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Abstract

Reforestation may help protect the health of endangered forest ecosystems. To implement this action, it is important to evaluate the effects of the planted species on soil quality. Previous studies have demonstrated that soil properties are closely driven by the effects of plant roots and plant remains (quantity and quality) reaching the soil surface. However, little research is available about the effects of plant species on soil quality of reforested sites compared to natural forest ecosystems. This study evaluates the changes in the main soil properties between two 30–40 year-old stand types in forest areas of northern Iran: i) two stands, each one comprising a natural species (*Parrotia persica* or *Pinus taeda*); and ii) two stands, each one with planted trees (*Quercus castaneifolia* or *Alnus glutinosa*). Compared to reforested sites, the soils with natural trees showed higher root weight density (+43%), pH (+17%), and organic carbon (+64%). These differences led to higher nutrient contents, microbial respiration, aggregate stability, and water retention in soils with natural trees, as confirmed by the correlation analysis. A principal component analysis provided a meaningful combined factor (the first principal component) that showed a clear discrimination in soil quality and fertility among natural and reforested species. The calculation of a soil quality index confirms that planted species may lead to an overall lower quality of soils with planted species compared to natural forest. Since the lower soil quality of planted forests can be also the result of unsuitable management practices, this study suggest that forest operations in reforested areas should be avoided, since this could lead to negative effects on soil quality and contribute to an increase in the risk of soil degradation.

Keywords: reforestation; organic carbon; nutrient content; microbial respiration; forest management.

1. Introduction

The health of forest ecosystems is endangered by several threats, such as deforestation, wildfire, and climate changes, which aggravate forest susceptibility to soil erosion

(Sasaki and Putz, 2009; Parhizkar et al., 2020a). The main rehabilitation and restoration practices include reforestation, which has been widely used in the Mediterranean basin to protect watersheds, often using conifers (Sheffer, 2012). In addition to natural forests, reforestation with tree or herbaceous species is a viable solution to control erosion on forest hillslopes in terrestrial ecosystems all over the world (Kooch et al., 2016) because. Well-developed and large vegetation cover increases water infiltration and evapo-transpiration of forest soils (De Baets et al., 2008; Li et al., 1992; 1995), which reduces surface runoff and soil loss (Fiener and Auerswald, 2003; Koskiaho, 2003; Li et al., 2013). In recent years, new restoration objectives have emerged, such as the biodiversity increase, and the use of shrubs species in hillslope restoration has been introduced. In addition, reforestation is a natural solution with a high potential to capture carbon under the expected climate change in the future (Fargione et al., 2018).

Vegetation species are able to noticeably change physical, chemical, and biological soil properties (Sanji et al., 2020; Kooch et al., 2016; Garcia et al., 1994). An interesting review by Schoenholtz et al. (2000) showed the basic role of forest plants in driving the soil quality indicators, and particularly the chemical and physical properties. With regard to Mediterranean forests, carbon and nitrogen content of both soil and litter are generally higher in mixed stands in comparison to monospecific forests (Lucas-Borja et al., 2012). Soil properties, with emphasis on soil water repellency and infiltration, are influenced by both plant composition and age and the related changes are more noticeable between managed and unmanaged forests (Zema et al., 2021a; 2021b). These authors also found that intense forest use and soil preparation may worsen hydrological properties of soils compared to unmanaged forest soils.

The changes in soil properties between natural and reforested areas have been highlighted in several studies (Maro et al., 1991; Wall and Hytönen, 2005; Miralles et al., 2007, 2009; Freier et al., 2010; Liao et al., 2012; Hoogmoed et al., 2014). For example, nutrient and exchangeable cation contents are different in soils with planted forests when compared with natural forests (Chen et al., 2005; Mohr et al., 2005; Nsabimana et al., 2008). Lemma et al. (2006) observed that, compared to natural forests, soil bulk density of planted forests is higher, whereas other authors report the reverse finding (Yang and Xie, 2002; Pibumrung et al., 2008). Inappropriate soil management practices, in addition to other factors, such as intensive past use, may play a key role in properties of forest soils (Osman, 2013). Lucas-Borja et al. (2012) found that machinery operations in recently afforested sites declined physical and chemical soil properties, and lowered activity of soil microbial communities in comparison to unmanaged sites of Mediterranean forests. Moreover, whereas in natural forests the soil properties are the effects of permanent species in the long term (Kooch et al., 2016), reforested sites are more subject to short-term changes in soil properties due to new species composition, soil preparation and past management. From these examples and other ample literature, it is clear that plant species may be considered as fundamental drivers of overall soil quality and the relations between soil and plants that cause alterations in soil properties are many and complex (Wilson and Agnew, 1992; Rafeie Jahed et al., 2014). Therefore, it is important to study by what extent planted species can be effective in modifying soil properties of forest areas and whether these changes are beneficial or not in terms of soil quality.

Up to now, the effects of plant species on chemical and physical properties of forest soil have been widely analyzed. However, while much literature focused on specific environments (e.g., Loess Plateau in China; Wang et al., 2014b, 2018a), shrub and grass species (e.g., De Baets et al., 2006; Zhang et al., 2013; Wang et al., 2021) and mainly explored the landscape scale (e.g., Li et al., 2015; Geng et al., 2021, again in Loess Plateau), less research is available on the difference in soil quality between planted forests and natural ecosystems. Relevant studies would provide a better understanding of the complex and unpredictable plant-soil relations in forest ecosystems, and this knowledge would help land managers selecting the most suitable species for afforestation. In these delicate ecosystems, the need for managing soil health is compulsory, to avoid land degradation and other improper management operations.

