https://doi.org/10.17221/54/2019-JFS

Evaluation of soil and litter quality indices using analysis hierarchical process (AHP) in Hyrcanian beech forest stands, Northern Iran (Case study: Korkoroud forests in Noshahr)

Atefeh Karimiyan Bahnemiri[1], Kambiz Taheri Abkenar[1], Yahya Kooch[2], Ali Salehi[1]*

[1]*Faculty of Natural Resource , Guilan University, Rasht, Guilan, Iran*
[2]*Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Mazandaran, Iran*
Corresponding author: taherikambiz@guilan.ac.ir; taherikambiz@yahoo.com

Citation: Karimiyan Bahnemiri A., Taheri Abkenar K., Kooch Y., Salehi A. (2019): Evaluating ecological potential of forest stands based on soil quality indices in Hyrcanian beech forest stands, Northern Iran (Case study: Korkoroud forests in Noshahr). J. For. Sci., 65: 397–407.

Abstract: The present study aimed to assess four forest stands, *Fagus orientalis* Lipsky-*Carpinus betulus* L.-*Acer velutinum* Boiss. (FO-CB-AV), *Fagus orientalis* Lipsky-*Carpinus betulus* L. (FO-CB), *Fagus orientalis* Lipsky-*Acer velutinum* Boiss. (FO-AV), and Pure *Fagus orientalis* Lipsky (FO) on basis of some soil quality indices in Mazandaran Province, northern Iran. Five samples per stand were taken (0–30 cm), the physical, chemical, and biological characteristics of soil were determined. Nine criteria were selected according to Principal Component Analysis as Minimum Data Set. According to the results, the highest value of litter Ca, density and biomass of earthworm, and C microbial biomass were found in FO-CB-AV. After applying the analytical hierarchy process, the calculated overall priority based on nine criteria showed that the FO-CB-AV stand had a higher ecological potential compared to the other stands. Therefore, the FO-CB-AV stand had more of appropriate conditions for improving soil quality in degraded forest regions compared to the other stands under current conditions.

Keywords: soil characteristics; forest ecosystems; ordinate hierarchically; canopy heterogeneity

The forest canopy affects many biochemical processes of soil organic and mineral layers (Wang et al. 2013). These forests of Hyrcanian have been under continuous degradation over the last few decades (Kooch et al. 2014), and there is an urgent need to maintain the functions of this unique forest ecosystem. Stability of forest ecosystems depends on the variability of soil characteristics under the effect of different tree species (Kooch et al. 2017). In mixed forests, canopy heterogeneity may create different structural units in terms of ecological, energy, and nutritional characteristics. Different management schemes have been planned for implementation such as documenting and exhibiting the forest disturbance as well as supervising and managing the region's remaining natural forest ecosystems (Poorzady, Bakhtiari 2009). Soil is an important component of terrestrial ecosystems as it preserves nutrient reserves and supports many biological processes (Marzaioli et al. 2010). The soil quality indices have been defined as soil processes and properties which are sensitive to changes in soil functions (Aparicio, Costa 2007). Different approaches have been developed

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for evaluating the soil quality indices including qualitative or semi-quantitative visual approaches (Ball et al. 2007; Shepherd 2009). Since the indicators have different effects on the development of forest stands, each of the indicators should be weighed given the importance for which we used analytical hierarchy analysis. This system is one of the most comprehensive systems designed for decision-making with multiple criteria, as this method provides the possibility of systematizing the problem in a hierarchical manner. It also takes into account different criteria of the problem (Ghodsipoor et al. 2006). This method involves a weighting matrix based on pairwise comparison of factors (Ayalew et al. 2005). These indicators have been suggested by most authors including minimum data set (MDS) based on the correlation between indicators and facilities, and Delphi data set (DDS) based on the importance of these indicators given soil quality (Govaerts et al. 2006; Zhang et al. 2011).

Having studied the application of AHP in evaluating urban forestry statistical methods, Jafari et al. (2012) stated that using AHP, the importance of each criterion and option could be calculated. The results suggested that the sampling method using aerial images which obtained the top priority in most criteria was chosen as the best method. The purpose of the present study is to evaluate the canopy composition of beech trees with accompany trees based on soil quality indicators according to Analytical Hierarchy Process (AHP). Using the results of this study, we can introduce suitable stands for increasing the quality and efficiency of soil in destructed ecosystems in the northern forests. Although the recent research has been in this regard, more about single trees and less has been expressed about the canopy composition of *Fagus orientalis* Lipsky trees with other trees. Since *Fagus orientalis* Lipsky is considered as valuable trees in the north of Iran, maintaining the production conditions in habitats by this species during exploitation is in the direction with continuous and optimal production by forest managers. Therefore, the study of the environmental conditions of this species is a necessity. So, the present study aimed to prioritize of forest stands based on soil and litter quality indices in hyrcanian beech forest stands. These results assist managers in managing degraded areas in north of country by employing suitable species with habitat conditions.

