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18 **Effects of plant species on soil quality in natural and planted areas of a forest park**
19 **in Northern Iran**

20

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34

35 **Abstract**

36

37 Reforestation may help protect the health of endangered forest ecosystems. To
38 implement this action, it is important to evaluate the effects of the planted species on
39 soil quality. Previous studies have demonstrated that soil properties are closely driven
40 by the effects of plant roots and plant remains (quantity and quality) reaching the soil
41 surface. However, little research is available about the effects of plant species on soil

42 quality of reforested sites compared to natural forest ecosystems. This study evaluates
43 the changes in the main soil properties between two 30–40 year-old stand types in forest
44 areas of northern Iran: i) two stands, each one comprising a natural species (*Parrotia*
45 *persica* or *Pinus taeda*); and ii) two stands, each one with planted trees (*Quercus*
46 *castaneifolia* or *Alnus glutinosa*). Compared to reforested sites, the soils with natural
47 trees showed higher root weight density (+43%), pH (+17%), and organic carbon
48 (+64%). These differences led to higher nutrient contents, microbial respiration,
49 aggregate stability, and water retention in soils with natural trees, as confirmed by the
50 correlation analysis. A principal component analysis provided a meaningful combined
51 factor (the first principal component) that showed a clear discrimination in soil quality
52 and fertility among natural and reforested species. The calculation of a soil quality index
53 confirms that planted species may lead to an overall lower quality of soils with planted
54 species compared to natural forest. Since the lower soil quality of planted forests can be
55 also the result of unsuitable management practices, this study suggest that forest
56 operations in reforested areas should be avoided, since this could lead to negative
57 effects on soil quality and contribute to an increase in the risk of soil degradation.

58

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

61

62 **1. Introduction**

63

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

66 (Sasaki and Putz, 2009; Parhizkar et al., 2020a). The main rehabilitation and restoration
67 practices include reforestation, which has been widely used in the Mediterranean basin
68 to protect watersheds, often using conifers (Sheffer, 2012). In addition to natural forests,
69 reforestation with tree or herbaceous species is a viable solution to control erosion on
70 forest hillslopes in terrestrial ecosystems all over the world (Kooch et al., 2016)
71 because. Well-developed and large vegetation cover increases water infiltration and
72 evapo-transpiration of forest soils (De Baets et al., 2008; Li et al., 1992; 1995), which
73 reduces surface runoff and soil loss (Fiener and Auerswald, 2003; Koskiaho, 2003; Li et
74 al., 2013). In recent years, new restoration objectives have emerged, such as the
75 biodiversity increase, and the use of shrubs species in hillslope restoration has been
76 introduced. In addition, reforestation is a natural solution with a high potential to
77 capture carbon under the expected climate change in the future (Fargione et al., 2018).
78 Vegetation species are able to noticeably change physical, chemical, and biological soil
79 properties (Sanji et al., 2020; Kooch et al., 2016; Garcia et al., 1994). An interesting
80 review by Schoenholtz et al. (2000) showed the basic role of forest plants in driving the
81 soil quality indicators, and particularly the chemical and physical properties. With
82 regard to Mediterranean forests, carbon and nitrogen content of both soil and litter are
83 generally higher in mixed stands in comparison to monospecific forests (Lucas-Borja et
84 al., 2012). Soil properties, with emphasis on soil water repellency and infiltration, are
85 influenced by both plant composition and age and the related changes are more
86 noticeable between managed and unmanaged forests (Zema et al., 2021a; 2021b). These
87 authors also found that intense forest use and soil preparation may worsen hydrological
88 properties of soils compared to unmanaged forest soils.

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

111 Up to now, the effects of plant species on chemical and physical properties of forest soil
112 have been widely analyzed. However, while much literature focused on specific

