [10]. Tree plantations allow the carbon to be sequestered in biomass, thus playing a vital role in the terrestrial carbon sink [11,12].

Carbon is stored in different parts of the land ecosystems the most important of which is soil. About 75% of carbon storage of the terrestrial ecosystems is found in soils (3 times more carbon stored in plants) [13]. Thus, soil plays a key role in carbon sequestration. Forest soils with reserves of 700 billion tons are the largest reservoir of carbon in forest ecosystems of the world [14]. Accurate and efficient estimation of soil C is vital to understanding and monitoring the role of afforestation in C sequestration [15]. Soil organic carbon (SOC) makes up a significant portion of the worlds terrestrial carbon stocks, and changes in land-use and land cover are changing soil carbon stocks [16]. It has been reported that more than 50% of total SOC is stored in the subsoil (at a depth below 50 cm) [17].

Sequestering carbon in the soil, ultimately as stable humus, may well prove a more lasting solution than temporarily sequestering it in biomass [18,19]. Soil sequestration would be the most effective factor in mitigating climatic warming in the long term. However, like any large-scale land use change, plantations can have unintended environmental and socioeconomic impacts that can jeopardize the overall value of carbon mitigation projects [20]. The most important factors affecting change in soil C were previous land use, climate and the type of forest established [21].

Forests offer two main options. First, the volume of atmospheric CO2 may be reduced by increasing forest biomass. This may be achieved through an expansion of forests-either by planting currently unforested land, or by allowing the existing forests to accumulate higher biomass. The second main approach is to utilize forest directly as a source of raw materials for energy production, usually referred to as bio-energy, which is considered a carbon-neutral energy source. Use of bio-energy represents a positive contribution towards the CO2 concentration problem if it replaces fossil fuels. Since trees are a terrestrial carbon sink [22], managed forests in theory can sequester carbon both in situ (biomass and soil) and ex-situ (products) [23].

It is estimated that in the one hectare of forested land, an average of 12 to 50 tons of carbon is stored in above-ground biomass [24]. However, there is strong variation in the carbon sequestration potential among different plantation species [25], regions and management. Hence, a careful choice of tree species used for the forestation occurring under the Kyoto protocol is needed to promote long-term climate change mitigation [26]. Variations in environmental conditions can affect carbon sequestration potential even within a relatively small geographic area [23,27].

Iran is located in the world's arid and semi-arid belt, where the lack of rain and its poor distribution, and high evaporation are its main climatic characteristics [28]. Carbon stored in Iran’s forests is estimated 180 million tons and absorbed carbon dioxide is 662 million tons [29]. Annual carbon uptake and carbon dioxide in the forests of Iran is respectively, 8 and 30 million tons [30].

The half wells (known as Chah Nimeh) are main water reservoirs located in Sistan plain in Iran and Afghanistan border areas. Afforestations around Chah Nimeh were implemented in order to get to multiple objectives including biological restoration to counter desertification, creation of forest parks, wildlife refuges strengthened, and carminative as well as other conservation and environmental objectives. The current research is an attempt to evaluate the significance of these afforestatins in terms of carbon sequestration in soils. Because in natural ecosystems the amount of carbon sequestration is higher, the higher will be its ecological capability.

MATERİALS AND METHODS

Study area

The half wells (known as Chah Nimeh) are large natural pits located in the distance of 50 kilometers from the city of Zabol. Excess water of the Helmand River flows into Chah Nimeh by a channel. The capacity of these reservoirs that have been converted as artificial lakes is 700 million cubic meters, located in the 41^{o} 61^{1} east and 54^{o} 30^{1} north latitude coordinates geographically (Fig 1).

Plants from the families of *Tamaricace, Poaceae, and Chenopodiaceae* are more frequent in the region. 3800 hectares of Chah Nimeh area were dedicated to cultivating forest species. Afforestation species in this area include: *Eucalyptus camaldulensis*, *Tamarix aphylla*, *Olea europaea* and *Pinus eldarica*.

Study area in terms of the climate and weather classification, is considered a part of Iran’ dry lands, because all the main characteristics of arid regions are found in this region such as the high level of solar radiation, the frequency range of daily and seasonal changes in temperature, low humidity, strong winds accompanied by dust storms and sand, low and scattered rainfall and high temporal and spatial variations of the region's climatic conditions.

