



Soil properties, labile pools of soil organic carbon and their variations under broadleaf and coniferous plantation in Hyrcanian forest, northern Iran

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Abstract

Afforestation, as a tool to mitigate carbon emission is constrained by available land area in several countries, but Iran has the potential of plantation. In doing so, differences in soil stocks between tree species could give an indication of the effects of future management changes. Hence, a better understanding of tree species traits on soil properties is required to predict how changes in ecosystems occur with tree species composition. This study investigated the effect of selected tree species on soil properties, carbon sequestration potential of tree species across soil profiles (0-200 cm) and evaluated the tree species effects on labile soil organic carbon pools to introduce a unique soil quality indicator. The study site was Shalman Research Station in the Hyrcanian forests, northern Iran. Our results showed significant alterations in soil properties by tree species with the greatest changes in the top soil layer. The greatest cation exchange capacity (CEC) difference (Δ 4.17) was found between *A. glutinosa* and *J. polycarpus* in 0-20 cm. The greatest differences (Δ 2.58) in mean weight diameter (MWD) of soil layers were found in the top soil layer between *A. glutinosa* and *T. distichum*. All species produced also a higher N and organic carbon concentration in the top soil layer (0-20 cm) in the following order: *A. glutinosa* > *Q. castaneifolia* > *P. caspica* > *J. polycarpus* > *T. distichum* > *P. taeda*. The varied amount of total soil organic carbon stocks was greater under Alder (*A. glutinosa*) and Oak (*Q. castaneifolia*) than other tree species with 206.24 and 195.26 (Mg.ha⁻¹), respectively; and *P. taeda* had the lowest amount (136.94 Mg ha⁻¹) across the soil profile. For all labile pools, *A. glutinosa* and *T. distichum* had the highest and the lowest percent of labile organic carbon, respectively. Consequently, the C_{min} in the range of 10.11-14.04% and microbial biomass carbon in the range of 1.05-1.66% shared the highest and lowest proportion of soil organic carbon across 0-200 cm depth, respectively. We concluded that broadleaf trees had great potential for carbon sequestration across soil depth and among them; alder had high effect on soil properties and soil organic matter.

Keywords: Labile soil organic carbon; Carbon stocks; Soil properties; Broadleaf; Coniferous; Water soluble organic carbon.

Introduction

Soil organic matter (SOM) represents a large dynamic and complex terrestrial sink of carbon (including 950 Pg carbon just in the top 1 meter) in the form of organic compounds derived from plant, animal or microbial biomass (Lal *et al.*, 2015). Due to the close association with soil properties and soil processes (Chen *et al.*, 2004), maintaining a satisfactory soil organic carbon content is essentially required for improving soil health and effective carbon sequestration management in various ecosystems.

Among the ecosystems studied, forests have been highlighted because of their large intrinsic carbon pool with a large proportion (70% of all SOC) of it being contained within their soil (Perez-Cruzado *et al.* 2012; Jobbágy and Jackson, 2000; Six *et al.*, 2002a). According to Kyoto Protocol (KP), carbon sequestration in terrestrial sinks can be used to offset greenhouse gas emission (Jandl *et al.*, 2007). However, the ability to utilize afforestation as a tool to mitigate carbon emission is constrained by available land area in several countries. In countries with a low forest cover, however an increase in the forested area is on the political agenda. The total area of natural and man-made forests is approximately 13.4 and 0.95 million hectares, respectively, which covers only 8.7 percent of the total land area (Sagheb-Talebi *et al.*, 2014). In this respect, Iran has the potential for plantation and afforestation. Plantation is becoming a key component of world forest resources and plays important roles in the context of overall sustainable forest management. Trees have extensive root systems which can grow deep into the mineral soil. The root-derived C inputs are critical sources for the SOC in deeper soil horizons (Kell, 2012). Specifically, root-derived C is more likely to be stabilized in the soil by physical and chemical interactions with soil particles than a shoot-derived C (Rasse *et al.*, 2005). Hence the incorporation of trees, in particular, improves soil properties and can result in greater net C sequestration (Young, 1997).

In forest management systems, differences in management, spatial

distribution of forest tree species and their diversity are assumed to influence the rate of soil carbon sequestration and accordingly the soil health (Ashton *et al.*, 2012; Lorenz and Lal, 2010). Important in this respect is the choice of tree species which affects soil organic carbon by the amount and quality of OM input through litter fall and root activity. Differences in soil stocks between tree species could give an indication of the effects of future management changes. Besides, a better understanding of tree species effects on soil properties (i.e. aggregate stability, BD, pH, EC, CaCO₃ and CEC) is required to predict how changes in ecosystems are altered with tree species composition. This knowledge may help guide tree species choice in case of afforestation with the aim of soil quality improvement. Many studies have shown SOM as a main soil quality indicator (Jinenez *et al.*, 2002). However, it is difficult to detect the reflection of changes in SOM (Ghani, 2003); thus, more attention has been paid to the labile SOM pools (Gregorich *et al.*, 2003; Kolar *et al.*, 2009). Of these, soil microbial biomass C (SMB-C) and water soluble organic carbon (WSOC) are the most active fraction of SOM which have been used as quick and sensitive indicators of SOM changes (Harison *et al.*, 1993, Ghani, 2003). WSOC is the part of dissolved organic carbon obtained by extracting a given mass or volume of soil with an aqueous solution (Piccolo, 1996). According to laboratory procedures and subsequent differences in extracting carbon compounds, two functional pools of WSOC are usually studied: cold water extractable organic carbon (CWEOC) and hot water extractable organic carbon (HWEOC) (Hamkalo and Bedernichek, 2014). Meanwhile, SMB has been suggested as a sensitive indicator that more quickly responds to environmental changes in soils (Wang and Wang, 2011). However, because of the time consuming process of SMB determination and considering direct relationship of SMB with WEOC, many researchers prefer to use WSOC sensitivity rather than SMB. In Iran, the potential use of labile organic carbon pools and assessing their sensitivity to

forest tree species as soil quality indicator, especially in carbon sequestration projects have not been investigated yet.

The objectives of this paper were: (a) to assess the potential of carbon storage between tree species across the soil profile and choice of appropriate tree species for afforestation with the aim of carbon sequestration., (b) to reveal the distribution of SOC and labile organic carbon pools under different tree species and potential of singular tree species to affect soil properties and (C) to evaluate which one of labile organic carbon pool/pools could be used as a sensitive soil quality indicator in the northern forests of Iran. According to conclusions arising from previous studies, we hypothesized that tree species affect organic carbon content across soil profile and broadleaves may enhance soil organic carbon stocks, labile organic carbon pools and therefore soil quality. We also hypothesized that using labile organic carbon pools as the soil quality indicators may describe better soil quality and soil health.

Materials and methods

Study area

The study was carried out in Shalman Seed and Seedling of Forest Tree Species Research Station; located in Guilan Province, at the town of Shalman (Langrud), Northwest of Iran, 37°09'25"-35" N and 50°13'6"-16" E at an altitude of -

16.0 m (Figure 1). The Guilan province is located in the southwest of Caspian Sea and has a humid subtropical climate. According to the 20 year of data collected at the Research Station, the average annual rainfall is 1180 mm. The average values of 35.5 mm and 181.0 mm are the lowest and highest amount of rainfall in July and October, respectively. The average annual temperature is 17.5°C and the mean of maximum and minimum air temperature are 26.3°C and 7.5°C in August and January respectively.

The soil moisture and temperature regimes of the study sites are aquic and mesic, respectively, and the soil is classified as aquepts according to the key for soil taxonomy 2010 (Soil Survey Staff, 2010), with medium texture class and inherited origin.

The Shalman Research Station consists of many indigenous and exotic forest tree species, including needle and broadleaf, planted in randomized plots (size range: 0.1-0.5 ha) at the same time (20 years old) on similar soil as explained by Vesterdal *et al.*, (2013) for “planned multispecies common garden experimental design”. In this study six compartments under different tree species were selected for sampling. These species are *Populus caspica*, *Quercus castaneifolia*, *Alnus glutinosa*, *Taxodium distichum*, *Pinus taeda* and *Juniperus polycarpos*.