113 environments (e.g., Loess Plateau in China; Wang et al., 2014b, 2018a), shrub and grass
114 species (e.g., De Baets et al., 2006; Zhang et al., 2013; Wang et al., 2021) and mainly
115 explored the landscape scale (e.g., Li et al., 2015; Geng et al., 2021, again in Loess
116 Plateau), less research is available on the difference in soil quality between planted
117 forests and natural ecosystems. Relevant studies would provide a better understanding
118 of the complex and unpredictable plant-soil relations in forest ecosystems, and this
119 knowledge would help land managers selecting the most suitable species for
120 afforestation. In these delicate ecosystems, the need for managing soil health is
121 compulsory, to avoid land degradation and other improper management operations.
122 To these aims, this study analyzes the effects of vegetation species on soil quality in
123 forest areas of northern Iran. More specifically, the changes in physico-chemical,
124 hydrological, and biological properties of soils planted with four forest natural (*Parrotia*
125 *persica* and *Pinus taeda*) or planted species (*Alnus glutinosa* and *Quercus castaneifolia*)
126 with the same age (about 30-40 years) have been studied in this area. Here, forest
127 biodiversity is rich (Parhizkar et al., 2020a), but intense deforestation has recently
128 increased erosion and, in general, degraded soil quality (Parhizkar et al., 2020b). It has
129 been hypothesized that the studied soil properties are affected by significant changes
130 due to the different characteristics of vegetal species. The study aims to contribute to the
131 understanding of the relationships between the soil properties and vegetal species in
132 forest areas that may help increase soil health.

133

134 **2. Materials and methods**

135

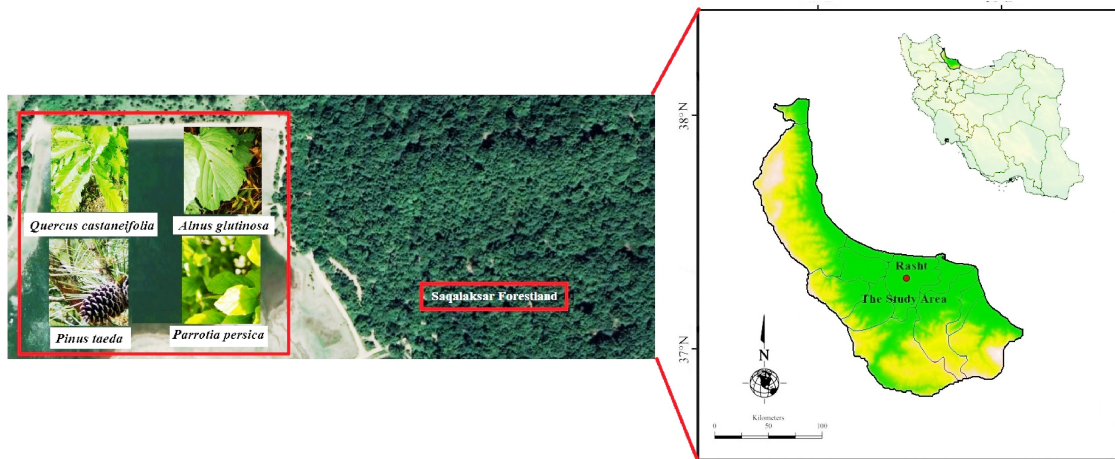
136 *2.1. Study area and experimental site*

137

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

146 The Saqalaksar Forest Areas Park is a forest with massive trees and plants in the Guilan
147 province. This area is located 15 km south of Rasht city (geographical coordinates
148 37°09'24" N, 49°31'50" E) at an altitude of 64 m above the mean sea level (Figure 1).

149



150

151 Figure 1 - Geographical location and aerial map (source: Google[®] Map[®]) of Saqalaksar

152 Forest Areas Park (Guilan province, northern Iran).

153

154 The biodiversity of plants in these forest areas is ample with more than 80 trees and

155 shrubs (Sagheb-Talebi, et al., 2005; Hosseini, 2003, Kartoolinejad, et al., 2007). The

156 dominant tree species are *Quercus castaneifolia* (hereinafter indicated as *Quercus c.*),

157 *Pinus taeda* (*Pinus t.*), *Parrotia persica* (*Parrotia p.*), and *Alnus glutinosa* (*Alnus g.*)

158 (Picchio et al., 2020; Mirabolfathy et al., 2018; Payam and Pourrajabali, 2020; Karimi

159 et al., 2018). These species are typical of northern Iran but grow in all southern Caspian

160 area (*Parrotia p.* and *Quercus c.*, well diffused also in Turkey and Azerbaijan),

161 southeastern United States (*Pinus t.*), and Europe, southwest Asia, and northern Africa

162 (*Alnus g.*).

