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Soil Carbon Sequestration Potential of Eldar Pine and Black Locust Afforestation in a Semi-Arid Zone of Iran

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Abstract: To obtain estimates of carbon sequestered following afforestation, we studied the amount of soil carbon sequestration in two 15-year old stands of needle-leaved eldar pine (*Pinus eldarica* Medw.) and broad-leaved black locust (*Robinia pseudoacacia* L.) and a control area (without afforestation) in South of Tehran, Iran. For this purpose, sample plots (30×30 m) were randomly chosen in either site. In each plot, samples from depths of 0-15, 15-30 and 30-60 cm of four soil profiles were taken for investigations. In laboratory, Soil Organic Carbon (SOC) content of samples was determined by the Walkley-Black method. No significant difference in the amount of soil carbon sequestration of two stands was detected, but each stand sequestered higher carbon content in soil compared to that of in control area. In all soil samples, the highest carbon sequestration was observed in upper layer of soil. Likewise, values of growth and biomass of eldar pine trees were greater than those of black locust trees. It was concluded that there is a great potential of afforestation, in increasing of soil carbon sequestration.

Key words: Afforestation, carbon sequestration, *Pinus eldarica*, *Robinia pseudoacacia*, soil

INTRODUCTION

Tree plantation contributes not only to soil conservation (Buresh and Tian, 1997), but also for enhancing the amount of soil organic carbon (SOC) and to mitigating carbon dioxide (CO_2) emission effects on climate change (Post *et al*., 2004; Paul *et al*., 2008). Climate change refers to long-term alterations in temperature, precipitation, wind and other elements of the Earth's climate system (Follett, 2001). Global warming is an alarming phenomenon that was recognized as early as 1975 by measuring increasing temperature trends (Mann *et al*., 2003). Numerous sources are reporting impacts of global warming such as increasing instances of atmospheric instabilities (sudden changes in temperature, precipitation, wind and other elements of the climate) (Tett *et al*., 1999), which are creating major concerns on an international level. The reason for the accelerated increase of global temperature in the past 60 years has being attributed largely to anthropogenic greenhouse gas (GHG) emissions (Rosso and Stenstrom, 2008). Naturally occurring GHGs include water vapor, CO_2, methane (CH_4) and nitrous oxide (N_2O) (Follett, 2001). The 1996 report of the International Panel on Climate Change (IPCC) states that there is clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC, 1996). Although there is no consensus as to how much change will occur, there is general agreement that it is worthwhile to reduce GHG emissions to decrease the risks that many scientists feel are associated with climate change (Follett, 2001; Yan *et al*., 2007).

Although CH_4 and N_2O need to be considered, many scientists now believe that anthropogenic additions of CO_2 to the atmosphere is the main factor of global warming (Bluemle *et al*., 1999). Since

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the beginning of industrial revolution in 19th century, CO_2 concentration of atmosphere has reached from 280 to 365 in million and it seams that in 21st century it will reach to 600 in a million that leads to increasing of average annual temperature up to 1 until 4.5°C (Korner, 2003). The realization that increasing the organic matter content of soils can effectively remove CO_2 from the atmosphere has made carbon sequestration an important research topic in soil science in recent years (Paustian *et al*., 1997; Batjes, 1998; Brevik *et al*., 2002). Since, about 75% of total terrestrial C is stored in the world's soils (Henderson, 1995), thus soil is the largest carbon reservoir in terrestrial ecosystems (Toyota *et al*., 2006) and forest soils hold about 40% of all belowground C (Dixon *et al*., 1994; Huntington, 1995). Therefore, even if afforestation only slightly affects soil C stocks at the local level, it could have a significant effect on the global C budget (Paul *et al*., 2002). Hence, using vegetation and tree plantation in the form of afforestation, in addition to making green space and wood production, can sequestrate carbon (Bordbar and Mortazavi, 2007).

Many studies have been conducted in several countries to assess the contribution of afforestation to the global C cycle at regional, national level and global scales and have explored the options to enhance C sequestration (Vleeshouwers and Verhagen, 2002; Marland *et al*., 2003; West and Marland, 2003; Dendoncker *et al*., 2004; Liao *et al*., 2006). Despite the recent surge in carbon sequestration research, there are still many gaps in our knowledge of this important topic from Iran. In this study, we investigated soil carbon sequestration in two artificial stands of needle-leaved eldar pine (*Pinus eldarica* Medw.) and broad-leaved black locust (*Robinia pseudoacacia* L.) in a semi-arid zone of Iran (South of Tehran).