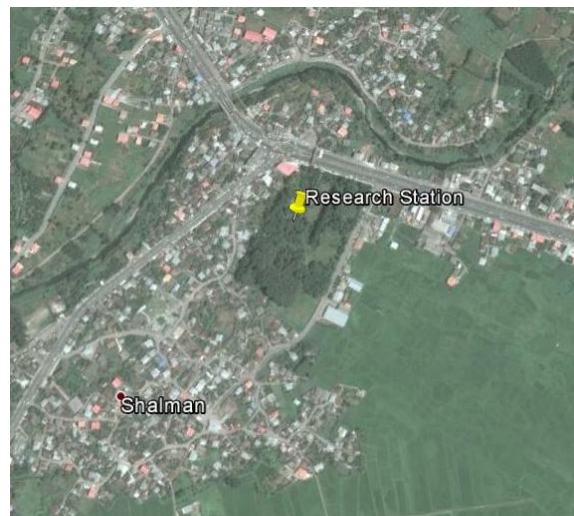
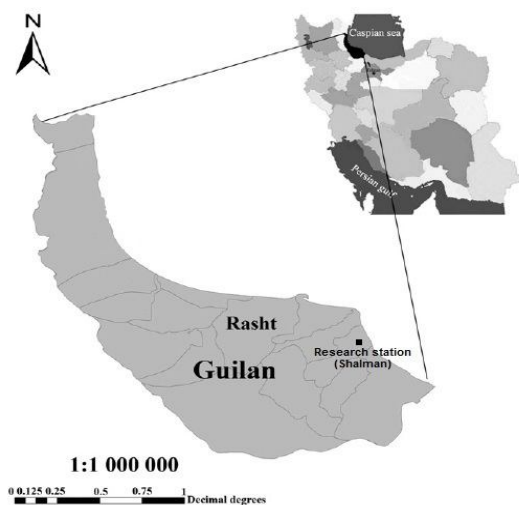


Figure 1. Location of the study area (Shalman Research Station, Guilan, Northern Iran)

P. caspica (Persian name: Sefid palat), is one of the native species of Hyrcanian temperate forests of northern Iran which is grown generally in humid climate, especially riverbanks where the ground water table is shallow. Therefore, this species has shallow and sensitive rooting system. Oak (*Q. castaneifolia*) also is one of the native species of Alborz mountain distributed in Hyrcanian forest. Oak is a deciduous broadleaf which covers about 6.5% of the Hyrcanian forest (Panahi *et al.*, 2011). Alder (*A. glutinosa*) is deciduous broadleaf and most widely introduced elsewhere and is distributed in the northern forests of Iran. Alder's water use is high, so it can be found on stream banks and riverbanks. Alder is noted for the symbiotic relationship in its rooting system for nitrogen fixing, therefore it improves soil fertility and is a pioneer species. Bald cypress (*T. distichum*) is a deciduous conifer and an exotic species which has been introduced from inundated soils of south east Coastal plains of the United States. Loblolly pine (*P. taeda*) is a fast growing needle leaf ever green conifer native to the Southeastern United States.

The loblolly pine has been introduced to and planted in mountains to lowlands of the Guilan Province since 1968 showing good adaption in northern forests of Iran (Pourbabaei and Roostami, 2007). Juniper (*J. polycarpus*) is one of the most common evergreen conifers and slow growing species. Juniper habitats are worldwide, including North America and Eurasia. Juniper is also well distributed in Iran, especially the northeastern forests in Golestan Province.

Sampling and analysis

Soil samples were collected in summer (July) 2014, when the soil had minimum moisture; and the water table was at the lowest depth (150 cm). According to the completely randomized block design, for every compartment, three soil profiles as three replications were made down to 200 cm. At each profile, soil samples were taken from ten 20 cm intervals: 0-20, 20-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-160, 160-180 and 180-200 cm (Figure 2). Sampling from intervals beneath the water table were taken immediately after pumping the water.



Figure 2. Soil profile and sampling from intervals

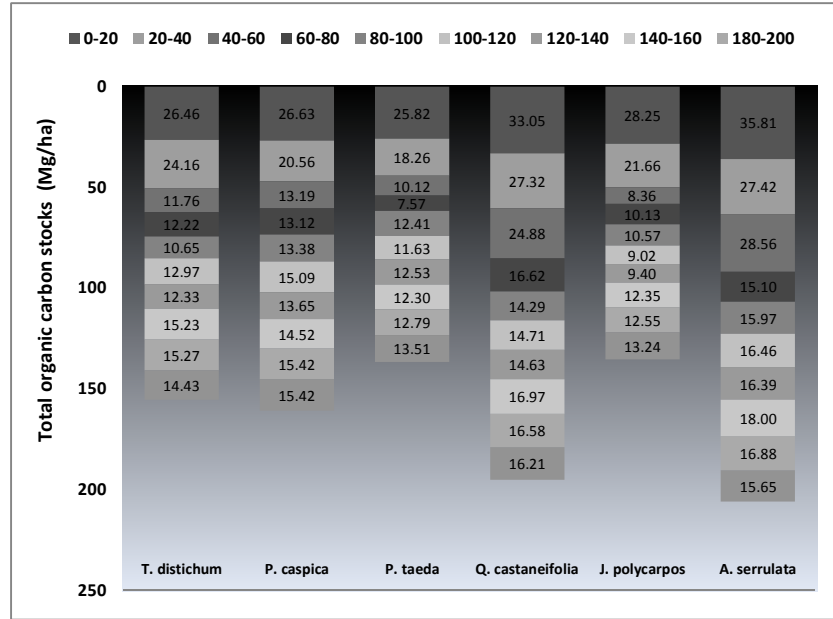


Figure 3. The total SOC stocks at different depths for tree species type

All soil samples were air-dried at room temperature (25 °C) and milled to pass through a 2 mm sieve followed by removing visible roots, organic residues, large debris and gravel; then samples were used for determination of chemical and physical properties: soil organic carbon (SOC) was measured using the dichromate oxidation method as described by Nelson and Sommers (1982), total nitrogen (TN) was determined according to Bremner and Mulvaney (1982), pH and EC were measured in saturated paste (McLean, 1982) and saturated paste extract (Miller and Curtin, 2008) respectively, cation exchange capacity was measured with standard method described by Rhoades (1982a), bulk density was determined by wax coating of soil clods method (Hao et al., 2008), CaCO₃ content was measured by titration method (Nelson, 1982), aggregate stability was measured and expressed as a mean weight diameter (MWD) according to Golchin and Asgari (2008), soil texture was determined as described by Kroetsch and Wang (2008) followed by oxidizing organic matter of soil samples with 6% H₂O₂ according to Theng et al. (1999). Soil organic carbon storage down to 200 cm depth by volume for different vegetation cover type is given by:

$$SOC_d = \frac{\sum_{i=1}^k OC_i \times BD_i \times D_i}{10}$$

Where SOC_d is the volume of the total soil organic carbon (Mg.ha⁻¹) across depth d (d=200 cm), OC_i is the concentration of soil organic carbon (g.kg⁻¹), BD_i (g.cm⁻³) and D_i (D=20 cm) are the dry bulk density and thickness layer i, respectively.

Soil microbial biomass C was measured by the chloroform fumigation extraction method (Vance et al., 1987); in brief duplicate 20 g soil subsamples were placed in 50 ml glass jars and moistened by adding distilled water to a soil moisture content of about 60% of water holding capacity. One jar was fumigated with chloroform for 24h at room temperature, then both fumigated and none fumigated soil samples were extracted with 0.5 M K₂SO₄ after 2 hours shaking. Carbon concentration in the extracts was measured by Shimadzu TOC analyzer. Microbial biomass C by applying the recovery factor of Wu et al (1996) and Wang et al., (2014) is given by:

$$MBC = \frac{E_C}{k_{EC}}$$

Where MBC is microbial biomass C, E_C is the difference in C concentration between fumigated and none fumigated soil samples and k_{EC} is the recovery factor, 0.35.

The carbon mineralization rate was determined by measuring soil respiration during 90 days of laboratory incubation experiment according to Beheshti *et al.* (2012); 50 g of room temperature dried soil sample was placed in plastic jars after moistening by adding distilled water to a soil moisture content of about 60% (w/w) of water holding capacity. Three jars without soil sample were considered as blank. Before the incubation, all soil samples in jars were kept for 72 hours in a dark room at a constant temperature (25°C) for restoring the biomass and microbial activity. During the specific time intervals the evolved CO₂ was trapped with a vial containing 10 ml 0.5 M NaOH in jars and replaced with the fresh one for the following time interval. For measuring the trapped CO₂-C in NaOH, titration of excess NaOH with the 0.5 M HCl was followed by precipitating of carbonate with 15% BaCl₂ solution. The cumulative CO₂-C evolved from the soil samples during the experiment was expressed as soil carbon mineralization which initially reported as the part of the total soil organic carbon and was used for comparison of soil organic matter differences of sampling sites.

Cold and hot water extractable organic C were measured according to the methods of Haynes and Francis (1993) modified by Ghani *et al.* (2003). For cold water extractable organic C, in brief 3 g from each air dried soil samples were put in centrifuge tubes and shaken with 30 ml distilled water for 30 minutes at 30 rpm as an end over end form at 20°C; the suspensions were centrifuged at 3500 rpm for 20 min and then carbon concentration was detected with Shimadzu TOC analyzer followed by the supernatant solution filtering through 0.45 µm membrane filters.

For hot water extractable organic C, similar sets were done but before the filtering of supernatant solution through 0.45 µm membrane filter, samples were put under steam of a hot water bath in 80°C for 18 hours and then carbon concentration was measured with Shimadzu TOC analyzer. For estimating total carbohydrate fraction (CHO_{HW}) in soil samples, 2 ml of supernatants solution from hot water

extractable carbon experiment was mixed with 1 ml 5% phenol solution, then 5 ml of sulphuric acid (98%) was added. After 45 minutes the absorbance of this mixture was read on a spectrophotometer at 490 nm (Yousefi *et al.*, 2008).