MATERIAL AND METHODS

Site description

The study was conducted in the third series forests of Korkoroud watershed and in watershed No. 38 located at northern latitude 36°33'15" to 37°45'36" and eastern longitude 51°23'45" to 51°27'45". The altitude of the whole series is 50 m and its maximum height is 1,400 m above sea level. Korkoroud forests are located at 2,807 hectares in the southern part of Chalus and Noshahr. In general, the soil of the studied area has calcareous and marlite origin. The mean annual rainfall is 890 mm and mean annual temperature is 17°C at the Noushahr city metrological station, which is 1 km away from the study area. The climate of the region is based on the Embereger weather formula with temperate winters. The relevant series has evolved a relatively deep soil, and at high points, sometimes shallow, soil texture is generally semi-heavy to heavy with clay content of more than 30 to 35%, indicating poor drainage of the soil, silty clay loam, and clay loam textures where the soil order name is Alfisols. The tree of beech (*Fagus orientalis* Lipsky), hornbeam (*Carpinus betulus* L.), alder (*Alnus subcordata* C.A.M., *Alnus glutinosa* Gaertn.), date-plum (*Diospyros lotus* L), and maple (*Acer velutinum* Boiss.) are dominant in the region, covering different altitudes (Shabani 2016).

Sampling method

After determining the studied area, single *Fagus orientalis* Lipsky trees (FO) were selected as the principal and central trees in the same diameter (50 cm). Then, the most important species associated with *Fagus* including *Carpinus betulus* L. (CB), *Acer velutinum* Boiss. (AV), and *Fagus orientalis* Lipsky (FO) were selected. The study treatments included FO tree surrounded by CB tree, FO tree surrounded AV tree, FO tree surrounded by CB and by AV trees, and FO tree surrounded by other FO trees, with five replications of each composition (Kooch et al. 2017).

Also, for greater precision, in this study first all tree groups were homogeneous in terms of physiographic conditions (slope, aspect and altitude), and the species surrounding the trees along with FO tree were preferably and frequently the same

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(Jeddi, Chaieb 2010). For the sampling of litters and then the most important characteristics of litter (C, N, C/N, K, P, Ca, and Mg) were measured (Hojati et al. 2008). Also, soil samples (30 × 30 × 30 cm) (Augusto et al. 2002) were taken in August 2017 under FO tree canopy (Kooch et al. 2017), on the four sides of the tree. Then, the samples were composited, a composited sample of each tree was selected, and eventually transferred to the laboratory for further work (Fig. 1).

In the laboratory, the most important physiochemical characteristics of the soil were measured (soil texture, bulk density, water content, pH, organic C, total N, C/N, available P, available K, available Ca, and available Mg). Total C and N contents in litter samples were determined in quadruplicate using dry combustion via an elemental analyzer (Fisons EA1108, Milan, Italy) calibrated by the BBOT [2, 5-bis-(5-tert-butyl-benzoxazol-2-yl)-thiophen] standard (Ther moQuest Italia s.p.a.). The litter P was measured by Olsen method (Olsen, Dean 1965). Finally, K, Ca, and Mg were measured by methods of atomic absorption and spectrophotometry (Ghazanshahi 2006).The obtained data were corrected for moisture content (Kooch et al. 2012).

The soils were air-dried and passed through 2-mm sieve. Bulk density was measured by Plaster (1985) method (clod method). Soil texture was determined by the Bouyoucos hydrometer method (Bouyocos 1962). Soil water content was measured by drying soil samples at 105°C for 24 hours. The soil pH was specified by an Orion Ionalyzer Model 901 pH meter in a 1:2.5, soil: water solution. Also, the soil organic C was determined via the Walkey-Black technique (Allison 1975).

The total N was measured using a semi-Micro-Kjeldhal technique (Bremner, Mulvaney 1982). The available P was determined by spectrophotometer through Olsen method (Homer, Pratt 1961). The available of K, Ca, and Mg (by ammonium acetate extraction at pH = 9) were determined by atomic absorption spectrophotometer (Bower et al. 1952).

The earthworms were collected during the soil sampling by hand sorting, washed with water, and weighed. Also, along with soil sampling, earthworms were collected manually and their density was measured. Earthworm biomass was determined according to the weight after 48 h of drying in the laboratory (Jordan et al. 1999).

