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Variations of soil physicochemical properties and vegetation cover under different altitudinal gradient, western Hyrcanean forest, north of Iran

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Abstract: This study was done to quantify the amount of soil organic matter and to evaluate physicochemical properties and vegetation cover changes along the altitudinal gradient. Nine altitudinal transects were selected from 100 m a.s.l. to 1 700 m a.s.l. Then, 160 circular plots of 1 000 m^2 area with a distance of 150 m from each other were studied. Soil texture, bulk density, particle density, soil base saturation, phosphorus and potassium values did not indicate any specific variation pattern. Whereas pH decreased powerfully, the highest and the lowest value of pH was measured at 100 m a.s.l. and 1 700 m a.s.l., respectively. Soil organic carbon content increased significantly with increasing altitude ($P \leq 0.01$). Density of trees decreased dramatically from 100 to 900 m a.s.l., whereas this trend was ascending from 1 100 to 1 700 m a.s.l. Density of shrub species increased with increasing altitude along the gradient and the highest value was revealed at 1 300 m a.s.l. The highest percentage of herbaceous species cover was found at a lower altitude and a decreasing trend was found along the altitudinal gradient.

Keywords: soil organic carbon; vegetation cover; species richness; human impact; altitudinal gradient

Soil organic matter is the fraction of the soil that consists of plant or animal tissues in various stages of breakdown (decomposition) (Tsozué et al. 2019). Formation of physicochemical properties and return rate of organic matter in forest ecosystems are affected by various environmental factors including climate, species composition, live microorganisms, time, human activities, management strategy, land use changes and topographic and geological conditions. These factors along with land form are effective on plant communities and soil properties (de Oliveria et al. 2015). Overall, it has been proved that climatic variations such as increasing rainfall and decreasing temperature along the altitudinal gradient are the most important factors which have significant effects on vegetation cover and soil properties. The quantitative relationship between soil organic matter and climatic factors has been investigated on a small scale and it was documented that soil organic matter has a positive and a negative relationship with rainfall and temperature, respectively.

In a mountainous forest ecosystem, altitude as a main factor has an impressive effect on environmental microclimate, vegetation cover and soil properties on a small scale (Bojko, Kabala 2017). High altitude locations are distinct by extreme solar radiation, low temperature, high temperature changes and low air pressure whereas higher temperature, different atmospheric humidity and high evapotranspiration capabilities are considerable at low altitude locations. Vegetation cover along altitudinal gradients has a substantial effect on soil organic matter (Bojko, Kabala 2017), biologic ac-

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tivities and soil physicochemical properties**.** On the other hand, the soil of a forest ecosystem is an important source of nutrients, including phosphorus, sulphur, sodium, calcium, magnesium and some micronutrients. In some cases, soil properties, including acidity, also affect the vegetation cover type in forest stand (Tsui et al. 2004).

Mountainous forest ecosystems have an important role in the global cycle of carbon and approximately 26% of terrestrial carbon were accumulated in these ecosystems (Garten Jr, Hanson 2006). Variation of soil organic matter along altitudinal gradients was studied over the world and it was shown that variation patterns were general in most forest ecosystems, but there were some exceptions (Djukic et al. 2010). Studies about the dynamics of soil organic matter in forest ecosystems indicated a positive and significant relationship between organic matter stock and altitudinal gradient (Sierra et al. 2017). Some studies have also shown that there is no significant relationship between the altitude and organic matter amount, or soil organic matter has decreased with increasing altitude. Hyrcanean forest in the north of Iran as a sensitive mountainous ecosystem is highly vulnerable with remarkable responses to changes along altitudinal gradients. Natural and anthropogenic disturbances in these forest ecosystems are significant, and anthropogenic destructions are considered as the greatest threat to protection of Hyrcanean forest ecosystems (Pourbabaei et al. 2014). It should be noted that these illegal disturbances over the last decades have led to a decrease in the vegetation cover and soil nutrient amount. Although soil degradation is a natural and renewable process, continuous anthropogenic destruction of high intensity and reducing carbon and other organic materials can lead to significant environmental challenges in forestry systems. On the global scale, the effect of climate and land use changes on soil ecosystems was reported. But in Hyrcanean forest, it has been less studied, especially in relation to altitudinal gradients. On the other hand, due to the complexity in forest ecosystem responses to altitudinal changes, our ability is still limited to predict the patterns of organic matter changes along the altitudinal gradient. The aim of this study was to evaluate differences in soil physicochemical properties along the altitudinal gradient and identify the effects of altitudinal changes on soil organic matter amount and vegetation cover. We hypothesized (*i*) an increase of soil organic matter amount along altitudinal gradients, (*ii*) a strong correlation of the physicochemical properties of soils with altitudinal classes and (*iii*) considerable changes of species composition related to altitudinal gradient which can affect soil properties.