Statistical analysis

Prior to analysis, data were tested for assumption of normality and homogeneity of variances by Shapiro–Wilk Test and Levene's Test, respectively. The experiments were of randomized complete block (RCB) designs. Vegetation types and soil depths were independent variables, and dependent variables included soil physico-chemical properties and soil labile organic carbon pools. Data for the same soil interval (ten 20 cm intervals) were subjected to two-way analysis of variance (ANOVA) using SAS software for Windows (SAS Institute, 2002), and all comparisons among the independent and dependent variables were conducted by least significant difference tests (LSD). Significance levels were set at $p < 0.05$ in all statistical analyses. Pearson linear correlations were used to assess the relationships among labile fractions of SOM and soil physico-chemical properties.

Results

Soil physical and chemical properties

Some chemical and physical soil properties under tree species plots in different layers are given in Table 1. ANOVA results indicate significant effects of tree species and depth as main factors and most of their interaction on the selected soil properties (Table 1). There were declining trend of CEC and MWD values down to profiles in all tree species plots. The greatest difference (Δ 4.17) was found between *A. glutinosa* and *J. polycarpus* in 0-20 cm with a CEC amount of 17.60 (c mol+ kg⁻¹) and 13.43 (c mol+ kg⁻¹), respectively. Besides, significant differences in aggregate stability between all species types was observed from 0-20 cm down to 140-160 cm, but no differences were found in any of the treatments in soil below 160 cm. However, the greatest differences (Δ 2.58) in MWD between soil layers was found in the top

layer (0-20 cm) with *A. glutinosa* and *T. distichum* having the maximum and minimum MWD values as 4.11 mm and 1.53 mm, respectively. Likewise, the effect of tree species and depth as main factors on pH, bulk density (BD), electric conductivity (EC) and CaCO_3 was statistically significant but insignificant for their interactions. Therefore, a significant negative trend of pH changes down to soil profile was seen, which means soil acidity as the main factor increases with soil depth in all tree species plots. Though the highest and lowest pH values for 0–20 cm were seen under Bald cypress and Oak with pH

values 6.72 and 7.37, respectively, however differences among the tree species was insignificant (Table 1). Similar to soil acidity, the bulk density (BD) was increased significantly for all treatments with depth. There were insignificant differences of BD between tree species across soil layers, however the lowest and highest BD values were found under Oak and Juniper (1.35 and 1.53 g.m^{-3}) for 0-20 cm. Despite significant effect of tree species and soil depth as the main factors, there was not special trend for EC and CaCO_3 values in the soil profile.

Table 1. Selected chemical and physical properties in different soil layers under tree species (mean \pm SEM, n=3)

Depth (cm)	Tree sp	BD (g cm^{-3})	CEC (cmol+ kg^{-1})	MWD (mm)	pH	EC dS.m^{-1}	CaCO_3 (g kg^{-1})
0-20	<i>T. distichum</i>	1.45 \pm 0.06 A(a)	14.00 \pm 0.23 C(a)	1.53 \pm 0.08C (a)	6.72 \pm 0.04 A(a)	0.90 \pm 0.01 A(a)	3.66 \pm 0.22 A(a)
	<i>P. caspica</i>	1.44 \pm 0.03 A(a)	16.04 \pm 0.18 B(a)	2.42 \pm 0.29B (a)	7.14 \pm 0.13 A(a)	1.01 \pm 0.01 A(a)	4.35 \pm 0.20 A(a)
	<i>P. taeda</i>	1.49 \pm 0.05A (a)	13.65 \pm 0.22 C(a)	1.76 \pm 0.11B C(a)	7.02 \pm 0.08 A(a)	0.97 \pm 0.01 A(a)	3.77 \pm 0.26 A(a)
	<i>Q. castaneifolia</i>	1.35 \pm 0.03A(a)	16.38 \pm 0.27 B(a)	3.61 \pm 0.18A (a)	7.37 \pm 0.05 A(a)	1.05 \pm 0.07 A(a)	4.88 \pm 0.23 A(a)
	<i>J. polycarpus</i>	1.53 \pm 0.03 A(a)	13.43 \pm 0.17 C(ab)	2.18 \pm 0.12B (a)	7.00 \pm 0.12 A(a)	0.93 \pm 0.04 A(a)	4.03 \pm 0.12 A(a)
	<i>A. glutinosa</i>	1.36 \pm 0.04 A(a)	17.60 \pm 0.31 A(a)	4.11 \pm 0.17A (a)	7.30 \pm 0.10 A(a)	1.12 \pm 0.07 A(a)	4.96 \pm 0.22 A(a)
	20-40	<i>T. distichum</i>	1.59 \pm 0.04 A(a)	14.26 \pm 0.13 C(a)	1.46 \pm 0.10C (a)	6.24 \pm 0.22 A(a)	0.82 \pm 0.03 A(a)
<i>P. caspica</i>		1.55 \pm 0.03 A(a)	15.07 \pm 0.16 B(b)	1.93 \pm 0.10B (ab)	6.60 \pm 0.07 A(a)	0.91 \pm 0.03 A(a)	4.28 \pm 0.20 A(a)
<i>P. taeda</i>		1.69 \pm 0.04 A(a)	13.40 \pm 0.25 D(ab)	1.60 \pm 0.13B C(a)	6.46 \pm 0.07 A(a)	0.89 \pm 0.06 A(a)	3.48 \pm 0.23 A(a)
<i>Q. castaneifolia</i>		1.55 \pm 0.03 A(a)	15.72 \pm 0.24 AB(b)	3.06 \pm 0.17A (b)	6.93 \pm 0.18 A(a)	1.00 \pm 0.01 A(a)	4.64 \pm 0.24 A(a)
<i>J. polycarpus</i>		1.67 \pm 0.03 A(a)	13.60 \pm 0.13 CD(a)	1.78 \pm 0.16B C(b)	6.68 \pm 0.16 A(a)	0.82 \pm 0.05 A(a)	3.79 \pm 0.21 A(a)
<i>A. glutinosa</i>		1.50 \pm 0.02 A(a)	16.04 \pm 0.28 A(b)	3.52 \pm 0.15A (b)	7.11 \pm 0.06 A(a)	1.05 \pm 0.05 A(a)	4.65 \pm 0.21 A(a)
40-60		<i>T. distichum</i>	1.66 \pm 0.04 A(a)	13.12 \pm 0.24 CD(b)	1.08 \pm 0.15E (b)	6.16 \pm 0.21 A(a)	0.77 \pm 0.02 A(a)
	<i>P. caspica</i>	1.61 \pm 0.05 A(a)	13.85 \pm 0.36 BC(c)	1.67 \pm 0.12C (bc)	6.40 \pm 0.07 A(a)	0.93 \pm 0.01 A(a)	4.25 \pm 0.15 A(a)
	<i>P. taeda</i>	1.70 \pm 0.02 A(a)	12.77 \pm 0.22 D(bc)	1.25 \pm 0.11D E(b)	6.23 \pm 0.06 A(a)	0.82 \pm 0.02 A(a)	3.32 \pm 0.22 A(a)
	<i>Q. castaneifolia</i>	1.59 \pm 0.03A (a)	14.47 \pm 0.31 B(c)	2.67 \pm 0.15B (c)	6.80 \pm 0.10 A(a)	0.96 \pm 0.01 A(a)	4.63 \pm 0.20 A(a)
	<i>J. polycarpus</i>	1.69 \pm 0.03 A(a)	12.99 \pm 0.06 D(bc)	1.50 \pm 0.04D C(c)	6.55 \pm 0.19 A(a)	0.80 \pm 0.07 A(a)	3.78 \pm 0.13 A(a)
	<i>A. glutinosa</i>	1.61 \pm 0.03 A(a)	15.51 \pm 0.28 A(bc)	3.11 \pm 0.15A (c)	6.75 \pm 0.08 A(a)	0.96 \pm 0.03 A(a)	4.59 \pm 0.17 A(a)
	60-80	<i>T. distichum</i>	1.65 \pm 0.03 A(a)	12.82 \pm 0.25 CD(bc)	0.64 \pm 0.10D (c)	6.12 \pm 0.22 A(a)	0.77 \pm 0.01 A(a)
<i>P. caspica</i>		1.68 \pm 0.05 A(a)	13.60 \pm 0.23 BC(cd)	1.32 \pm 0.11B (c)	6.40 \pm 0.17 A(a)	0.98 \pm 0.01 A(a)	4.51 \pm 0.17 A(a)

