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INFLUENCE OF SOIL PHYSICOCHEMICAL PROPERTIES ON BIOMETRICAL AND PHYSICAL FEATURES OF PERSIAN OAK WOOD

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ABSTRACT

This article investigates the relationships between soil characteristics (physical and chemical) and wood properties of Persian oak in three different elevation sites. For this purpose, 27 trees were randomly chosen and cut in Zagros forests in western Iran. The test samples were prepared at the stem (breast height) to examine physical and biometrical properties. For each elevation site, four soil samples were obtained at a 0-20 cm soil depth under the canopy of each tree to measure soil properties, including clay, silt soil, sand soil, electrical conductivity, pH, nitrogen, phosphorus, potassium, and organic matter content. Then, the relationship of soil and wood properties was determined by principal component analysis. Results specified that there are a positive correlation between wood density and volumetric swelling with clay and available potassium. Moreover, the results revealed a positive correlation between fiber length, cell wall thickness, and fiber diameter with electrical conductivity, sand percentage, and total nitrogen content, respectively.

Keywords: *Quercus brantii*, soil properties, wood density, wood fiber, wood quality.

INTRODUCTION

Zagros forest in western Iran covers more than five million ha (Nazari *et al.* 2021). This forests consists sub-Mediterranean, semiarid temperate climate, mainly consisting of deciduous, broad-leaved trees (Olfat and Pourtahmasi 2010). *Crategus spp*. and *Pyrus spp., Quercus spp*. (oaks), and *Pistacia mutica* (wild pistachio) (Ghazanfari *et al.* 2004) are the three main wood tree species in this district. The ring-porous tree species *Quercus brantii* (covering more than 50 % of the Zagros forest area) has dominated tree woody species in the

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Zagros forests growing at 450 m to 2700 m altitudes (Sagheb-Talebi 2005). Native to western Asia and with more than 50 % coverage of the Zagros forests in Iran, it is one of the ecologically and economically most important tree species (Safari *et al*. 2022). They play an important role in water protection, water regulation, and soil protection, as well as perform sanitary and recreational functions. Persian oak is a big tree with height of 20 m and a big spherical crown and it has generally ovoid leaves with serrated margins. The fruit of *Q. brantii* is elongated and oval in velvety white bowl and conical (Alikhani *et al*. 2014). It has been reported that climate and environmental factors affect the quality of wood (Zobel and van Buijtenen 1989, Nazari *et al.* 2020). Climatic factors (temperature and rainfall), geographic features (latitude, elevation, and slope), biotic factors (animals, plants, humans, fungi, bacteria), and physical and chemical properties of soil can impact wood properties (Topaloglu *et al.* 2016, Nazari *et al.* 2021). Although numerous studies investigated the relationships between ecological indexes and wood properties (Rossi 2015, Topaloglu *et al.* 2016, Sousa *et al.* 2018), our knowledge is still limited regarding the relation between soil properties and variations in wood quality.

Research on the physical and chemical properties of the soil that determine the properties of wood is complicated because it is affected by many other factors, such as the age of the tree, heredity, etc., and the relationship between parameters. Although the physical and chemical properties of the soil have a key role in the growth of trees and wood quality, their effects on wood properties are still rarely investigated. (Marini *et al.* 2021). Rigatto *et al.* (2004) indicated that there is a significant correlation between soil physicochemical properties and wood quality. Cutter *et al.* (2004) found that sites with favorable soil properties significantly influenced the wood density. Tufekcioglu *et al.* (2005) studied the influence of soil characteristics on hybrid poplar growth in Turkey and concluded that the content of clay and Mg^{+2} was negatively correlated with the pH of the soil, while the range of phosphorus and sand of the soil was positively correlated with hybrid poplar growth. Bektas *et al.* (2003) investigated the site effect on heartwood and sapwood portions of Turkish Calabrian pine. They stated that the differences in heartwood and sapwood might be related to ecological indicators such as elevation, lime content, soil organic matter, and soil type. Yáñez-Espinosa *et al.* (2001) indicate that soil texture and water salinity are closely associated with the anatomical characteristics of Mexican mangrove populations. Kiaei (2014) pointed out that there is a significant correlation between soil clay and sand with wood properties of Eldar pine (*Pinus eldarica*), in contrast a negative relationship between wood properties and soil chemical properties was found. In Iran, there is no study related to the influence of soil physical and chemical properties on the wood properties of Persian oak.