To these aims, this study analyzes the effects of vegetation species on soil quality in forest areas of northern Iran. More specifically, the changes in physico-chemical, hydrological, and biological properties of soils planted with four forest natural (*Parrotia persica* and *Pinus taeda*) or planted species (*Alnus glutinosa* and *Quercus castaneifolia*) with the same age (about 30-40 years) have been studied in this area. Here, forest biodiversity is rich (Parhizkar et al., 2020a), but intense deforestation has recently increased erosion and, in general, degraded soil quality (Parhizkar et al., 2020b). It has been hypothesized that the studied soil properties are affected by significant changes due to the different characteristics of vegetal species. The study aims to contribute to the understanding of the relationships between the soil properties and vegetal species in forest areas that may help increase soil health.

2. Materials and methods

2.1. Study area and experimental site

The forest soils of Northern Iran are affected by degradation due to anthropogenic activities, such as inappropriate management, vegetation removal, and illegal logging (Emadodin, 2008; Bahrami et al., 2010; Parhizkar et al., 2020a; 2020b). According to the Köppen-Geiger classification, the studied area is characterized by a typical Mediterranean climate, *Csa* type (Kottek et al., 2006). The average annual temperature and precipitation are 16.3 °C and 1360 mm, respectively (IRIMO, 2016). In some parts of this forest trees and other plants were planted and subjected to different management operations.

The Saqalaksar Forest Areas Park is a forest with massive trees and plants in the Guilan province. This area is located 15 km south of Rasht city (geographical coordinates 37°09'24" N, 49°31'50" E) at an altitude of 64 m above the mean sea level (Figure 1).

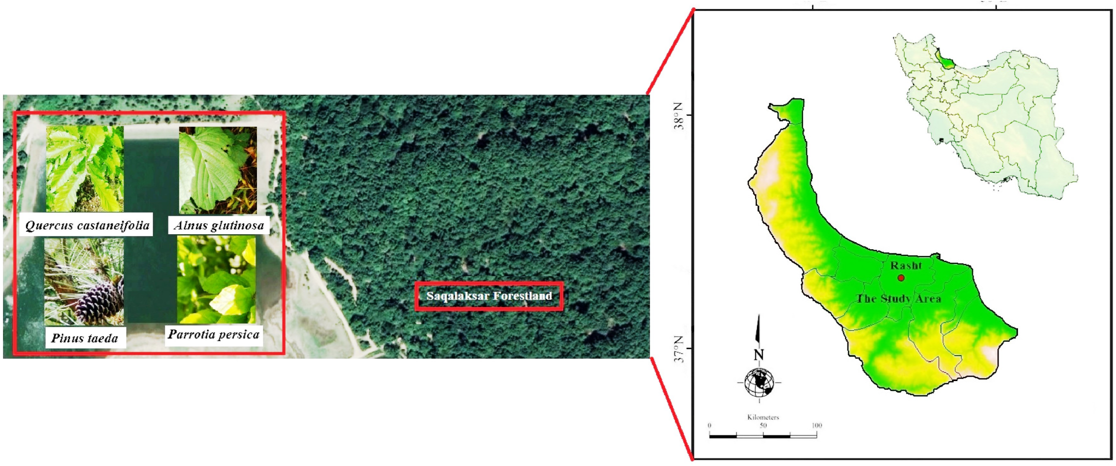


Figure 1 - Geographical location and aerial map (source: Google® Map®) of Saqalaksar Forest Areas Park (Guilan province, northern Iran).

The biodiversity of plants in these forest areas is ample with more than 80 trees and shrubs (Sagheb-Talebi, et al., 2005; Hosseini, 2003, Kartoolinejad, et al., 2007). The dominant tree species are *Quercus castaneifolia* (hereinafter indicated as *Quercus c.*), *Pinus taeda* (*Pinus t.*), *Parrotia persica* (*Parrotia p.*), and *Alnus glutinosa* (*Alnus g.*) (Picchio et al., 2020; Mirabolfathy et al., 2018; Payam and Pourrajabali, 2020; Karimi et al., 2018). These species are typical of northern Iran but grow in all southern Caspian area (*Parrotia p.* and *Quercus c.,* well diffused also in Turkey and Azerbaijan), southeastern United States (*Pinus t.*), and Europe, southwest Asia, and northern Africa (*Alnus g.*).

Other shrub and herbaceous species in the area are *Artemisia annua* L., *Cynodon dactylon* L., *Pers.*, *Hedera helix* L., *Hedera pastuchovii Woron, Ex* Grossh., *Hypericum androsaemum* L., *Hypericum perforatum* L., *Juncus bufonius* L., *Juncus glaucus* Ehrh., *Mentha pulegium* L., *Morus alba* L., *Primula heterochoroma* Starf., *Prunus domestica* L., *Scutelaria albida* L., and *Solanum dulcamara* L.