	<i>P. taeda</i>	1.70±0.01 A(a)	12.61±0.25 D(bc)	0.75±0.10C D(c)	6.16±0.05 A(a)	0.80±0.02 A(a)	3.26±0.17 A(a)
	<i>Q. castaneifolia</i>	1.66±0.03 A(a)	14.25±0.09 B(c)	2.24±0.16A (d)	6.44±0.10 A(a)	0.97±0.01 A(a)	4.78±0.18 A(a)
	<i>J. polycarpus</i>	1.66±0.04 A(a)	12.58±0.28 D(cd)	1.11±0.09B C(d)	6.38±0.07 A(a)	0.85±0.08 A(a)	3.81±0.21 A(a)
	<i>A. glutinosa</i>	1.63±0.04 A(a)	14.87±0.31 A(cd)	2.53±0.13A (d)	6.51±0.05 A(a)	0.94±0.03 A(a)	4.91±0.15 A(a)
	<i>T. distichum</i>	1.67±0.03 A(a)	12.65±0.23 B(bc)	0.57±0.07B (c)	6.15±0.12 A(a)	0.80±0.02 A(a)	3.68±0.13 A(a)
	<i>P. caspica</i>	1.69±0.05 A(a)	13.01±0.17 B(de)	0.78±0.08B (d)	6.43±0.14 A(a)	1.01±0.01 A(a)	5.11±0.19 A(a)
80-100	<i>P. taeda</i>	1.71±0.03 A(a)	12.63±0.19 B(bc)	0.62±0.11B (cd)	6.20±0.06 A(a)	0.83±0.01 A(a)	3.34±0.14 A(a)
	<i>Q. castaneifolia</i>	1.65±0.02 A(a)	14.22±0.25 A(c)	1.20±0.09A (e)	6.44±0.07 A(a)	1.00±0.03 A(a)	4.96±0.11 A(a)
	<i>J. polycarpus</i>	1.74±0.03 A(a)	12.27±0.13 B(d)	0.81±0.08B (e)	6.38±0.08 A(a)	0.89±0.02 A(a)	3.99±0.01 A(a)
	<i>A. glutinosa</i>	1.73±0.02 A(a)	14.77±0.35 A(cd)	1.43±0.13A ()	6.44±0.07 A(a)	1.00±0.00 A(a)	5.24±0.17 A(a)
	<i>T. distichum</i>	1.67±0.04 A(a)	12.18±0.25 D(cd)	0.48±0.08A (c)	6.15±0.07 A(a)	0.84±0.02 A(a)	4.45±0.24 A(a)
	<i>P. caspica</i>	1.71±0.04 A(a)	12.99±0.08 BC(de)	0.53±0.07A (d)	6.50±0.14 A(a)	1.04±0.04 A(a)	5.00±0.11 A(a)
100-120	<i>P. taeda</i>	1.73±0.04 A(a)	12.60±0.31 CD(bc)	0.53±0.07A (de)	6.18±0.03 A(a)	0.88±0.02 A(a)	3.86±0.17 A(a)
	<i>Q. castaneifolia</i>	1.68±0.03 A(a)	13.49±0.25 AB(d)	0.65±0.05A (f)	6.44±0.09 A(a)	1.05±0.05 A(a)	4.69±0.25 A(a)
	<i>J. polycarpus</i>	1.73±0.02 A(a)	12.30±0.16 CD(cd)	0.61±0.04A (ef)	6.36±0.07 A(a)	0.91±0.05 A(a)	4.47±0.25 A(a)
	<i>A. glutinosa</i>	1.71±0.00 A(a)	14.10±0.26 A(a)	0.70±0.07A (e)	6.44±0.04 A(a)	1.00±0.06 A(a)	4.97±0.19 A(a)
	<i>T. distichum</i>	1.69±0.05 A(a)	11.51±0.22 B(d)	0.45±0.04A B(c)	6.12±0.04 A(a)	0.90±0.02 A(a)	4.06±0.20 A(a)
	<i>P. caspica</i>	1.69±0.05 A(a)	12.55±0.35 A(e)	0.46±0.03A B(d)	6.30±0.09 A(a)	1.03±0.04 A(a)	4.80±0.23 A(a)
120-140	<i>P. taeda</i>	1.74±0.04 A(a)	12.01±0.24 AB(cd)	0.41±0.06B (e)	6.19±0.05 A(a)	0.89±0.02 A(a)	3.95±0.07 A(a)
	<i>Q. castaneifolia</i>	1.66±0.02 A(a)	12.44±0.27 AB(e)	0.47±0.05A B(f)	6.30±0.06 A(a)	1.06±0.02 A(a)	4.67±0.13 A(a)
	<i>J. polycarpus</i>	1.75±0.04 A(a)	11.59±0.23 AB(e)	0.55±0.03A B(f)	6.31±0.08 A(a)	0.91±0.03 A(a)	4.01±0.25 A(a)
	<i>A. glutinosa</i>	1.71±0.03 A(a)	12.59±0.28 A(e)	0.58±0.05A (f)	6.42±0.05 A(a)	0.97±0.03 A(a)	4.74±0.22 A(a)
	<i>T. distichum</i>	1.72±0.03 A(a)	11.44±0.18 B(d)	0.44±0.07B (c)	6.05±0.09 A(a)	0.94±0.01 A(a)	3.90±0.36 A(a)
	<i>P. caspica</i>	1.70±0.02 A(a)	11.62±0.20 AB(f)	0.45±0.09B (d)	6.16±0.06 A(a)	1.02±0.04 A(a)	4.61±0.28 A(a)
140-160	<i>P. taeda</i>	1.72±0.03 A(a)	11.49±0.21 B(d)	0.42±0.06B (e)	6.15±0.02 A(a)	0.96±0.03 A(a)	3.85±0.20 A(a)
	<i>Q. castaneifolia</i>	1.70±0.02 A(a)	12.00±0.18 A(e)	0.45±0.05B (f)	6.26±0.04 A(a)	1.05±0.04 A(a)	4.24±0.22 A(a)
	<i>J. polycarpus</i>	1.74±0.04 A(a)	11.26±0.09 B(e)	0.45±0.03B (f)	6.19±0.06 A(a)	0.93±0.01 A(a)	3.83±0.26 A(a)
	<i>A. glutinosa</i>	1.72±0.04 A(a)	12.02±0.11 A(ef)	0.54±0.06A (f)	6.16±0.06 A(a)	1.01±0.02 A(a)	4.26±0.21 A(a)
	<i>T. distichum</i>	1.70±0.00 A(a)	11.46±0.21 ABC(d)	0.39±0.03A (c)	6.00±0.00 A(a)	0.97±0.01 A(a)	3.81±0.11 A(a)
	<i>P. caspica</i>	1.72±0.02 A(a)	11.49±0.28 ABC(f)	0.38±0.06A (d)	6.10±0.02 A(a)	1.02±0.02 A(a)	4.65±0.23 A(a)
160-180	<i>P. taeda</i>	1.73±0.03 A(a)	11.40±0.16 BC(d)	0.38±0.05A (e)	6.12±0.03 A(a)	0.98±0.03 A(a)	3.91±0.15 A(a)
	<i>Q. castaneifolia</i>	1.69±0.02 A(a)	12.05±0.05 A(e)	0.42±0.02A (f)	6.16±0.03 A(a)	1.07±0.07 A(a)	4.30±0.25 A(a)

	<i>J. polycarpus</i>	1.75±0.05 A(a)	11.12±0.07 C(e)	0.43±0.03A (f)	6.17±0.06 A(a)	0.97±0.05 A(a)	3.76±0.20 A(a)
	<i>A. glutinosa</i>	1.75±0.04 A(a)	11.77± 0.20AB(ef)	0.52±0.04A (f)	6.18±0.04 A(a)	1.05±0.05 A(a)	4.43±0.18 A(a)
	<i>T. distichum</i>	1.74±0.04 A(a)	11.54±0.30 A(d)	0.39±0.04A (c)	6.00±0.07 A(a)	0.97±0.01 A(a)	3.85±0.21 A(a)
	<i>P. caspica</i>	1.71±0.03 A(a)	11.44±0.25 A(f)	0.38±0.06A (d)	6.10±0.04 A(a)	0.99±0.02 A(a)	4.61±0.26 A(a)
180- 200	<i>P. taeda</i>	1.73±0.02 A(a)	11.54±0.33 A(d)	0.38±0.04A (e)	6.09±0.05 A(a)	0.98±0.01 A(a)	4.04±0.14 A(a)
	<i>Q. castaneifolia</i>	1.69±0.03 A(a)	11.80±0.15 A(e)	0.42±0.03A (f)	6.20±0.07 A(a)	1.07±0.03 A(a)	4.29±0.24 A(a)
	<i>J. polycarpus</i>	1.74±0.04 A(a)	11.27±0.24 A(e)	0.43±0.03A (f)	6.19±0.05 A(a)	0.96±0.03 A(a)	3.81±0.30 A(a)
	<i>A. glutinosa</i>	1.73±0.03 A(a)	11.59±0.19 A(f)	0.49±0.04A (f)	6.19±0.01 A(a)	0.99±0.07 A(a)	4.49±0.15 A(a)
Two-way ANOVA result (mean squares)							
Tree Specious (T)	0.27 **	17.06 **	4.91**	0.65 **	0.14 **	6.74 **	
Depth (D)	0.142 **	30.79 **	12.09 **	1.58 **	0.04**	0.55 **	
T×D	0.003 ^{ns}	0.84 **	0.53 **	0.03 ^{ns}	0.004 ^{ns}	0.17 ^{ns}	

BD, bulk density; CEC, cation exchange capacity; MWD, mean weight diameter and EC, electric conductivity. ns, not significant, ** Significant at P<0.01 and * Significant at P<0.05. Within a column mean values with different capital letters at each soil depth are significantly different between tree species type at P<0.05; within a column mean values with different small letter for each tree species type are significantly different between depths at P<0.05.