MATERIAL AND METHODS

Study area. The Hyrcanian forests as deciduous broadleaved forests are spread out along the southern shores of the Caspian Sea and northern slopes of the Alborz Mountains (Pourbabaei et al. 2014). These forests with high plant species diversity are richer than mixed broadleaved forests of central Europe, north of Turkey and Caucasus (Marvi Mohajer 2007). Some tree species such as *Fagus orientalis*, *Quercus castaneifolia*, *Carpinus betulus*, *Parrotia persica*, *Acer velutinum*, *Acer cappadocicum*, *Fraxinus excelsior*, *Taxus baccata*, *Tilia begonifolia*, *Ulmus glabra*, *U. carpinifolia*, *Alnus glutinosa*, *A. subcordata*, *Gleditsia caspica* are the most dominant in Hyrcanian forests. The Asalem watershed basin was selected for this study (latitude from 37°36'31'' to 37°44'40''N, longitude from 48°35'17'' to 48°56'26''E). The climate is temperate and humid. Mean annual precipitation is 945 mm and temperature is 12.4 °C. According to the USDA soil classification, Alfisols and Inceptisols are common soil types. The altitude is from 100 to 2 500 m a.s.l. Three different vegetation types were created in this area including a mixed forest of *Carpinus betulus* at low altitudes, beech forests at middle altitudes and *Quercus macranthera* forests at high altitudes. Dairy farmers and local people are present in this area during the spring and summer seasons and they exert a lot of negative effects on ecosystems by grazing livestock, girdling, and excessive cutting of trees and shrubs (Figure 1).

Sampling method. Sampling was done from 2017 to 2018 along altitudinal gradients. A range of elevations from 100 to 1 700 m a.s.l. was selected as the lowest and the highest locations which created three different vegetation layers in this area, including a mixed forest with relative dominance of *Carpinus betulus* at low altitudes, beech forests at middle altitudes and *Quercus macranthera* forests at high altitudes. Nine altitudinal transects were selected within 200 m intervals from each other along the altitudinal gradients. Totally, 160 circular plots of 1 000 m^2 area

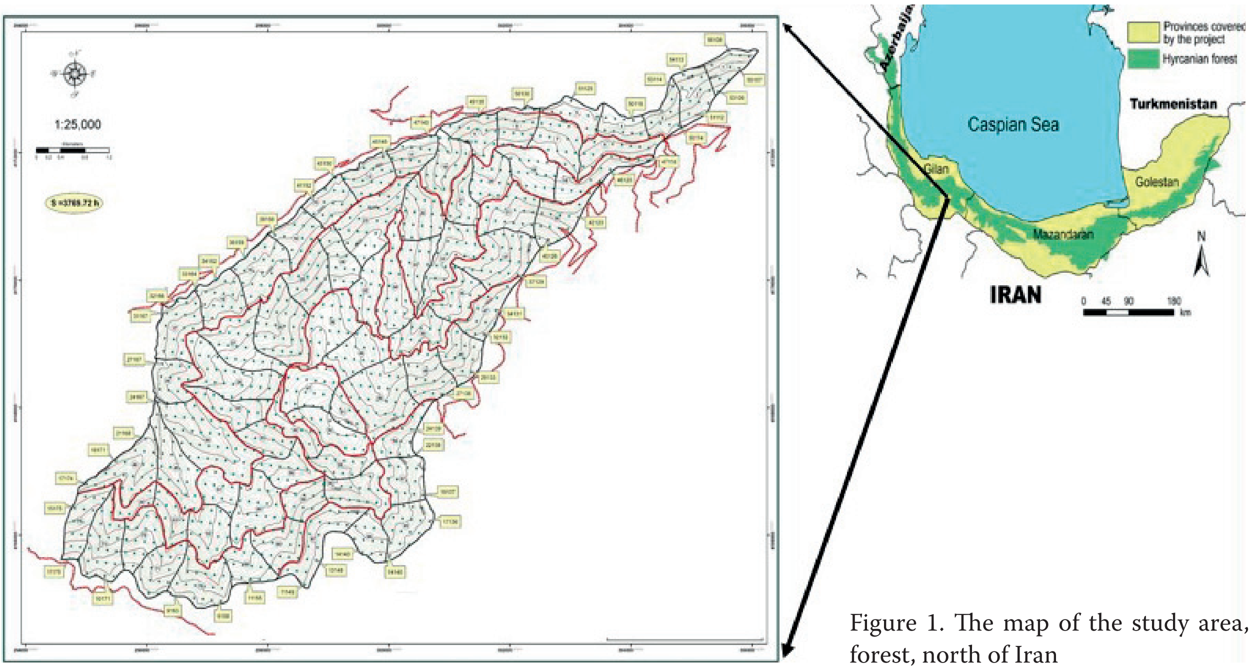

Figure 1. The map of the study area, forest, north of Iran

were established with a distance of 150 m from each other by a systematic random sampling method including 16 plots per 100 m altitude and 18 plots for each transect from 300 m to 1 700 m. Sampling was carried out in two steps including vegetation and soil sampling. In each established plot, tree species with a diameter at breast height (DBH 1.3 m above ground) larger than 7.5 cm were identified. The number of each shrub species was counted. In herbaceous layer, Whittaker nested plot sampling and minimal area method were used to survey the percentage cover of each herbaceous species according to the Braun-Blanquet scale (Mueller-Dombois, Ellenberg, 1974). Then, Flora Iranica (Rechinger 1989), Flora of Turkey (Davis 1970), Flora of Iran and the Colourful Flora of Iran (Ghahreman 1978) were used to identify dried species (Asadi et al. 2011). As for soil sampling in each plot, four soil samples were randomly taken from 0–30 cm depth of mineral soil, and after mixing one compositesoil sample was prepared (approximately 500 g) (Salehi et al. 2013).