Principal Component Analysis (PCA) is an algorithm in biometrics. It is a statistical technique that makes use of orthogonal transformation to transform a set of data of probably linked variables into a set of values of unrelated linear variables. It is also a tool that reduces multidimensional data to lower dimensions while retaining most of the information. (Karamizadeh *et al.* 2013). PCA is a sorting method that develops theoretical variables and reduces the total residual sum of squares after fitting a straight line to the species data. The best wood properties values for the sites are selected by PCA (Kooch *et al.* 2008).

Considering the importance of the chemical and physical properties of the soil to the wood quality and the value of Persian oak to Iranian forests, this research aimed was to investigate the influence of soil properties on physical properties (dry density and volumetric swelling) and wood fiber properties (fiber length, cell wall thickness, and fiber diameter) in three different elevations and to inspect the relationship between wood properties with soil. The relationship of mentioned variables was determined by PCA.

MATERIALS AND METHODS

Study site and sampling

This study was carried out in trees of Persian oak (*Quercus brantii* Lindl) collected from tree sites (three forest sample stands along an altitudinal gradient, below 1900, 1900-2000 and above 2200 m a.s.l.) in the oak forests of Bazoft. Due to their remote location and the absence of evidence of human impact, it is assumed that all stands have been developed under the influence of natural impacts and disturbances. In each site, nine plots were implemented, accordingly the 27 plots were selected in study area. In each plot, all live trees of at least 7,5 cm diameter at breast height (DBH 1,3 m above the root collar) were identified, and their diameter at breast height, height, crown length and perpendicular diameters were recorded within 0,1-hectare plot. The caliper, Vertex and diameter tape were used to measurements of trees diameters, height and crown diameter, respectively. Then stand-level variables such as stand basal area (square meter per hectare), stand density (the number of trees per hectare), stand quadratic mean diameter) QMD) (cm) and tree-level variables such as stem basal area (m^2), stem volume (m^3), crown diameter (m) and crown basal area (m^2) in each site were calculated. Then in each plot, those dominant trees that healthy with the largest diameters at breast height (DBH) without any defects and reaction wood were sampled and one disc was taken from the tree trunk at DBH for the determination of wood properties. Then, the tree age at breast height (ABH) was obtained by counting the annual rings of the sampled disks (Figure 1). Finally, the mean annual diameter increment (MADI) was obtained by dividing DBH by the number of annual rings. In total, 27 healthy trees (9 trees× 3 sites) were selected. The main dimensions of the tree and site properties are presented in Table 1.

Wood physical properties

Physical properties, namely oven-dry density and volumetric swelling were measured from 5 cm thick disks cut down from each tree. The disks were cut from the stem diameter at breast height (DBH = 1,30 m aboveground). Sample tests were prepared following ISO 13061-14 (2016). The wood sample size was 3×2×2 cm^3. Two hundred seventy samples were prepared from various portions of the disks. The size of samples in both green and oven-dry situations was measured with a slide caliper. An electronic balance was used to measure the oven-dry density. Dimensional changes from the green to dry conditions were considered to calculate the volumetric swelling. The mentioned physical properties were determined in accordance with the formula (Equation 1 and Equation 2):

$$D_0 = \frac{M_0}{V_0} \quad (1)$$

$$\alpha_V = \frac{V_S - V_0}{V_0} \quad (2)$$

Where: D_0 - oven-dry density ($g{\cdot}cm^{-3}$), M_0 - oven-dry mass (g), V_0 - oven-dry volume (cm^3), α_v - volumetric swelling (%), Vs. - volume in state of saturate (cm^3).

