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Soil Quality Indices in Pure and Mixed Forest Stands of Southern Caspian Region

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ABSTRACT The present study aimed to assess pure planted species (*i.e.*, *Alnus subcordata* L., *Populus deltoids* L., *Taxadium distichum* L. Rich) and a mixed natural forest (*i.e.*, dominated by *Quercus castaneifolia* C. A. Mey. - *Carpinus betulus* L. - *Parrotia persica* C. A. Meyer) on basis of some soil quality indices in Mazandaran Province, northern Iran. Sixteen samples per stand were taken from the top 10 cm of soil and bulk density, texture, water content, pH, EC, organic C, total N, available nutrients, earthworm biomass, microbial respiration, fine root biomass with organic C and total N of litter layer were determined. Nine criteria (*i.e.*, silt, EC, K, Ca, Mg, microbial respiration, fine root biomass, nitrogen mineralization and litter C/N) were selected according to Principal Component Analysis (PCA) as Minimum Data Set (MDS). The analytical hierarchy process (AHP) method was employed to assign the data integration in an index. The calculated overall priority based on nine criteria, showed that the *A. subcordata* forest type had higher ecological potential (0.370) compared to the other stands. Whereas, *P. deltoids* mixed natural forest and *T. distichum* with ecological potential of 0.295, 0.213 and 0.122 had next priorities, respectively. As a conclusion, the N-fixing species, *A. subcordata*, was found more efficient in improving soil quality in degraded forest regions.

Key words: *Broad-leaved species, Forest Seed Centre of Khazar, Hyrcanian Forest, Needle-leaved species, Soil characteristics*

1 INTRODUCTION

The Hyrcanian or northern forests of Iran stretch up to an altitude of 2800 m above sea level and encompass different forest types thanks to the 80 tree and shrub species found there (Sagheb-Talebi *et al.*, 2014). It is obvious that these forests 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. National forest management officials have acknowledged this fact and have initiated action for the sustainable management of the Caspian Forests. Different management schemes have been planned for implementation, such as documenting and exhibiting the forest disturbance, and supervising and managing the region's remaining natural forest ecosystems (Poorzady and Bakhtiari, 2009). Abandoning agriculture and tree planting for commercial or restoration purposes are also two main methods of forest restoration. There have been many

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plantations of endemic and exotic species in degraded forest areas which have certainly had many effects on the ecosystem, specifically on soil fertility and nutrients. Despite the existence of extensive afforested areas and the amount of time since plantation, few studies offer a critical overall examination of the development and ecological consequences of afforestation in the Hyrcanian region (Haghdoost *et al.,* 2011), especially those related to soil properties.

Soil is an important component of terrestrial ecosystems because it preserves nutrient reserves and supports many biological processes. To preserve this resource and its functions, it is necessary first of all to know the conditions and the processes occurring in it, for example, through the determination of soil quality (SQ) (Carter, 2002; Marzaioli *et al.*, 2010). The SQ indices have been defined as soil processes and properties that are sensitive to changes in soil functions (Aparicio and Costa, 2007). It is important to build a simple, sensitive, and workable indicator method for SQ evaluation (Dumanski and Pieri, 2000). The SQ may be affected by human management practices (*e.g.* forest plantation) because these may cause alterations in soil physical, chemical and biological properties (Caravaca *et al.,* 2003).

Different methods have been developed for SQ evaluation, from qualitative or semi quantitative visual approaches (Ball *et al.,* 2007; Shepherd, 2009) to quantitative methods based on laboratory analysis and calculating SQ indices using mathematic and statistical methods (Andrews *et al.,* 2004). The SQ indices have been successfully applied at many scales and locations (Arshad and Martin, 2002; Aparicio and Costa, 2007; Masto *et al.,* 2008). These indicators should be a combination of chemical, physical, and biological properties (Aparicio and Costa, 2007; Qi *et al.,* 2009; Lima *et al.,* 2013). Several authors have proposed sets of SQ indices (Masto *et al.,* 2008; Marzaioli *et al.,* 2010), and have evaluated SQ based on the total data set (TDS) indicator method they selected. Also, representative indicators were suggested by many authors, such as the minimum data set (MDS), selected according to correlation between indicators and measurement facility and the Delphi data set (DDS), selected according to the importance of the indicators to SQ based on the opinion of experts (Herrick, 2000; Zhang *et al.,* 2004; Rezaei *et al.,* 2006; Govaerts *et al.,* 2006; Zhang *et al.*, 2011).