Laboratory analyses and soil properties. All prepared soil samples were transferred to soil laboratory for analyses. All of the soil samples were air-dried and passed through a 2 mm mesh. Soil texture using a hydrometer (Salehi et al. 2013), particle density (P.D.) by a pycnometer method, bulk density (B.D.) by a clod method (Blake et al. 1965; Grossman, Reinsch 2002) and soil base saturation were measured (Scharenbroch, Bockheim 2007) as physical soil properties. For chemical properties, pH by a potentiometric method in H_2O (pH H_2O) with a soil-to-solution ratio of 1:2.5 (De Feudis et al. 2016), soil organic carbon (OC) by the Walkley and Black method, available phosphorus (P) according to the Olsen method (Iatrou et al. 2014) and exchangeable potassium (K) extracted by using 1 M ammonium acetate at pH 7.0 and analyzed with a flame photometer were determined (Jackson 1967)

Statistical analyses. To study the normality of data distribution and examine the equality of variances, Kolmogorov-Smirnov and Levene's test were used, respectively. ANOVA was carried out to compare measured parameters among the altitudinal classes. In addition, Tukey's post-hoc ($P < 0.05$) test was used to compare means. Linear regressions and Pearson's correlation were performed to correlate the physicochemical properties of soils with altitudinal classes. All analyses were performed with SPSS 16.0 (IBM, Armonk, USA) and SAS software (SAS Institute Inc., Cary, USA).

RESULTS

Physical properties of soil along altitudinal gradient

Soil base saturation showed the highest value at 1 700 m a.s.l. with an average of about 42.57% while the lowest value of base saturation was found at 100 m a.s.l. (38.07%). Soil particles were studied as sand, clay and silt. The average of sand particles varied between 41.49 ± 3.1% and 47.66 ± 1.5%. The greatest value was measured at 1 700 m a.s.l. but 100 m a.s.l.

Table 1. Physical properties (mean ± SE) of soil along the altitudinal gradient (P.D. – particle density, B.D. – bulk density)

Altitudinal gradient (m a.s.l.)	Base saturation (%)	Sand (%)	Clay (%)	Silt (%)	P.D. (g·cm^{-3})	B.D. (g·cm^{-3})	Soil porosity (%)
100	38.07 ± 1.61	41.49 ± 3.1	24 ± 2.9	34.51 ± 1.3	2.21 ± 0.04	1.46 ± 0.07	33.71 ± 2.84
300	41.91 ± 1.72	42.56 ± 3.06	23 ± 3.7	34.44 ± 3.3	2.23 ± 0.05	1.49 ± 0.07	32.81 ± 3.58
500	42.02 ± 2.3	42.26 ± 0.6	24.31 ± 1.7	33.43 ± 1.5	2.27 ± 0.13	1.37 ± 0.07	39.04 ± 1.54
700	42.60 ± 1.9	44.35 ± 3.1	22.54 ± 2.1	33.11 ± 2.02	2.26 ± 0.10	1.39 ± 0.05	37.51 ± 3.21
900	43.74 ± 2.1	46.99 ± 3	19.33 ± 3.1	33.68 ± 2.2	2.10 ± 0.03	1.40 ± 0.06	33.53 ± 2.37
1 100	44.74 ± 2.6	42.98 ± 3.04	23.57 ± 3.3	33.45 ± 1.4	2.08 ± 0.02	1.50 ± 0.05	27.66 ± 3.06
1 300	43.98 ± 1.3	46.30 ± 2.3	17.67 ± 1.8	36.03 ± 1.7	2.17 ± 0.07	1.42 ± 0.04	33.84 ± 2.99
1 500	44.83 ± 3.1	46.51 ± 2.8	18.5 ± 2.5	34.99 ± 1.3	2.09 ± 0.03	1.44 ± 0.08	31.48 ± 3.1
1 700	45.27 ± 3.76	47.66 ± 1.5	24.38 ± 1.6	27.96 ± 1	2.02 ± 0.07	1.57 ± 0.07	31.58 ± 2.6
F - value	0.8^{ns}	1.35^{ns}	1.46^{ns}	0.37^{ns}	1.22^{ns}	0.84^{ns}	0.19^{ns}

** and * and ^{ns} indicate significant differences at 0.01 and 0.05 level and no significant differences between attitudinal classes

had the lowest average of sand particles. In relation to clay particles, the altitude of 1 300 m a.s.l. indicated the lowest average (17.67 ± 1.8), but the highest average was documented for 1 700 m a.s.l. (24.37 ± 1.6). The average of silt particles was different between altitudinal gradients, with an average of 33.1 ± 2.02 percent at 700 m a.s.l. and 34.99 ± 1.3 percent at 1 500 m a.s.l. (Table 1). The highest and the lowest average of particle and bulk density was at 500 m a.s.l. (2.27 ± 0.13 and 1.37 ± 0.07) and 1 700 m a.s.l. (2.02 ± 0.7 and 1.57 ± 0.07). The highest average of soil porosity was found at 500 m a.s.l. (39.04 ± 1.54), whereas 1 100 m a.s.l. had the lowest average (27.66 ± 3.06) (Table 1).

Table 2. Pearson's correlation coefficients of physical properties of soil with altitudinal classes (P.D. – particle density, B.D. – bulk density)

Parameter	Correlation coefficient (*r*)	Sig. (2-tailed)
P.D.	0.088	0.4
B.D.	0.10	0.32
Sand (%)	0. 34	0.7
Clay (%)	0.72	0.5
Silt (%)	0.56	0.59

Analyses of Pearson's correlation revealed a positive correlation between sand, clay and silt particles with increasing altitude. The highest correlation coefficient was computed for clay ($r = 0.72$) (Table 2). Among physical properties, the correlation between sand and clay was significantly negative ($r = -0.78$, $P \leq 0.01$) while a significantly positive correlation was found between clay and B.D. ($r = 0.32$, $P \leq 0.01$). On the other hand, there was a positive correlation of silt particles with P.D. and clay ($r = 0.31$ and 0.34, $P \leq 0.01$, respectively). But the correlation between silt and sand particles was negative ($r = 0.36$, $P \leq 0.01$) (Table 3).