Soil microbial respiration (SMR) was determined by measuring the CO_2 evolving in 3 days of incubation at 25°C (Alef 1995). Then, the microbial biomass of carbon and nitrogen was determined by trituration with chloroform and extracted with potassium sulfate through Valkey-Black and Kjeldahl technique (Aliasgharzad 2009). For soil nematodes, 100 g of the soil sample was determined, then isolated and counted using Biermann and centrifuge techniques and based on the dry weight of the soil, the number was calculated in 100 g of dry soil. For measuring microbial respiration of soil, fresh soil samples were stored at 4°C and microbial respiration was measured and calculated via bottle in pack method (Alef 1995).

Statistical analysis

Initially, the data normality was studied by Kolmogorov-Smirnov test and the homogeneity of the data variance was studied using Levon's test. One-way analysis of variance was employed to study the difference or non-difference between litter and soil properties in relation to different canopy compositions. Tukey test was also utilized for multiple mean comparison. Non-parametric Kruskal-Wallis test was used to study the significant changes in soil across different canopy compositions (given that the data were not normal and not turned normal through conversion method). Statistical analysis of all data was performed using software SPSS (Version 20, IBM). In order to evaluate the studied forest stands based on soil quality index among all of the measured characteristics, first, using the principal component analysis (PCA), the most important parameters were separated. Then, in order to evaluate different forest stands based on multiple criteria we used analytical hierarchical process (AHP). The first stage in AHP is to create a general structure in which the purpose, criteria, sub-criteria, and options are represented. In AHP, the components of each level are compared to their respective component at the higher level as a pair and their weights are calculated, known as relative weights. Then, by combining them the relative weights of each option are determined which are called absolute weight. In this study, the purpose was selecting the best stand based on 9 criteria at the second level and sub-criteria at the third level.

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RESULTS

Litter qualitative

The results of the mean comparison of litter characteristics showed a significant difference at $P < 0.05$ across all characteristics. FO-AV stand had the lowest carbon, C/N ratio. Also, the highest nitrogen was observed in FO-CB stand, and the minimum value was observed in FO-AV stand. In addition, the amounts of available P, available Ca in FO-CB-AV stand were higher than those of other stands. Finally, pure FO stand showed the maximum value of C (Table 1).

Physicochemical and microbial characteristics of the soil

The results of the mean comparison of soil characteristics showed a significant difference at $P < 0.05$ across all characteristics except for sand,

Table 1. Mean values (five replications in all case) of the litter and soil variable for study forest stands of *Fagus orientalis-Carpinus betulus* L.-*Acer velutinum* Boiss. (FO-CB-AV), *Fagus orientalis-Carpinus betulus* L. (F-C), *Fagus orientalis-Acer Velutinum* Boiss (F-A) and Pure *Fagus orientalis* (Pure F)