Morphologic wood properties

Franklin (1945) was applied to separate the individual wood fiber. In detail, Saturation of wood samples (15×10×2 mm^3) in a mixture (1:1) of oxygenized water and acetic acid were performed, and then the samples were maintained inside an oven for 48 hours at 65 ºC ± 5 °C. After maceration, the samples were washed in distilled water. Finally, they were submerged to distilled water, shacked, and fiber parameters such as fiber length, cell wall thickness, and fiber diameter were evaluated under a light microscope. From each slice, at least 50 fibres were used for the measurements.

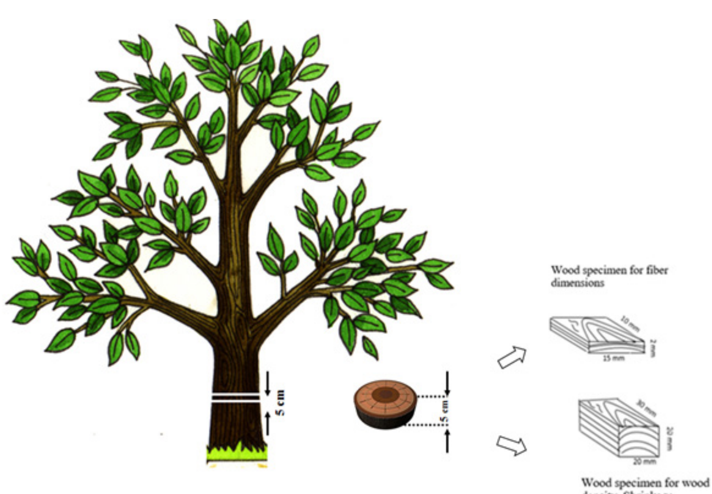

Figure 1: Diagram of sample preparation from a disk of *Q. brantii* to measure the physical properties and fiber dimensions (redrawn from Nazari *et al.* (2020)).

Soil study

To calculate soil properties, four soil samples were obtained at a 0-20 cm soil depth under the canopy of each tree and mixed. Physicochemical properties of soil were measured, including the percentage of clay, percentage of silt, percentage of sand, electrical conductivity (Ec), soil reaction (pH), total nitrogen (N), available phosphorus (P), available potassium (K), and percentage of organic matter.

Soil treatments were air-dried, then passed through a 2 mm sieve. Analysis of soil samples was carried out at the laboratory of Agricultural and Natural Resources Research Center of Isfahan Province, Isfahan, Iran. Percentage of clay, percentage of silt, percentage of sand were calculated by the hydrometer method (Bouyoucos 1962). The pH and EC were determined using a pH/EC meter. The total nitrogen was calculated using the Kjeldahl method (Zarinkafsh 1993). Phosphorus content was calculated by the Olsen method (Nelson and Sommers 1996). Available potassium was measured by Flame photometry (Zarinkafsh 1993). Organic matter content was estimated as in Walkley and Black (1934).

Analysis study

In this study, the influence of different sites was studied on the wood properties. Analysis of variance (ANOVA) and Duncan's test were applied to differentiate the significance of means and their grouping, respectively. PCA was also considered for determining the relationships of the site conditions and soil properties with the wood properties.

RESULTS AND DISCUSSION

Table 1 gives descriptive statistics analysis of *Q. brantii* population in three studied sites.

Table 1: Site conditions, soil physical and chemical properties, and stand-level variables at three altitudes.