Soil chemical properties along altitudinal classes

Evaluation of pH along altitudinal classes showed that this property decreased significantly ($P \leq 0.01$)

Table 3. Pearson's correlation coefficients between soil physicochemical properties

Parameter	pH	OC (g·kg^{-1})	P (mg·kg^{-1})	K (mg·kg^{-1})	P.D.	B.D.	Sand (%)	Clay (%)	Silt (%)
pH	–								
OC	–0.474**	–							
P	0.118	–0.067	–						
K	0.069	0.098	0.095	–					
P.D.	0.077	0.070	–0.06	–0.09	–				
B.D.	0.05	0.073	0.14	0.191	–	–			
Sand	–0.006	0.44	0.41	0.039	0.09	–0.11	–		
Clay	0.113	0.086	–0.17	0.06	0.18	0.32**	–0.78**	–	
Silt	–0.162	–0.062	–0.34	–0.15	–0.13	0.31**	–0.36**	0.34**	–

OC – organic carbon, P – phosphorus, K – potassium, P.D. – particle density, B.D. – bulk density, ** indicates significant correlations at $P < 0.01$ between soil properties and altitudinal classes

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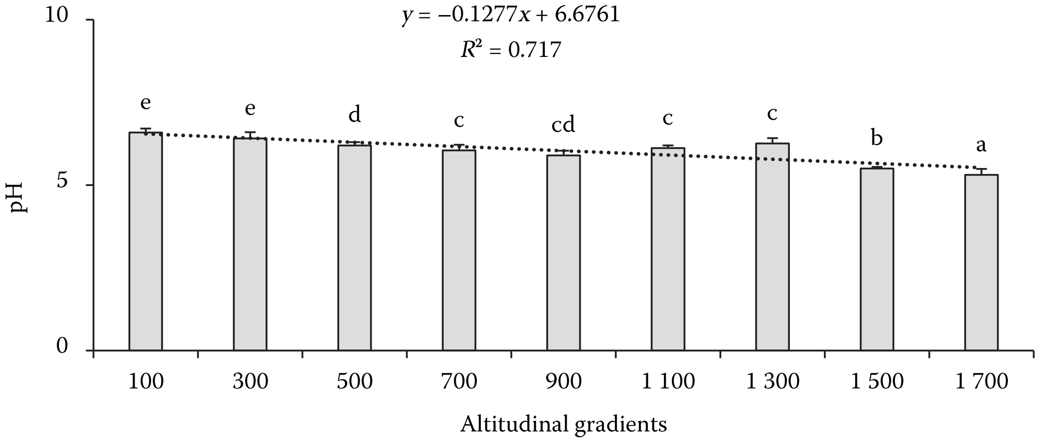

Figure 2. Variations of pH along altitudinal classes, different letters show significant differences between altitudinal classes at 0.01 level

with increasing altitude and also there was a significant negative correlation between pH and altitude (r = 0.586, $P \leq 0.01$). The highest and the lowest value of pH was measured at 100 m a.s.l. (6.59 ± 0.12) and 1 700 m a.s.l. (5.31 ± 0.18), respectively (Figure 2).

Figure 3 indicates the soil organic carbon content along gradients. There was a significant positive correlation between the soil organic carbon content and altitudinal classes (R^2 = 0.9405, $P \leq 0.01$) and soil organic carbon showed a significantly ($P \leq 0.01$) ascending trend with increasing altitude. The lowest average of organic carbon was found at 100 m a.s.l. (3.86 ± 0.29 g·kg^{-1}) and the highest average was obtained at 1 700 m a.s.l. (7.28 ± 0.26) (Figure 2).

The pattern of soil total potassium and available phosphorus along altitudinal classes did not indicate any significant variations. Available phosphorus fluctuated between 96.5 ± 0.75 and 21.4 ± 21.8 mg·kg^{-1}. The average of soil available phosphorus was 5.5 ± 0.45 and 5.21 ± 019 mg·kg^{-1}at 100 and 500 m a.s.l. and the lowest average was recorded at 900 m a.s.l. with 4.20 ± 0.16 mg·kg^{-1} (Figure 4), whereas the maximum value was found at 1 300 m a.s.l., which created the first peak in the variation trend. Exchangeable potassium had an increasing trend from 100 to 1 100 m a.s.l. with a slight variation trend. In this regard, the lowest and the highest average of soil exchangeable potassium was obtained at 100 m a.s.l. (159.33 ± 6.98 mg·kg^{-1}) and 1 100 m a.s.l. (187/9 ± 14.75 mg·kg^{-1}). But, the average of this property decreased from 1 300 to 1 700 m a.s.l. (Figure 5).