MATERIALS AND METHODS

The study site is located in Shahr-e Rey, 5 km South of Tehran-Iran (Latitude 35° 37′ N, Longitude 51°23′ E, 1005 m above sea level). The climate of the site is semi-arid with mild-cold winters and 7 months (Mid April-Mid November) dry season. Average annual rainfall and average annual temperature are 232 mm and 13.3°C, respectively. The highest rainfall is in March and the lowest in August. The warmest month occurs in August and the coldest in January (Tabari *et al*., 2008).

The examination was made in October 2006. Experiments were conducted at two even-aged (15 years) artificial stands of *P. eldarica* and *R. pseudoacacia* with clay-loam soil in two fields. Also, an area without afforestation near to either both stands was selected. For soil sampling, four sample plots (30×30 m) were randomly chosen in either of both stands. In each plot, four soil profiles were dug to take the samples from depths of 0-15, 15-30 and 30-60 cm. This collection provided 48 soil samples in each stand from three depths. At the end of soil sampling, three representative soil samples of three depths from each plot were taken by mixing of samples of each layer in each plot (decreasing of samples quantity for chemical analysis) according to Habibi (1992). In control area (without afforestation), also two soil profiles were dug and soil samples taken from three mentioned depths. In laboratory, the soil samples air-dried, crushed and passed through a 2 mm sieve. Soil texture was determined using the hydrometer method according to Bouyoucos (1962). Soil Organic Carbon (SOC) content was determined by the Walkley-Black method (Nelson and Sommers, 1996).

To determine growth status of two study stands, in selected sample plots, hundred percent inventory was conducted from diameter at breast height (d.b.h.) and total height. Standing volume of each tree was determined by using form factor (~0.5) and formula made by Zobeiri (1994) (Eq. 1).

$$V = 0.4 * D^2 * H \tag{1}$$

Where:
D = Diameter at breast height (d.b.h.),
H = Total height
V = Standing volume

Average growth parameters of two stands (*P. eldarica* and *R. pseudoacacia*), were compared using independent-samples t-test (Pelosi and Sandifer, 2003). Differences of SOC between two stands and control area (without afforestation) and also due to depth in the profile in each field were tested using one-way ANOVA. Simple linear regression analysis was used to determine the relationship between SOC (%) and growth parameters. All the data were analyzed using the SPSS statistical package (Lindaman, 1992).

RESULTS

Since growth status of forest stand might influence on changes in soil C, hence growth parameters of two stands were studied. Figure 1 shows diameter distribution of two studied stands. Accordingly, curves are normal form (i.e., the trees are more frequent in center than in sides), demonstrating even-aged stands. The highest number of trees was found at diameter class of 20 and 18 cm, respectively grown in eldar pine and black locust stands. Independent-samples t-test indicated that values of growth and biomass of *P. eldarica* trees were greater than those of *R. pseudoacacia* trees (Table 1).

Results demonstrate that there was not a significant difference in the amount of soil carbon sequestration in depth of 0-60 cm of two stands, but each stand sequestered higher carbon content in soil than that in control area (Table 2). Also in depths of 0-15, 15-30 and 30-60 cm, both stands stored greater carbon in soil compared to that in control area. It was greater in 0-15 and 15-30 cm layers than deeper layer in *P. eldarica* and *R. pseudoacacia* stands (Fig. 2). In all soil samples, the highest carbon sequestration was observed in upper layer of soil (Table 2, Fig. 3).

Table 1: Comparison of growth parameters of two stands (Mean±SD)

Growth parameters	*P. eldarica*	*R. pseudoacacia*	t-value	df	p-value
Diameter at breast height (cm)	12.880 ± 0.615^a	12.030 ± 0.510^a	2.15	6	0.07^{ns}
Height (m)	8.640 ± 0.527^a	6.730 ± 0.150^b	6.24	6	0.001**
Standing volume (m^3)	0.059 ± 0.009^a	0.047 ± 0.003^b	2.58	6	0.042*

Different superscripts in row indicate significant difference; **Significant in 0.01 probability level; *Significant in 0.05 probability level; ^{ns}not significant difference

Table 2: Soil properties in tree stands and control area (0-60 cm)

Soil properties	*P. eldarica*	*R. pseudoacacia*	Area without afforestation
Clay (%)	28.52	26.04	30.00
Silt (%)	36.00	33.78	35.44
Sand (%)	35.48	35.00	37.22
Texture	Clay loam	Clay loam	Clay loam
SOC (%)	0.896 ± 0.086^a	1.00 ± 0.107^a	0.690 ± 0.021^b