A common feature of these based-indicator methods is that they are all identified and described by scientists and land managers according to their own terminology (Ditzler and Tugel, 2002). The present study aimed to assessment of planted species (*Alnus subcordata* L., *Poplus deltoids* L., *Taxadium distichum* L. Rich) and a mixed natural forest (dominated by *Quercus castaneifolia* C. A. Mey. - *Carpinus betulus* L. - *Parrotia persica* C. A. Meyer) on basis of SQ indices in Mazandaran Province, northern Caspian region.

2 MATERIALS AND METHODS

2.1 Study area

The study area, Forest Seed Centre of Khazar, is located in the southern of Mahmudabad City, in Mazandaran Province, north of Iran. This area expends between 36° 38′ N and 52° 16′ E latitudes and longitudes, respectively. The study plantations composed of *A. subcordata* L., *P. deltoids* L. and *T. distichum* L. Rich. These plantations were planted in 1999 at a spacing of 4×4 m (Soleimany Rahimabady *et al.,* 2015). Beside these planted stands, a mixed natural forest dominated by *Q. castaneifolia* C. A. Mey. – *C. betulus* L. – *P. persica* C. A. Meyer was considered (Figure 1). The mean of maximum and minimum temperature were 24.4°C (in June) and 7.6°C (in December), respectively. The most of annual precipitation was 163 mm (in October) (Soleimany Rahimabady *et al.,* 2015). The climate is temperate moist and the mean of altitude from sea surface at the study site is nearly 30 m. The total slope aspect of region is facing north (Soleimany Rahimabady *et al.,* 2015).

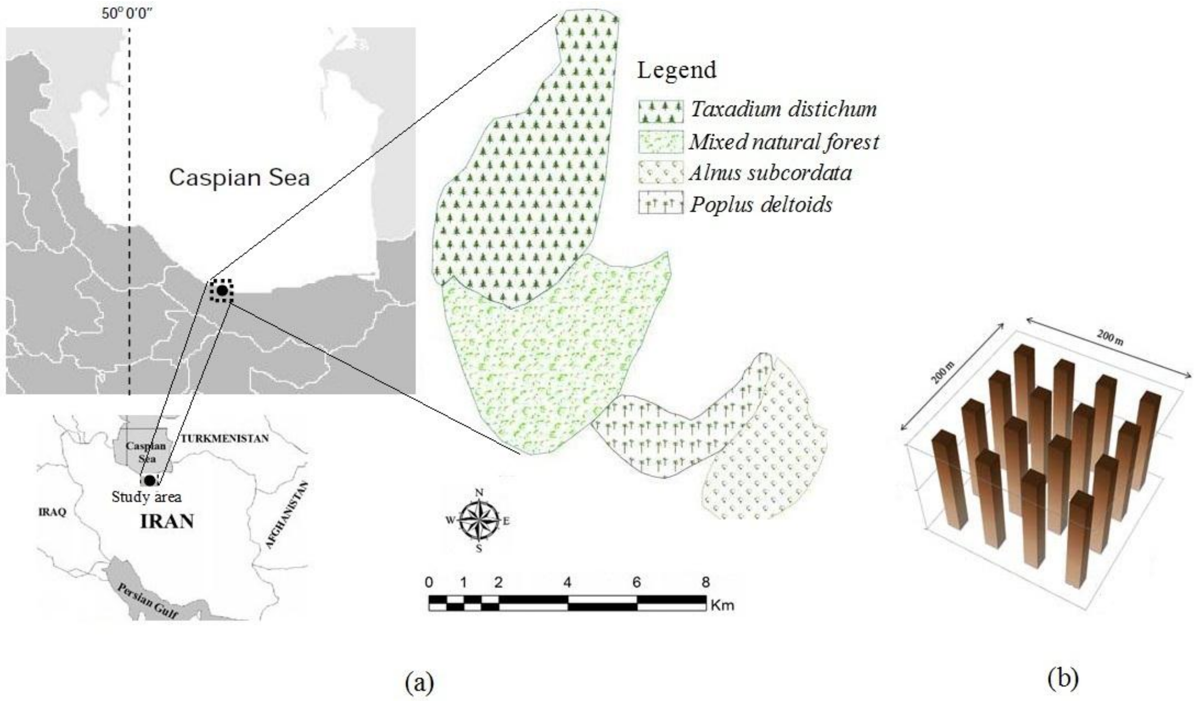

Figure 1 Site locations of study area in Mazandaran Province, north of Iran (a) and schematic representation of the experimental design adopted for each forest stand (b)

