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EFFECTS OF AFFORESTATION ON CARBON STOCKS IN FANDOGHLOO FOREST AREA

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Afforestation of grasslands is increased in Fandoghloo region of northwestern Iran, which has been used for grazing. Carbon (C) stocking of pure and mixed *Pinus nigra*, *Cedeus libani* and *Picea abies* afforested stands (20 years-old) in Ardabil, Iran was assessed. C stocking of tree biomass and litter were defined based on plot-scale measurements. Soil organic carbon (SOC) stocking was determined using soil cores at three depths 0-15, 15-30 and 30-50 cm. An increase in the total ecosystem carbon stock after the afforestation was recorded. The highest total C stocking was estimated to be 55.57 Mg ha^{-1} for the mixed *P. nigra – C. libani* and it was 25.006 Mg ha^{-1} in the degraded rangeland. The aboveground biomass C varied from 2.4 Mg ha^{-1} in the degraded rangeland to 19.28, 15.1, 6.17, 4.55, and 3.87 Mg ha^{-1} in the *P. nigra-C. libani*, *P.nigra*, *P. abies- P.nigra*, *C. libani* and *P. abies* stands, respectively. The amount of litter carbon stock ranged from 0.53 Mg ha^{-1} in the degraded rangeland to 3.51, 3.06, 2.03, 1.55, 1.41 Mg ha^{-1} in the *P. abies - P. nigra*, *P. nigra - C. libani*, *P. nigra*, *C. libani* and *P. abies* stands, respectively. The soil carbon stock increased from 21.41 to 30.11, 28.58, 28.41, 27.45 and 25.43 Mg ha^{-1} in the *C. libani*, *P. nigra*, *P. nigra - C. libani*, *P. abies - P.nigra* and *P. abies* stands, respectively. Significant interactions were observed between stand and soil depth on carbon stock after afforestation with coniferous species in grassland. According to the results, the major ecosystem C pool is attributed to aboveground biomass. The total ecosystem C difference between the degraded rangeland and mixed *P. nigra - C. libani* stand was 30.56 Mg ha^{-1}. The highest SOC accumulation was observed in the surface layer of the *C. libani* (34.95 Mg ha^{-1}), but the accumulation rate is species dependent. The results highlighted the importance of coniferous afforestation on degraded grassland that will most presumably improve the amount of carbon stock and therefore, decrease the negative impacts of increasing CO_2 concentrations. As a matter of fact, the selection of appropriate species and plantation will be considered in the next afforestation projects.

Keywords: Carbon stocking, pure and mixed afforestation, *Pinus nigra, Cedeus libani, Picea* abies, Fandoghloo.