Here, an experimental site was identified for this study, with *Quercus c.* and *Alnus g.* as planted species, and *Parrotia p.* and *Pinus t.* as natural species. The area covered by these species is about 40–50% of the total area of the park.

The reforestation with *Quercus c.* and *Alnus g.* was carried out in combination with some forest management practices, such as burning slash and logging residues that may have altered the quality of the forest soils. However, in this experimental investigation soils were sampled out of the area interested by heavy management, in order to attribute the changes in soil quality to the effects of the species rather than to other anthropogenic factors, such as soil management practices. *Alnus g.*, as black alder bud gemmotherapy, is a source of timber and consequently is of great economic importance. These species are dependent on moisture availability of the forest sites (Zar and Amini, 2012). *Quercus c.* is one of the most important native oak species of Iran (Payam and Pourrajabali, 2020). *Parrotia p.* is a deciduous tree, specifically native of northern Iran (Sefidi et al., 2011; Karimi et al., 2018). This is a highly ornamental tree or large shrub that can grow also at a height of 20–25 m and tolerates drought, heat, wind, and cold (Gilman and Watson, 2014). It has unique exfoliating bark and colorful flowers (Sefidi et al., 2011). This species has broadleaf deciduous trees/shrubs, 6-15 m high, and rounded with upright, wide-spreading branches and often with several trunks. Leaves are alternate, simple, and 6-12 cm long by 2.5-6 cm wide. *Pinus t.* is an exotic and fast-growing coniferous species (Picchio et al., 2020), which is used for commercial plantations. Its needles hold three single elements together, which are often slightly rotated.

The soils of the area are homogenous, prevalently silty clay loam, according to SDSD (2017), with sand, silt, and clay contents of 19.1 ± 0.54%, 47.2 ± 0.35%, and 33.7 ± 0.41%, respectively.

2.2. Soil sampling and analysis

The sampling procedure was adopted in accordance with the work by Kooch et al. (2016). In more detail, in an area of 15 hectares, two ha were selected for each tree species. Surrounding rows of trees were not considered during sampling to decrease the border effects. Soil profiles (30 × 30 cm) were dug along the parallel transects in the central part of each tree species. Samples of soils covered by the four vegetal species were randomly collected in the experimental site at a depth between 0 and 30 cm with twelve replications (totaling forty-eight samples). The soil water content (WC) was measured at one date, that is immediately after sampling by oven-drying soils for 24 h in oven at 105°C. These measurements provided similar WCs among the samples (27.5 ± 1.32%). Due to the random sampling procedure, all sampled points were considered as spatially independent.

After collection, the soil samples were transported to the Soil Testing Laboratory of the College of Agriculture of the Guilan University to measure the main physical, chemical, and biological properties of the sampled soils. In the laboratory, the soil samples were air-dried and sieved through a 2-mm mesh. As physical properties, the aggregate stability (measured by the mean weight diameter, MWD, and bulk density, BD) were determined using the wet-sieving and oven-drying methods, respectively (Kemper and Rosenau, 1986). With regard to the chemical properties, the pH and electrical conductivity (indicator of salinity) were determined on 1:2.5 soil:water samples (Hesse, 1971), whereas the Walkley-Black technique was used to measure the soil organic carbon (OC; Allison, 1975). The content of the following soil elements were also measured: total nitrogen (TN), by Kjeldahl method (Bremner and Mulvaney, 1982); total phosphorous (TP), potassium (K), calcium (Ca), and magnesium (Mg), using the methods reported by Claessen (1997). Concerning the biological properties, the root weight density (RWD) was determined using a washing method on a 1-mm sieve with subsequent oven-drying at 65°C for 24 h and final root weighing. The microbial respiration (MR) was measured as an indicator of soil biological activity (Anderson, 1982).

2.3. Statistical analysis

One-way analysis of variance (ANOVA) assessed the statistical significance of the differences in the soil properties (considered as the dependent variables) among the different vegetation species (independent variables). The distance among sampling points was always higher than 200 meters. Tukey test was used for the post-hoc comparisons at a p-level < 0.05. Prior to the statistical analysis, the normality of sample distribution was checked using QQ-plots, and the data were square root-transformed whenever necessary. Then, Pearson's matrix was calculated to find possible correlations among the soil properties (Rodgers and Nicewander, 1988). The latter were further processed using principal component analysis (PCA), to select a few derivative parameters and to cluster soil samples in groups related to the vegetal species studied. All statistical analyses were conducted using the SPSS 17.0 (SPSS Inc., Chicago, IL, USA) and XLSTAT 9.0 (Addinsoft, Paris, France) software.

2.4. Calculation of soil quality index

A Soil Quality Index (SQI) of soils with natural or natural species was calculated, based on the combination of parameters measured on sampled soils and the outcomes of the PCA. SQI aggregates all soil parameters into a single number that is easier and quick to interpret for species comparison.

The index proposed by Andrews et al. (2002a; 2002b) was adopted with some modifications according to similar quality indexes applied by other studies for different purposes (Rodríguez-Dìaz et al., 2008; Zema et al., 2015, for assessing the performance of collective irrigation agencies). The choice of this index is justified by the higher objectivity compared to other indexes that are commonly used to evaluate the soil quality, but rely mainly on subjective expert opinion and literature review to classify the soil parameters (Mukherjee et al., 2014). In fact, the expression of this SQI is based on statistical processing of soil parameters measured in the given experimental conditions and thus is more objective.