2.2 Soil sampling and laboratory analysis

Four hectare areas (200×200 m) were selected for each stand forest in the study region. Soil sampling was carried out during the summer time using a randomly systematic method. Four soil profiles (20×20 cm) were dug along the four parallel transects in the central part of each afforested stand, thus resulting in 16 soil samples for each stand at 0-10 cm depth (Lafleur *et al.,* 2015). The same sampling procedure was carried out also for the mixed natural forest. Litter samples, simultaneously with soil samples, were collected from each stand. Total C and N contents in litter samples were determined in quadruplicate, using dry combustion with an elemental analyzer (Carrillo *et al.,* 2012). 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 (Bouyoucos, 1962). Soil water content was measured by drying soil samples at 105° C for 24 hours. Soil pH was determined using an Orion Ionalyzer Model 901 pH meter in a 1:2.5, soil: water solution. EC (electrical conductivity) was determined using an Orion Ionalyzer Model 901 EC meter in a 1:2.5, soil: water solution. Soil organic C was determined using the Walkey - Black technique (Allison, 1975).

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

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collected during the soil sampling by hand-sorting, washed with water and weighed. Biomass was defined as the weight of the worms after drying for 48 h on filter paper at room temperature (Jordan *et al.*, 1999). Soil microbial respiration (SMR) was determined by measuring the CO_2 evolved in 3 days incubation experiment at 25°C (Alef, 1995). Fine roots (< 2 mm diameter) were removed from each sample and dried at 70 °C to a constant mass (Neatrour *et al.*, 2005). The buried-bag technique was used to estimate soil N mineralization (Asadiyan *et al.*, 2013). Whole of these soil characters were chosen by expert opinion and literature review as important indices in soil quality (Herrick, 2000; Zhang *et al.*, 2004; Govaerts *et al.*, 2006; Rezaei *et al.*, 2006; Zhang *et al.*, 2011). Table 1 is showing the values of studied characteristics in litter and soil layers.

2.3 Data analysis and processing

In order to synthesize all the information provided by selected parameters, a SQ index was calculated. According to Karlen *et al.* (2003), three steps are involved in the elaboration of a quality index: (1) definition of a Minimum Data Set (MDS), (2) score assignation to each indicator by mathematical functions and (3) data integration in an index. Principal component analysis (PCA) is widely used for defining a MDS and reducing data redundancy through correlation analysis among soil properties (Andrews *et al.*, 2002; Govaerts *et al.*, 2006; Li *et al.*, 2007).

Table 1 Mean values (sixteen replications in all case) of the litter and soil variable for study forest stands of *Alnus subcordata* C. A. M. (AS), *Poplus deltoids* L. (PD), *Taxadium distichum* L. Rich. (TD) and mixed natural forest of *Quercus castaneifolia* C. A. Mey. - *Carpinus betulus* L. - *Parrotia persica* C. A. Meyer (QC-CB-PP)