INTRODUCTION

Nowadays humanity facing challenges at global level, resulting from climate change which is a consequence of increasing greenhouse gases, especially CO_2 (Nakakaawa, 2010). Soil and tree biomass are reflected to have a large possibility for impermanent and a lot of time carbon storage (Houghton, 2005; Gower, 2003). Improvement of carbon stock by increasing the area of forested lands (afforestation) has been recommended as an efficient factor to reduce elevated CO_2 agglomeration and thus provide to the prevention of global warming (Watson, 2000; IPCC, 2001). Some international organizations such as UNFCCC also encourage afforestation plans as an effective solution to decrease atmospheric carbon concentration (UNFCCC, 1997). The study of the impacts of tree plantation on the carbon stock is described by various researchers (Zinn, 2002; Lemma, 2006; Nosetto, 2006; Yuksek and Yuksek, 2011; Hansson 2013; Zhag, 2013; Varamesh, 2014), although the contribution of afforestation was known in biomass carbon stocking ,the impacts of afforestation on soil carbon stock were less certain because of effective dynamic components such as rainfall, physico-chemical properties of soil, the age of planted stand (Guo and Gifford, 2002; Paul, 2002), but, the results of different studies regarding the afforestation effects are inconsistent in the case of on net SOC accretion. Therefore, more research needed to understand the accumulation potential of SOC under afforestation in degraded grasslands (Varamesh *et al.*, 2014). The afforestation could be a very useful method for restoring degraded soils and ecosystems (IPCC, 2000) and in the global scale, this method is considered as soil conservation , desertification ,and an increase of carbon stock (Kumar *et al.*, 2001; Maestre and Cortina, 2004; Nosetto *et al.*, 2006). In a study, Giuffre *et al.* (2003) obtained significant differences by evaluating of soil organic carbon between the afforested regions compared with the rangeland in the Patagonia, Argentina. Nosetto *et al.* (2006) found that the afforestation with *Pinus Ponderosa* in grassland of Patagonia increases above -and belowground carbon stocks ,and Mireia (2010) noted a significant increase in soil organic carbon in the plantation of *Pinus halepensis*. Fonseca *et al.* (2012) found that biomass carbon was over 78 Mg per hectare, but the soil characterizes the major carbon sink with more than 85 Mg per hectare. Also, they estimated the values of above 5.3 Mg/ha and over 1.3 Mg/ha for mean annual carbon increases in the biomass and soil. Heras *et al.* (2013) claimed that in the short-term, the carbon stored in the live biomass at afforested stand level was reduced, but the positive effect on productivity permits to restore and exceed the initial amount of carbon in the medium-term. Among the different ecosystems, coniferous forests were considered as great resources of carbon stocks (Gucinski *et al.,* 1995). Several researchers (Akala and Lal, 2001; Xiao-Wen *et al.,* 2009) have focused on the importance of afforestation and suitable species selection to enhance the carbon stocking. Thus, attention to forest ecosystem compartments contribution in carbon stocking is important, due to its necessity to recognize the potential of carbon stock of forest ecosystem to consider complex of trees, understory, soil and litter (Uri *et al.*, 2012). The *Pinus nigra*, *Cedrus libani*, and *Picea abies* are known for afforestation in Iran. However, there are few studies about the effects of afforestation on the total carbon stock of ecosystem with these species in the degraded grasslands of Iran. As a result, definite purposes were to investigate the proportions of carbon stock in the compartments (soil, above – belowground biomass and litters) of coniferous planted stands and degraded grasslands, evaluate the depth pattern of soil organic carbon content at three depths, define the tendency and alterations in C pool of afforestation and determine the relationships of SOC with physico-chemical soil characteristics. The basic assumption of this study was relatively homogeneous biophysical conditions of the stands.

MATERIALS AND METHODS

***Study area description*:** The Fandoghloo forest area is in the northwest of Iran (northeast of Ardabil), between latitudes 38° 22' to 38° 24' N and longitudes 48° 31' to 48° 34' E (Fig. 1). It is distributed over an area of 50 ha. The mean annual precipitation is 379 mm and the mean annual temperature is 8.8°C. The elevation of the forested area ranges of 1350 to 1500 m above sea level. The study area including pure and mixed *Pinus nigra*, *Cedeus libani* and *Picea abies* afforested stands. In the past, afforested areas were barren land which was previously mainly used for grazing and were planted by the mentioned species almost 20 years ago. The soil texture of the area is loam and clay loam.

***Sampling and inventory method of soil litter and trees*:** Surrounding rows of stands were not considered during sampling to avoid bordering effects (Varamesh *et al.,* 2014). Using a randomly systematic method, sampling point of soil and litter pools were done in places where organic carbon accumulates to characterize carbon storage and distribution. Tree allometric equations were used to assess C accumulation in tree compartments. Field sampling and inventory in randomly systematic way was conducted during the October, (2013) using six squares 400 m^2 (20-20 m^2) in each type of afforested system, i.e. *Picea abies*, *Cedrus libani* and *Pinus nigra*.