163 Other shrub and herbaceous species in the area are *Artemisia annua* L., *Cynodon*

164 *dactylon* L., *Pers.*, *Hedera helix* L., *Hedera pastuchovii* Woron, Ex Grossh., *Hypericum*

165 *androsaemum* L., *Hypericum perforatum* L., *Juncus bufonius* L., *Juncus glaucus* Ehrh.,

166 *Mentha pulegium* L., *Morus alba* L., *Primula heterochroma* Starf., *Prunus domestica*

167 L., *Scutellaria albida* L., and *Solanum dulcamara* L.

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

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

190 The soils of the area are homogenous, prevalently silty clay loam, according to SDSD
191 (2017), with sand, silt, and clay contents of $19.1 \pm 0.54\%$, $47.2 \pm 0.35\%$, and $33.7 \pm$
192 0.41% , respectively.

193

194 *2.2. Soil sampling and analysis*

195

196 The sampling procedure was adopted in accordance with the work by Kooch et al.
197 (2016). In more detail, in an area of 15 hectares, two ha were selected for each tree
198 species. Surrounding rows of trees were not considered during sampling to decrease the
199 border effects. Soil profiles (30×30 cm) were dug along the parallel transects in the
200 central part of each tree species. Samples of soils covered by the four vegetal species
201 were randomly collected in the experimental site at a depth between 0 and 30 cm with
202 twelve replications (totaling forty-eight samples). The soil water content (WC) was
203 measured at one date, that is immediately after sampling by oven-drying soils for 24 h
204 in oven at 105°C . These measurements provided similar WCs among the samples (27.5
205 $\pm 1.32\%$). Due to the random sampling procedure, all sampled points were considered
206 as spatially independent.

207 After collection, the soil samples were transported to the Soil Testing Laboratory of the
208 College of Agriculture of the Guilan University to measure the main physical, chemical,
209 and biological properties of the sampled soils. In the laboratory, the soil samples were
210 air-dried and sieved through a 2-mm mesh. As physical properties, the aggregate
211 stability (measured by the mean weight diameter, MWD, and bulk density, BD) were
212 determined using the wet-sieving and oven-drying methods, respectively (Kemper and
213 Rosenau, 1986). With regard to the chemical properties, the pH and electrical

214 conductivity (indicator of salinity) were determined on 1:2.5 soil:water samples (Hesse,
215 1971), whereas the Walkley-Black technique was used to measure the soil organic
216 carbon (OC; Allison, 1975). The content of the following soil elements were also
217 measured: total nitrogen (TN), by Kjeldahl method (Bremner and Mulvaney, 1982);
218 total phosphorous (TP), potassium (K), calcium (Ca), and magnesium (Mg), using the
219 methods reported by Claessen (1997). Concerning the biological properties, the root
220 weight density (RWD) was determined using a washing method on a 1-mm sieve with
221 subsequent oven-drying at 65°C for 24 h and final root weighing. The microbial
222 respiration (MR) was measured as an indicator of soil biological activity (Anderson,
223 1982).

224

225 *2.3. Statistical analysis*

226

227 One-way analysis of variance (ANOVA) assessed the statistical significance of the
228 differences in the soil properties (considered as the dependent variables) among the
229 different vegetation species (independent variables). The distance among sampling
230 points was always higher than 200 meters. Tukey test was used for the post-hoc
231 comparisons at a p-level < 0.05. Prior to the statistical analysis, the normality of sample
232 distribution was checked using QQ-plots, and the data were square root-transformed
233 whenever necessary. Then, Pearson's matrix was calculated to find possible correlations
234 among the soil properties (Rodgers and Nicewander, 1988). The latter were further
235 processed using principal component analysis (PCA), to select a few derivative

236 parameters and to cluster soil samples in groups related to the vegetal species studied.
237 All statistical analyses were conducted using the SPSS 17.0 (SPSS Inc., Chicago, IL,
238 USA) and XLSTAT 9.0 (Addinsoft, Paris, France) software.

239

240 *2.4. Calculation of soil quality index*

241

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

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

255 The SQI consists of some compound “levels” that coincide with the first two PCs. Each
256 level of a forest species is determined by the linear combination of the standardized

257 value (using a linear scoring function, Andrews et al., 2002a; 2002b; Mukherjee et al.,
258 2014) of each soil property by the corresponding factor loading on the PCs (Rodríguez-
259 Díaz et al., 2008; Zema et al., 2015).