The SQI consists of some compound “levels” that coincide with the first two PCs. Each level of a forest species is determined by the linear combination of the standardized value (using a linear scoring function, Andrews et al., 2002a; 2002b; Mukherjee et al., 2014) of each soil property by the corresponding factor loading on the PCs (Rodríguez-Dìaz et al., 2008; Zema et al., 2015).

Therefore, the SQI of a given forest species "j" was calculated by the following equation:

$$SQI(j) = \sum_{i=1}^{n} \alpha_i \ L_i \qquad (1)$$

where:

- α_i = weight that depends on the percent variance of the PC "i" (Rodríguez-Dìaz et al., 2008; Zema et al., 2015)

- L_i = value of the level "i"

- n = number of PCs taken into consideration.

3. Results

3.1. Changes in soil properties

Parrotia p. and *Alnus g.* showed the maximum and minimum root weight density (0.85 ± 0.02 and 0.51 ± 0.01 kg/m^3, respectively), with intermediate values detected for *Pinus t.* (0.76 ± 0.03 kg/m^3) and *Quercus c.* (0.61 ± 0.01 kg/m^3), and all these values were significantly different among the studied tree types (Table 1). Moreover, all soil properties were significantly different among the investigated species ($p < 0.05$), except for the bulk density and electrical conductivity. The bulk density ranged between 1254.71 ± 23.51 (*Parrotia p.*) and 1275.8 5± 13.90 kg/m^3 (*Quercus c.*), whereas the electrical conductivity was about 0.23–0.24 dS/m. The aggregate stability was significantly lower in the soils sampled under *Alnus g.* (MWD of 0.58 ± 0.06 mm) and *Quercus c.* (0.47 ± 0.09 mm) compared to *Parrotia P.* (0.74 ± 0.03 mm) and *Pinus t.* (0.69 ± 0.0 mm). The latter species showed the lower pH (7.34 ± 0.11, *Parrotia p.,* and 7.26 ± 0.10, *Pinus t.*), whereas the other soils were slightly acidic (pH of 6.28 ± 0.19, *Alnus g.*, and 6.24 ± 0.16, *Quercus c.*) (Table 1).

The organic carbon content was significantly higher in the soils with *Parrotia p.* (3.33 ± 0.26%) and *Pinus t.* (3.21 ± 0.47%) compared to *Alnus g.* (2.18 ± 0.40%) and *Quercus c.* (1.88 ± 0.61%). Also the nutrient content (total N, P and K) showed significant differences between *Parrotia p.* (TN of 0.21 ± 0.03%, TP of 21.71 ± 2.33 mg/kg, and K of 298.04 ± 5.40 mg/kg) and *Pinus t.* (TN of 0.24 ± 0.02%, TP of 19.10 ± 1.68 mg/kg, and K of 281.70 ± 14.36 mg/kg) on one side, and *Alnus g.* (TN of 0.12 ± 0.02%, TP of 29.23 ± 1.24 mg/kg, and K of 197.36 ± 6.59 mg/kg) and *Quercus c.* (TN of 0.13 ±

0.02%, TP of 9.04 ± 1.44 mg/kg, and K of 203.34 ± 2.67 mg/kg) on the other side. The same gradients *Parrotia p.* > *Pinus t.* > *Alnus g.* > *Quercus c.* were noticed in calcium and magnesium content, which were in the ranges 123.50 ± 2.28 to 204.44 ± 2.04 mg/kg (Ca) and 13.89 ± 2.87 to 50.23 ± 2.37 mg/kg (Mg) (Table 1).

Finally, the microbial respiration showed the highest value in soils with *Parrotia p.* and *Pinus t.* (0.44 ± 0.02 and 0.43 ± 0.03 g of CO_2 per kg of soil, respectively), whereas the lowest MRs were measured in soils covered by *Alnus g.* (0.32 ± 0.03 g_{CO2}/kg) and *Quercus c.* (0.32 ± 0.03 g_{CO2}/kg) (Table 1).

Table 1 - Main properties (mean ± standard deviation, n = 4) of soils sampled under four vegetation species in Saqalaksar Forest Areas Park (northern Iran).

Soil properties	**Plant species**			
	Parrotia p.	***Pinus t.***	***Alnus g.***	***Quercus c.***
RWD (kg/m^3)	0.85 ± 0.02a	0.76 ± 0.03b	0.51 ± 0.01d	0.61 ± 0.01c
BD (kg/m^3)	1254.71 ± 23.51a	1270.42 ± 20.72a	1266.33 ± 21.42a	1275.85 ± 13.90a
MWD (mm)	0.74 ± 0.03a	0.69 ± 0.04a	0.58 ± 0.06b	0.47 ± 0.09c
pH	7.34 ± 0.11a	7.26 ± 0.10a	6.28 ± 0.19b	6.24 ± 0.16b
EC (dS/m)	0.24 ± 0.02a	0.23 ± 0.02a	0.24 ± 0.02a	0.24 ± 0.02a
OC (%)	3.33 ± 0.26a	3.21 ± 0.47a	2.18 ± 0.40b	1.88 ± 0.61b
TN (%)	0.21 ± 0.03a	0.24 ± 0.02b	0.12 ± 0.02c	0.13 ± 0.02c
TP (mg/kg)	21.71 ± 2.33a	19.10 ± 1.68b	9.23 ± 1.24c	9.04 ± 1.44c
K (mg/kg)	298.04 ± 5.40a	281.70 ± 14.36b	197.36 ± 6.59c	203.34 ± 2.67c
Ca (mg/kg)	204.44 ± 2.04a	201.24 ± 5.62a	132.47 ± 3.07b	123.50 ± 2.28c
Mg (mg/kg)	50.23 ± 2.37a	35.80 ± 2.42b	25.40 ± 1.65c	13.89 ± 2.87d
MR (gCO_2/kg)	0.44 ± 0.02a	0.43 ± 0.03a	0.32 ± 0.03b	0.30 ± 0.01b