	Site	1	2	3
Site conditions	Altitude (m a.s.l)	<1900	1900-2200	2200<
	Latitude (N) m	3558237	3558169	3556283
	Longitude (W) m	416736	418247	416161
	Mean annual precipitation (mm)	329	329,5	330
	Mean annual temperature (°C)	15,3	13,8	12,8
Stand-level traits	Basal Area (m^2)	79,94	100,84	97,80
	Stand Density (N/ha)	147	94	126
	Quadratic mean diameter (cm)	86,46	118,18	98,97
Soil physical properties	Percentage of clay (%)	32,56	33,82	36,13
	Percentage of silt (%)	43,24	45,43	42,66
	Percentage of sand (%)	24,20	20,75	21,41
	electrical conductivity (Ec)	1,06	0,77	0,72
	soil reaction (pH)	7,74	7,74	7,72
Soil chemical properties	Total nitrogen (Nsoil)(%)	0,18	0,25	0,21
	Available phosphorus (Psoil)(mg/kg)	9,45	9,57	9,06
	Available potassium (Ksoil)(mg/kg)	448,30	470,08	538,07
	Percentage of organic matter (OM) (%)	1,81	2,47	2,96

Physical properties

According to the ANOVA results, there are no significant differences in dry wood density between different sites. However, the sites affected the volumetric swelling (V_S) ($P < 0,01$) (Table 3), with the highest and lowest values measured at sites 2 and 1, respectively. Nevertheless, no significant differences were found between sites 2 and 3. The average values of V_S were 17,34 % ± 4,13 % (Table 4).

Biometric properties

The analysis of variance shows that, in addition to the regular changes of fiber length at different sites, the influence of sites on fiber length was highly significant ($p < 0,01$ Table 2). In addition, the value of fiber length declined with raising altitudes (Table 3). The average values of fiber length were 0,87 mm ± 0,08 mm. ANOVA results indicated significant differences in fiber diameter among the sites ($P < 0,01$; Table 2), with the maximum and minimum values which are measured at sites 1 and 2, respectively. It was found that there are no significant differences between sites 2 and 3. The mean fiber diameter values were 20,50 µm ± 1,25 µm (Table 3). Analysis showed no statistically significant differences between the sites for cell wall thickness.

Table 2: Analysis of variance (ANOVA) of wood properties at different sites.

Wood properties		Sum of squares	df	Mean square	F	Sig.
H	Height (m)	27,04	2	13,52	2,98	0,07 ^{ns}
		108,80	24	4,53		
		135,84	26			
DBH	DBH (cm)	7240,52	2	3620,26	4,78	0,18 ^{ns}
		18172,22	24	757,18		
		25412,74	26			
SBA	Stem basal area (m^2)	2,50	2	1,25	5,586	0,01 **
		5,39	24	0,22		
		7,89	26			
SV	Stem volume (m^3)	76,04	2	38,02	4,10	0,03 *
		222,35	24	9,26		
		298,40	26			
CBA	Crown basal area (m^2)	180,98	2	90,49	1,74	0,19 ^{ns}
		1247,85	24	51,99		
		1428,84	26			
CD	Crown diameter (m)	3,10	2	1,55	2,12	0,14 ^{ns}
		17,54	24	0,73		
		20,64	26			
WDD	Wood dry density (g/cm^3)	0	2	0	0,35	0,71 ^{ns}
		0,09	24	0		
		0,1	26	194,36		
VS	Volumetric swelling (%)	388,72	2	2,25	86,27	0 **
		54,07	24			
		442,79	26			
FL	Fiber length (mm)	0,13	2	0,07	40,44	0 **
		0,04	24	0		
		0,18	26			
FD	Fiber diameter (µm)	18,02	2	9,01	9,51	0 **
		22,74	24	0,95		
		40,77	26			
CWT	Cell wall thickness (µm)	0,02	2	0,01	0,19	0,83 ^{ns}
		1,33	24	0,05		
		1,35	26			
ADI	Annual diameter increment	0,05	2	0,03	2,27	0,12 ^{ns}
		0,27	24	0,01		
		0,33	26			

ADI: Annual diameter increment, CBA: crown basal area (m^2), CD: Crown diameter (m), CWT: cell wall thickness (µm), DBH: tree diameter at breast height (cm), FD: fiber diameter (µm), FL: fiber length (mm), H: Height (m), SBA: stem basal area (m^2), SV: stem volume (m^3), Vs: Volumetric swelling (%), WDD: woody dry density (g/cm^3).