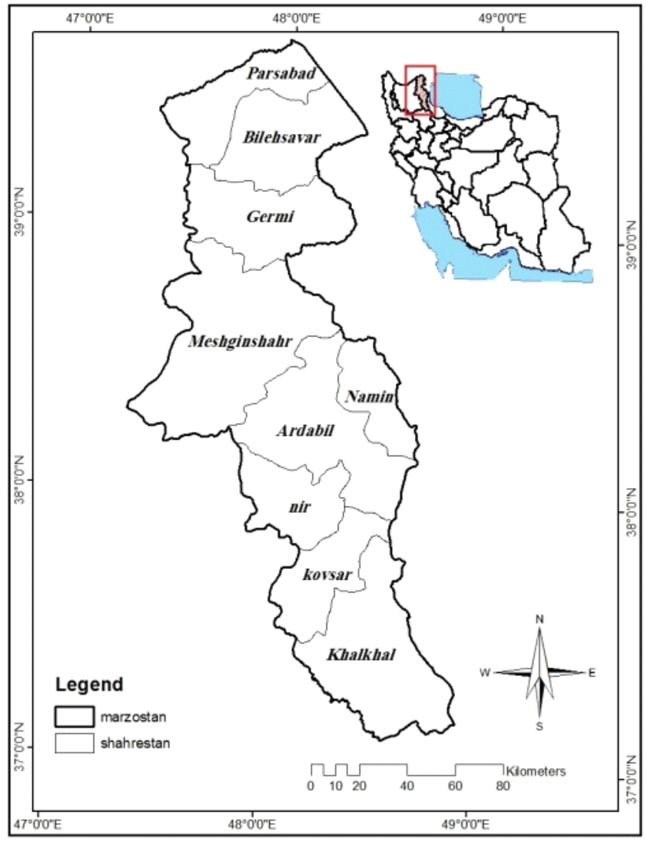

Figure 1. A general view and location of the study area in Ardabil Province and Iran.

***Calculation of above and belowground biomass*:** In 20 × 20 m plots, quantitative properties like total height (H), trunk height (HC), diameter at breast height (DBH) and two perpendicular diameters of the canopy (W & L) of all tree species within the plot were measured. To calculate tree biomass and to compute trunk, canopy and root volume, the following steps were followed (Hernandez *et al.*, 2004):

First, the basal area of tree was computed using equation 1 and then the tree volume was gained using equation 2. Finally, the biomass of trunk (kilogram) was computed according to the equation 3.

$$Ab = \pi x r^2 \quad (1)$$

r = the breast height radius of the tree, π= 3.14

$$V = Ab \times H \times Kc \quad (2)$$

Ab = basal area, H = height, Kc= 0.5463

$$Biomass = V \times WD \times 1000 \quad (3)$$

V= volume of the trunk, WD= wood density

Since the full sampling of tree roots is time demanding and expensive and also in order to avoid destructive sampling methods, the root biomass was calculated using equation 4 (Hernandez *et al.*, 2004)

$$BGB = Volume AGB \times 0.2 \quad (4)$$

BGB = Below-Ground biomass AGB = Above-Ground biomass

The canopy volume of trees was computed by the equation 5.

$$V(m^3) = \frac{\Pi \times Db^2}{12} \quad (5)$$

Note: π = 3.14Db = diameter of the crown (to calculate Db, the average of the field measurements L and W is taken and used as the diameter of the crown: Db = (L + W)/2); Hc = height from the ground to the base of the crown.

The carbon Stock of biomass was calculated based on equation below

$$Biomass_{(total)} \times C = 0.55$$

Soil and litter sampling **:** Four soil profiles were dug in the four corners of the 400 m^2 plot, then samples of soil were collected at three depths (0-15, 15-30, and 30-50 cm) (Lemma, *et al.*, 2006; Uri *et al.*, 2012), thus 72 soil samples were collected for each stand at three depths of soil. Bulk density of soil was characterized for calculation of the soil carbon, nitrogen and phosphorous storage. Thus, samples were taken from three soil depths (0–50 cm) using a stainless steel cylinder to avoid soil compacting and soil structure protecting (Uri *et al.*, 2012). In each soil sample, litter and large plant material (e.g., root and shoots) were removed, then air dried and 2 mm sieved (Lemma, *et al.*, 2006). The biomass of grass, shrubs and forbs species along with litter were collected in 0.25 m^2 plots (0.5_0.5 m^2). Sub samples were dried using oven and the values of dry matter coefficients were estimated and used to obtain dry matter from fresh weight.