Notes: RWD = root weight density; BD = bulk density; MWD = medium weight diameter of soil aggregates; EC = electrical conductivity; OC = organic carbon; TN= total nitrogen; TP = total phosphorous; MR = microbial respiration; different letters in each line indicate significant differences ($p < 0.05$, Tukey test) between vegetal species.

3.2. Correlation analysis

The analysis of Pearson's matrix shows that most of the analyzed soil properties were significantly ($p < 0.05$) correlated ($r > 0.70$). In more detail, the root density was positively correlated with almost all the other properties (except the electrical conductivity and bulk density). Significant and positive correlations ($r > 0.77$) were also found between the mean weight diameter and organic carbon. The latter property was positively correlated with all macro- (N, K, P) and micronutrients (Ca and Mg) ($r > 0.76$). Finally, strong correlations ($r > 0.77$) were detected among microbial respiration and pH on one side and root density, aggregate stability, organic matter, and nutrients on the other side (Table 2).

Table 2 - Correlation matrix among the main properties of soils sampled under four vegetation species (Parrotia p., Pinus t., Alnus g, and Quercus c.) in Saqalaksar Forest Areas Park (northern Iran).

Soil properties	RWD	BD	MWD	pH	EC	OC	TN	TP	K	Ca	Mg	MR
RWD		-0.189	**0.699**	**0.906**	-0.142	**0.742**	**0.777**	**0.915**	**0.942**	**0.906**	**0.799**	**0.853**
BD			-0.277	-0.239	0.183	-0.153	-0.090	-0.145	-0.198	-0.225	**-0.352**	-0.255
MWD				**0.805**	-0.217	**0.772**	**0.763**	**0.844**	**0.801**	**0.836**	**0.860**	**0.768**
pH					-0.195	**0.790**	**0.867**	**0.925**	**0.946**	**0.953**	**0.856**	**0.902**
EC						-0.245	-0.257	-0.140	-0.177	-0.212	-0.126	**-0.293**
OC							**0.766**	**0.828**	**0.772**	**0.842**	**0.780**	**0.840**
TN								**0.869**	**0.862**	**0.874**	**0.682**	**0.774**
TP									**0.968**	**0.952**	**0.863**	**0.872**
K										**0.965**	**0.868**	**0.890**

Ca											**0.891**	**0.931**
Mg												**0.849**
MR												

Notes: RWD = root weight density; BD = bulk density; MWD = medium weight diameter of soil aggregates; EC = electrical conductivity; OC = organic carbon; TN= total nitrogen; TP = total phosphorous; MR = microbial respiration; significant parameters at $p > 0.05$ are reported in bold.

3.3. Principal component analysis

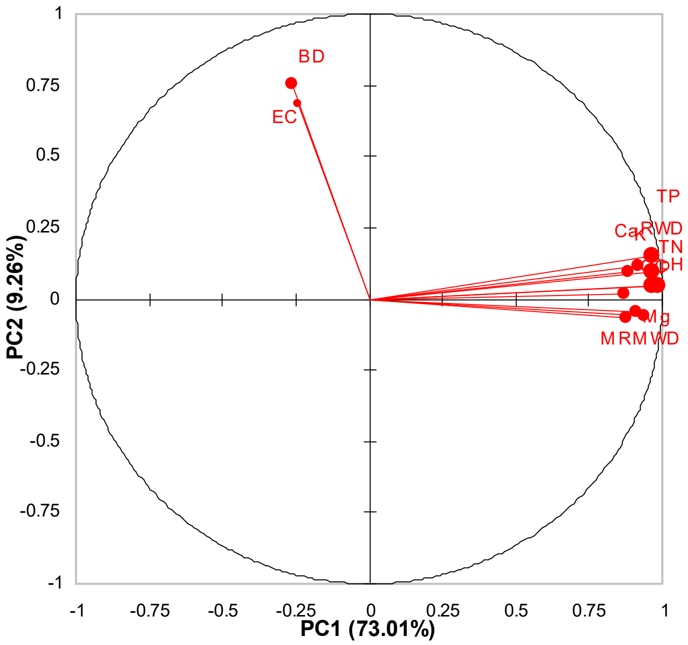
The application of PCA to the properties of the soil samples collected under the four vegetation species provided two principal components (PCs), which explained more than 80% of the total variance of the soil properties; PC_1 alone explained 73% of this variance. Both the eigenvalues associated to these PCs were higher than one. Almost all of the analyzed soil properties had significant loadings on PC_1 (higher than 0.76), whereas only the bulk density and electrical conductivity influenced PC_2 (Table 3 and Figure 2a).