260 Therefore, the SQI of a given forest species “j” was calculated by the following
261 equation:

262

$$263 \quad SQI(j) = \sum_{i=1}^n \alpha_i L_i \quad (1)$$

264

265 where:

266 - α_i = weight that depends on the percent variance of the PC “i” (Rodríguez-Díaz et al.,
267 2008; Zema et al., 2015)

268 - L_i = value of the level “i”

269 - n = number of PCs taken into consideration.

270

271 3. Results

272

273 3.1. Changes in soil properties

274

275 *Parrotia p.* and *Alnus g.* showed the maximum and minimum root weight density (0.85
276 ± 0.02 and $0.51 \pm 0.01 \text{ kg/m}^3$, respectively), with intermediate values detected for *Pinus*
277 *t.* ($0.76 \pm 0.03 \text{ kg/m}^3$) and *Quercus c.* ($0.61 \pm 0.01 \text{ kg/m}^3$), and all these values were
278 significantly different among the studied tree types (Table 1). Moreover, all soil
279 properties were significantly different among the investigated species ($p < 0.05$), except
280 for the bulk density and electrical conductivity. The bulk density ranged between
281 1254.71 ± 23.51 (*Parrotia p.*) and $1275.85 \pm 13.90 \text{ kg/m}^3$ (*Quercus c.*), whereas the
282 electrical conductivity was about $0.23\text{--}0.24 \text{ dS/m}$. The aggregate stability was
283 significantly lower in the soils sampled under *Alnus g.* (MWD of $0.58 \pm 0.06 \text{ mm}$) and
284 *Quercus c.* ($0.47 \pm 0.09 \text{ mm}$) compared to *Parrotia P.* ($0.74 \pm 0.03 \text{ mm}$) and *Pinus t.*
285 ($0.69 \pm 0.0 \text{ mm}$). The latter species showed the lower pH (7.34 ± 0.11 , *Parrotia p.*, and
286 7.26 ± 0.10 , *Pinus t.*), whereas the other soils were slightly acidic (pH of 6.28 ± 0.19 ,
287 *Alnus g.*, and 6.24 ± 0.16 , *Quercus c.*) (Table 1).

288 The organic carbon content was significantly higher in the soils with *Parrotia p.* ($3.33 \pm$
289 0.26%) and *Pinus t.* ($3.21 \pm 0.47\%$) compared to *Alnus g.* ($2.18 \pm 0.40\%$) and *Quercus*
290 *c.* ($1.88 \pm 0.61\%$). Also the nutrient content (total N, P and K) showed significant
291 differences between *Parrotia p.* (TN of $0.21 \pm 0.03\%$, TP of $21.71 \pm 2.33 \text{ mg/kg}$, and K
292 of $298.04 \pm 5.40 \text{ mg/kg}$) and *Pinus t.* (TN of $0.24 \pm 0.02\%$, TP of $19.10 \pm 1.68 \text{ mg/kg}$,
293 and K of $281.70 \pm 14.36 \text{ mg/kg}$) on one side, and *Alnus g.* (TN of $0.12 \pm 0.02\%$, TP of
294 $29.23 \pm 1.24 \text{ mg/kg}$, and K of $197.36 \pm 6.59 \text{ mg/kg}$) and *Quercus c.* (TN of $0.13 \pm$

295 0.02%, TP of 9.04 ± 1.44 mg/kg, and K of 203.34 ± 2.67 mg/kg) on the other side. The
296 same gradients *Parrotia p.* > *Pinus t.* > *Alnus g.* > *Quercus c.* were noticed in calcium
297 and magnesium content, which were in the ranges 123.50 ± 2.28 to 204.44 ± 2.04 mg/kg
298 (Ca) and 13.89 ± 2.87 to 50.23 ± 2.37 mg/kg (Mg) (Table 1).

299 Finally, the microbial respiration showed the highest value in soils with *Parrotia p.* and
300 *Pinus t.* (0.44 ± 0.02 and 0.43 ± 0.03 g of CO₂ per kg of soil, respectively), whereas the
301 lowest MRs were measured in soils covered by *Alnus g.* (0.32 ± 0.03 gCO₂/kg) and
302 *Quercus c.* (0.32 ± 0.03 gCO₂/kg) (Table 1).

