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Research paper

Effects of Four Afforestation Stands on Some Physical, Chemical and Biological Properties of Soil in Northern Iran

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ABSTRACT Selected species for afforestation have different effects on soil quality in addition to differences in their growth. The aim of current study was to investigate the effects of afforestation with four tree species, including chestnut-leaved oak, loblolly pine, black alder and Persian maple on the soil properties in the northwest of Iran. For this purpose, eight sample plots of 400 m^2 were conducted in the study area and diameter and total height of the trees were measured. Then, eight soil samples were taken from a depth of 0 to 30 cm of each stand and transferred to the soil laboratory to be investigated some physical, chemical and biological properties of the soil. Hence, a total number of 16 different soil parameters of the four stands were measured and compared using ANOVA. Besides, the correlation between different soil properties and their relationship with tree species was analyzed, using principal components analysis (PCA). The results showed that among the studied stands, the loblolly pine had a higher mean diameter, mean height, basal area and volume. Regarding soil properties, alder stand possessed the highest porosity and the lowest bulk density. The pine stand, however, was estimated to possess the highest value of basal respiration, substrate induced respirations, microbial carbon biomass, organic carbon, total nitrogen, C/N ration, absorbable potassium and the lowest pH value. Finally, the maple stand possessed the highest amount of absorbable phosphorus. Based on the results of this study, pine species due to its high diameter growth and positive effects on most soil properties is recommended for afforestation in Hyrcanian region and similar habitats in west Asia.

KEYWORDS: bulk density, loblolly pine, organic carbon, substrate induced respirations.

Introduction

Given the trend of deforestation in the world, the importance of afforestation is inevitable.

Afforestation plays an important role in soil conservation by creating extensive canopy cover on the soil and regular networks of roots under the soil surface (Rahman et al. 2017). Also, afforestation's could change the biodiversity indicators, amount and quality of absorbed water, and air humidity in its habitat (Hagen-Thorn et al. 2004). Globally, afforestation is considered to be the most important tool of atmospheric carbon sequestration, which is the main cause of global warming (Cloy and Smith 2018).

Therefore, afforestation has a special importance in economic, environmental and social aspects, which are the main axes of sustainable development (Teoman Güner et al. 2021).

After afforestation and development of its canopy, direct sunlight on the soil will be prevented and soil properties will be affected by new environmental conditions (Mijangos et al. 2014). The first effects of afforestation on soil can be related to changes in soil temperature and humidity as well as reduced soil impact from rainfall (Poeplau and Don 2013). After balancing the first soil parameters, other soil conditions also will change gradually over the time (Hou et al. 2020). The most important changes in soil quality after afforestation can be examined in three categories of physical, chemical and biological properties of the soil (Deluca and Boisvenue 2012). However, most of the physical properties of the soil are directly related to the bedrock structure and the main materials that make it up. The effects of changes in soil organic matter, effects of tree roots and changes in soil moisture can affect the physical properties of the soil (Teoman Güner et al. 2021).

Soil chemical properties, such as acidity, organic carbon content, nitrogen, and soil phosphorus, are also clearly affected by vegetation (De-wit et al. 2015, Arias-Navarro et al. 2017). Litter volume, decomposition rate and chemical composition determine the amount of soil elements and its fertility (Strand et al. 2016). By changing the physical and chemical properties of the soil, significant changes will also be made in the microbial population of the soil and as a result, the microbial respiration and the microbial biomass of the soil will change (Motaghikhah et al. 2021).

Studies show that in many cases, afforestation makes different changes in soil properties. For example, Teoman-Güner et al. (2021) in their study reported the better effects of Black pine afforestation on different soil characteristics than Scots pine. In another study, Hou et al. (2020) examined the effects of afforestation on sloping lands and found that the organic carbon of topsoil was significantly increased by afforestation. From an environmental point of view, afforestation with tree species that causes a major change in the soil quality of an area, especially areas with a history of natural forest disrupts the normal functions of the habitat. For example, a study by Rahmati et al. (2020) showed that afforestation with loblolly pine compared to Chestnut-leaved oak caused more severe changes in soil acidity in forest areas of northern Iran.

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They, therefore, recommended a mixed cultivation of loblolly pine with native broadleaf species.

Investigation of afforestation with different species and its effect on the soil can lead to proper management of forests especially in specific and sensitive vegetative areas. In 10^{th} July of 2020, world heritage committee of UNESCO inscribed Iran's Hyrcanian forests, to the world heritage list. The results of current study can be expanded to Azerbaijan Hyrcanian forests and also similar forests of west Asia and east Europe, such as some parts of Turkey, Georgia, Armenia and south Ukraine (especially Crimean peninsula) forests.

In the past decades, due to the importance of afforestation in wood production and its effect on conservation of natural forests, extensive afforestation with native deciduous and fast-growing coniferous species such as loblolly pine has been done in the north of Iran, especially on the shores of the Caspian Sea. Because of the passage of several decades of this afforestation's, it will be important to study the effects of different tree species on physical, chemical and biological properties of soil. The results of current study will lead to the recognition the effects of tree species on soil properties and better management of these stands in the future.