Plotting the sample scores on the first two PCs, evident differences in soil properties emerged among the vegetation species. Two well-differentiated groups were evidenced with a clear distinction of samples of soils with *Parrotia p.* and *Pinus t.* (associated to positive values of PC_1) and soils with *Alnus g.* and *Quercus c.* (negative PC_1) (Figure 2b).

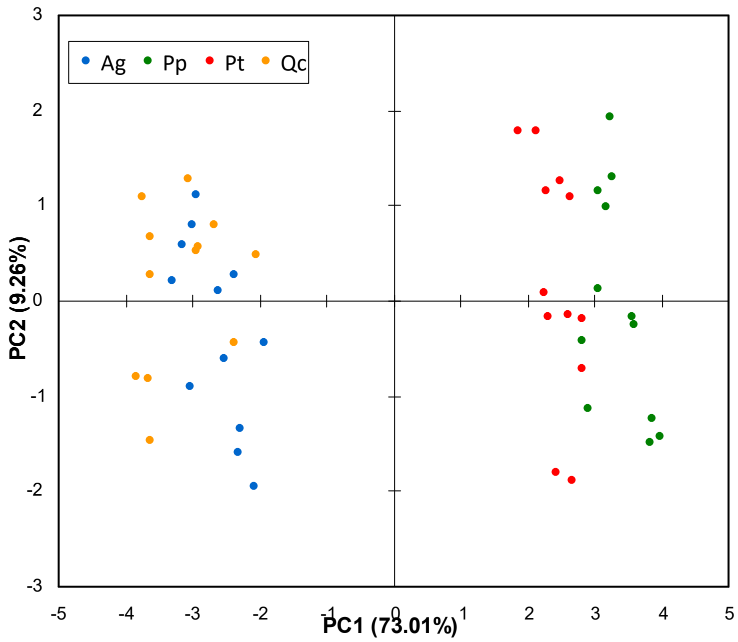
Table 3 - Loadings and contributions of the original variables—soil properties of soils sampled under four vegetation species (Parrotia p., Pinus t., Alnus g, and Quercus c.) in Saqalaksar Forest Areas Park (northern Iran) of PCA on the first two principal components (PC_1 and PC_2) (significant parameters at P > 0.05 are reported in bold).

Original variables	**Loadings**		**Contributions**	
	PC_1	**PC_2**	**PC_1**	**PC_2**
RWD	0.918	0.115	**0.842**	0.013
BD	-0.260	0.756	0.068	**0.571**
MWD	0.877	-0.068	**0.770**	0.005
pH	0.963	0.043	**0.928**	0.002
EC	-0.245	0.687	0.060	**0.472**
OC	0.872	0.016	**0.761**	0.000
TN	0.883	0.098	**0.780**	0.010
TP	0.968	0.150	**0.937**	0.022
K	0.969	0.093	**0.939**	0.009
Ca	0.984	0.043	**0.969**	0.002
Mg	0.911	-0.049	**0.829**	0.002
MR	0.937	-0.061	**0.879**	0.004

Notes: RWD = root weight density; BD = bulk density; MWD = medium weight diameter of soil aggregates; EC = electrical conductivity; OC = organic carbon; TN= total nitrogen; TP = total phosphorous; MR = microbial respiration; significant parameters at p > 0.05 are reported in bold.



(a)



(b)

Figure 2 - Loadings of properties (a) and scores (b) on the first two principal components provided by PCA applied to soils sampled under four vegetation species

(Pp, *Parrotia p.,* Pt, *Pinus t.,* Ag, *Alnus g,* and Qc, *Quercus c.)* in Saqalaksar Forest Areas Park (northern Iran).

3.4. Soil quality indexes of the forest species

The highest value of SQI was found for soils sampled under *Pinus t.* (336.1), while the lowest soil quality was detected in soils with *Quercus c.* (SQI = 282.1). Soil quality was higher also in the areas with *Parrotia p*. (SQI = 331.6), but low in soils reforested with Alnus g. (SQI = 291.3) (Table 4).

Table 4 - Parameters for calculation of the Soil Quality Index (SQI) for soils sampled under four vegetation species (*Parrotia p., Pinus t., Alnus g.* and *Quercus c.*) in Saqalaksar Forest Areas Park (northern Iran).

Forest species	**Level**		**Weight**		**Weighted level**		**SQI**
	L_1	L_2	α_1	α_2	L_1	L_2	
Parrotia p.	4.420	0.963	73.01	9.26	322.7	8.92	331.6
Pinus t.	4.487	0.912			327.6	8.45	336.1
Alnus g.	3.866	0.977			282.3	9.05	291.3
Quercus c.	3.737	1.004			272.8	9.30	282.1

4. Discussions

The large influence of vegetation species on the main properties of forest soils found in this study is not new, because research carried out in different environmental conditions has shown that plant and tree species are key drivers for soil quality (e.g., Lindenmayer and Franklin, 2000; Yang et al., 2004; Zhang et al., 2008; Miralles et al., 2009; Hoogmoed et al., 2014; Scheibe et al., 2015; Dawud et al., 2016; Gillespie et al., 2020). Regarding the experimental context, the studies carried out in Iran have proved that changes in plant and tree species heavily affect soil properties (Shahriary et al., 2012; Salehi et al., 2013; Kooch et al., 2016; Sanji et al. 2020). In addition to these studies, the current investigation has highlighted noticeable differences among soils with planted species and soils with natural species and the same soil texture and the homogeneity of soil forming processes (Foth, 1990).