303

304 Table 1 - Main properties (mean \pm standard deviation, n = 4) of soils sampled under
 305 four vegetation species in Saqalaksar Forest Areas Park (northern Iran).
 306

Soil properties	Plant species			
	<i>Parrotia p.</i>	<i>Pinus t.</i>	<i>Alnus g.</i>	<i>Quercus c.</i>
RWD (kg/m ³)	0.85 \pm 0.02a	0.76 \pm 0.03b	0.51 \pm 0.01d	0.61 \pm 0.01c
BD (kg/m ³)	1254.71 \pm 23.51a	1270.42 \pm 20.72a	1266.33 \pm 21.42a	1275.85 \pm 13.90a
MWD (mm)	0.74 \pm 0.03a	0.69 \pm 0.04a	0.58 \pm 0.06b	0.47 \pm 0.09c
pH	7.34 \pm 0.11a	7.26 \pm 0.10a	6.28 \pm 0.19b	6.24 \pm 0.16b
EC (dS/m)	0.24 \pm 0.02a	0.23 \pm 0.02a	0.24 \pm 0.02a	0.24 \pm 0.02a
OC (%)	3.33 \pm 0.26a	3.21 \pm 0.47a	2.18 \pm 0.40b	1.88 \pm 0.61b
TN (%)	0.21 \pm 0.03a	0.24 \pm 0.02b	0.12 \pm 0.02c	0.13 \pm 0.02c
TP (mg/kg)	21.71 \pm 2.33a	19.10 \pm 1.68b	9.23 \pm 1.24c	9.04 \pm 1.44c
K (mg/kg)	298.04 \pm 5.40a	281.70 \pm 14.36b	197.36 \pm 6.59c	203.34 \pm 2.67c
Ca (mg/kg)	204.44 \pm 2.04a	201.24 \pm 5.62a	132.47 \pm 3.07b	123.50 \pm 2.28c
Mg (mg/kg)	50.23 \pm 2.37a	35.80 \pm 2.42b	25.40 \pm 1.65c	13.89 \pm 2.87d
MR (gCO ₂ /kg)	0.44 \pm 0.02a	0.43 \pm 0.03a	0.32 \pm 0.03b	0.30 \pm 0.01b

307 Notes: RWD = root weight density; BD = bulk density; MWD = medium weight diameter of soil
 308 aggregates; EC = electrical conductivity; OC = organic carbon; TN= total nitrogen; TP = total
 309 phosphorous; MR = microbial respiration; different letters in each line indicate significant differences (p
 310 < 0.05, Tukey test) between vegetal species.

311

312 3.2. *Correlation analysis*

313

314 The analysis of Pearson's matrix shows that most of the analyzed soil properties were
315 significantly ($p < 0.05$) correlated ($r > 0.70$). In more detail, the root density was
316 positively correlated with almost all the other properties (except the electrical
317 conductivity and bulk density). Significant and positive correlations ($r > 0.77$) were also
318 found between the mean weight diameter and organic carbon. The latter property was
319 positively correlated with all macro- (N, K, P) and micronutrients (Ca and Mg) ($r >$
320 0.76). Finally, strong correlations ($r > 0.77$) were detected among microbial respiration
321 and pH on one side and root density, aggregate stability, organic matter, and nutrients
322 on the other side (Table 2).

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

325

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												

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

328 3.3. Principal component analysis

329

330 The application of PCA to the properties of the soil samples collected under the four
331 vegetation species provided two principal components (PCs), which explained more
332 than 80% of the total variance of the soil properties; PC₁ alone explained 73% of this
333 variance. Both the eigenvalues associated to these PCs were higher than one. Almost all
334 of the analyzed soil properties had significant loadings on PC₁ (higher than 0.76),
335 whereas only the bulk density and electrical conductivity influenced PC₂ (Table 3 and
336 Figure 2a).

337 Plotting the sample scores on the first two PCs, evident differences in soil properties
338 emerged among the vegetation species. Two well-differentiated groups were evidenced
339 with a clear distinction of samples of soils with *Parrotia p.* and *Pinus t.* (associated to
340 positive values of PC₁) and soils with *Alnus g.* and *Quercus c.* (negative PC₁) (Figure
341 2b).