Litter and soil features	FO-CB-AV	FO-CB	FO-AV	Pure FO	*F*-test	*P*-value
	SE ± mean	SE ± mean	SE ± mean	SE ± mean		
Liter C (%)	44.16 ± 2.86^{c}	40.59 ± 1.8^{ab}	50.5 ± 1.57^{a}	50.24 ± 2.3^{b}	4.78	0.014
Liter N (%)	2.32 ± 0.13^{b}	2.41 ± 0.28^{a}	0.64 ± 0.03^{ab}	0.66 ± 0.05^{ab}	36.59	0.000
C/N Liter	19.37 ± 1.98^{ab}	18.33 ± 3.17^{ab}	79.28 ± 3.38^{a}	77.02 ± 6.31^{b}	71.76	0.000
P (%) Liter	3.66 ± 0.18^{a}	2.68 ± 0.16^{b}	1.92 ± 0.33^{bc}	2.64 ± 0.12^{ac}	9.49	0.001
Liter Ca (%)	1.94 ± 0.16^{a}	1.13 ± 0.13^{ab}	0.63 ± 0.09^{ac}	0.65 ± 0.09^{ac}	23.46	0.000
Liter K (%)	2.13 ± 0.05^{b}	2.25 ± 0.02^{a}	1.32 ± 0.12^{ac}	1.23 ± 0.12^{ac}	14.58	0.000
Liter Mg (%)	0.7 ± 0.07^{b}	0.70 ± 0.05^{a}	0.37 ± 0.02^{ac}	0.37 ± 0.01^{ab}	15.74	0.000
Bulk density ($g \cdot cm^{-3}$)	1.41 ± 0.06^{ab}	1.37 ± 0.03^{ac}	1.06 ± 0.01^{bc}	1.66 ± 0.09^{a}	16.78	0.000
Sand (%)	28 ± 1.48^{a}	45.4 ± 10.89^{a}	27 ± 3.37^{a}	26 ± 4.16^{a}	2.27	0.119
Silt (%)	38.6 ± 1.74^{c}	26 ± 3.8^{ab}	42 ± 1.78^{b}	42.4 ± 4.11^{a}	6.27	0.005
Clay (%)	33.4 ± 2.61^{a}	27.6 ± 7.46^{a}	31 ± 2.44^{a}	31.6 ± 2.63^{a}	0.2	0.889
Water contant (%)	39.45 ± 1.32^{b}	31.52 ± 0.88^{ab}	40.56 ± 2.43^{a}	38.25 ± 1.64^{c}	5.89	0.007
pH (1:2.5 H_2O)	7.43 ± 0.05^{a}	7.19 ± 0.18^{b}	6.04 ± 0.27^{c}	7.12 ± 0.21^{abc}	9.363	0.001
Soil C (%)	4.24 ± 0.46	4.74 ± 0.35	6.15 ± 0.97	6.9 ± 0.31	2	0.155
Soil N (%)	0.48 ± 0.05^{b}	0.49 ± 0.03^{a}	0.31 ± 0.04^{d}	0.33 ± 0.06^{c}	3.3	0.047
Soil C/N	8.76 ± 0.32^{abd}	9.57 ± 0.16^{abc}	19.38 ± 0.79^{b}	20.34 ± 0.73^{a}	104	0.000
Available P ($mg \cdot kg^{-1}$)	33.06 ± 2.17^{a}	24.15 ± 2.75^{b}	13.51 ± 1.67^{ac}	27.09 ± 4.68^{c}	7.21	0.003
Available K ($mg \cdot kg^{-1}$)	523.6 ± 19.52^{a}	335.5 ± 25.75^{ab}	168.6 ± 13.74^{ac}	345.8 ± 31.26^{ab}	34.99	0.000
Available Ca ($mg \cdot kg^{-1}$)	245.6 ± 12.33^{c}	247.7 ± 17.9^{b}	108.2 ± 14.8^{abc}	277 ± 8.79^{a}	29.74	0.000
Available Mg ($mg \cdot kg^{-1}$)	62 ± 1.3^{a}	58.6 ± 2.48^{b}	40 ± 4.46^{abc}	56.6 ± 2.46^{c}	11.33	0.000
C microbial biomass ($mg \cdot kg^{-1}$)	801.6 ± 4.73^{a}	734.8 ± 16.82^{b}	564.8 ± 21.06^{ab}	500.8 ± 33.5^{ab}	42.51	0.000
N microbial biomass ($mg \cdot kg^{-1}$)	63.52 ± 2.31^{a}	48.39 ± 2.2^{b}	44.95 ± 4.67^{ac}	42.13 ± 5.77^{ac}	5.55	0.008

*results from the ANOVAs are included (*F*-test and *P*-value), different letters in each line indicate significant differences ($P < 0.05$ by Duncan test) between forest stands

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Table 2. Kruskal-Wallis test and ranking average of biological characteristics in different compositions

	Earthworm density ($n \cdot m^{-2}$)	Earthworm biomass ($mg \cdot m^{-2}$)	Nematode ($n \cdot 100$ g soil)	Microbial respiration ($mg_{CO_2} \cdot g^{-1} \cdot day^{-1}$)
Fagus-Carpinus-Acer	57.05	56.88	54.8	52.02
Fagus-Carpinus	53.6	54	45.58	44.28
Fagus-Acer	23.5	23.5	38.22	37.22
Pure *Fagus*	27.85	27.62	23.4	28.48
Chi-square	6.61	7.48	49.44	37.85
Df	3	3	3	3
Sig.	0.000	0.000	0.000	0.011

Df – degree of freedom, Sig. – significant at $P < 0.05$, n – number of individuals

clay, organic C and water content. FO-AV stand had the highest total nitrogen and silt content. Also, the pH, water contant, available P, available K, available Ca, and microbial biomass of carbon, nitrogen in FO-CB-AV stand were higher than those of other stands. Finally, pure FO stand showed the minimum value of and C/N ratio, and microbial biomass of carbon, nitrogen (Table 1).

Biological characteristics of soil

The soil biological characteristics including soil density and earthworm biomass, nematodes, and microbial respiration, were measured across different stands. Non-parametric Kruskal-Wallis test was used for abnormal data. The results revealed that at the confidence level of 95%, each of the variables was significant among the different stands. According to the results, FO-CB-AV stand had the maximum earthworm density, while FO-AV showed the minimum value. Also, the highest amount of earthworm biomass was found in FO-CB stand, while the lowest minimum was observed in FO-CB-AV, pure FO, and FO-AV stands. Finally FO-CB-AV stand had the maximum total nematode and microbial respiration (Table 2).