Soil organic carbon and nitrogen

Significant differences in SOC among tree species plots were observed at 0-20 cm to 140-160 cm. The greatest change (Δ 5.86) in SOC content between tree species plots was found in *A. glutinosa* and *J. polycarpus* plots with 8.83 (g.kg⁻¹) and 2.50 (g.kg⁻¹) respectively in 40-60 cm layer; whereas, a lower difference (Δ 1.00) was found between *Q. castaneifolia* and *J. polycarpus* with the SOC concentration of 4.80 (g.kg⁻¹) and 3.80 (g.kg⁻¹) respectively in 180-200 cm. The greatest SOC content was observed in *A. glutinosa* with 13.11 (g.kg⁻¹) in the top soil layer. Except 60-80, 160-180 and 180-200 cm, *A. glutinosa* had the highest content of SOC. In these layers *Q. castaneifolia* had the greatest organic carbon. All species had a higher organic carbon concentration in the top soil layer (0-20 cm) in the following order: *A. glutinosa* > *Q. castaneifolia* > *P. caspica* > *J. polycarpus* > *T. distichum* > *P. taeda* (Table 2).

Similarly, N concentration varied widely among tree species and its distribution at soil profiles. *A. glutinosa* with 1.45 (g.kg⁻¹) had the greatest N concentration at top soil layer between all tree species and across soil depths. Likewise SOC, for all tree species a higher N concentration was found

in 0-20 cm that followed the same order. The greatest change (Δ 0.65) in N concentration was observed between *A. glutinosa* and *J. polycarpus* plots with 0.89 (g.kg⁻¹) and 0.24 (g.kg⁻¹) respectively in 40-60 cm layer; and similar to SOC, very low differences (Δ 0.19) was observed between *Q. castaneifolia* and *J. polycarpus* with N concentration of 0.65 (g.kg⁻¹) and 0.46 (g.kg⁻¹) respectively in 180-200 cm.

Soil organic C and N distribution for each tree species in the soil profile had the same trend; decreasing with increasing soil depth. In contrast, the differences between C and N concentrations among tree species in the soil profile diminished with increase in soil depth. Consequently, the higher SOC:TN ratios with considerable differences between tree species plots were found in the top soil layer (0-20 cm) with the following order: *P. taeda* > *T. distichum* > *J. polycarpus* > *P. caspica* > *Q. castaneifolia* > *A. glutinosa*; Therefore *P. taeda* with 11.89 was found as the greatest SOC:TN ratio in the whole soil profile; approximately the lowest SOC:TN with significant differences (P<0.05) among the tree species plots were observed in sub layers specially in three deep layers (140-200 cm).

Table 2. Vertical distribution of soil organic carbon and labile carbon pools under different tree species (mean ± SEM)

Depth (cm)	Tree sp	SOC (g kg ⁻¹)	TN (g kg ⁻¹)	SOC:TN	HWEOC (mg kg ⁻¹)	CWEOC (mg kg ⁻¹)	CHO _(HW) (mg kg ⁻¹)	C-MIN (mg kg ⁻¹)	MBC (mg kg ⁻¹)
0-20	<i>T. distichum</i>	9.06±0.65BC(a)	0.80±0.02E(a)	11.37±1.05AB(a)	440.27±23.91E(a)	255.24±7.34 F(a)	211.23±4.23 F(a)	1280.14±6.94 D(a)	114.47±5.52F(a)
	<i>P. caspica</i>	10.09±0.63B(a)	0.91±0.02C(a)	11.03±0.49AB(a)	801.11±16.47C(a)	415.44±5.77 C(a)	360.00±9.17 C(a)	1609.16±7.77 C(a)	194.29±5.46C(a)
	<i>P. taeda</i>	8.61±0.52C(a)	0.72±0.02F(a)	11.89±0.38A(a)	280.06±9.12 E(a)	246.24±5.66 E(a)	246.24±5.66 E(a)	1250.03±11.14 E(a)	165.43±7.89D(a)
	<i>Q. castaneifolia</i>	12.22±0.45A(a)	1.29±0.02B(a)	9.49±0.20BC(a)	945.52±16.29B(a)	480.27±5.81 B(a)	2066.34±12.27 B(a)	231.25±5.37B(a)	231.25±5.37B(a)
20-40	<i>J. polycarpus</i>	9.21±0.51BC(a)	0.82±0.02D(a)	11.22±0.45AB(a)	570.55±6.61D(a)	310.26±5.88 D(a)	319.25±5.06 D(a)	1301.08±7.71 D(a)	143.10±4.44E(a)
	<i>A. glutinosa</i>	13.11±0.43A(a)	1.45±0.03A(a)	9.06±0.10C(bc)	1030.06±13.65A(a)	560.12±7.60 A(a)	655.20±5.54 A(a)	2222.75±5.77 A(a)	272.04±4.16A(a)
	<i>T. distichum</i>	7.63±0.99AB(a)	0.75±0.02B(b)	10.25±1.36A(ab)	430.96±16.72F(a)	250.65±7.06 E(a)	193.56±4.57 E(b)	1010.09±4.50 D(b)	108.84±5.36E(a)
	<i>P. caspica</i>	8.63±0.61A(ab)	0.91±0.01A(a)	9.44±0.58A(b)	691.64±19.09C(b)	360.50±5.58 C(b)	276.13±9.25 C(b)	1325.00±4.92 C(b)	169.78±6.51C(a)
40-60	<i>P. taeda</i>	5.41±0.42C(b)	0.51±0.04D(c)	10.53±0.14A(ab)	610.45±15.72D(a)	290.01±4.63 D(a)	231.87±5.37 D(b)	760.19±4.86 F(b)	150.26±4.93C(ab)
	<i>Q. castaneifolia</i>	8.80±0.41A(b)	0.90±0.03A(b)	9.77±0.12A(a)	874.65±11.62B(b)	400.24±5.09 B(b)	471.77±5.55 B(b)	1436.19±6.10 B(b)	209.97±4.99B(ab)
	<i>J. polycarpus</i>	6.51±0.48BC(a)	0.63±0.03C(b)	10.36±0.33A(a)	500.24±9.92E(b)	280.16±5.05 D(b)	246.80±2.40 D(b)	896.58±7.12 E(b)	125.04±4.44D(ab)
	<i>A. glutinosa</i>	9.17±0.55A(b)	0.90±0.02A(b)	10.13±0.35A(a)	980.88±8.43A(b)	440.06±7.50 A(b)	550.33±5.22 A(b)	1507.21±5.00 A(b)	250.20±4.55A(ab)
60-80	<i>T. distichum</i>	3.52±0.58B(b)	0.44±0.01C(h)	8.17±1.63A(ab)	350.72±11.80E(b)	160.27±6.07 E(b)	147.04±4.12 E(c)	460.07±5.04 D(c)	84.98±4.17F(a)
	<i>P. caspica</i>	6.40±0.53A(b)	0.91±0.01A(a)	7.04±0.49A(d)	574.77±17.62C(c)	310.58±5.43 C(c)	230.32±5.82 C(c)	950.18±5.36 C(c)	141.81±5.17C(a)
	<i>P. taeda</i>	2.97±0.49B(cd)	0.29±0.02D(c)	10.14±0.89A(bc)	490.49±14.36D(b)	205.00±5.45 D(b)	156.95±6.25 D(c)	400.14±5.30 E(c)	124.96±4.29D(b)
	<i>Q. castaneifolia</i>	7.82±0.43A(b)	0.85±0.02B(c)	9.19±0.29A(ab)	791.20±14.68B(c)	360.07±5.37 B(c)	403.64±6.03 B(c)	1258.37±7.04 B(c)	185.12±5.45B(b)
80-100	<i>J. polycarpus</i>	2.50±0.51B(c)	0.24±0.02E(f)	10.23±1.54A(a)	480.83±10.02D(b)	210.01±6.36 D(c)	235.24±3.28 C(b)	338.91±3.96 F(c)	105.00±4.87E(b)
	<i>A. glutinosa</i>	8.83±0.50A(b)	0.89±0.02A(b)	9.91±0.33A(a)	855.09±13.60A(c)	410.16±11.35 A(c)	480.28±4.89 A(c)	1394.44±5.73 A(c)	210.12±3.53A(b)
	<i>T. distichum</i>	3.71±0.64B(b)	0.47±0.01D(f)	7.92±1.52AB(ab)	114.24±7.40F(c)	100.27±5.63 E(c)	50.79±5.78 F(d)	450.07±6.61 D(c)	50.10±2.62E(b)
	<i>P. caspica</i>	3.91±0.44AB(c)	0.55±0.02B(d)	7.08±0.56B(d)	445.21±11.91C(d)	155.05±4.75 C(d)	169.22±7.92 C(d)	560.10±4.71 C(d)	103.40±5.10B(b)
100-120	<i>P. taeda</i>	2.23±0.38C(d)	0.24±0.02F(f)	9.29±0.64AB(bc)	225.39±12.37E(c)	160.10±6.00 C(c)	69.83±3.22 E(d)	291.05±3.47 F(d)	86.09±6.39C(c)
	<i>Q. castaneifolia</i>	5.00±0.14A(c)	0.60±0.03A(c)	8.41±0.23AB(bc)	660.62±8.48B(b)	190.13±4.37 B(d)	330.56±7.62 B(d)	751.14±5.11 A(d)	120.72±4.75AB(c)
	<i>J. polycarpus</i>	3.05±0.36BC(bc)	0.28±0.02E(e)	10.84±0.77A(a)	265.30±6.36D(d)	140.31±3.80 D(d)	132.59±4.85 D(c)	338.44±4.63 E(d)	73.03±4.22D(c)
	<i>A. glutinosa</i>	4.61±0.34A(c)	0.51±0.02C(d)	9.02±0.30AB(bc)	745.30±5.96A(a)	220.08±6.19 A(d)	380.15±4.02 A(d)	719.06±5.00 B(d)	126.03±4.39A(c)
100-120	<i>T. distichum</i>	3.21±0.43DE(b)	0.46±0.02C(g)	7.13±1.29A(b)	96.19±6.12D(d)	80.30±5.76 C(d)	39.34±3.06 C(e)	320.03±5.25 D(d)	33.26±4.26B(c)
	<i>P. caspica</i>	3.91±0.54BC(c)	0.54±0.01AB(de)	7.16±0.80A(d)	194.97±8.17B(b)	105.59±4.33 B(e)	76.12±4.56 B(e)	520.02±3.05 C(e)	45.18±4.31A(c)
	<i>P. taeda</i>	3.61±0.41CD(c)	0.37±0.02D(d)	9.79±1.44A(bc)	148.57±7.32C(c)	110.84±5.11 B(d)	47.43±4.17 C(e)	251.06±4.56 E(e)	44.14±3.15AB(d)
	<i>Q. castaneifolia</i>	4.31±0.49AB(c)	0.60±0.03A(c)	7.14±0.48A(d)	404.25±7.34A(a)	130.06±4.03 A(c)	210.11±3.45 A(e)	619.04±4.55 B(e)	52.38±3.71A(d)
100-120	<i>J. polycarpus</i>	3.03±0.42E(bc)	0.29±0.02E(e)	10.24±0.64A(a)	180.84±5.66B(b)	110.01±4.07 B(e)	81.07±3.86 B(d)	318.31±4.93 D(d)	43.28±3.13AB(d)
	<i>A. glutinosa</i>	4.60±0.37A(c)	0.51±0.01BC(d)	9.06±0.62A(bc)	425.41±6.24A(a)	110.05±4.21 B(e)	210.00±5.48 A(e)	701.69±4.32 A(e)	58.30±4.67A(d)
	<i>T. distichum</i>	3.90±0.54 AB(b)	0.55±0.02A(d)	7.08±0.72C(b)	57.53±6.27D(d)	40.62±4.54 D(e)	23.30±3.64 D(f)	319.98±3.57 D(d)	25.11±2.52C(cd)
	<i>P. caspica</i>	3.91±0.43 AB(c)	0.53±0.01AB(e)	7.40±0.70C(d)	90.22±6.78C(c)	76.05±3.70 B(f)	31.25±5.26 D(f)	480.07±4.60 C(f)	27.35±3.99BC(d)
100-120	<i>P. taeda</i>	3.35±0.50 BC(c)	0.38±0.02C(d)	8.65±0.88AB(c)	90.76±10.08C(c)	55.18±4.68 C(e)	31.47±3.71 D(f)	282.40±3.91 E(d)	30.04±2.49ABC(e)
	<i>Q. castaneifolia</i>	4.40±0.52 AB(c)	0.56±0.03A(f)	7.87±0.58BC(cd)	215.38±5.56B(b)	80.13±5.02 B(f)	95.83±5.47 B(f)	586.75±4.89 B(f)	34.20±3.69AB(e)
	<i>J. polycarpus</i>	2.62±0.44 C(bc)	0.30±0.02D(e)	8.63±0.84AB(b)	109.07±4.58C(c)	100.02±4.62 A(e)	45.03±2.16 C(e)	279.05±5.12 E(e)	37.03±2.67A(f)
	<i>A. glutinosa</i>	4.81±0.40 A(c)	0.51±0.02B(d)	9.48±0.54A(abc)	268.03±7.04A(a)	95.00±5.25 A(ef)	110.07±3.76 A(f)	685.35±4.77 A(f)	37.03±3.85A(f)