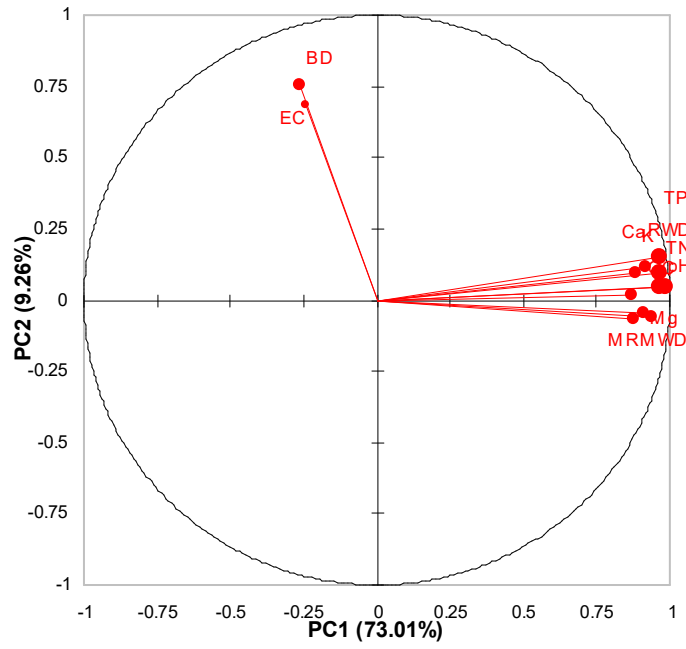
342

343 Table 3 - Loadings and contributions of the original variables—soil properties of soils
 344 sampled under four vegetation species (Parrotia p., Pinus t., Alnus g, and Quercus c.) in
 345 Saqalaksar Forest Areas Park (northern Iran) of PCA on the first two principal
 346 components (PC₁ and PC₂) (significant parameters at P > 0.05 are reported in bold).
 347

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

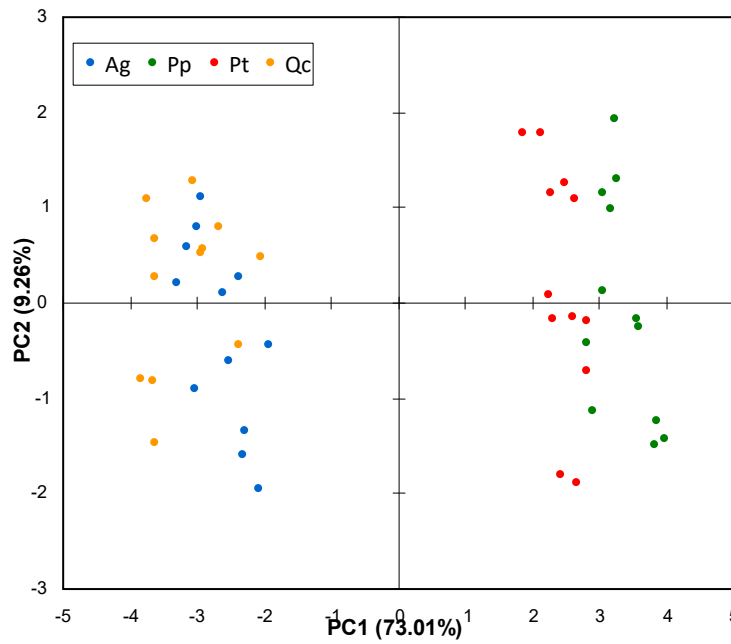
348 Notes: RWD = root weight density; BD = bulk density; MWD = medium weight diameter of soil
 349 aggregates; EC = electrical conductivity; OC = organic carbon; TN= total nitrogen; TP = total
 350 phosphorous; MR = microbial respiration; significant parameters at p > 0.05 are reported in bold.
 351

352



353

(a)



354

(b)

355 Figure 2 - Loadings of properties (a) and scores (b) on the first two principal

356 components provided by PCA applied to soils sampled under four vegetation species