***Laboratory analyses*:** The value of bulk density was measured using dividing the oven-dried mass (105°C) of the <2 mm fraction. The Bouyoucos hydrometer method was used to determine the soil texture (Bouyoucos, 1962). The amount of soil pH was characterized potentiometrically in a 1:2.5 (v/v) soil:water suspension. EC was determined with (soil:water ratio, 1:2). The total N was measured using Kjeldahl. The soil phosphorus content was measured by flow injection method using Tecator ASTN 9/84 and total organic C determined according to the Walkey -Black technique.

The total soil carbon stock (Mg ha^{-1}) within each soil depth was estimated using following relationship (Lemma *et al.*, 2006).

Total soil carbon stock (Mg ha^{-1}) = OC (g kg^{-1}). Ø. µ.10

OC = Organic Carbon, Ø is soil depth (m), µ = bulk density (Mg m^{-3}).

***Statistical analysis*:** All of data were analyzed using the SPSS 19.0. The variable normality test was checked by the Kolmogorov– Smirnov; meanwhile, the equality of the variances was examined by the Levene’s test.

The two-way analysis (ANOVA) was used to analyze the differences in soil properties among afforested stands and depths. Also, interactions between independent factors were

Table 1. Soil properties in stands and Rangeland.

Soil properties	Depth (cm(	Stand					
		Pinus	*Cedrus*	*Picea abies*	*Pinus-Cedrus*	*Picea- Pinus*	*grassland*
PH_{H2O}	0-15	5.63±0.03	5.85±0.13	5.49±0.058	5.81±0.05	5.51±0.0500	5.53±0.07
	15-30	5.65±0.03	5.40±0.026	5.54±0.086	5.83±0.12	5.45±0.0100	5.72±0.10
	30-50	5.50±0.03	5.43±0.0066	5.59±0.057	5.62±0.07	5.61±0.0057	5.71±0.06
Bulk density	0-15	1.44±0.003	1.51±0.0033	1.49±0.030	1.54±0.078	1.41±0.003	1.37±0.041
)g/cm^{-3}(	15-30	1.51±0.003	1.50±0.012	1.55±0.041	1.62±0.05	1.31±0.006	1.50±0.044
	30-50	1.61±0.009	1.53±0.0003	1.59±0.036	1.46±0.015	1.53±0.003	1.57±0.050
)dS m^{-1}EC(	0-15	0.023±0.0007	0.0063±0.0012	0.02±0.0023	0.022±0.0006	0.02±0.0007	0.02±0.003
	15-30	0.031±0.0006	0.0073±0.0003	0.02±0.0026	0.021±0.0037	0.02±0.0003	0.03±0.337
	30-50	0.018±0.0003	0.011±0.0033	0.02±0.0023	0.021±0.0012	0.01±0.0003	0.03±0.003
Sand (%)	0-15	25.67±0.3	28.33±0.88	33.42±1.82	25.33±2.33	26.33±0.33	40.33±4.26
	15-30	29.67±0.3	26.00±0.21	33.75±2.25	35.00±0.31	29.00±0.58	44.33±7.17
	30-50	29.67±2.18	31.00±0.57	32.92±2.43	29.00±1.00	29.33±0.33	38.00±4.51
Clay (%)	0-15	32.00±0.6	31.00±0.57	28.17±1.13	32.33±1.20	31.00±0.58	23.67±0.33
	15-30	28.67±0.33	30.67±0.66	28.67±1.16	28.33±0.33	31.67±0.33	21.00±1.00
	30-50	31.67±0.33	27.33±0.33	30.33±1.01	32.67±1.20	34.00±0.25	22.33±2.60
Silt (%)	0-15	42.33±0.7	40.67±0.33	38.42±1.81	42.33±1.20	42.67±0.33	36.00±4.58
	15-30	41.67±0.33	43.33±0.66	37.58±1.42	36.67±0.33	39.33±0.67	34.67±7.70
	30-50	38.67±1.85	41.67±0.33	36.75±2.14	38.33±0.33	36.67±0.33	39.67±6.70

Values are means ±SE of triplicate soil analysis.

tested. The Duncan's test was employed to separate the averages of the dependent variables which were affected by treatment, significantly.