Table 2.

120-140	<i>T. distichum</i>	3.61±0.48 AB(b)	0.52±0.01B(c)	6.96±0.73D(b)	50.37±4.78D(d)	20.29±4.33 C(f)	18.02±0.87 BC(f)	250.02±3.44 D(e)	24.24±2.52AB(d)
	<i>P. caspica</i>	4.50±0.52 A(c)	0.53±0.01B(c)	8.46±0.83AB(c)	64.20±6.15CD(f)	50.15±4.99 B(g)	19.20±3.59 BC(fg)	480.00±4.32 C(f)	26.47±3.50AB(d)
	<i>P. taeda</i>	3.61±0.40 AB(c)	0.41±0.02C(d)	8.71±0.63AB(c)	33.44±3.77E(f)	88.35±7.74 C(f)	10.43±0.37 C(g)	249.21±4.09 D(ef)	20.14±2.51B(f)
	<i>Q. castaneifolia</i>	4.40±0.46 A(c)	0.60±0.03A(d)	7.26±0.46CD(d)	111.22±6.53B(g)	85.18±6.31 A(f)	50.22±3.38 A(g)	552.05±4.43 B(g)	32.95±3.53A(e)
	<i>J. polycarpus</i>	2.70±0.42 B(bc)	0.35±0.02D(d)	7.55±0.69BCD(b)	70.00±4.94C(f)	55.14±3.30 B(f)	26.63±4.12 B(f)	258.02±4.66 D(f)	28.71±4.06AB(c)
140-160	<i>A. glutinosa</i>	4.80±0.20 A(c)	0.50±0.01B(d)	9.52±0.13A(ab)	140.11±5.12A(g)	88.02±5.43 A(f)	50.27±5.27 A(g)	600.35±5.20 A(g)	30.16±2.69AB(c)
	<i>T. distichum</i>	4.41±0.61 AB(b)	0.61±0.02B(c)	7.22±0.79AB(b)	55.05±5.87BC(d)	23.00±3.74 E(f)	16.42±0.95 C(f)	240.43±3.85 D(f)	23.94±2.40BC(d)
	<i>P. caspica</i>	4.00±0.47 AB(c)	0.58±0.02B(bc)	6.83±0.61B(d)	59.78±4.56B(f)	35.09±4.44 CD(h)	18.48±0.24 C(fg)	320.20±4.10 B(gh)	25.06±2.20ABC(d)
	<i>P. taeda</i>	3.59±0.47 AB(c)	0.55±0.03C(b)	6.53±0.57B(d)	41.48±5.10C(f)	29.33±3.21 DE(f)	12.46±1.17 C(g)	233.29±4.09 D(g)	21.19±2.92C(f)
	<i>Q. castaneifolia</i>	5.00±0.00 AB(c)	0.65±0.03A(d)	7.72±0.34AB(cd)	100.00±4.88A(g)	48.00±4.03 B(g)	50.01±3.60 A(g)	437.53±3.94 A(h)	31.93±2.72A(e)
160-180	<i>J. polycarpus</i>	3.53±0.33 B(bc)	0.45±0.03D(c)	7.81±0.40AB(b)	53.15±4.1BC(f)	43.02±4.34 BC(f)	18.52±4.44 C(f)	270.03±4.56 C(e)	24.05±3.13BC(e)
	<i>A. glutinosa</i>	5.20±0.55 A(c)	0.60±0.03B(c)	8.67±0.51A(c)	95.39±4.68A(h)	65.02±4.24 A(g)	33.18±3.48 B(g)	449.42±4.56 A(h)	29.89±1.71AB(f)
	<i>T. distichum</i>	4.49±0.47 A(b)	0.62±0.02AB(c)	7.22±0.60AB(b)	23.13±4.62C(d)	23.14±2.14 B(f)	7.52±0.92 B(g)	250.05±3.66 D(e)	17.53±2.73C(e)
	<i>P. caspica</i>	4.21±0.48 A(c)	0.57±0.02C(c)	7.36±0.69A(d)	20.02±4.83C(g)	20.14±3.11 B(f)	6.60±1.83 B(g)	315.06±4.28 C(h)	16.60±2.98C(e)
	<i>P. taeda</i>	3.71±0.47 A(bc)	0.57±0.02C(b)	6.50±0.55B(d)	25.52±4.81C(f)	19.02±4.67 B(f)	6.21±0.76 B(g)	238.79±4.92 E(gf)	18.34±1.63BC(f)
180-200	<i>Q. castaneifolia</i>	4.90±0.42 A(c)	0.65±0.02A(d)	7.52±0.23A(cd)	88.39±5.39A(g)	28.05±4.72 B(h)	34.25±3.22 A(f)	397.08±5.13 B(f)	30.96±1.58A(e)
	<i>J. polycarpus</i>	3.60±0.34 A(c)	0.45±0.02C(c)	8.02±0.40A(b)	51.06±4.24B(f)	19.15±4.26 B(g)	24.25±9.11 A(h)	258.30±1.53 D(f)	23.99±2.72ABC(e)
	<i>A. glutinosa</i>	4.79±0.46 A(c)	0.60±0.02B(c)	7.92±0.51A(d)	77.54±5.18A(h)	40.12±3.24 A(h)	30.56±4.40 A(f)	417.39±5.31 A(i)	28.05±2.42AB(f)
	<i>T. distichum</i>	4.16±0.60 A(b)	0.62±0.01AB(c)	6.71±0.84B(b)	24.00±3.38D(d)	20.56±3.90 B(f)	7.19±1.00 D(g)	240.01±3.98 C(f)	15.96±2.91C(e)
	<i>P. caspica</i>	4.49±0.55 A(c)	0.59±0.03BC(c)	7.57±0.61AB(d)	20.00±4.58D(g)	20.22±2.78 B(f)	7.10±0.77 D(g)	325.04±3.38 B(g)	16.07±1.19C(e)
Tree Species (T) Depth (D) T×D		0.246**	0.22**	10.34**	438077.84**	50632.52**	173475.70**	0.664**	0.30**
		0.414**	0.188**	23.94**	137876.1621**	330841.56**	377670.32**	1.132**	2.520**
		0.014**	0.014**	2.11**	28116.13**	5662.66**	13710.53**	0.012**	0.01**

Two-way ANOVA result (mean squares)

HWEOC, hot water organic extractable carbon; CWEOC, cold water extractable organic carbon; CHO_(HW), hot water extractable carbohydrate; SOC, Soil organic carbon; MBC, microbial biomass carbon; C_{min}, carbon mineralization and TN, Total nitrogen. ns not significant, ** Significant at P<0.01 and * Significant at P<0.05. Within a column, mean values with different capital letters at each soil depth are significantly different between tree species type at P<0.05; within a column mean values with different small letter at each tree species type are significantly different between depths at P<0.05.