More specifically, the soils with natural trees (*Parrotia p.* and *Pinus t.)* showed significantly higher organic carbon content (on average +63.5%) compared to the soils with the investigated planted species *(Alnus g.* and *Quercus c.*). The higher organic matter measured in the planted forest may be due both to root presence of the vegetation (De Baets et al., 2006, 2007) as well as greater accumulation of organic carbon due to the higher root density found in soils with natural species (Reicosky and Forcella, 1998) already detected by other authors (e.g., Maro, 1991; Liao et al., 2012; Wang et al., 2018; Zhang et al., 2016). On average, *Parrotia p.* and *Pinus t.* showed a root weight density higher by 43.2% compared to *Alnus g.* and *Quercus C.* This is also shown by the high correlation established between organic carbon and root weight density, found in this study and stated also by Ernst (2004). In the same environmental conditions, Parhizkar et al. (2020a; 2020b) also found that soils with higher vegetation cover and well-developed root systems have higher organic matter content. This suggests that those forest management operations (such as whole-tree harvesting, deforestation, changes in tree species composition, and forest fires), which may cause a reduction in organic carbon in planted forests, should be avoided (Johnson and Curtis, 2001), particularly in those delicate environments subject to degradation factors, such as the forests of northern Iran. It is well-known that soils with a high content of organic matter, due to root weight density of a well-developed forest cover (Miralles et al., 2009; Quideau et al., 2001; Wang et al., 2018) had good micro- and macro-porosity, which determines higher aggregate stability. As a matter of fact, plant roots bind soil particles at the soil surface (An et al., 2010), increasing the soil infiltration rate (De Baets et al., 2007) and providing additional surface roughness (Gyssels et al., 2005).

In addition to this main outcome, this study has shown that the higher organic carbon content measured in soils sampled under natural trees compared to planted species leads to a general improvement of soil quality. More specifically, beneficial changes in all the main physical, chemical, and biological properties investigated in these studies were detected in soil with natural species compared to planted trees. About the physical parameters, significant differences in bulk density and electrical conductivity were not shown by the statistical analysis (presumably due to the same foliage characteristics and litter quality; Haghdoost et al., 2011). This lack of significance contrasts with the results of other studies, which found that soil bulk density is lower under the presence of plant roots because the roots contribute to create a system of continuous pores (Angers and Caron, 1998; David, 2000; Gyssels et al., 2005; Shinohara et al., 2016). Conversely, a significantly higher aggregate stability (shown by mean weight diameter) was found in soils with natural species because of the higher organic matter content. This result has important environmental issues because a higher aggregate stability of soils plays a basic role in improving the hydrological characteristics of soils. As a matter of fact, stable aggregate increases soil macroporosity, enhancing infiltration (with clear reduction in runoff and erosion rates) and water retention of soil (with higher water supply in semi-arid ecosystems). Moreover, these changes in soil physical properties are also beneficial to improve the soil hydrological response, such as reduced runoff generation ability and low soil erodibility in vegetated soil (Miralles et al., 2009; Germer et al., 2010). Organic matter is a cementing agent and can help increase the water content of soils (Minasny et al., 2017). This is in accordance with other studies (Rawls et al., 2003; Wolf and Snyder, 2003), which reported high water content in soils with high amounts of organic matter.

Conversely, the lower aggregate stability detected in soils with planted species may limit root growth, and plant cover and biomass in reforested soils, as a result of the differences in ecosystem water cycles between planted and natural forests (Jackson et al., 2005; van Dijk and Keenan, 2007). Another reason for the lower aggregate stability in the soils with *Quercus c.* and *Alnus g.* is presumably related to management operations; according to Gol (2009), the stability of aggregates is changed by human activities that therefore can determine a reduction of available water in the soil.

Soil pH was significantly higher in soils with *Parrotia p.* and *Pinus t.* compared to the planted forest (on average +16.6%). The lower pH detected in the planted forest could be indicative of different risks for soil health (Shabanpour et al., 2020), for example, soluble phosphorus fix in acid soils, resulting in low available phosporous (Chase and Singh, 2014). The higher pH of soils with natural species is in close accordance with other authors (e.g., Jackson et al., 2005, Berthrong et al., 2009), who showed significant reduction in soil pH (about 0.3 units) in planted forests compared with non-forested lands. Conversely, Liao et al. (2012) did not found significant differences in soil pH between planted and natural forests.

Concerning the nutrient content of the studied soils both nitrogen and phosphorous are of natural origin, coming from degradation of vegetal and animal residues. The presence of these elements from anthropogenic nature can be excluded, since the human settlements are quite far from the experimental areas. The higher contents of N, P, and K (as macronutrients) as well as Ca and Mg (micronutrients) in the natural forest compared to the soils with planted trees may be due to both the higher organic carbon content and pH (Shabanpour et al., 2020), and this is confirmed by the correlation analysis (higher macro- and micronutrients with organic carbon content). As a matter of fact, the absorption capacity of base cations by clay particles strictly depends on the soil pH because this capacity loses when soil acidity increases (Duan et al., 2004); moreover, under acid conditions, soil organic matter is difficult to mineralize, and then soil nutrient content does not increase (Nsabimana et al., 2008). The reductions in soil nutrient content (N, P, K, Ca and Mg) in soils with planted forest compared to the natural species could be caused by burning slash and logging residues during site preparation and uptake of cations into aboveground biomass by roots of *Alnus g.* and *Quercus c.* species (Berthrong et al., 2009; Liao et al., 2012).