Different superscripts in row indicate significant ($p<0.01$) difference

Table 3: Significance of SOC (%) between different depths of each study field

Variable	Study fields	F-value	df	p-value
SOC (%)	*P. eldarica*	26.20	2	0.000**
	R. pseudoacacia	14.04	2	0.002**
	Control (without afforestation)	32.03	2	0.000**

**Significant in 0.01 probability level

Table 4: Relationship between height, diameter and standing volume of tree with SOC (%)

Species	Growth parameters	Linear regression
SOC (%) of *P. eldarica*	Height (m)	$H = 1.21\ C+7.41$; $R^2 = 0.87$, $p<0.05$
	Diameter (cm)	$D = 5.15\ C+6.31$; $R^2 = 0.82$, $p<0.05$
	Standing volume (m^3)	$V = 0.079\ C-0.020$; $R^2 = 0.86$, $p<0.05$
SOC (%) of *R. pseudoacacia*	Height (m)	$H = 1.59\ C+5.30$; $R^2 = 0.85$, $p<0.05$
	Diameter (cm)	$D = 4.13\ C+8.61$; $R^2 = 0.80$, $p<0.05$
	Standing volume (m^3)	$V = 0.032\ C-0.018$; $R^2 = 0.81$, $p<0.05$

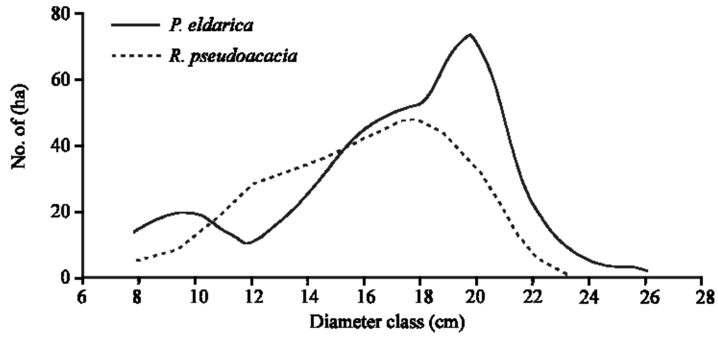

Fig. 1: Distribution of d.b.h. classes in two study stands

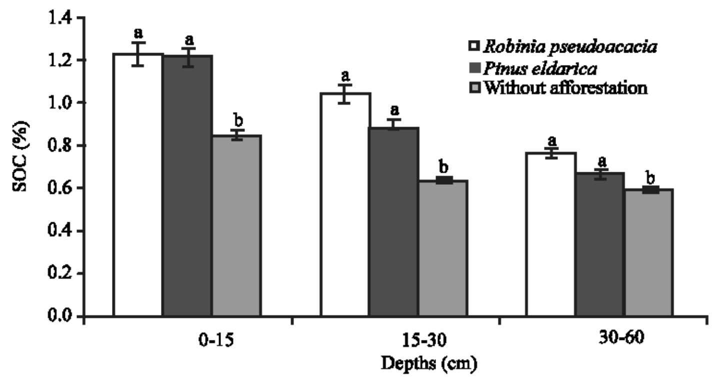

Fig. 2: Comparison of SOC (%) in similar depths (0-15, 15-30 and 30-60 cm) between stands of *P. eldarica and R. pseudoacacia* and control area (without afforestation); Error bars are±SE

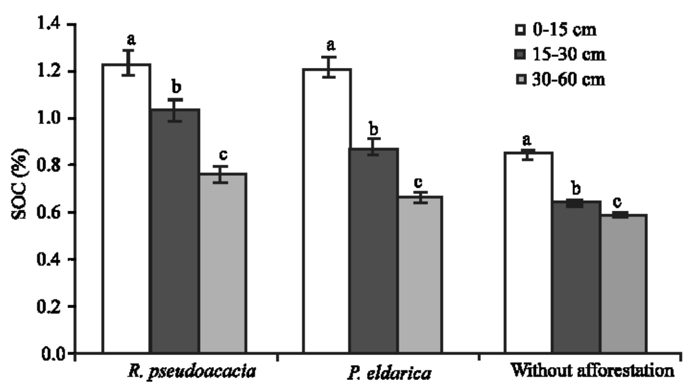

Fig. 3: Comparison of SOC (%) among different depths (0-15, 15-30 and 30-60 cm) of soil in each study field; Error bars are±SE