The varied amount of total SOC stocks was greater under Alder (*A. glutinosa*) and Oak (*Q. castaneifolia*) than other tree species with 206.24 and 195.26 (Mg.ha⁻¹), respectively; and *P. taeda* had the lowest amount at 136.94 (Mg ha⁻¹) across the soil profile (Figure 3). The effect of tree species on SOC stocks was measured for each soil interval as well: approximately higher amount of SOC stocks in 0-20 and 20-40 cm than other layers was the common pattern for all tree species. In these layers, the highest amounts with 35.81 and 33.05 (Mg.ha⁻¹) (for 0-20) and; 27.42 and 27.32 (Mg ha⁻¹) (for 20-40 cm) were found under Alder (*A. glutinosa*) and Oak (*Q. castaneifolia*) respectively. Although the SOC stocks generally decreased strongly after second layer for *J. polycarpus*, *T. distichum* and *P. taeda*, however SOC stocks with 28.56, 24.88 (Mg ha⁻¹) under Alder (*A. glutinosa*) and Oak (*Q. castaneifolia*), respectively were still high (Figure 3).

Labile organic carbon pools

The C content of each of the labile organic carbon pools varied between tree species and soil depth (Table 2). A negative trend in all labile organic carbon pools was observed with soil depth. Similar to total SOC, the highest and significant differences ($P > 0.05$) at each labile organic carbon pool were observed in the uppermost layers. After 12 weeks of laboratory incubation, respired organic carbon (C_{min}) ranged 2222.75-1250.03 (mg.kg⁻¹) and the highest differences (Δ 972.72), were reported from *A. glutinosa* and *P. taeda* plots at 0-20 cm layer. SMB-C was significantly affected by tree species plots; this significance was less pronounced after 60-80 cm. As a great significant difference, in 0-20 interval, SMB ranged 357.13-136.00 (mg.kg⁻¹) reported from *A. glutinosa* and *T. distichum* plots, respectively. Likewise SMB- C, *A. glutinosa* and *T. distichum* were found as the highest and the lowest (0-20 cm) in HWEOC, CWEOC and CHO_{HW} with the range of 440.27-1030.06, 255.24-560.12 and 211.23-655.20 (mg.kg⁻¹). Additionally, influences of tree species types on “labile organic carbon to SOC” ratios were

observed across soil profiles (Table 4). For all labile pools, *A. glutinosa* and *T. distichum* had the highest and the lowest percent of labile organic carbon, respectively. Consequently, the C_{min} in the range of 10.11-14.04% and SMB-C in range of 1.05-1.66% had the highest and lowest proportion of SOM across 0-200 cm depth, respectively.

Discussion

Because of the small scale of the experimental site and the plantation of tree species types adjacently; generally, the soil alteration was insignificant, especially while soils under trees developed from the same parent material, therefore it is assumed that the soils of the studied area were similar before plantation. Consequently, observable differences in soil characteristics, originated from tree species impacts on soil medium. This assumption had been the base for other similar studies (Smolander and Kitunen, 2002; Reich *et al.*, 2005; chen *et al.*, 2004).

Depth and soil chemical and physical properties

For all tree species types, as a main factor, EC was approximately decreased with depth down to 40-60 and 60-80 cm layers and then gradually increased. This trend could hypothetically arise from mostly organic components, received from top soils, especially through litter fall and then release of soluble salts at top soil layers due to biological activities, consequently leaching of ions down to nearly 40-60 cm where water table rise, during seasonal rainfall. Beheshti *et al* (2012) reported high EC values due to salt accumulation in whole profile as a result of shallow water table and waterlogged condition for rice cultivation. The significant positive correlation (0.771) was found between CaCO₃ content and pH values (Table. 3), further, roots of growing plants produced carbon dioxide and small amounts of organic acids which increase soil acidity; which could explain the declining of pH values down to soil profile at each tree species plots.

Soil bulk density is an important parameter in soil organic carbon sequestration studies. BD has been frequently related to SOM (Perie and Ouimet, 2008). The inverse correlation between SOM and BD is normal. In general, the natural BD increases with soil depth due to decrease in SOM and porosity. As expected, our results showed BD values had negative correlation with SOC (Table 3). This can confirm the results of other studies on forest soils (Don et al., 2007; Heuscher et al., 2005; Grüneberg et al., 2014). Besides, BD was generally increased across the soil profiles due to the weight of overburdened soil (Grüneberg et al., 2014).

Many studies showed that aggregate stability as one of the soil physical properties can be used to evaluate soil quality in agricultural and forest management systems (i.e., Golchin and Asgari, 2008; Beheshti et al., 2012; An et al., 2010; Parsakhoo et al., 2014 and Ramesh et al., 2015) and SOM with its fractions is the main factor to control aggregate stability which have positive

correlation with aggregation (Diaz et al., 1994; Golchin et al., 1995; Cerdà., 1998). Golchin et al. (1995) reported that macro aggregates are stabilized by carbohydrate within aggregates. Increasing aggregate stability in the top soil layer under forest and shrub vegetation was reported by An et al. (2010). They showed that the higher SOM and carbohydrate content, especially in 0-10 cm affected aggregate stabilization through bridging between clay particles. These findings were similar to our results and confirm them. CEC is linked to SOM content, therefore the high level of CEC in the top soil layers of tree species plots can be explained by the presence of organic matter. Our results are in line with findings of other researchers which showed higher soil organic carbon contents have higher CEC and vice versa (i.e. Yimer et al., 2006; Demssie et al., 2012; Rezaei and Gilkes, 2005). CEC changes can also be caused by natural processes such as occurrence of base cations i.e. Ca²⁺, therefore besides abatement of SOM, lower soil pH can cause a decline in CEC across soil profiles.

Table 3. Correlation coefficient among basic soil properties and labile soil organic carbon pools

	BD	HWEOC	CWEOC	CHO _{HW}	CEC	pH	EC	CaCO ₃	C:N	SOC	MWD	MBC	C _{Min}
HWEOC	-0.915**												
CWEOC	-0.805**	0.900**											
CHO _(HW)	-0.865**	0.960**	0.964**										
CEC	-0.824**	0.904**	0.980**	0.952**									
pH	-0.900**	0.856**	0.734**	0.797**	0.796**								
EC	-0.931**	0.958**	0.895**	0.934**	0.914**	0.904**							
CaCO ₃	-0.818**	0.890**	0.929**	0.909**	0.930**	0.771**	0.906**						
C:N	-0.816**	0.756**	0.654**	0.707**	0.712**	0.839**	0.865**	0.680**					
SOC	-0.868**	0.893**	0.870**	0.892**	0.890**	0.869**	0.926**	0.857**	0.699**				
MWD	-0.828**	0.911**	0.976**	0.956**	0.997**	0.800**	0.915**	0.918**	0.718**	0.886**			
MBC	-0.776**	0.878**	0.956**	0.949**	0.907**	0.647**	0.832**	0.871**	0.528**	0.816**	0.906**		
C _{Min}	-0.523**	0.653**	0.613**	0.646**	0.560**	0.448**	0.561**	0.543**	0.156*	0.640**	0.562**	0.699**	
TN	-0.834**	0.828**	0.734**	0.768**	0.755**	0.813**	0.913**	0.733**	0.925**	0.777**	0.759**	0.641**	0.441**

HWEOC, hot water extractable organic carbon; CWEOC, cold water extractable organic carbon; CHO_{HW}, hot water extractable carbohydrate; CEC, cation exchangeable capacity; EC, electric conductivity; SOC; Soil organic carbon; MWD, mean weight diameter; MBC, microbial biomass carbon; C_{min}, carbon mineralization and TN, total nitrogen.