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

359

360 3.4. Soil quality indexes of the forest species

361

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

366

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

370

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

371

372 4. Discussions

373

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

385 More specifically, the soils with natural trees (*Parrotia p.* and *Pinus t.*) showed
386 significantly higher organic carbon content (on average +63.5%) compared to the soils
387 with the investigated planted species (*Alnus g.* and *Quercus c.*). The higher organic
388 matter measured in the planted forest may be due both to root presence of the vegetation
389 (De Baets et al., 2006, 2007) as well as greater accumulation of organic carbon due to
390 the higher root density found in soils with natural species (Reicosky and Forcella, 1998)
391 already detected by other authors (e.g., Maro, 1991; Liao et al., 2012; Wang et al., 2018;
392 Zhang et al., 2016). On average, *Parrotia p.* and *Pinus t.* showed a root weight density
393 higher by 43.2% compared to *Alnus g.* and *Quercus C.* This is also shown by the high
394 correlation established between organic carbon and root weight density, found in this
395 study and stated also by Ernst (2004). In the same environmental conditions, Parhizkar

396 et al. (2020a; 2020b) also found that soils with higher vegetation cover and well-
397 developed root systems have higher organic matter content. This suggests that those
398 forest management operations (such as whole-tree harvesting, deforestation, changes in
399 tree species composition, and forest fires), which may cause a reduction in organic
400 carbon in planted forests, should be avoided (Johnson and Curtis, 2001), particularly in
401 those delicate environments subject to degradation factors, such as the forests of
402 northern Iran. It is well-known that soils with a high content of organic matter, due to
403 root weight density of a well-developed forest cover (Miralles et al., 2009; Quideau et
404 al., 2001; Wang et al., 2018) had good micro- and macro-porosity, which determines
405 higher aggregate stability. As a matter of fact, plant roots bind soil particles at the soil
406 surface (An et al., 2010), increasing the soil infiltration rate (De Baets et al., 2007) and
407 providing additional surface roughness (Gyssels et al., 2005).

408 In addition to this main outcome, this study has shown that the higher organic carbon
409 content measured in soils sampled under natural trees compared to planted species leads
410 to a general improvement of soil quality. More specifically, beneficial changes in all the
411 main physical, chemical, and biological properties investigated in these studies were
412 detected in soil with natural species compared to planted trees. About the physical
413 parameters, significant differences in bulk density and electrical conductivity were not
414 shown by the statistical analysis (presumably due to the same foliage characteristics and
415 litter quality; Haghdoost et al., 2011). This lack of significance contrasts with the results
416 of other studies, which found that soil bulk density is lower under the presence of plant
417 roots because the roots contribute to create a system of continuous pores (Angers and
418 Caron, 1998; David, 2000; Gyssels et al., 2005; Shinohara et al., 2016). Conversely, a
419 significantly higher aggregate stability (shown by mean weight diameter) was found in

420 soils with natural species because of the higher organic matter content. This result has
421 important environmental issues because a higher aggregate stability of soils plays a
422 basic role in improving the hydrological characteristics of soils. As a matter of fact,
423 stable aggregate increases soil macroporosity, enhancing infiltration (with clear
424 reduction in runoff and erosion rates) and water retention of soil (with higher water
425 supply in semi-arid ecosystems). Moreover, these changes in soil physical properties are
426 also beneficial to improve the soil hydrological response, such as reduced runoff
427 generation ability and low soil erodibility in vegetated soil (Miralles et al., 2009;
428 Germer et al., 2010). Organic matter is a cementing agent and can help increase the
429 water content of soils (Minasny et al., 2017). This is in accordance with other studies
430 (Rawls et al., 2003; Wolf and Snyder, 2003), which reported high water content in soils
431 with high amounts of organic matter.

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

439 Soil pH was significantly higher in soils with *Parrotia p.* and *Pinus t.* compared to the
440 planted forest (on average +16.6%). The lower pH detected in the planted forest could
441 be indicative of different risks for soil health (Shabanpour et al., 2020), for example,
442 soluble phosphorus fix in acid soils, resulting in low available phosphorous (Chase and
443 Singh, 2014). The higher pH of soils with natural species is in close accordance with

444 other authors (e.g., Jackson et al., 2005, Berthrong et al., 2009), who showed significant
445 reduction in soil pH (about 0.3 units) in planted forests compared with non-forested
446 lands. Conversely, Liao et al. (2012) did not found significant differences in soil pH
447 between planted and natural forests.