Litter and soil features	AS	PD	TD	QC-CB-PP	*F* test	*p* value
Litter C/N	21.6^{d}	29.28^{c}	63.67^{a}	42.74^{b}	90.393	0.000
Bulk density (g cm^{-3})	1.59^{a}	1.56^{ab}	1.33^{c}	1.41b^{c}	5.325	0.003
Sand (%)	32.50	25.87	29.00	22.87	1.255	0.298
Silt (%)	34.62^{b}	39.75^{ab}	42.37^{ab}	46.75^{a}	3.712	0.016
Clay (%)	32.87	34.37	28.62	30.37	1.032	0.385
Water content (%)	36.76	37.75	34.56	38.72	1.165	0.330
pH (1:2.5 H_2O)	7.16^{a}	7.05^{a}	6.01^{c}	6.56^{b}	12.277	0.000
EC (ds m^{-1})	0.29^{a}	0.26^{b}	0.16^{d}	0.22^{c}	32.156	0.000
Soil C/N	4.50b	5.46^{b}	28.70^{a}	10.37^{b}	11.688	0.000
Available P (mg kg^{-1})	24.57^{a}	22.30^{a}	12.65^{b}	15.79^{b}	15.904	0.000
Available K (mg kg^{-1})	337.37^{a}	328.25^{a}	156.68^{c}	257.81^{b}	35.084	0.000
Available Ca (mg kg^{-1})	256.25^{a}	208.68^{b}	122.81^{d}	177.31^{c}	50.674	0.000
Available Mg (mg kg^{-1})	57.43^{a}	52.12^{b}	36.81^{d}	44.00^{c}	34.335	0.000
Earthworm biomass (mg m^{-2})	41.98^{a}	34.50^{ab}	6.23^{c}	26.26^{b}	10.696	0.000
Soil microbial respiration (mg CO_2-C g_{soil}^{-1} day^{-1})	0.48^{a}	0.43^{b}	0.30^{d}	0.36^{c}	22.856	0.000
Fine root biomass (g m^{-2})	64.60^{b}	65.09^{b}	36.93^{c}	94.18^{a}	99.292	0.000
Nitrogen mineralization rate (mg kg^{-1} day^{-1})	0.31^{a}	0.08^{b}	-0.26^{c}	-0.24^{c}	95.401	0.000

*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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To select a representative MDS, the PCA method was used because of its MDS selection ability (Doran and Parkin, 1994). We performed standardized PCA of all data that showed statistically significant differences between different forest types via one-way analysis of variance (ANOVA) using the SPSS 19.0 statistical software package. The analytical hierarchy process (AHP) method was used to assign the data integration in an index (Lai *et al.*, 2002; Komac, 2006). An abstract view of such a hierarchy is shown in Figure 2.

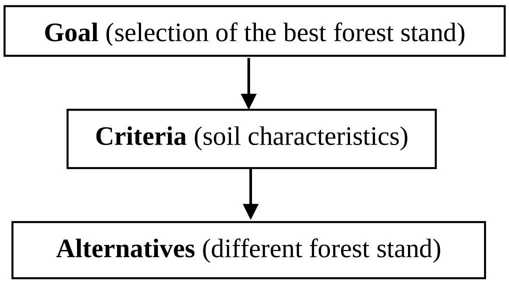

Figure 2 A schematic diagram of the AHP process

In this research, Expert Choice software was used for determination of the best forest stand on basis of SQ indices using of AHP.

3 RESULTS

The soil characteristics having significant differences between the different forest types, thus, included for the PCA were: bulk density, silt, pH, EC, soil C/N, available nutrients (*i.e.*, P, K, Ca and Mg), earthworm biomass, microbial respiration, fine root biomass, nitrogen mineralization and litter C/N (Tables 1 and 2). The first and two component had Eigen value >1 (Table 2). The highly weighted variables under PC1 and PC2 were litter C/N ratio (-0.917), nitrogen mineralization (0.826), Ca (0.825), K (0.810), Mg (0.804), microbial respiration (0.785), EC (0.783), fine root biomass (0.759) and Silt (0.710), thus, were retained for the MDS (Table 2).

Table 2 PCA results of SQ indices having significant differences between the different forest stands

Principal components	**PC1**	**PC2**
Eigen value	6.843	1.371
Percent	48.879	9.791
Cumulative percent	48.879	58.669
	Eigen vectors- PC1	Eigen vectors- PC2
Bulk density (g cm^{-3})	0.451	0.042
Silt (%)	-0.264	***0.710***
pH (1:2.5 H_2O)	0.664	0.078
EC (ds m^{-1})	***0.783***	0.111
Soil C/N	-0.623	-0.168
Available P (mg kg^{-1})	0.694	-0.145
Available K (mg kg^{-1})	***0.810***	0.141
Available Ca (mg kg^{-1})	***0.825***	0.106
Available Mg (mg kg^{-1})	***0.804***	-0.118
Earthworm biomass (mg m^{-2})	0.635	0.023
Soil microbial respiration (mg CO_2-C g $soil^{-1}$ day^{-1})	***0.785***	-0.107
Fine root biomass (g m^{-2})	0.347	0.759
Litter C/N	-0.917	-0.060
Nitrogen mineralization rate (mg $kg^{-1}day^{-1}$)	***0.826***	-0.400