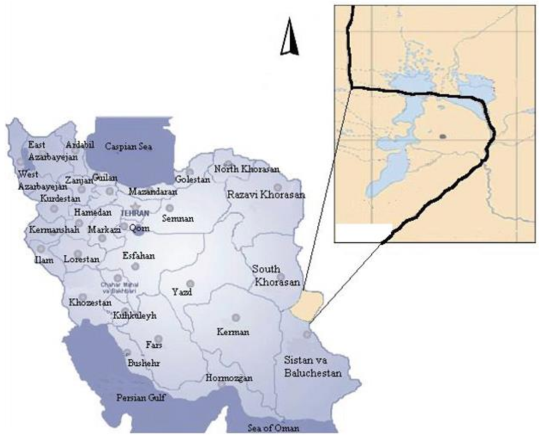

Fig. 1. The location of study area.

Maximum, minimum and average rainfalls in Sistan plain are respectively 123, 17 and 59 mm. Most of the atmospheric fallouts occur in winter, and January with 29 percent of total rainfall is the most rainfall month. Weather station data indicate that the minimum temperature and maximum temperature belong to January (1.24^{oc}) and July (41.60^{oc}), respectively. High temperatures and high sunshine hours made this region have the greatest amount of evaporation compared to other parts of the country (4775 mm per year). Another factor affecting the climate of the area is strong winds blowing in winter and spring alternately, and in summer constantly. These winds flow from the North and North West and are recognized as "120-day winds" during the warm season that begin in mid-June and continue until early October. The wind speed is 80 mph.

Sampling

Four forest stands of Pine, Tamarisk, Olive and Eucalyptus along with the surrounding bare lands (control plot) were selected randomly in this area. To reduce boundary effects, a few planting rows around each stand were not considered for sampling. In each forest stand, 10 plots (5m × 5m) were established in a systematic random way, and within each plot after removing litter layer, the soil from two depths 0-15cm and 16-30 cm was sampled.

To minimize error, the sampling was performed in combination. In this case, the soil samples were taken from the four corners of the plot, then samples were pooled and one sample was harvested from each depth in every plot [31]. Thus, 10 combined samples were harvested in each depth in each forest stand and transferred to the laboratory. Samples were dried in air. Then, after crushing clods, separating the roots, rocks and other impurities, samples were milled and passed through sieve 5.0 mm [32,33]. Bulk density was studied by hunk in grams per cubic centimeter [34]. The organic carbon was determined using Walkley and Black method [35]. The amount of carbon sequestration was calculated according to the equation 1 [36].

$$Cs=10000\times OC\ (\%)\times Bd\times e \quad (1)$$

Where Cs = the amount of organic carbon sequestration (g/ m^2); OC = organic carbon; Bd = Soil bulk density (gr/cm^3); e = depth of sampling (cm)

Data analysis

To analyze the data, SPSS software version 19 was employed. Data normality and homogeneity of variance were analyzed using Smirnov-Kolmogorov test and Levene test, respectively. One-way ANOVA was used for total assessment of forest stands. Moreover, Duncan's test was used for multiple comparisons of means at the 5% level. Plot graph was prepared through Excel software.

RESULTS

Table 1 show the descriptive statistics of organic carbon (OC) and soil carbon sequestration (SCS) for 0-15 cm and 16-30 cm soil depths. Statistical analysis showed that there were significant differences between the types of afforestation in terms of organic carbon and SCS in soil (Table 2). Duncan's test showed that in depth of 0-15 cm soil, organic carbon in Pine stand (0.97%) is significantly greater than Olive plantation (0.50%) and the control (bare land) (0.42) (p<0.05). In addition, the organic carbon in Tamarisk and Eucalyptus stands found to be more than the unplanted area at 95 percent level. Organic carbon averages in the 16-30 cm soil in Pine and Eucalyptus stands did not differ significantly, while they were more than the control (bare land). There was no significant difference between Tamarisk and Olive plantations in these terms (Table 3).

Table 1. Descriptive statistics of organic carbon (OC) and soil carbon sequestration (SCS) for 0-15 cm and 16-30 cm soil depths.