The physical and chemical characteristics of the soil samples are shown in Table 1. The pH value of the soil (H_2O, 1:1) ranges from 5.43 to 5.85 and EC ranges from 0.1 to 0.0063 dS m^{-1}. Texture from loam in *p. nigra* stand to clay-loam in the other stands. The increase in bulk density with increasing depth was gained in more stands.

RESULTS

Some of the quantitative parameters of the stands are given in Table 2. Pure stand of *P. nigra* in most parameters had higher values compared to other stands. The highest amount of Trunk Height was in the C. *libani* and greatest canopy volume was observed in the P. *nigra – C. libani.*

***Total carbon stock in the ecosyst*:** The total carbon stock of ecosystem has changed from 25.006 Mg ha $^{1-}$in degraded rangeland to 55.57 Mg ha^{-1} in the mixed *P. nigra – C. libani* , 49.01Mg ha^{-1} in the *P. nigra* 38.7 Mg ha^{-1} in the mixed *P. abies - P. nigra* 37.84 ,Mg ha^{-1} in the pure *C. libani* and 31.68Mg ha^{-1} in the pure *P. abies* stands (Fig. 2).

The carbon stock in the aboveground biomass showed significant increase after the afforestation in degraded rangeland ($p<0.001$). (Fig. 2), so that it has increased from 2.4Mg ha^{-1} in the rangeland to 19.28 15.1 ,6.17 ,4.55 ,3.87 Mg ha^{-1} in the *P. nigra – C. libani*, *P.* nigra, *P. abies - P. nigra*, *C. libani* and *P. abies* stands, respectively (Fig. 2). The carbon stock in the belowground biomass showed significantly higher values after degraded rangeland afforestation in the all stands ($p<0.001$). So, it increased from 0.67in the degraded rangeland to 4.82, 3.79, 1.60, 1.15, 4.82 and 10.97 Mg ha^{-1} in the *P. nigra – C. libani*, *P. nigra*, *P. abies - P. nigra*, *P. libani* and *P. abies* stands, respectively (Fig. 2). The carbon stock in the ecosystem litter had the same trend mentioned above .Therefore, a significant difference ($p<0.001$) was observed in the carbon stock which the values ranged from 0.53 in the rangeland to 3.07, 2.027, 1.55, 1.41, 3.51 Mg ha^{-1} in the *P. abies - P. nigra*, *P. nigra – C. libani*, *P. nigra*, *C. libani* and *P. abies* stands, respectively (Fig. 2). The amount of carbon stock in the soils showed significant differences in the range of 21.41 in the rangeland and 30.11, 28.58, 27.45, 25.43 30.11 Mg ha^{-1} in the *C. libani*, *P. nigra*, *P. nigra – C. libani*, *P. abies - P. nigra* and *P. abies* stands, respectively (Fig. 2). In general ,the impacts of the degraded rangeland afforestation on the carbon stock in the ecosystem compartments showed significant difference increased .

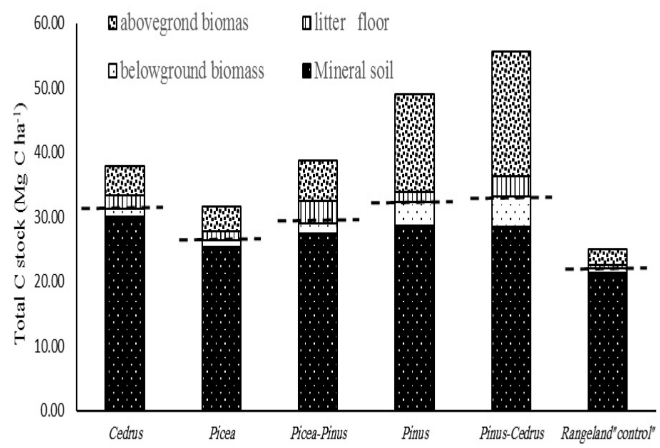

Figure 2. The amount of total C (soil, litter, above and below ground) in each stand.