Bold-italic factor loading correspond to the indicators included in the MDS

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Different forest types were assessed, using of AHP approach, with respect to nine criteria of soil properties that were retained for the MDS (Figure 3). Inconsistency ratio values for every soil features in AHP are shown in Figures 3 and 4. According to our findings, the inconsistency ratios were less than 0.1 for whole of characters. Results are indicating that the maximum of local priority is belonging to *A. subcordata* on basis of EC, available nutrients (K, Ca and Mg), microbial respiration and N mineralization. Mixed natural forest had higher local priority with regarding to silt and fine root biomass characters, whereas the *T. distichum* had more local priority based on litter C/N (Figure 3). Determination of the criteria role in assessment of different forest types and selection of the best forest stand as well as calculation of criteria weight were also carried out. For this purpose, the matrixes of paired comparisons were prepared and the criteria weights were calculated by arithmetic mean (Figure 4). Sensivity analysis is according to reported results also (Figure 5). The calculated overall priority showed that based on soil quality indices, the *A. subcordata* (0.370) forest type had higher ecological potential compared to the other stands. Whereas, *P. deltoids* (0.295), mixed natural forest (0.213), and *T. distichum* (0.122) had next priority, respectively (Table 3).

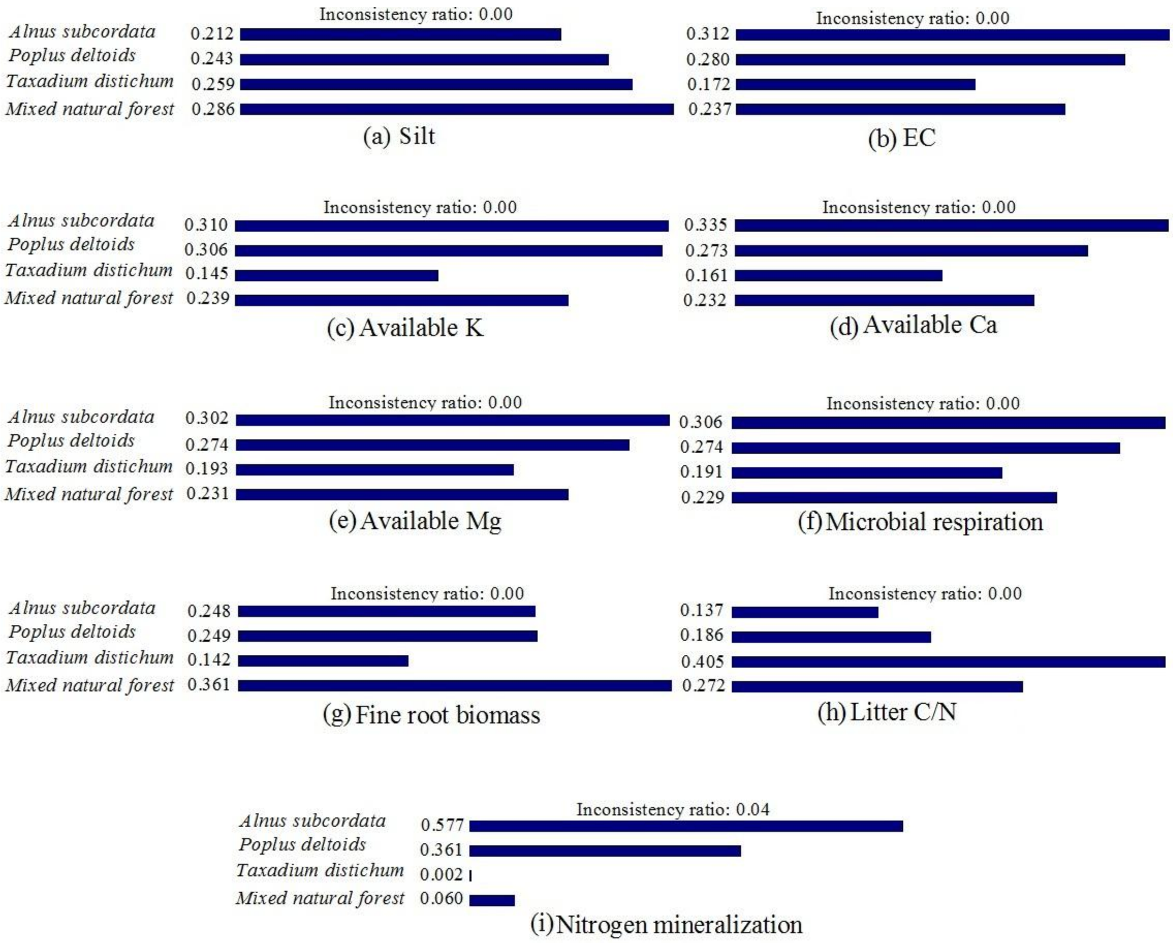

Figure 3 Local priority of different forest stands on basis of soil silt (a), EC (b), available K (c), available Ca (d), available Mg (e), microbial respiration (f), fine root biomass (g), litter C/N (h) and nitrogen mineralization (i)

Figure 4 Criteria priority based on arithmetic mean

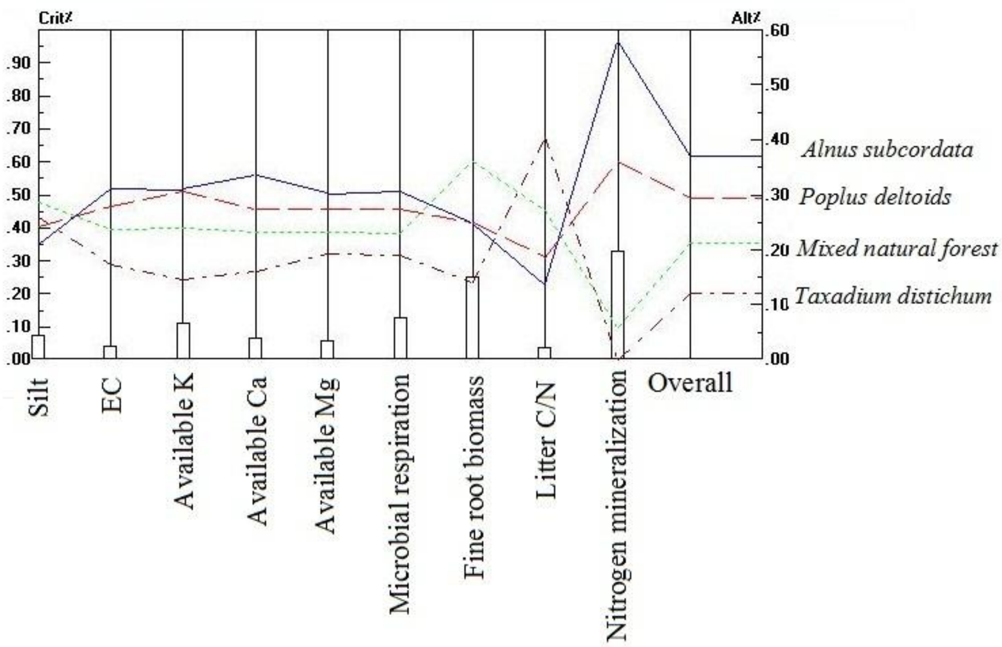

Figure 5 Sensivity analysis based on performance alternative

Table 3 Overall priority of different forest stands on based on soil quality indices

Forest types	Overall priority	Class
Alnus subcordata	0.370	1
Poplus deltoids	0.295	2
Mixed natural forest	0.213	3
Taxadium distichum	0.122	4

4 DISCUSSION

The study of SQ indices under each species was an approach to evaluate the performance of that species. Almost all of the nine indicators used with the MDS method can be found in previously created MDS indicator methods (Doran and Parkin, 1994; Karlen and Stott, 1994; Larson and Pierce, 1994; Singer and Ewing, 2000; Ditzler and Tugel, 2002; Masto *et al.,* 2008; Marzaioli *et al.,* 2010; Soleimany

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Rahimabady *et al.,* 2015). Among soil texture fractions, silt content was significantly higher under mixed natural forest in comparison to *T. distichum*, *P. deltoids* and *A. subcordata* plantation. This suggests a different evolution of the soil profile when covered by forest, especially in terms of erosion (Kooch *et al.*, 2012 a, b).