Vegetation characteristics and species richness along altitudinal gradient

The percent of vegetation cover and density of woody species showed significant changes along the altitudinal gradient. According to the results, a decreasing trend was found from 100 to 900 m a.s.l. for

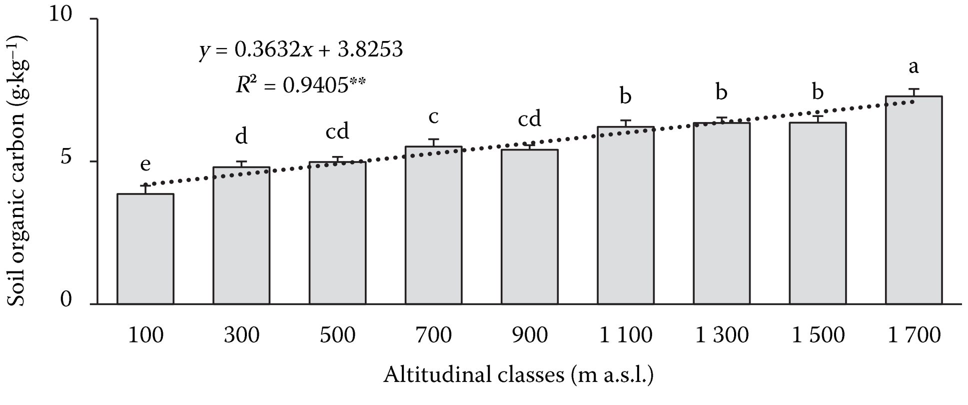

Figure 3. Variations of soil organic carbon (g·kg^{-1}) along altitudinal classes, different letters show significant differences between altitudinal classes at 0.01 level

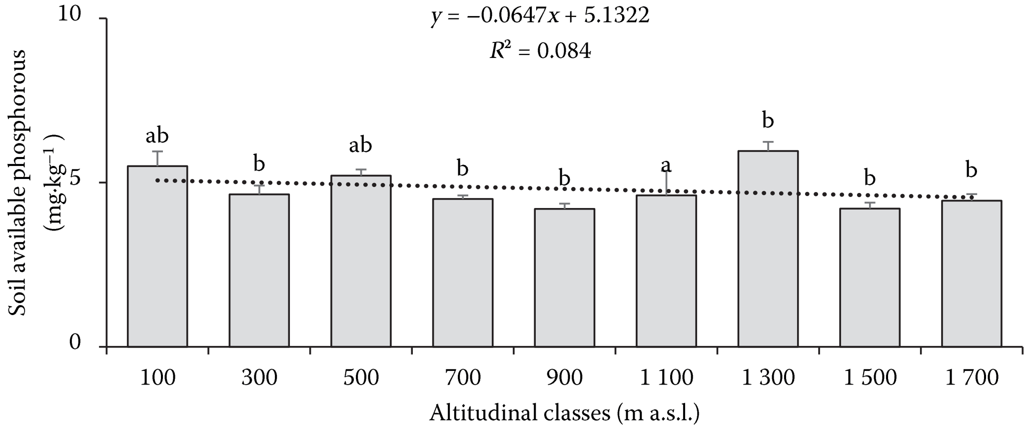

Figure 4. Variations of soil available phosphorous (mg·kg^{-1}) along altitudinal classes, different letters show significant differences between altitudinal classes at 0.01 level

tree species density and the lowest density was observed at 100 m a.s.l. with an average of 350.6 (N·ha^{-1}). Moreover, the density of tree species was considerable at 300, 500, 700 and 900 m a.s.l. with an average of 458.3, 391.6, 393.8 and 382.8 (N·ha^{-1}), respectively. The density of tree species increased dramatically from 1 100 to 1 700 m a.s.l., the highest value was found for 1 700 m a.s.l., with an average about 527.2 (N·ha^{-1}). Density of shrub species indicated an incremental pattern from 100 to 1 300 m a.s.l. The highest and the lowest value were found for 100 and 1 300 m a.s.l. with 311.8 and 1021.2 species per hectare. Results of the herbaceous layer showed the highest percentage at a lower altitude and the percentage of vegetation cover revealed a slight change from 100 to 900 m a.s.l. At the middle altitude (700 to 1 100 m a.s.l.), the lowest and the highest value was obtained for 700 m a.s.l. (36.55%) and 900 m a.s.l. (44%), respectively (Figure 6).

The composition of vegetation cover for all layers along the altitudinal gradient is shown in Table 4. The variation of composition was considerable for all layers and the species dominance showed a determined change with increasing altitude. Generally, the density of species did not show a homogeneous pattern along the altitudinal gradient, and some increasing and decreasing trends were recorded. Some species were present only in a low altitudinal class and some in higher classes only. In the tree layer, *Parrotia persica, Dyospyrus lotus, Alnus subcordata, Pterocarya fraxinifolia, Carpinus betulus,* and *Gleditsia caspica* were dominant at 100 and 300 m a.s.l. Dominance of *Dyospyrus lotus* and *Carpinus betulus* was higher at 500 to 700 m a.s.l. *Fagus orientalis* had the highest