*Significant at $p < 0,05$ probability level; ** Significant at $p < 0,01$ probability level; ns not-significant at $p < 0,05$ probability level.

Table 3: Average (± SD) of physical and morphological properties of *Q. brantii.*

Site		1	2	3
Height (m)	H	9,92±1,74a	7,47±1,24a	8,56±1a
DBH (cm)	DBH	84,33±16,41a	85,56±20,69a	119,67±39,67a
Stem basal area (m^2)	SBA	0,57±0,23b	0,60±0,30b	1,23±0,72a
Stem volume (m^3)	SV	2,99±1,75b	2,37±1,53b	6,20±4,72a
Crown basal area (m^2)	CBA	23,05±7,22a	19,15±5,87a	16,77±8,32a
Crown diameter (m)	CD	5,36±0,84a	4,89±0,73a	4,53±0,96a
Wood dry density (g/cm^3)	WDD	0,77±0,04a	0,79±0,09a	0,78±0,06a
Volumetric swelling (%)	VS	12,01±1,31b	20,55±1,32a	19,46±1,81a
Fiber length (mm)	FL	0,94±0,02a	0,90±0,03b	0,77±0,06c
Fiber diameter (μm)	FD	21,64±1,64a	19,87±0,24b	19,95±0,29b
Cell wall thickness (μm)	CWT	5,76±0,22a	5,75±0,33a	5,81±0,05a
Annual diameter increment	ADI	1±0,12a	0,95±0,13a	1,06±0,06a

ADI: Annual diameter increment, CBA: crown basal area (m^2), CD: Crown diameter (m), CWT: cell wall thickness (μm), DBH: tree diameter at breast height (cm), FD: fiber diameter (μm), FL: fiber length (mm), H: Height (m), SBA: stem basal area (m^2), SV: stem volume (m^3), Vs: Volumetric swelling (%), WDD: woody dry density (g/cm^3).
Values with different letters per row have significant differences with Duncan's test.

Principal component analysis (PCA)

PCA discoveries hypothetical components that account for most of the variance in multivariate data (Davis 1986, Harper 1999). For plotting goals, PCA can reduce the data set to only two components (the first two variables). It can also be assumed that the most critical components are related to other main variables. In other words, it is necessary to discover the best axis between each axis before PCA can obtain a real axis. PCA scree plot of the studied variables is illustrated in Figure 2. The 'Scree plot' can also indicate the number of essential components. The plot showed a line plot of principal components in multivariate statistics. It can indicate the number of variables to retain in main components to keep in PCA.

Correlation between soil, wood properties, and sites using PCA

In Table 4, the eigenvalues and proportion of variance showed using the component axes. The first six principal components (PCs) have eigenvalues > 1 and contribute ~89,09 % of the total variation in the set of data. Therefore, these PCs provide a decent approximation of the variation in the 21 axes (Figure 2). Jolliffe and Cadima (2016) showed that the threshold of cumulative ~70 % variation is appropriate to keep the PCs for PCA. Although the first four PCs have eigenvalues > 1 and contribute ~75,42 %, these PCs will be complicated to visualize at once, and these PCs need to implement pairwise visualization (Table 4).