** Significant at P<0.01 and * Significant at P<0.05

Table 4. Percentage ratios (%) of labile organic carbon to soil organic carbon of soil profiles (0-200 cm) under different tree species

Tree sp	HWEC:SOC	CWEC:SOC	CHO _{HW} :SOC	MBC:SOC	C _{Min} :SOC
<i>T. distichum</i>	3.44	2.04	1.50	1.05	10.11
<i>P. caspica</i>	5.48	2.87	2.21	1.42	12.74
<i>P. taeda</i>	5.62	2.92	2.00	1.65	10.26
<i>Q. castaneifolia</i>	6.95	2.96	3.65	1.56	13.68
<i>J. polycarpus</i>	5.75	3.19	2.82	1.54	11.10
<i>A. glutinosa</i>	7.29	3.21	3.92	1.66	14.04

SOC: Soil organic carbon, HWEC: Hot water extractable organic carbon, CWEC: Cold water extractable organic carbon, CHO_{HW}: Hot water extractable carbohydrate, MBC: Microbial biomass carbon and C_{Min}: Carbon mineralization via respiration

Soil properties and tree species traits

According to the results, besides significant differences between tree species as the main factor, the broadleaf and conifer (needle leaf) groups are also different in their effects. This is the important factor identified as responsible for underlying differences in soils beneath tree species. Most research showed that leaf decomposition is faster for broadleaved than for coniferous species (Kavvadias *et al.*, 2001); because of the low quality nature and nutrient content of coniferous litter (Alvarez *et al.*, 2008); For example, differences in soil acidity among soils under tree species attributed to differences in litter calcium concentrations (Reich, 2005). Hence broadleaf trees like those selected in this research with high Ca^{2+} content induced increases in soil pH. Furthermore, compared with broadleaf, conifer needles contain more components that are difficult to decompose, resulting in less elements release and consequently poor incorporation in the mineral top soil (Wang *et al.*, 2014). This can be explained by low content of soil organic matter in *T. distichum*, *P. taeda* and *J. polycarpos*. Our findings were inconsistent with the study of Diaz-Pines *et al.* (2011). In their experiment, Scots pine stored significantly more organic carbon than Pyrenean oak in the uppermost layer of the mineral soil (0-5 cm), due to the low litter fall C inputs and basal area. Differently, Van Nevel *et al.*, (2014) reported the oak stands produced less, but high quality litter fall than the pine stands, therefore top soils in oak stands had higher pH, CEC and lower C:N than in pine stands.

The C:N ratio is another important indicator of soil quality and fertility in forest ecosystems. Therefore, the effect of the soil C:N ratio is tree species dependent (Cools *et al.*, 2014). Our findings showed that, the broadleaf plantations (*P. caspica*, *Q. castaneifolia* and *A. glutinosa*) had a lower litter C:N ratio than the coniferous plantations (*T. distichum*, *P. taeda* and *J. polycarpos*). The results are in accord with those reported by other researchers which

showed broadleaves litter had lower C:N ratio (i.e., Jandle, 2007; Van Nevel *et al.*, 2014).

Many researchers have shown that aggregate stability is one of the important features of soil quality (Schoenholtz *et al.*, 2000), besides, organic matter and its fractions are the aggregation supplies which sequestered within aggregates and protected against degradation (Carter and Gregorich, 1996). Therefore, organic matter tends to increase aggregate stability (Kara and Baykara, 2014; Mandiola *et al.*, 2011). We found increasing aggregate stability approximately in the following order: *A. glutinosa* > *Q. castaneifolia* > *P. caspica* > *J. polycarpos* > *T. distichum* > *P. taeda*, which was in the same order as that of the organic carbon content. Meanwhile, the results showed significant relationships between soil microbial biomass C and MWD values (Table 3). Kara and Baykara (2014) reported a significant correlation between SMB and aggregate stability which confirmed our findings. SMB produces binding agents which help the making and stabilization of aggregates. Numerous studies have shown that mycorrhizal fungi improves formation of the soil structure and its stability by charge and adhesive mechanisms (Golchin *et al.*, 1995; Rilling and Mummey, 2006; Six *et al.*, 2004), therefore the contribution of mycorrhizal fungi to the aggregation process and its stabilization has been proven previously (Graft and Frei, 2013). Additionally, similar to organic carbon, nitrogen content and C:N ratio were considered as soil structure stability indices which can explain soil structures beneath N fixer alder which were higher than other tree species. Mixing of N fixers induced significant positive increase in the concentration of soil N and C (Johnson and Curtis, 2001). Compared to non N fixers, Resh *et al.* (2002) found 20%–100% more soil C under N fixer species. In addition, Binkley and Giardina (1998) reported N content of litter fall increases 4-10 times which consequently increase N concentration in forest soils due to the occurrence of nitrogen fixer species.

Variations of labile organic carbon pools beneath tree species

In agreement with many studies (i.e. Jiang and Xue, 2006; Vesterdal *et al.*, 2013; Golchin and Asgari, 2008; Beheshti *et al.*, 2012), our results revealed dependency of SOC to vegetation types. However, the strongest relationships were found between soil labile organic carbon pools and tree species. The percentage ratios of WSOC to SOC as well as their concentrations were in the following order: HWEOC > CWEOC > CHO_{HW} (Table 4). WSOC extraction with hot water kills living cells, then making their component extractable. Also a vast range of non-microbial organic matter extracts (i.e. root exudates, soluble carbohydrates and amino acids) are derived using hot water (Hamkalo *et al.*, 2014 and Ghani *et al.*, 2003). In accord with our results, some earlier studies (i.e., Gregorich *et al.*, 2003) have shown that extracted hot water organic carbon content was twofold more than cold water extraction (Table 4). Meanwhile, some researchers believed that CHO_{HW} was the important fraction of HWEOC, which originated by SMB and generally related to aggregate stability (Hynes and Beare, 1997; Ball *et al.*, 1996).

Comparison of WSOC pools, MBC and C_{min} among tree species showed higher content in broadleaves than coniferous, which was in line with other similar research (i.e. Wang and Wang, 2007; Wang and Wang, 2011). We did not find any literature regarding the effect of different tree species type on the labile SOC (i.e., extractable water soluble carbon and microbial biomass) in forest soils of Iran. For instance, Wang and Wang (2011) in the Huiltong National Research Station of Forest Ecosystem, China reported, beside higher content of 0-10 cm soil layer than 10-20 cm, broadleaf forest had higher concentration of cold and hot water soluble soil organic matter, SMB-C and soil respiration rate. Likewise, Smolander and Kitunen (2002) found higher values of SMB-C and WSOC in Birch forest rather than Spruce and Pine forests. Other similar results were reported by Jiang and Xue (2006). They concluded due to larger organic C storage, SMB and WSOC in soil

beneath broadleaf forest were significantly higher than those under Masson pine and Chinese fir. Liu and Luo, (1990) also reported great MBC content in broadleaf forest soils. Large volume of litter input with a variety of nutrient elements in soils under broadleaf trees provide optimum condition for microbial activity and consequently improved humification process. Further, conifers have shallower rooting systems than broadleaves; therefore their organic carbon is accumulated in the soil surface (Jandl *et al.*, 2007). Finally, in these acid soils under conifers, soil fauna are less active, decreasing the amount of humus mixed with mineral soil and subsequently more material on the forest floor being left.

It has been reported that water soluble organic carbon pools are correlated with each other and total SOM (Carter, 2002; Ghani, 2003) which support our results (Table 3). Occurrence of the greatest correlation between WSOC than total SOC pools with MBC was the important relationship which was shown in these research with the order of CWEOC > CHO_{HW} > HWEOC (Table 3). Our findings are inconsistent with other research: Ghani (2003) as well Wang and Wang (2011) reported higher correlation of HWEOC with MBC than other labile pools under forest ecosystem. Subsequently, they introduced HWEOC as a unique sensitive soil quality indicator. The inconsistency in results is probably due to the detection of changes induced by tree species types across the whole soil profile rather than the uppermost soil layers (in general 0-30 cm) in these studies. In the study of total and labile pools of SOC changes, between cultivated and undisturbed soils in northern India, Benbi *et al.* (2015) showed that although pool sizes are significantly different in various land uses, however these changes are similar to total SOC. Hence, they reported no single pool as a sensitive indicator of land use induced changes in SOC. Consequently, they introduced a composite of soil indicators for distinguishing different land use systems. Similarly, due to close correlation coefficient of most labile organic carbon pools (HWEOC, CWEOC and

CHO_{HW}) with SMB-C, no single pool could be used as a sensitive soil indicator for tree species types.

Conclusion

This study has clearly demonstrated that tree species type can mediate soil physico-chemical properties and also labile water soluble organic carbon pools in Shalman research station as part of the northern forest (Hyrcanian) of Iran. The broadleaf tree species had positive effects on soil properties and a high content of SOM in labile pools; this result means broadleaves could create a more favorable condition for soil health. Broadleaves had also great

potential for carbon sequestration across soil depth. Due to mycorrhizal fungi symbiotic nitrogen fixers, among broadleaf species, alder had great effect on soil properties and SOM. Finally, the use of labile organic carbon pools as a soil quality indicator were more effective than bulk SOM, however, no single and more sensitive organic carbon pool as a soil quality indicator of forest tree species changes was selected. We suggest that the complex of soil organic carbon pools including CWEOC, CHO_{HW} and HWEOC could be used for monitoring of managements in northern forest ecosystems of Iran.

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