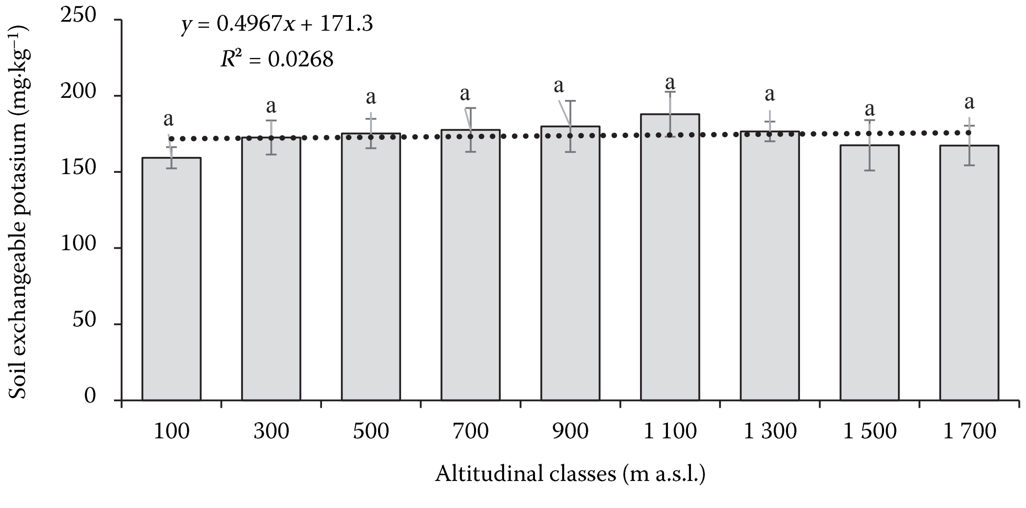

Figure 5. Variations of soil exchangeable potassium (mg·kg^{-1}) along altitudinal classes, different letters show significant differences between altitudinal classes at 0.01 level

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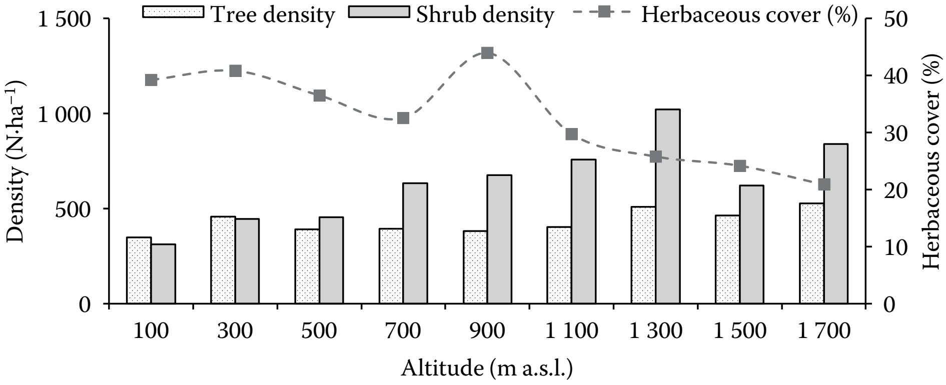

Figure 6. Herbaceous cover (%), tree and shrub density along the altitudinal gradient

density from 900 to 1 700 m a.s.l. In addition, other species including *Carpinus betulus, Acer cappadocicum, Quercus macranthera* and *Carpinus orientalis* were present at these altitudes with lower density than beech species. In the shrub layer, remarkable changes were documented in the presence and absence of species along the gradient. At the lower altitude, *Hypericum androsaemum, Mespilus germanica, Prunus divaricata, Crataegus microphylla* and *Viscum album* had the highest density whereas a decreasing trend was found for the density of this species at the higher altitude. The dominance of *Vaccinium arctostaphyllos* and *Ilex spinigera* increased significantly. In the herbaceous layer, the percentage cover of *Microstegium vimineum, Oplismenus undulatifolius, Pteridium aqualinum, Carex divolsa, Smilax excelsa, Prunella vulgaris, Dactylis glomerata, Brachypodium sylvaticum* and *Rubus hyrcanus* was higher at 100 to 500 m a.s.l. While their percentages decreased with increasing altitude, and the highest cover belonged to *Corydalis marschalliana, Mercuria lisperennis* and *Festuca drymeia* (Table 4).

Table 4. Characteristics of the studied area along the altitudinal gradient (m a.s.l., position – south, north aspect)

Altitude	Slope (%)	Dominant species		
		Tree layer	Shrub layer	Herbaceous layer
100	30.5	*Parrotia persica, Diospyros lotus, Alnus subcordata, Carpinus betulus, Gleditsia caspica*	*Hypericum androsaemum, Crataegus microphylla, Prunus divaricata, Mespilus germanica*	*Oplismenus undulatifolius, Microstegium vimineum, Brachypodium sylvaticum, Pteridium aqualinum, Pteriscretica, Carex divolsa, Rubus hyrcanus*
300	57.85	*Diospyros lotus, Parrotia persica, Carpinus betulus, Acer cappadocicum*	*Hypericum androsaemum, Viscum album, Pteridium aqualinum*	*Microstegium vimineum, Oplismenus undulatifolius, Brachypodium sylvaticum, Pteriscretica, Prunella vulgaris, Viola alba, Smilax excelsa*
500	60	*Diospyros lotus, Carpinus betulus*	*Hypericum androsaemum, Mespilus germanica*	*Brachypodium sylvaticum, Microstegium vimineum, Oplismenus undulatifolius, Dactylis glomerata, Prunella vulgaris*
700	68	*Carpinus betulus, Dyospyrus lotus, Fagus orientalis,*	*Hypericum androsaemum, Mespilus germanica*	*Microstegium vimineum, Rubus hyrtus*
900	53	*Fagus orientalis, Carpinus betulus, Acer cappadocicum*	*Hypericum androsaemum, Vaccinium arctostaphyllos*	*Brachypodium sylvaticum, Poa nemoralis, Rubus hyrtus*
1 100	46	*Fagus orientalis, Carpinus betulus, Quercus castaneifolia, Acer cappadocicum*	*Ilex spinigera, Hypericum androsaemum*	*Mercurialis perennis, Brachypodium sylvaticum, Matteucciastrut hiopteris, Athyrium filixfemina,*
1 300	67	*Fagus orientalis, Carpinus betulus, Carpinus orientalis, Acer cappadocicum, Quercus macranthera*	*Ilex spinigera, Vaccinium arctostaphyllos*	*Corydalis marschalliana, Viola odorata, Festuca drymeia*
1 500	47	*Fagus orientalis, Quercus macranthera*	*Ilex spinigera, Vaccinium arctostaphyllos*	*Galium odoratum, Festuca drymeia*
1 700	45	*Fagus orientalis, Quercus macranthera*	*Ilex spinigera, Vaccinium arctostaphyllos,*	*Galium odoratum*