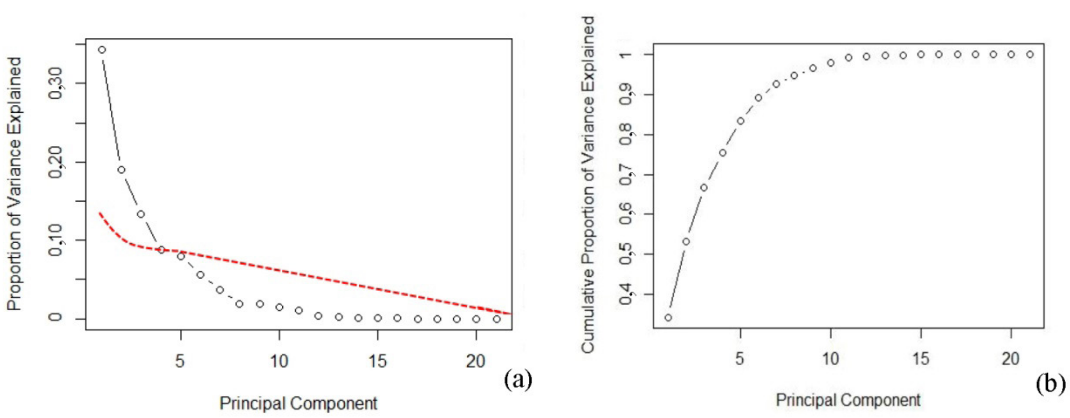

Figure 2: (a) The scree plot for finding the optimal number of principal components, and (a) Cumulative proportion of variance is explained.

In Table 4, the first and second PCs are the major to describe variance across the factors (soil and wood factors). The percentage of eigenvalue for the two PCs is 34,31 % and 18,95 % respectively. The place of soil variables, wood features, and sites in different parts of Figure 2 and Figure 3 is based on the correlation coefficient between factors.

Table 4: Percentage of variance and eigenvalues of PCA.

Axis	Eigenvalue	Percentage of variance
1	7,21	34,31
2	3,98	18,95
3	2,81	13,36
4	1,85	8,80
5	1,68	8
6	1,19	5,67
7	0,77	3,67
8	0,40	1,92
9	0,39	1,84
10	0,32	1,52
11	0,23	1,10
12	0,08	0,38
13	0,05	0,23
14	0,02	0,09
15	0,02	0,07
16	0,01	0,05
17	0	0,01
18	0	0,01
19	0	0,01
20	0	0
21	0	0

Eigenvectors and correlation coefficients between soil and wood factors

As shown in Table 5, eigenvectors include scores that show the weight of each factor (soil and wood factors) on the two PCs (-1< eigenvectors<+1); Kent and Coker (1992) demonstrated that if the score of the eigenvector is close to ±1 for each factor, the factor is more important to weigh on the PCs. The eigenvectors for fiber length, volumetric swelling, percentage of clay, percentage of organic matter, and Ec for the first PC, the value of DBH, height, stem basal area, and stem volume for the second PC is more significant relative to other eigenvectors factors. These factors perform the main role in explaining the first and second PCs of alteration.

Table 5: Eigenvectors of soil and wood factors for the first six PCs.

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
DBH	-0,23	-0,35*	-0,06	0,21	-0,07	0,08
H	0,04	-0,43*	-0,08	0,16	-0,27	0,04
CD	0,16	0,13	0,32	0,43*	-0,06	-0,23
SBA	-0,24	-0,35*	-0,05	0,20	-0,06	0,05
CBA	0,15	0,13	0,34	0,42*	-0,05	-0,24
SV	-0,20	-0,39*	-0,05	0,17	-0,11	0,07
ADI	-0,09	-0,11	0,28	0,18	0,46*	-0,02
WDD	-0,03	-0,12	-0,30	0,20	0,10	-0,61*
FL	0,30*	-0,10	-0,26	0,19	-0,03	0,15
FD	0,21	-0,24	-0,06	-0,27*	-0,15	0,02
CWT	-0,05	0,05	0,31	0,22	-0,03	0,63*
VS	-0,29*	0,18	-0,22	0,16	-0,04	0,07
Nsoil	-0,06	0,16	-0,10	0,32	-0,35*	0,03
Psoil	0,04	0,17	0,01	-0,15	-0,61*	-0,08
Ksoil	-0,18	0,10	0,25	-0,03	-0,39*	-0,11
pH	0,30	0,08	-0,27*	0,17	-0,02	0,13
sand	0,26	-0,25	0,26*	-0,10	-0,04	-0,06
clay	-0,36*	0,01	0,10	-0,11	0,00	-0,10
silt	0,07	0,28	-0,38*	0,26	0,08	0,16
OM	-0,36*	0,09	-0,01	-0,06	0,01	-0,03
Ec	0,34*	-0,18	0,10	-0,03	-0,02	-0,01