	N	Minimum	Maximum	Mean	Std. Deviation
OC (0-15 cm)	50	.10	1.90	.6680	.40327
OC (16-30 cm)	50	.04	2.00	.6786	.44181
SOC (0-15 cm)	50	1.05	24.80	8.4105	5.23077
SOC (16-30 cm)	50	1.14	24.80	9.0229	5.33725

Table 2. Statistical analysis (ANOVA) of organic carbon (OC) and soil carbon sequestration (SCS) for 0-15 cm and 16-30 cm soil depths.

		Sum of Squares	df	Mean Square	F	Sig.
OC	Between Groups	1.935	4	.484	3.607	.012
(0-15 cm)	Within Groups	6.034	45	.134		
	Total	7.969	49			
OC	Between Groups	2.129	4	.532	3.221	.021
(16-30 cm)	Within Groups	7.436	45	.165		
	Total	9.565	49			
SCS	Between Groups	305.489	4	76.372	3.320	.018
(0-15 cm)	Within Groups	1035.196	45	23.004		
	Total	1340.685	49			
SCS	Between Groups	206.733	4	51.683	1.956	.118
(16-30 cm)	Within Groups	1189.092	45	26.424		
	Total	1395.826	49			

Table 3. Organic carbon percent in two soil depths of afforestations with their standard error in the parenthesis.

	Pinus	Tamarisk	Eucalyptus	Olive	Bare land	ANOVA
0-15 cm	0.97(0.13) a	0.67 (0.10) abc	0.78 (0.16) ab	0.50 (0.06) bc	0.42 (0.08) c	*
16-30 cm	0.89 (0.13) a	0.71 (0.11) ab	0.89 (0.19) a	0.55 (0.08) ab	0.35 (0.09) b	**

ANOVA results: *, p<0.05; *, p<0.01. Mean values with the same letter within the soil layer do not differ significantly with each other (Duncan).

Also, Duncan's test showed that in the depth of 0-15 cm soil carbon sequestration in Pine stand (12.66 t/ha) was significantly greater than the control (Bare land) (6678 kg/ha) and Olive stand (6.27 T/ha) (p<0.01). The carbon sequestration in Tamarisk (9.22 T/ha) and Eucalyptus (8.18 T/ha) did not indicate significant differences with other plantations and bare land at 95 percent level (Fig. 1). Carbon sequestration rate in the second depth of soil, in Pine (11.61 t/ha) was higher than Olive species (6.27 t/ha) (p<0.01). There was no significant difference among Eucalyptus (10.41 t/ha), Tamarisk (9.77 t/ha), and bare land (7.05 t/ha) in this soil depth (p<0.05, Fig. 2).

DISCUSSION

Soil C sequestration following afforestation has been the subject of a substantial body of research, which suggests that the direction and magnitude of SOC changes are determined by many factors and processes, such as climate, stand age and soil depth [37-39]. The major sources of carbon storage are vegetation, especially forests. Forests serve as carbon reserves and stabilizers. When forests grow, they gradually store the carbon in wood textures and soil organic carbon matter over time [40]. Carbon is stored in plant tissues such as leaves and wood, and then in autumn dried leaves fell and decompose resulting in an increase in the amount of organic matter.

Carbon sequestration rate in upper soil in the Pine, Eucalyptus and Tamarisk is more than the bare area (control). This can be due to an accumulation of litter on the soil surface and its decomposition trend. Also, the amounts of organic matter derived from Walkley and Black method in Pine (1.66), Tamarisk (1.15) and Eucalyptus (1.34) afforestations were more than bare land (0.72). Vesterdal [41] in a study of 1 to 19 years old plantations, showed that the highest concentration of carbon is made in the soil depth of 5 cm. Woomer *et al.* [42] studying on the amount of carbon stored in soils and plants in Senegal, concluded that about 60% of soil organic carbon is stored at a depth of 20 cm below the surface. The rate of carbon sequestration in the soil surface of Olive afforestation is less than the control area and has the lowest carbon sequestration among other stands, suggesting afforestation with olive species is not able to increase carbon sequestration. Although the amount of organic matter in the soil of the Olive stand is somewhat more, but the average values of its soil bulk density was measured lower than bare land. For this reason, the amount of carbon stored in the soil under Olive plantation was calculated lower than the control area.