***The carbon stock in the* soil:** After rangeland afforestation with coniferous species, significant ($p<0.05$) interactions were observed between stand and soil depth carbon stock. In general, the soil carbon stocks increased in all layers, (0-15cm, upper, 15-30cm, middle, and 30-50cm, lower layers) (Fig. 2). The highest carbon stock in the mineral soil was observed in the surface layer of the *C. libani* (34.95 Mg ha^{-1}), and in *P. nigra* stands with amount of 28.98 and 33.23 Mg ha^{-1} for middle and lower layers, respectively (Fig. 3). The carbon stock in the upper, middle and lower layer of each stand showed statistically significant differences among the *P. nigra, P. abies – P. nigra,* and *C. libani* stands (Fig. 3). The rangeland, *P. nigra - C. libani* and *P. abies* stands showed no significant differences in the depths considered. The rangeland afforestation effects on the carbon stock presented differences with the depth changes.

Table 2. Stand characteristics of the *Pinus nigra, Cedrus, Picea abies, Pinus-Cedrus* and *Picea- Pinus* stands.

Stand parameter	Stands				
	Pinus nigra	***Cedrus***	***Picea abies***	***Pinus-Cedrus***	***Picea- Pinus***
DBH (cm)	17.27±0.305a	12.47±0.018d	13.14±0.706c	15.75±0.027b	15.67±0.088b
Tree height (m)	7.61± 0.315a	6.25±0.123d	6.96±0.070bc	6.73±0.093cd	7.28±0.041ab
Trunk Height (m)	3.17±0.018d	3.68±0.043a	3.48±0.038b	3.28±0.006c	3.28±0.015c
Canopy volume (m^3/ha)	9.72±0.069b	3.58±0.006d	6.54±1.094c	12.49±0.012a	5.73±0.033c
basal area (m^2/ha)	0.024±0.000a	0.01±0.000d	0.013±0.001d	0.02±0.001b	0.018±0.000c
Stand volume (m^3/ha)	0.13±0.015a	0.04±0.003d	0.051±0.006cd	0.09±0.001b	0.072±0.003bc

Values followed by the same letter within a row are not statistically different (Duncan, P < 0.05).

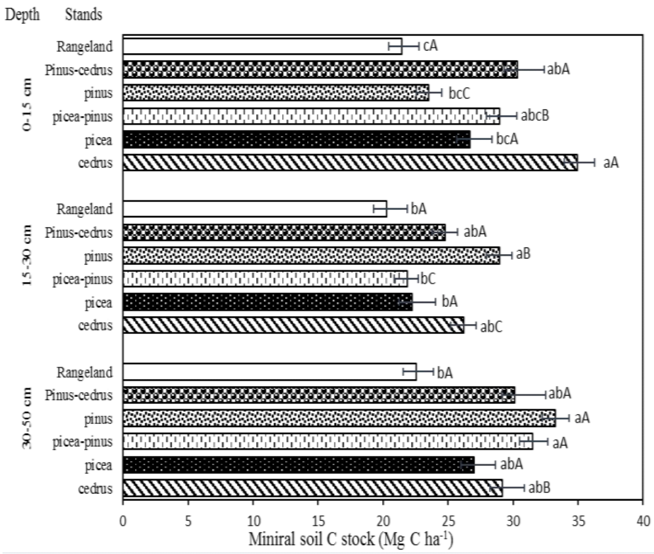

Figure 3. Soil C stocks distribution in stands (Mean±SE).

DISCUSSION

Establishment of coniferous species on the degraded grassland caused an increase in the carbon stock of ecosystem. Considering 20 years of establishment of coniferous species in the degraded grassland the amount of annual Carbon stocking in the mixed *P. nigra – C. libani*, *P. nigra*, mixed *P. abies – P. nigra*, pure *C. libani*, and *P. abies* stands were 1.60, 1.26, 0.72, 0.67, 0.35 Mg C ha^{-1} y^{-1}, respectively.