The soil EC of the different species significantly follows the *A. subcordata* > *P. deltoids* > mixed natural forest > *T. distichum*. These differences may be caused by different foliage properties and the litter quality (Nsabimana *et al.,* 2008; Haghdoost *et al.*, 2011). Available K of soils of the *A. subcordata* was significantly higher than the soils of *P. deltoids*, mixed natural forest and *T. distichum*. In the present study, *A. subcordata* plantation with the highest K content can be attributed to rapid recycling of soil nutrients from trees (Chase and Singh, 2014). The lowest soil available K in *T. distichum* might be related to K retranslocation, nutrition and nutrient return (Rostamabadi *et al.,* 2013). Hardwoods, including *A. subcordata*, typically contain a much greater amount of Ca^{2+} than to conifers, when growing on comparable sites (Ovington, 1956; Ovington, 1962). Soil Mg^{2+} had often been reported to be an element prone to leaching (Laskowski *et al.,* 1995). The difference in the behavior of Mg may be due to the selective immobilization of nutrients by microbes (Rostamabadi *et al.*, 2013). According to Hagen-Thorn *et al.* (2004), conifer species compared to hardwood stands, due to higher tendency to absorb base cations namely Mg makes reduced concentrations of these nutrients in the soil.

SMR was the lowest in *T. distichum* plantation as compared to other forest types. The highest SMR was found under *A. subcordata* plantation than can be related to the content of total N as an N-fixing species (Mo *et al.,* 2004). Fine root biomass was significantly greater for the mixed natural forest than for the plantations. Lee and Jose (2003) reported that hardwood forests had greater fine root biomass production compared to conifer forests. The big trees in the natural stand probably contributed to a comparatively higher fine root biomass (Tamooha *et al.,* 2008). According to Nadelhoffer and Raich (1992), fine root production and aboveground production were linked with one another and were affected by similar factors. Height and diameter increments were measured to relate with the fine root production (Dipesh and Schuler, 2013). A similar influence of stand structure on root productivity has been reported in other studies (Le Goff and Ottorini, 2001; Hertel *et al.*, 2009). The average D.B.H of trees was found to be a good predictor for fine root biomass and productivity (Drexhage and Colin, 2001; Le Goff and Ottorini, 2001; Hertel *et al.,* 2009). Small diameter stems caused a significant reduction in fine root biomass (Joslin *et al.*, 2000, Jones *et al.,* 2003). Also different composition of tree species in the natural forest, compared with the monoculture plantations, may explain the higher fine root biomass in the mixed natural forest (Yang *et al.*, 2003; Yang *et al.*, 2004).

Valverde-Barrantes *et al.* (2014) find that most of the canopy tree species in their forest behave in largely the same way, with equal fine root proliferation in high resource patches. As a result of this species roots tend to aggregate in nutrient rich soils, resulting in a greater diversity of species within a given patch. They further find that fine root biomass and species diversity are greater in these soils (Jones, 2015). Dipesh and Schuler (2013) pointed that younger stands have less fine root production than the older stands. Fine roots could be easily affected by soil environmental factors (Eissenstat *et al.*, 2000; Xu *et al.,* 2013). The soil in *A. subcordata* and *P. deltoids* was more fertile and was in favor of the growth of fine root. The rich nutrients were in favor of fine root growth. The high fertility in the upper soil layer was a vital

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factor affecting fine roots plantation (Wang *et al.*, 2014).

Nitrogen-fixing species plantations could increase soil nitrogen mineralization (Berg *et al.,* 2001; Rothe *et al.,* 2002). The difference in soil nitrogen mineralization was due to difference in availability of labile N substrates (McKinley *et al.,* 2008). High-quality litter decrease microbial immobilization of nitrogen, and result in enhanced Nmin and plant available N (McKinley *et al.,* 2008). Van der Krift *et al.* (2001) found soil N mineralization of 5- and 15-year-old mixed poplar stands were greater than those of corresponding pure poplar stands. It has been reported that there was a negative relationship between the C/N and soil nitrogen mineralization in various ecosystems (Van der Krift *et al.,* 2001; Arslan *et al.,* 2010). We found a less nitrogen mineralization in forest types with higher C/N that is similar with Zeller *et al.* (2000) and Arslan *et al.* (2010) findings.