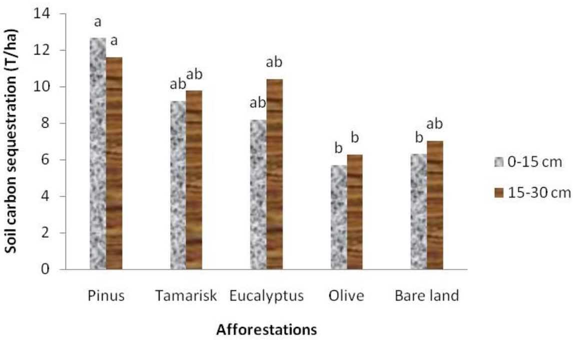

Fig. 2. Soil carbon sequestration in 0-15 cm and 15-30 cm depths in the different planted species

Also the results showed that the rate of carbon sequestration in depth of 16 to 30 cm of soil in the Pine, Eucalyptus and Tamarisk afforestations was higher than in bare land (control). To a certain proportion of annual precipitation, soil organic carbon storage increases as evapotranspiration decreases. Since evapotranspiration in Chah Nimeh is high, the organic carbon content sets low. Sequestration of carbon is associated with vegetation percent, plant species and amount of plant debris litter, type of land use and management. In case of appropriate establishment of vegetation in the area, soil organic carbon will increase in long-term, because soil organic carbon changes are gradual [43]. The root is an important component of ecosystems to sequester carbon, but because the study area is hot and dry and the ground water level is low in the region, the roots of trees did not have much development in this region. Roots and its coexistence with micro organisms are of the factors that affect carbon sequestration in soil including forested areas and afforestation areas. As a guess, the nitrogen fixing bacteria maybe low in the plants' roots. So, carbon sequestration is less in second depth of soil. Varamesh *et al.* [31] stated that soil organic carbon at a depth of 0-15 cm was more than 15-30 cm depth. Also, Amiqy *et al*. [44] measured the amount of organic carbon in the soil surface layer 0-25 cm to be greater than the 25- 50 cm layers. Zhao *et al.* [45] documented that afforestation not only affects soil organic carbon (SOC) stocks in surface soil, but also strongly influences it in deep soil.

Forest type is also effective on carbon sequestration. Among land ecosystems, the conifer forests are the most important carbon-storing trees. Their contribution to mitigating climate change is considerable, because of their ability to absorb carbon dioxide from the atmosphere through photosynthesis and carbon storage potential in living and non-living components [46]. In this study it was found that carbon sequestration in soils beneath conifers (Pine) was greater than the soils under broadleaf species which is consistent with other studies [47-50] in their study in Scotland found that the conifer species increased density of surface litter, in other words, increased the soil organic carbon.

The results showed that the highest rates of carbon sequestration associated to Pine among the tree species, because the amount of its organic matter had the highest value in the surface, and so carbon sequestration in 0-15 cm of Pine plantation is more than 16-30 cm depth. Then the forest stands of Tamarisk and Eucalyptus had the most amount of carbon sequestration. This is because these species are resistant to dehydration and are salt-friendly. The carbon sequestration of these afforestations in second depth is greater than the first because their organic matter content is greater than the first depth, and perhaps due to the activity of root mass of the plant. In general, species that grow in dry areas have greater root biomass and volume. The olive stand had the least amount of carbon sequestration among the afforestations. Also, carbon sequestration in the second depth is greater than the first depth.

The different C content and stocks at 0-15 and 16-30cm depths is very important and determined by both organic matter dynamics and soil properties, which are in turn affected by vegetation. Reviews have shown that carbon biomass is influenced by forest type, climate, soil, topography, and human activity [24]. However, the changes in soil organic carbon that follow forestation are still under debate, and are influenced by vegetation production, soil conditions, land use history, the type of forest established, and forest management [27,51]. SOC after planting may increase [16,52-54] or decrease [12,51,55,56]. However, most reviews have presented initial losses in SOC, followed by slight increases [21,54,57,58].

CONCLUSIONS

The results showed that in this arid region, afforestation with species of Pine, Eucalyptus and Tamarisk increases the amount of carbon sequestration in soil. This research proved that the effects of afforestation varied with plant species. Moreover, it managed to show that needle leave species led to an increase in soil organic carbon storage more than hardwoods. Given that carbon sequestration is a measure of ecosystem stability, and by recognition of species which have a greater ability to sequester carbon, as well as through managing those factors affecting the process of carbon sequestration, reclamation and restoration of land can be achieved more successfully.

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