Main challenging issue was quantifying the soil and biomass carbon stock (Uri *et al*., 2012). The study revealed that carbon stock in the soil was higher than the other sections (85.60, 80.28, 79.58, 70.85, 58.30 and 51.11 in the *P. abies*, *C. libani*, *P. abies - P. nigra*, *P. nigra*, and *P. nigra – C. libani* stands, respectively. These results indicated the integral importance of soil in the carbon stocking of ecosystem. Peltoniemi *et al.* (2004) expressed that a significant amount of carbon was stored in the forest soils than the forest biomass. Similar results were described by Garten and Charles (2002).

According to the EC / UN-ECE (2003), the carbon stock of forest soils in Europe was 1/5 times more than biomass. In contrast, other studies indicated the high proportion of biomass in the total ecosystem carbon stock (Uri *et al*., 2012; De Wit *et al.*, 2006; Peichl and Arain, 2006). Conflicting results on the soil carbon stock could be due to the influence of various factors on this matter. It was apparent that the type of tree species affected the carbon stock by the amount and quality of organic matter input by litter, root activity and microclimate change (Jandl *et al.*, 2007; Lugo and Brown, 1993).

Also, Osher *et al.* (2003) expressed that the change of soil carbon stock associated with land use changes is in relation to soil mineralogy. In our study, it was found that the type of tree species had a direct impact on the carbon stock in the mineral sector of soil. Furthermore, a significant correlation was found among the clay, clay- silt, and soil carbon stock (Fig. 4a, c), while a significant negative correlation was found between the percentages of sand and soil carbon stock (Fig. 4b).

Bauer *et al.* (1987) believed that the soil organic carbon was related to the clay of soil. Garten (2002); Powers (2002) and Schlesinger *et al.* (2008) confirm our findings. They found that carbon stocking correlated with the silt and clay of soil. A high percentage of sand in the spruce stand (Table 1) could be a significant factor in the low carbon stock than the other stands. Rapid carbon aggregation and turnover in the Coarse-grained soils (Richter *et al.*, 1999) could be effective to decrease the soil carbon stock in the pure spruce stand (Fig. 2) The clay and organic carbon were often formed as aggregate, and therefore they had much more affinity to bind organic matter compared to the sand (El Tahira *et al.*, 2009). In this regard, Borchers and Perry (1992) observed that the concentration of organic matter was less in the sandy soils than the clay and silt soils.

In this study, different distributions of the soil organic carbon were determined in the soil layers of considered stands (Fig. 2). The increasing trend of carbon stock was observable in the pure pine (Fig. 2). Such a trend was seen to augment the bulk density with the increase of depth in this stand (Table 1). In general, a positive correlation between bulk density and the soil carbon stock was found in this study (Fig. 3d).

However, the differences in the amount of sand, clay and silt in the different depths could be the reason of different carbon distribution in the soil layers. The differences among tree species in the terms of the root activity region had remarkable impacts on these differences. The root decomposition (especially thin roots) was important processes affecting the density and carbon stock (Steele, 1997).

PH was one of the important soil properties which influenced the availability of the soil nutrients (Beery and Wilding, 1971) high soil pH in the surface soil layer of *C. libani* stand than other stands could cause to high mineral carbon stock of soil. Because there was the appropriate condition for degradation in the surface layer of this stand than the other stands which in turn increased the carbon stock in the higher levels of soil. Thuille and Schulze (2006) noted the decrease of fauna activity of acidic soil which could also result in high carbon stock in the surface layer of pine – cedar stand.