ADI: mean annual diameter increment; CBA: crown basal area; CD: crown diameter; CWT: cell wall thickness; DBH: tree diameter at breast height; FL: fiber length; FD: fiber diameter; H: tree height; SBA: stem basal area; SV: stem volume; VS: volumetric swelling; WDD: oven-dry density; clay: percent of clay; Ec: electrical conductivity; Ksoil: available potassium; Nsoil: total nitrogen; OM: percent of organic matter; Ph: soil reaction; Psoil: available phosphorus; sand: percent of sand; silt: percent of silt.
*Features that contributed most for Axes 1–6.

As shown in Figure 3, the first PC describes 34,31 % of the total alteration. This PC is most greatly correlated with the soil properties available potassium, pH, percentage of sand, percentage of clay, percentage of organic matter, Ec; and wood properties crown basal area, crown diameter, fiber length, and volumetric swelling. The second PC explains 18,95 % of the alteration highly influenced by the soil properties total nitrogen, available phosphorus, percentage of silt, and wood properties DBH, height, stem basal area, stem volume, annual diameter increment, wood dry density, and fiber diameter.

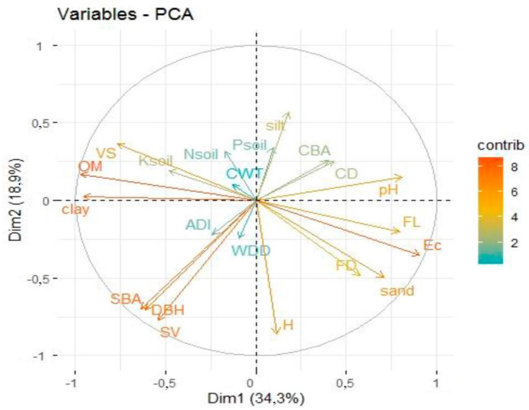

Figure 3: Distribution of soil and wood factors in the two first PCs.

ADI: mean annual diameter increment, CBA: crown basal area, CD: crown diameter, clay: percent of clay, CWT: cell wall thickness, DBH: tree diameter at breast height, Ec: electrical conductivity, FL: fiber length, FD: fiber diameter, H: tree height, Ksoil: available potassium, Nsoil: total nitrogen, OM: percent of organic matter, pH: soil reaction, Psoil: available phosphorus, sand: percent of sand, SBA: stem basal area, silt: percent of silt, SV: stem volume, VS: volumetric swelling, WDD: oven-dry density.

In Figure 4, we see that sites were placed separately from each other. The PCA analysis of the soil physical and chemical factors and wood physical and biometric parameters drive an independent distribution of the samples that seem grouped when they relate to the same site (Figure 4). Therefore, PCA displays apparent relationships of wood features fiber length and fiber diameter and soil properties Ec, pH, and percentage of sand in site 1 (bottom right). The PCA data also shows that site 2 (upper center) has the highest relationship with the crown basal area, crown diameter, cell wall thickness and percentage of silt, total nitrogen, and available phosphorus. Site 3 (left) has the best relationship with volumetric swelling, stem basal area, DBH, and stem volume, and percentage of organic matter, percentage of clay, and available potassium (Figure 4).

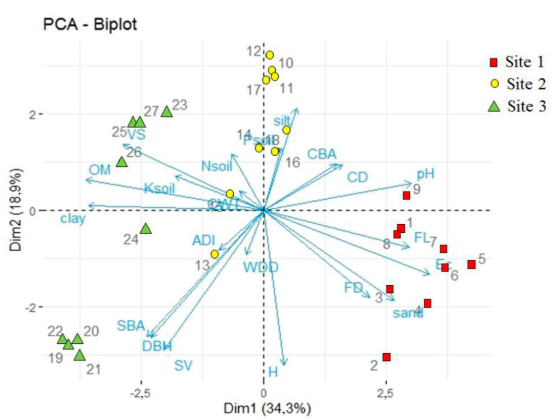

Figure 4: Distribution of soil and wood factors and forest sites in the two first PCs axes.