Prioritization of forest stands

The characteristics of N, C/N, Ca, K of litter, bulk density, soil C/N, C microbial biomass, earthworm density, and earthworm biomass were selected as the minimum data set (Table 3). The forest stands were evaluated by AHP method using nine characteristics of soil and litter characteristics. The incompatibility rate of each of the soil and litter characteristics was determined by the method (Fig. 2 and 3).

In accordance with the results, the incompatibility rate for all parameters was calculated to be less than or equal to 0.1. The highest mean relative weight regarding litter N, litter K, litter Ca, C/N ratio of litter, bulk density, soil C/N, C microbial biomass, earthworm density, and earthworm biomass belonged to FO-CB-AV stand. FO-CB stand showed the highest amount of N and K of litter, and FO-CB-AV stand had the largest values of Ca of litter, density and biomass of earthworm, and C microbial biomass. Also, the highest C/N of litter was observed by FO-AV stand (Fig. 1). The contribution of indicators to evaluating different forest stands and selection of the best forest stands were calculated through weighting each index (Fig. 3). Also, according to the results of the sensitivity analysis, the highest potential based on the overall priority of the quality indicators belonged to FO-CB-AV, FO-CB, FO-AV, and pure FO stands, respectively (Table 4 and Fig. 4).

DISCUSSION

The presence of high amounts of nutrients in forest stands can represent more be suitable habitat conditions. Our results clearly indicated differences in the forest floor and soil properties under pure beech stands compared to mixtures with hornbeam and maple. The parameters related to biological activities were generally lower under pure beech, while those associated with carbon content were higher. The evaluation of existing forest stands using AHP revealed that the highest priority of soil and litter nutrients was found in FO-CB-AV for-

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Table 3. PCA results of litter and soil indices having significant differences between the different forest stands

Principal components	PC1	PC2
Eigen value	10.075	4.44
Percent	40.3	17.762
Cumulative percent	40.3	58.061
	Eigen vectors PC1	Eigen vectors PC2
Litter C	–0.612	0.28
Litter N	**0.914**	–0.186
Litter C/N	**0.928**	0.132
Litter P	0.661	0.305
Litter Ca	**0.872**	–0.008
Litter Mg	0.779	–0.174
Litter K	**0.835**	–0.231
Bulk density	0.233	0.863
Sand	0.422	–0.298
Silt	–0.512	0.328
Clay	–0.167	0.156
Water contant	–0.301	0.058
pH	0.621	0.474
Soil C	–0.424	0.263
Soil N	0.662	0.048
Soil C/N	**–0.917**	0.218
Available P	0.608	0.437
Available K	0.753	0.427
Available Ca	0.406	0.744
Available Mg	0.705	0.418
C microbial biomass	**0.852**	–0.270
N microbial biomass	0.595	–0.090
Earthworm density	**0.878**	–0.045
Earthworm biomass	**0.695**	–0.009
Total nematode	0.585	–0.364
Soil microbial respiration	0.341	–0.104

values in bold – important characteristics of litter and soil from the principal component analysis

est stand. So far, no accurate evaluation has been performed on the stands in the study area using multiple criteria. Kooch and Bayranvand (2017) reported that the higher forest floor N content and lower organic layer thickness reflect faster litter decay under mixed beech stands. According to the results, the soil nitrogen across different stands was significantly different in the following order: FO-CB > FO-CB-AV > pure FO > FO-AV. These differences may be due to different foliage characteristics and litter quality (Nsabimana et al. 2008; Haghdoost et al. 2011). Therefore, the faster turnover of forest floor N in the organic layer of the mixed stands can be explained by differences in the forest floor quality (Kooch, Bayranvand 2017). The increased forest floor quality in mixed beech stands was also paralleled by enhanced soil fertility (i.e., low acidity, higher amounts of N, P, K, Ca, and Mg, and low C/N ratio) in the upper mineral soil (Jacob 2010).