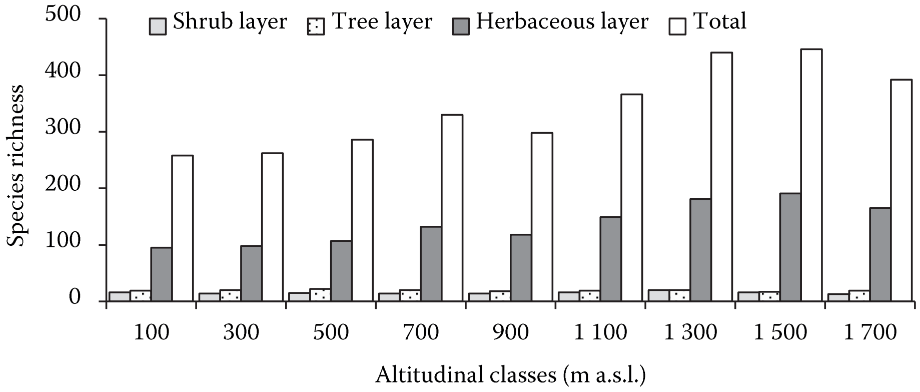

Figure 7. Species richness change of tree, shrub and herbaceous layers along the altitudinal gradient (all layers are shown in each altitudinal class)

Species richness was measured for all layers and results indicated that the lowest and the highest richness was found at 100 and 1 500 m a.s.l. with 258 and 446 species (N·ha^{-1}), respectively. Among the different layers of vegetation, the herbaceous layer had the greatest impact on total species richness, and the richness value in this layer significantly increased along the altitudinal gradient while the variation of species richness in the woody layer showed fewer fluctuations and varied between 30 and 35 species along the altitudinal gradient (Figure 7).

DISCUSSION

On the global scale, topography is a main factor to control the content of soil organic carbon and also as a regulator it has an important impact on its cycle. Among topographical factors, the altitude is an effective determinant of forest composition to evaluate the spatial pattern of soil organic carbon and physical properties of soil. It also has a determinative role in biological functions and composition of forest ecosystems by affecting the amount of precipitation, temperature, relative humidity and solar radiation. Soil organic carbon showed significant differences along the altitudinal gradient. In addition, the organic carbon content significantly increased with increasing altitude. A positive correlation between soil carbon content and altitudinal classes has been proved by other studies (Sierra et al. 2017). Carbon input, the rate of organic matter decomposition and tree species composition are the main factors which effect the soil organic carbon content (Pollierer et al. 2007). In mountain forests, changes in carbon content are directly dependent on carbon input through plant debris decomposition and transformation decomposition. Therefore, these changes can be attributed to different rate of organic matter decomposition, frequency and activity of soil microorganisms, litter volume, root system, soil texture and other environmental factors such as base saturation, temperature and species composition along the altitudinal gradient (Tsui et al. 2004).

It is expected that the content of organic carbon increases under favourable conditions of temperature, humidity, and optimal environmental conditions for microbial decomposers. However, wet soil with a lower temperature at a higher altitude is a limiting factor for organic matter decomposition. Moreover, this increase in organic carbon at a higher altitude may be associated with a shorter period for plant growth. Different topographical conditions are effective on plant growth, biomass production, activities of microorganisms and balance of the carbon cycle (Meliyo et al. 2016). It is considered that the rainfall total at a higher altitude is higher than that at a lower altitude, therefore litterfall must be poorer in nutrients due to the leaching of elements from the soil. However, the amount of soil chemical elements in the studied area showed an increasing trend for organic carbon content along the gradient. A significant increase of soil organic carbon with increasing altitude was shown in other studies (Njeru et al. 2017; Sierra et al. 2017). However, there is no stable pattern between the distribution of soil organic carbon and altitude. Segnini et al. (2013) indicated different results of organic carbon change in Taiwan and Peruvian forest ecosystems. Results of Kumar et al. (2013) showed that organic carbon decreased with increasing altitude due to a change in the rate of organic matter decomposition along the altitudinal gradient.

On the other hand, an increase of organic carbon at a higher altitude can be a result of lower available phosphorus content in those conditions (Lemenih, Itanna 2004). According to the results, there was no discernible pattern of changes in phosphorus along the elevation gradient which was consistent with the findings of Ediriweera et al. (2008). It was stated that variations of phosphorus at different altitudes with differences in the nutrient content of soil can be related to geological changes. The highest value of phosphorus was found at 1 300 m a.s.l. It can be attributed to the higher density of tree species at this elevation. More than half of the phosphorus content is stored in the tree biomass (Grant et al. 2005), hence the quantity and quality of litterfall are important effective factors on phosphorus content and nutrient products.