ADI: mean annual diameter increment, CBA: crown basal area, CD: crown diameter, clay: percent of clay, CWT: cell wall thickness, DBH: tree diameter at breast height, Ec: electrical conductivity, FL: fiber length, FD: fiber diameter, H: tree height, Ksoil: available potassium, Nsoil: total nitrogen, OM: percent of organic matter, pH: soil reaction, Psoil: available phosphorus, sand: percent of sand, SBA: stem basal area, silt: percent of silt, SV: stem volume, VS: volumetric swelling, WDD: oven-dry density, 1-27: number of trees.

The width of the annual rings will be closely related to the wood density, which is important in ring-porous species. The density of wood affect the main features of wood quality. Therefore, wood quality can change with tree genetic, site conditions e.g. the soil components, light and water, and other factors (Vintoniv *et al.* 2007, Grześkiewicz 2007, Hemery *et al.* 2008, Sopushynskyy and Teischinger 2013). The density of wood is generally lower on more fertile soils, which are conductive to faster tree growth. This lead to an increase in the percentage of wood vessels with thinner fiber walls on fertile soils (Lima *et al.* 2010, Mevanarivo *et al.* 2020).

According to PCA results, wood density has a negatively correlate with silt and phosphorus and a weak positive correlation with clay, sand, and potassium content. Similar results were also observed by Kiaei (2014). Parsa (1993) stated that sandy soils reduce the density of the wood. Maharani and Fernandes (2015) demonstrated that mineral elements (N, P, K) had a major correlation with fiber length and wood density on *Shorea leprosula*, and these elements had a notable correlation with wood density on *S. parvifolia*. In the meantime, these elements had a non- considerable correlation with fiber length.

A number of studies have reported how components in the soil, especially the nitrogen content, affect wood properties. Variation of wood density with components in the soil might vary according to the amount of the nutrients present or applied, and on the species (Downes *et al.* 2014, Eufrade-Junior *et al.* 2017, Mevanarivo *et al.* 2020).

Volumetric swelling is positively correlated with available potassium, organic matter content, clay, and total nitrogen. Meanwhile, it is negatively correlated with Ec. Moya and Perez (2008) reported that normal radial shrinkage and normal tangential shrinkage were the best-correlated factors with soil properties, even though that the less correlated factors were normal volumetric shrinkage and specific gravity.

In the current study, fiber length positively correlated with the Ec and negatively correlated with the available potassium, while fiber diameter positively correlated with soil sand percentage. It was found that the fiber diameter had no significant correlation with elements of N, P, and K. Cell wall thickness is positively correlated with the total nitrogen and available potassium. In contrast, available phosphorus and percentage of organic matter presented a weak relationship with cell wall thickness. Larson (1994) demonstrated that the mineral elements have direct effects on vascular cambium. For the particular case of phosphorous, this element increases cell division in the vascular cambium, and this element allows improved performance in plants. The increase in cambial activity is followed by changes in the structure, mainly because of pores of larger size, fibers with thinner cell walls, and more significant, presence of parenchyma cells. Moya and Perez (2008) found such anatomical structures make a diminution in the normal tangential shrinkage.

CONCLUSIONS

In this study, the relationship between soil physicochemical properties and some wood properties of Persian oak was investigated. Soil characteristics (physical and chemical) had a significant influence on oak wood properties. It can be stated that soil physical properties correlated with fiber diameter, while soil chemical properties associated with cell wall thickness. Meanwhile, soil physical and chemical properties correlated with wood dry density, volumetric swelling, and fiber length. Zagros forests are particularly important for protecting soil and water supply and they are known as a second renewable source of cellulose in Iran that are threatened by environmental factors such as climate change, disease and pests, and human activities. To forests rehabilitate with oak species, soil with a high content of potassium, nitrogen, and organic matter is suggested because these factors play a crucial role in the wood properties and wood quality.

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