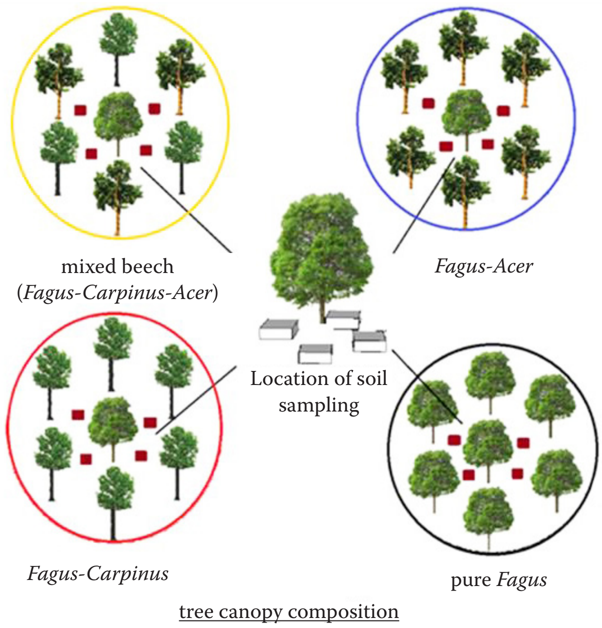

Fig. 1. Overview of the sampling method

The striking differences between beech-dominated stands and mixed stands suggest that the presence of beech trees contributed to the differences observed in the soil acidity and available nutrients. The relative mean weight of the forest stands of FO-CB and FO-CB-AV shows that these two stands have the highest levels of litter Ca and K compared to other stands. The low available Ca and K under stands with abundance of *Fagus* species is the result low pH in this stands compared of other stands without abundance of Fagus species (Driscoll et al. 2001; Langenbruch et al. 2012); AV and CB species also raise soil Ca, K, and pH (Bayranvand 2015). Accordingly, the two factors of leaf loss and soil pH have caused changes in the amount of nutrients under the stands (Langenburch et al. 2012). Finally, the composition of FO, CB, and AV species caused increased litter decomposition under the existing stands, thereby increased Ca, Mg, and K under these stands com-

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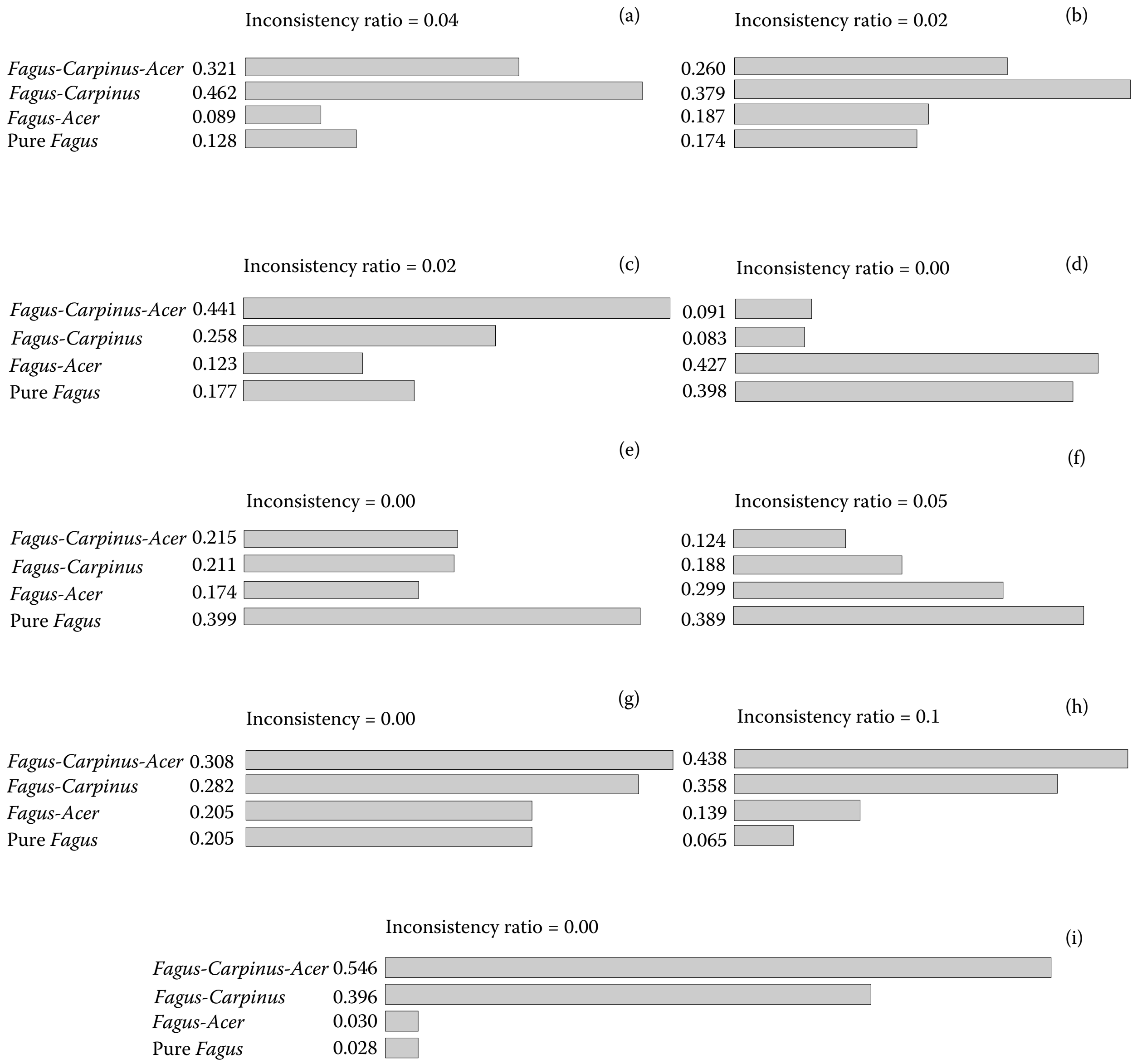