The litter production and its degradation had a significant effect on the soil fertility (Pragasan and Parthasaratly, 2005) and it was considered as a notable factor by which tree species could affect soil organic matter (Finzi, 1998). The high carbon stock in the biomass and litter on the forest floor in the mixed *P. nigra – C. libani* (Fig. 2) could significantly be due to the high significant canopy of this stand than the others. (Table 1). The litter resulted from trees were the main source of carbon in the forest ecosystems (De Marco, 2013) and the

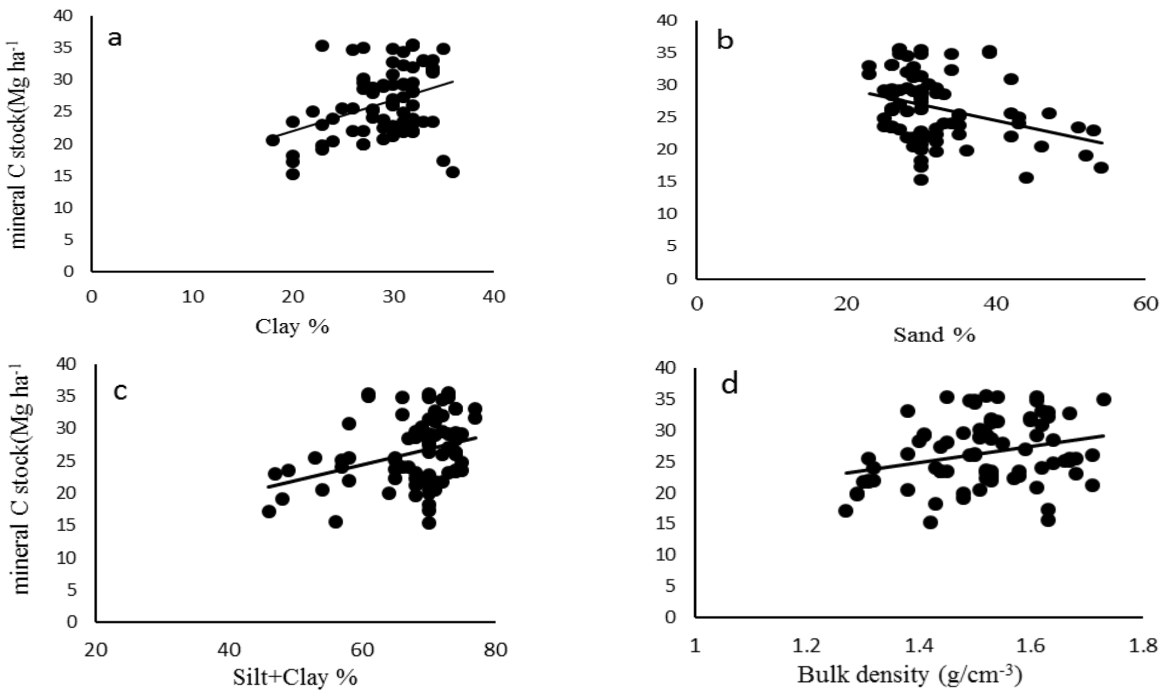

Figure 4. Correlation between C content (Mg ha^{-1}) and Soil textural (Clay, Clay+silt and Sand) and bulk density. All are significant in 0.001 level except bulk density in level 0.05 density.

high canopy could be an integral source of litter and aboveground biomass in this stand. In total, 40.21 percent of the total carbon stock was in the aboveground *P. nigra – C. libani* stand. Accordingly, development of root would increase by the increase of canopy. In this stand, the highest belowground carbon stock included roots had significant difference than the other stands and it possessed 8.67 percent contribution of total carbon stocks of ecosystem.

In this study, the properties of species in the terms of growth of stem, branch, and leaf had significant impact on the rate of carbon accumulation in the above- and belowground biomass. In total, the amount of carbon accumulation in the coniferous ecosystems had significant increase in the degraded rangeland.

***Conclusions*:** This study showed that the afforestation of degraded grasslands in the study area has a high potential of atmospheric carbon stocking and reduce the effect of high CO_2 concentrations in a short time period. Biomass and soil C stocks differed depending on tree species. Further information may be worked out through the advance methodology extensive research and consideration of more factors in the future studies. Moreover, we can say that the maintenance or increase in carbon stock of forests has been linked to economic and external benefits, such as climate change mitigation, biodiversity improvement, water storage and regulation of local climate at landscape level.

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