Linear regression analysis was used to evaluate the relationship between percent of SOC (depth of 0-60 cm) and growth parameters. Significant and positive correlation was found between diameter at breast height, height and volume of trees with percent of SOC (Table 4). Also there was a positive and significant correlation ($p<0.05$) between standing volume in hectare and SOC (%) in stands of *P. eldarica* and *R. pseudoacacia.*

DISCUSSION

Present study displayed that eldar pine stand compared to black locust stand had greater growth and biomass production. Indeed, increased growth and biomass were resulted from facilitated early leaf initiation and a net increase in the number of leaves. An increase in leaves could have captured more solar energy for metabolic use, fixed more CO_2 and produced greater photosynthates and growth. This hypothesis is supported by Ceulemans *et al*. (1993) and Myers *et al*. (1996). With regard to greater growth of eldar pine stand, *P. eldarica* trees played more role in carbon sequestration from CO_2 atmosphere. Enhancing in growth and biomass may improve soil carbon sequestration (Mahmmodi *et al*., 2008). A positive correlation between diameter at breast height, height and standing volume of trees in both stands with quantity of SOC (%) also supports this inference. Bordbar and Mortazavi (2007) with a study on potential of carbon sequestration in afforestations of *Eucalyptus camaldulensis* Dehnh. and *Acacia salicina* Lindl. in a dry area, suggested that studied species followed by increasing in biomass production provided enhancing in soil carbon sequestration.

Little changes were found between SOC (%) of eldar pine stand and black locust stand. Similar findings were reported by Delgado *et al*. (1987), Turner and Lambert (1988) and Majd Taheri and Jalili (1997). In fact, lower SOC (%) in the eldar pine stand may be attributable to the slow decomposition of litter and lower rate of carbon in the conifer needles compared to hardwood leaves (O'Connell and Sankaran, 1997; Paul *et al*., 2002). However Paul *et al*. (2002) reported that there was a significant effect of forest type on change in soil C, but Johnson (1992) reported that forest species can have either no effect or large effects on soil C.

Present results showed that the SOC (%) in both stands was significantly higher than that in control area. Changes in soil C following afforestation have been shown in several studies (Harrison *et al*., 1995; Trouve *et al*., 1996; Binkley and Resh, 1999; Jug *et al*., 1999; Richter *et al*., 1999), so that following afforestation, changes inevitably occur in the quality, quantity, timing and spatial distribution of soil C (Paul *et al*., 2002). Most studies indicate that there is generally an initial decrease in soil C after afforestation followed by a gradual increase that it attributable to site preparation (Ross *et al*., 1999; Gifford, 2000; Turner and Lambert, 2000). There are many abiotic factors affecting the extent of changes in soil C, including site preparation, previous land use, climate, soil texture, soil conditions, type of tree species, age of afforestation, tending operations, fertility of site, site management, harvesting and many other factors (Paul *et al*., 2002; Yan *et al*., 2007; Luxmoore *et al*., 2008), so that the potential for soil C sequestration varies greatly among different regions. For example, soil texture strongly influences C dynamics and there are discrepancies among studies that have compared change in soil C following afforestation in soils with different textures (Franzluebbers, 1999; Percival *et al*., 2000), Climate factors have a significant effect on change in soil C following afforestation and it is commonly observed that soil C accumulation increased with enhancing mean annual precipitation (Nilsson *et al*., 1995; Simmons *et al*., 1996), Thinning and harvesting increase the return of C to the soil through tree residues and root decomposition (Henderson, 1995; Johnson and Curtis, 2001).

CONCLUSION

According to the results of this study and earlier studies, it may be mentioned that using vegetation and trees plantation in the form of afforestation, in addition to making green space and wood production and other advantages of plantations, atmosphere CO_2 by photosynthesis process is sequestrated in the form of carbonic compositions in biomass, soil and wood productions. This leads to fertility of sites with a low SOC rate, decreasing of atmosphere CO_2 and finally decreasing of global temperature. In Iran also, with afforestation in dry areas we can help to increase carbon sequestration and decreasing the effects of green house gasses on the global warming. In this field, due to complex issues in the natural ecosystems and affects of climate factors and other elements on CO_2 absorption in trees, broader researches are needed. Also according to existence potentials in every region, we propose that studies should be done in fields such as: effects of environmental pollutions on CO_2 absorption in tree stands, natural forests potential in carbon sequestration, mineralization rate of organic carbon in different forest soils, effects of tending operations on carbon sequestration of forest stands, potential of carbon sequestration by employed tree species in afforestations, reflection trend of carbon reserved in different organs and parts of a stand.

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