Generally, it has been accepted that some variations in species composition and microbial activities occurred with increasing altitude. Species composition is a principal factor for changes of carbon content in mineral and organic horizons of soil. During the last decades, the effect of different forest stands on organic carbon content has been studied over the world (Berendes, Roem 2000; Parras-Alcántara et al. 2015; Pescador et al. 2015; Bojko, Kabala 2016; Njeru et al. 2017, Sierra Causeret 2018; Tsozué et al. 2019) and a high correlation between carbon content, species richness and composition has been confirmed. As it was shown, species richness and density of tree species including beech stands increased along altitudinal classes, which led to a decrease in the rate of organic matter decomposition and finally to an increase in soil organic carbon content. Mahmoudi Taleghani et al. (2007) showed higher carbon content in the organic layer of *Fagus orientalis* and *Quercus castaneifolia* stands and pointed out the effective role of *Fagus orientalis*. Meanwhile, the lower organic carbon content at the lower altitude can be derived from lower density of *Fagus orientalis* and higher density of *Carpinus betulus* and *Alnus* sp., which decreased organic carbon content by a higher rate of litter decomposition (Esmailzadeh et al. 2011).

A decreasing pattern of species richness at higher altitudes as stands with unstable condition under environmental stresses is justifiable. Actually, livestock grazing, soil destruction, different land use by local people, vegetation cover change and lack of reasonable and logical management in these areas are great factors contributing to an decrease in the richness of woody species, increase of soil erosion rate, removal of sensitive species, dominance of invasive species and eventually reduction in carbon content. Durán Zuazo et al. (2013) stated that the lower density of vegetation cover on mountain forest ecosystems at the lower altitude is a reason for increasing runoff, erosion and decreasing organic carbon content. In fact, the vegetation cover of lower density can lead to a decrease of soil organic matter amount by acceleration of organic matter decomposition and destruction of soil texture and structure.

Variations of total soil potassium indicated a descending trend from 1 300 to 1 700 m a.s.l. Over these altitudinal classes, the slope is an important factor for higher leaching of potassium. Potassium as an element can be used in exchangeable form by plants. Accessible amount of this element in the soil depends on leaching percentage. Potassium does not combine with organic compounds of soil and it cannot get out of soil in gaseous form, whereas it is easily leached from the soil (Shahouei 2006). Various studies showed that potassium absorption by plants from the soil is strongly influenced by the concentration of the elements calcium and magnesium in the soil. With increasing altitude and consequently with increasing base saturation, bivalent cations, including calcium and magnesium, are more absorbed by soil particles, and therefore monovalent cations such as potassium are easily leached from the soil (Seibert et al. 2009). The soil at lower altitudes is a soil with greater thickness and less leaching which can be a source of accumulation of soluble ions, including potassium (Tsui et al. 2004). On the other hand, higher density of woody species at higher altitudes and increasing stem flow can be other reasons for increasing the exchangeable potassium of soil at these altitudes. Indeed, the canopy of trees has an impressive role in the concentration of nutrients such as potassium in the surface layers of soil by changing the chemical composition of stem flow (Mahdavi Ardakani et al. 2011).

In addition to soil organic matter, pH and soil texture are affected by changes in species richness and composition (Russel 2002). The lower density of tree and shrub species at low altitudes can be related to the higher percentage of clay and silt which create unfavourable conditions for regeneration. Whereas the percentage of sand particles was increased at higher altitudes, which creates optimal soil conditions for establishment of tree species. This result is consistent with Kooch et al. (2012). The positive correlation between soil organic carbon and percentage of sand particles confirms this result. Esmailzadeh et al. (2011) also revealed that the percentage of sand particles in the soil texture along the altitude was considered as the most important factor which affected the

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organic carbon content. Changes of soil texture, especially during a short period of time, have been less affected by plant species and several factors including severe physical and mechanical changes, surface soil erosion, soil compaction by livestock and changes in soil parent materials are required over a longer time period (Salehi et al. 2013).

Results showed a decreasing trend of pH from 100 to 1 700 m a.s.l. Differences in species composition and soil organic matter along the altitudinal classes can also affect the acidity of soils by producing different organic acids. Moreover, in mountain forest ecosystems, pH is strongly influenced by some environmental factors such as slope and aspect. Actually, a decrease of pH at the higher altitudes may be a result of leaching of base cations due to more precipitation and higher degree of slope (Tsui et al. 2004).

CONCLUSION

Survey of the relationship of plant species with other biotic and abiotic factors in forest ecosystems forms an important part of ecological studies. Vegetation cover, plant biomass are directly affected by physicochemical properties of soil along the altitudinal gradient. Composition and structure of plants communities are affected by environmental factors such as soil, topography and climatic conditions. In fact, these factors cause the establishment of plant species in different habitats. Overall results of this study indicated that altitude was the most important factor which can be effective on forest ecosystem composition and physicochemical properties of soil. In all vegetation layers, dominance of species changed with altitude. Density of trees showed a descending trend at lower and middle altitudes, but it was increased at higher altitudinal classes. For the shrub layer, the highest density was revealed at a higher altitude whereas the higher percentage of herbaceous species was found at a lower altitude and a decreasing trend was found along the altitudinal gradient. Evaluation of soil properties indicated that the values of some soil properties were increased with increasing altitude including pH, soil organic carbon and nitrogen content. There were no significant changes in base saturation, soil texture, bulk and particle density, potassium and phosphorus. These results can be helpful to scientists and forest managers to understand the interactive relationships between landscape, vegetation and soil properties in mountain ecosystems to implement protection plans, increase plant biodiversity and restore these forests.

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