In regard to the biological changes detected in the studied soils, the higher microbial respiration in samples collected under *Parrotia p.* and *Pinus t.* could be another consequence of the higher amount of soil nutrients (OC, TN, TP, Ca, Mg, K) and soil pH. This is corroborated by their highly significant correlations with microbial respiration (MR) found in our statistical analysis (Table 2 and 3). Other authors have shown that soil parameters like soil pH and nutrient availability are critical factors driving the structure of soil bacteria communities (Lauber et al., 2009; Goldfarb et al., 2011; Griffiths et al., 2011; Kuramae et al., 2012; Sánchez-Marañón et al., 2017; Miralles et al., 2020a, 2020b; Rodríguez-Berbel et al., 2020) and therefore foreseeably its activity. Soil pH influences soil microbial composition because it affects numerous essential soil parameters that may drive changes in soil microbial communities such as nutrient availability, salinity, cationic metal solubility, organic carbon properties, and soil moisture, and it also influences the physiological activity of the soil bacteria (Lauber et al., 2009). In contrast, the soil microbial population is affected by the higher production of biomass and subsequently by the accumulation of more organic matter content (Shabanpour et al., 2020). A reduction in organic matter content of soil (e.g., following deforestation) can reduce the microbial respiration of soils by greater than 100%, and a reduced microbial activity in soils is related to lower levels of available organic carbon (Nael et al., 2004). Kiani et al. (2004) stated that when the rate of fresh plant residues increases in forest areas, the soil microbial respiration rises, which strictly depends on the nutrient contents of soil (i.e., P, K, Ca, and Mg) (Mganga et al., 2016).

The changes detected in soil properties between soils with planted species and natural forest soils are clearly evidenced by the two clusters of samples (soils with *Parrotia p.* and *Pinus t.* vs. soils with *Alnus g.* and *Quercus c.*) provided by the PCA. This statistical analysis showed a main derivative factor (the first PC), which combines all those soil properties that are influenced by pH and organic carbon content and thus lead to different soil quality between natural and planted soil forests. Conversely, the second PC is linked to other two soil properties (the bulk density and electrical conductivity) that are not significantly different among the studies species and thus are not able to significantly discriminate the related soil quality. Also in the studies of Lucas-Borja et al. (2019) and Shabanpour et al. (2020) - the latter carried out in the same environment - the differences in soil properties among different land uses (abandoned farmland, intensive cropland, grassland, forest areas, and woodland) were evident, and well-differentiated groups, one for each land use, were clustered. This result is confirmed by the calculation of SQI, which showed the lower soil quality under planted species compared to natural forests.

Overall, from the results of this investigation, it can be inferred that among the investigated soils, the natural species support a high content of organic matter and nutrients in forest soils, whereas the planted species may lead to lower quality and fertility.

5. Conclusions

This study has evaluated the changes in soil properties in planted and natural forest areas of northern Iran. Forming factors (parent material, climate, geomorphology, and time) of the investigated forest areas were the same, so the differences in soil properties can be attributed to the influence of the four studied vegetal species. Compared to planted forest areas, the soils with natural trees showed higher root weight density, pH, and organic carbon. These differences led to higher nutrient contents, microbial respiration, aggregate stability, and water retention in soils with natural trees, as confirmed by the correlation analysis. The PCA provided a meaningful combined factor (the first PC) that showed a clear discrimination in soil quality and fertility between natural and planted species. The SQI confirms that planted species may lead to an overall lower quality of soils with planted species compared to natural forest. Therefore, the results of this investigation confirmed the working hypothesis that soil properties are affected by significant changes due to the different characteristics of vegetal species. The overall lower soil quality of planted forests can be aggravated by unsuitable management practices (such as burning slash and logging residues), if carried out in the planted forest areas. This means that reforestation in combination with these practices should be avoided in delicate forest environments, such as the semi-arid forest areas of northern Iran or forest parks worldwide, because these actions may lead to lower soil quality with possible negative effects on ecosystem health.

Funding: Faculty of Agricultural Sciences, University of Guilan.

Acknowledgments

The authors thank the Faculty of Agricultural Sciences, University of Guilan for their support and experimental assistance. This work was also supported by the Spanish Ministry of Economy, Industry and Competitiveness Research Project BIORESOC (CGL2017-88734-R) and FEDER-Junta de Andalucía Research Projects: RESTAGRO (UAL18-RNM-A021-B) and Restauración de suelos agrícolas abandonados en zonas semiáridas para mejorar la productividad y calidad del suelo y potenciar el secuestro de carbono (P18-RT-4112). Isabel Miralles is grateful for funding received from the Ramón y Cajal Research Grant (RYC-2016-21191) from the Spanish Ministry of Economy, Industry and Competitiveness (MINECO).

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