Fig. 2. Local priority of different forest stands on basis of litter N (a), litter K (b), litter Ca (c), litter C/N (d), bulk density (e), soil C/N (f), C microbial biomass (g), earthworm density (h), and earthworm biomass (i)

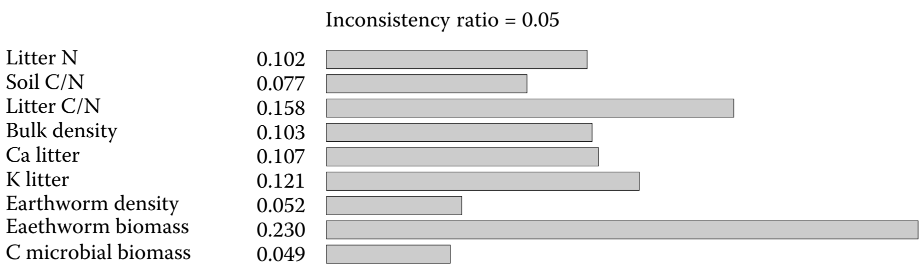

Fig. 3. Criteria priority based on arithmetic mean

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Table 4. Overall priority of different forest stands on based on litter and soil indices

Forest Stand	Overall priority	Class
Fagus-Carpinus-Acer	0.308	1
Fagus-Carpinus	0.282	2
Fagus-Acer	0.205	3
Pure *Fagus*	0.205	4

class 1-4 – prioritize the stands based on the results analysis hierarchical process (AHP)

pared to pure FO stand. The results of this study are consistent with the findings of Gao et al. (2014). The ability of tree species to change the chemical soil properties related to acidity and base cations has been shown to be largely mediated by forest floor quality (Dijkstra 2003; Reich et al. 2005), which fits our results concerning forest floor quality and soil acidity in stands with different diversity levels. The higher forest floor quality and improved soil fertility supported greater biological activities in the mixed stands than in the pure beech (Knops et al. 2002).

The increase Of earthworm density and biomass was found under FO-CB-AV stand compared to other stands, which is due to the increase in soil Ca and pH under FO-CB-AV stand. The results of this study are in line with the results of Nilsson et al. (2001). Also, the low earthworm density and biomass under pure *Fagus orientalis* stand suggests a reduction in pH and Ca (Mevin et al. 2013), and a high C/N in litter directly influencing the reduction in soil organisms (Kooch et al. 2018). In general, more earthworms preferred litters high in nutrients with low C/N (Kooch et al. 2017). Sun et al. (2013) reported that the good condition of soil (higher pH, N, and available nutrients) under mixed beech cover can cause greater activities of soil organisms, earthworm, and nematodes (Sun et al. 2013; Kooch et al. 2016) following decomposition of organic matter. The evaluation of the studied stands revealed that pure FO and FO-AV stands had a higher soil C/N than the rest of the stands. The results of our study are congruent with the findings of Bayranvand et al. (2015). In addition to soil total N, soil C/N is an important index of the balance of nutrients (Kara et al. 2014). The rise of frequency of Fagus species increases the C/N ratio (Cao et al. 2014). The high C/N ratio, reduces absorption of mineral nitrogen by plants due to the low activity of microorganisms in the soil (Adel et al. 2014). Soil microbial respiration is a major process which controls the C loss from terrestrial ecosystems (Haque et al. 2014).