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

464 In regard to the biological changes detected in the studied soils, the higher microbial
465 respiration in samples collected under *Parrotia p.* and *Pinus t.* could be another
466 consequence of the higher amount of soil nutrients (OC, TN, TP, Ca, Mg, K) and soil
467 pH. This is corroborated by their highly significant correlations with microbial

468 respiration (MR) found in our statistical analysis (Table 2 and 3). Other authors have
469 shown that soil parameters like soil pH and nutrient availability are critical factors
470 driving the structure of soil bacteria communities (Lauber et al., 2009; Goldfarb et al.,
471 2011; Griffiths et al., 2011; Kuramae et al., 2012; Sánchez-Marañón et al., 2017;
472 Miralles et al., 2020a, 2020b; Rodríguez-Berbel et al., 2020) and therefore foreseeably
473 its activity. Soil pH influences soil microbial composition because it affects numerous
474 essential soil parameters that may drive changes in soil microbial communities such as
475 nutrient availability, salinity, cationic metal solubility, organic carbon properties, and
476 soil moisture, and it also influences the physiological activity of the soil bacteria
477 (Lauber et al., 2009). In contrast, the soil microbial population is affected by the higher
478 production of biomass and subsequently by the accumulation of more organic matter
479 content (Shabanpour et al., 2020). A reduction in organic matter content of soil (e.g.,
480 following deforestation) can reduce the microbial respiration of soils by greater than
481 100%, and a reduced microbial activity in soils is related to lower levels of available
482 organic carbon (Nael et al., 2004). Kiani et al. (2004) stated that when the rate of fresh
483 plant residues increases in forest areas, the soil microbial respiration rises, which strictly
484 depends on the nutrient contents of soil (i.e., P, K, Ca, and Mg) (Mganga et al., 2016).
485 The changes detected in soil properties between soils with planted species and natural
486 forest soils are clearly evidenced by the two clusters of samples (soils with *Parrotia p.*
487 and *Pinus t.* vs. soils with *Alnus g.* and *Quercus c.*) provided by the PCA. This statistical
488 analysis showed a main derivative factor (the first PC), which combines all those soil
489 properties that are influenced by pH and organic carbon content and thus lead to
490 different soil quality between natural and planted soil forests. Conversely, the second
491 PC is linked to other two soil properties (the bulk density and electrical conductivity)

492 that are not significantly different among the studies species and thus are not able to
493 significantly discriminate the related soil quality. Also in the studies of Lucas-Borja et
494 al. (2019) and Shabanpour et al. (2020) - the latter carried out in the same environment -
495 the differences in soil properties among different land uses (abandoned farmland,
496 intensive cropland, grassland, forest areas, and woodland) were evident, and well-
497 differentiated groups, one for each land use, were clustered. This result is confirmed by
498 the calculation of SQI, which showed the lower soil quality under planted species
499 compared to natural forests.

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

504

505 **5. Conclusions**

506

507 This study has evaluated the changes in soil properties in planted and natural forest
508 areas of northern Iran. Forming factors (parent material, climate, geomorphology, and
509 time) of the investigated forest areas were the same, so the differences in soil properties
510 can be attributed to the influence of the four studied vegetal species. Compared to
511 planted forest areas, the soils with natural trees showed higher root weight density, pH,
512 and organic carbon. These differences led to higher nutrient contents, microbial
513 respiration, aggregate stability, and water retention in soils with natural trees, as
514 confirmed by the correlation analysis. The PCA provided a meaningful combined factor
515 (the first PC) that showed a clear discrimination in soil quality and fertility between

516 natural and planted species. The SQI confirms that planted species may lead to an
517 overall lower quality of soils with planted species compared to natural forest. Therefore,
518 the results of this investigation confirmed the working hypothesis that soil properties are
519 affected by significant changes due to the different characteristics of vegetal species.
520 The overall lower soil quality of planted forests can be aggravated by unsuitable
521 management practices (such as burning slash and logging residues), if carried out in the
522 planted forest areas. This means that reforestation in combination with these practices
523 should be avoided in delicate forest environments, such as the semi-arid forest areas of
524 northern Iran or forest parks worldwide, because these actions may lead to lower soil
525 quality with possible negative effects on ecosystem health.

526

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528

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530

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540

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