Litter C/N was the lowest in *A. subcordata* plantation as compared to other species and mixed natural forest. The narrow C/N was a precondition for the fast decomposition of organic matter (Ohta and Kumada, 1978). The C/N in the foliage of broadleaf species in the temperate zone is on average 25 (Vitousek *et al.,* 1988). C/N in organic litter was narrowed, because their dying led to the input of organic matter rich in nitrogen. Narrow C/N in the litter fall under *A. subcordata* monocultures caused the greatest part of carbon to be converted into CO_2 by oxidative processes as the end of product of organic matter decomposition. Because of the decomposition of *A. subcordata* dead organic residues into end products, there was no intensive accumulation of organic C and N under *A. subcordata* plantations (Miletić *et al.,* 2012). Significantly higher C/N were found in the *T. distichum* stand these results underline the more recalcitrant nature of coniferous litter, probably due to the hard cuticle of needles, and could suggest a longer mean residence time of this organic matter (Kooch *et al.,* 2012b). According to our findings, based on different SQ indices, the *A. subcordata* forest type had higher ecological potential compared to the other stands. Whereas, *P. deltoids*, mixed natural forest, and *T. distichum* had next priority, respectively.

5 CONCLUSION

Due to increasingly destruction of Hyrcanian Forests, plantation with native species was an appropriate method for rehabilitation and reconstruction of destroyed forest areas. To select a species, in addition to growth quantity and quality the effects of species in ecosystem, restoration should also be noted. Evaluation of trees in terms of soil moderator of different habitats conditions and classification of tree species based on achieved results were necessary. It appears using AHP gives a broad perspective in relation to the assessment of forest stands and can be considered an appropriate strategy. Using of AHP approach, as a conclusion, the N-fixing species, *A. subcordata*, is more efficient in improving soil quality in degraded land.

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شاخص‌های کیفیت خاک در توده‌های جنگلی خالص و آمیخته منطقه جنوبی دریای خزر

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چکیده پژوهش حاضر با هدف ارزیابی گونه‌های خالص کاشته شده (شامل توسکا ییلاقی، صنوبردلتوئیدس، دارتالاب) و توده طبیعی آمیخته (با غالبیت گونه‌های بلوط- ممرز- انجیلی) بر مبنای برخی شاخص‌های کیفیت خاک در استان مازندران، شمال ایران، صورت پذیرفت. در هر یک از توده‌های مورد بررسی، تعداد ۱۶ نمونه خاک (۱۰-۰ سانتی‌متری) برداشت و مشخصه‌های چگالی ظاهری، بافت، محتوی رطوبت، pH، هدایت الکتریکی، کربن آلی، نیتروژن کل، عناصر غذایی قابل جذب، زیتوده کرم‌های خاکی، تنفس میکروبی، زیتوده ریزریشه‌ها، کربن و نیتروژن لاشبرگ در محیط آزمایشگاه اندازه‌گیری شد. از بین متغیرهای مورد بررسی، نه معیار (سیلت، هدایت الکتریکی، پتاسیم، کلسیم، منیزیم، تنفس میکروبی، زیتوده ریزریشه، معدنی شدن نیتروژن، نسبت کربن به نیتروژن لاشبرگ) بر مبنای تحلیل مؤلفه‌های اصلی به عنوان حداقل مجموعه داده‌ها انتخاب شدند. به‌منظور ادغام مجموعه داده‌ها در یک شاخص، تحلیل فرآیند سلسله مراتبی (AHP) به‌کار گرفته شد. وزن نهایی محاسبه شده بر مبنای نه معیار نشان داد که توده جنگلی توسکا دارای توان اکولوژیکی (۰/۳۷۰) بالاتری نسبت به توده‌های دیگر می‌باشد و توده‌های صنوبر طبیعی آمیخته و دارتالاب به ترتیب با توان اکولوژیکی ۰/۲۹۵، ۰/۲۱۳و ۰/۱۲۲ در مراحل بعدی قرار می‌گیرند. به‌عنوان نتیجه‌گیری، می‌توان اظهار نمود که گونه تثبیت‌کننده ازت، توسکا ییلاقی، دارای بازدهی بیش‌تری برای بهبود کیفیت خاک در مناطق جنگلی تخریب‌یافته داشته است.

کلمات کلیدی: جنگل‌های هیرکانی، گونه‌های پهن‌برگ، گونه‌های سوزنی‌برگ، مرکز بذر جنگلی خزر، مشخصه‌های خاک

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