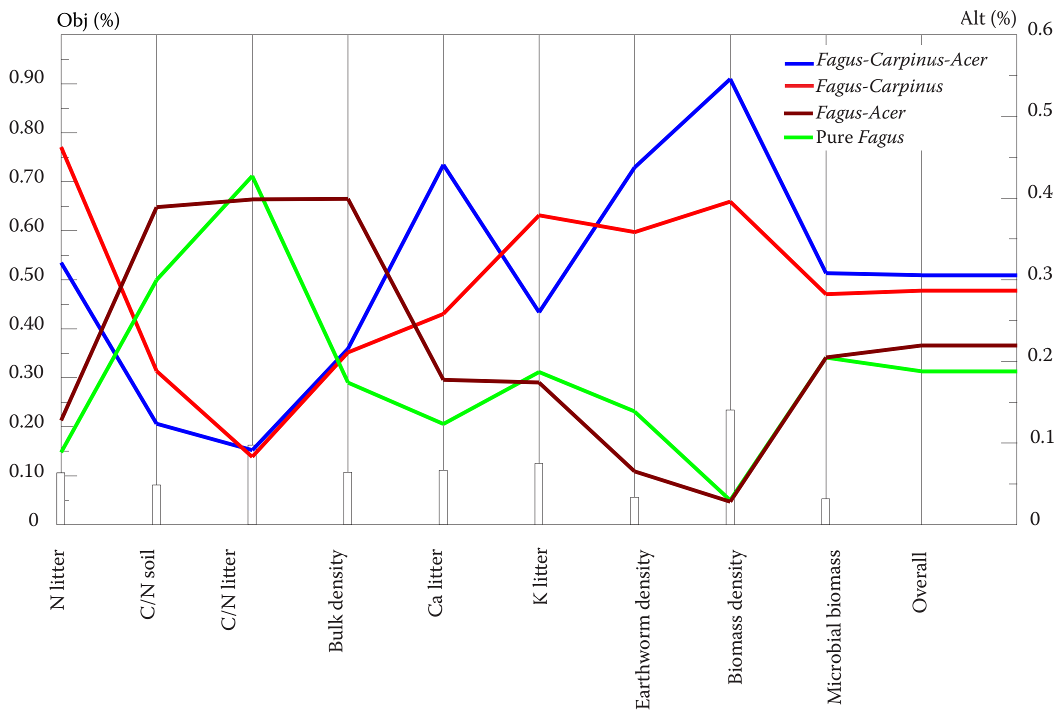

Fig. 4. Sensivity analysis based on performance alternative

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Different values of soil microbial index in the study area suggested that the litter quality values for different stands are very variable (Singh et al. 2012). The results of the present study indicated that FO-CB-AV and pure FO stands had the highest and lowest amount of C microbial biomass, respectively, which can be attributed to good litter quality and the higher rate of decomposition (Burton et al. 2010). Consistent with the results of this study, Kooch et al. (2017) found a negative relationship between soil C/N and soil microbial activity. However, the results of the present study are inconsistent with the results of Kooch et al. (2018). They stated that the pure *Fagus orientalis* stand had the maximum amount of C microbial biomass. The calculated overall priority also suggested the suitability of the conditions for FO-CB-AV (based on the criteria studied) compared to the osther stands, followed by FO-CB, FO-AV, and pure FO, respectively. In a study in Darabkala, Sari, Kooch and Najafi (2010) concluded that *Acer velutinum* stand had the maximal ecological potential in the region while the mixed stand showed the lowest overall priority.

Bayranvand (2015) evaluated some of the qualitative indicators of the type of the studied area. He found that the mixed types of *Acer velutinum* and alder in terms of quality index were more suitable than other types, while the mixed types of *Fagus orientalis-Carpinus betulus* L. and *Fagus orientalis* presented the lowest quality index. The present study has been inconsistent with the above finding, So that the best conditions belonged to FO-CB stand.

Indeed, the results of this study indicated that the changes in the canopy composition from pure FO to mixed stands of FO along with other broadleaved species appeared to increase the intensity of C and N cycling. In response, it can influence the rate of soil acidification, nutrients, and biological activities in the top soil. In addition, the admixture of valuable mixed broad-leaved tree species to beech stands – i.e., CB and AV increased the size and rate of N cycling between soil and vegetation and also within the soil. The results suggest that in the sites allowing the production of broadleaf tree species with nutrient-rich, easily decomposable foliage, the establishment and promotion of these species is an important silvicultural tool to counteract natural or anthropogenic soil acidification and to maintain soil productivity.

CONCLUSION

The admixture of valuable broad-leaved tree species to beech stands – i.e., hornbeam and maple – increased the size and rate of N cycling between soil and vegetation and also within the soil. According to the results, the highest litter N content of litter was in FO-CB > FO-CB-AV> FO > FO-AV respectively. Also according to the results obtained, FO-CB stand had the highest amount of litter K, while FO-CB-AV stand showed the highest amounts of litter Ca, earthworm density and biomass, and C microbial biomass. Also, the highest C/N ratio of litter was claimed by FO-AV stand. According to the results of the sensitivity analysis, the highest potential based on the overall priority of the quality indicators belonged to FO-CB-AV, FO-CB, FO-AV, and pure FO stands, respectively. Overall, it can be concluded that FO-CB-AV stands compared to other stands more improved soil characteristics.

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Received for publication May 4, 2019
Accepted after corrections October 23, 2019