Material and Methods

Study area

The present study was carried out in the afforestation of Radar-Poshteh region (East longitude of 49° 44′ 02′ - 49° 44′ 08′ and North latitude of 37° 04′ 01′ - 37° 04′ 58′) of Gilan province located in northern Iran (Fig. 1). The annual rainfal of the study area is 1,264.5 mm and its average annual temperature is 16° C. The slope of the study area is between 0 and 30%. The studied cultivars include alder (*Alnus glutinosa* (L.) Gaertn), maple (*Acer velutinum* Boiss.), oak (*Quercus castaneifolia* C. A. Mey.) and pine (*Pinus taeda* L.). The total area of each studied land is 4 hectares, the age of the studied land is 25 years and their planting distance is 3×3 meters.

Methods

Inventory and data collection

In order to conduct the present study, eight sample plots of 400 square meters (20 × 20 m) in each stand (32 sample plots for four stands) were performed by a randomized systematic sampling method and net size of 50 × 50 m (Moslemi Seyed Mahalle et al. 2019). First, the diameter and total height of the trees in the sample plots were measured and recorded. Then, a mixed soil sample was taken from a depth of 0 to 30 cm from the four corners and the center of the plot and transferred to the laboratory. To investigate the biological properties of the soil, soil samples were sieved and placed in aluminum foil and transferred to a laboratory in a cold chamber.

Estimation of quantitative characteristics of stands

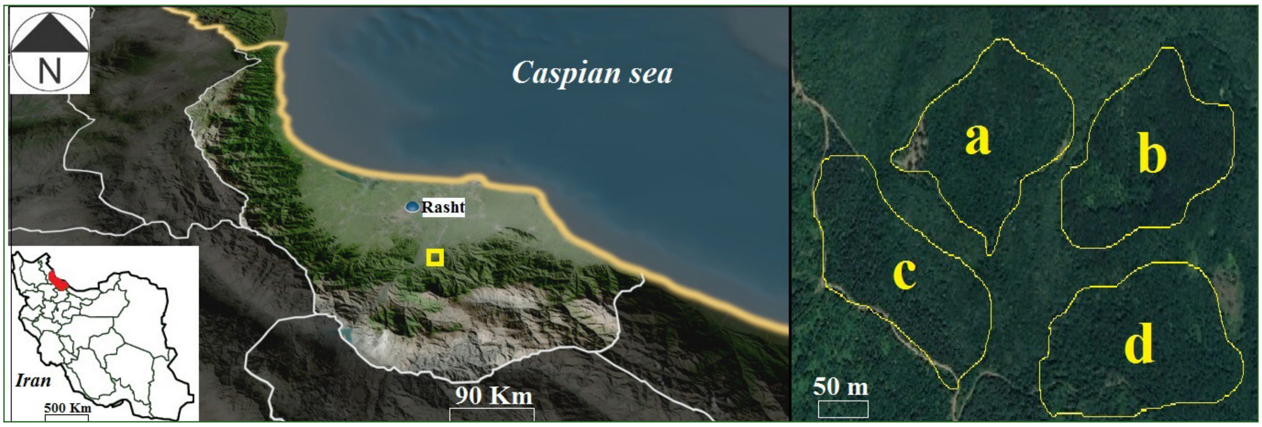
First, distributions of trees by diameter classes curve was drawn, using the diameter data of trees. Then, the mean diameter and height of trees of the four stands were calculated. Basal area and volume of trees per hectare calculated using equations (1) and (2) respectively (Rahmati et al. 2020).

$$G = \frac{\sum (\frac{\pi}{4} \times \left(\frac{d}{100}\right)^2}{a} \quad (1)$$

$$V = \frac{\sum g \times h \times f}{a} \quad (2)$$

Where: G is the basal area per hectare (m^2), d is the diameter of each tree (cm), a is plot area (ha), V is stand volume per hectare (m^3), g is basal area of each tree, h is the height of each tree, and f is the shape coefficient of each the tree species (0.49 for *Pinus taeda* L. (Fadaei et al. 2008) and 0.49, 0.52 and 0.48 for *Alnus glutinosa* (L.) Gaertn, *Acer velutinum* Boiss. and *Quercus castaneifolia* C. A. Mey. respectively (Pourshakouri Allahdeh and Hasanzad Navroudi 2008)).

Figure 1 - Location of the studied stands on the map (a: maple, b: oak, c: pine and d: alder).



Measurement of soil properties

In this study, three categories of soil properties including physical, chemical and biological properties were studied. For this purpose, the percentage of clay, silt and sand particles was measured using hygrometry method. The particle and bulk density of soil was measured using cylinder and pycnometer methods respectively. Finally, the soil moisture and soil porosity were measured using weighting method and equation (3), respectively (Jafari Haghighi 2003, Ridvan 2004, Mirzaeetalarposhti et al. 2009, Bouyoucos 1962).

$$P\% = 100 - \frac{Pd}{Bd} \times 100 \quad (3)$$

Where P% is the percentage of soil porosity, Pd is the particle density and Bd is the bulk density of the soil (Blake and Hartge 1986).

In order to investigate the chemical properties of soil, the percentage of soil organic carbon was measured using Walkely-Black method; the amount of total nitrogen was measured by Kjeldahl digestion method; the concentration of absorbable phosphorus in soil was measured using Olsen (1954) method; soil absorbable potassium was measured using flame photometer and soil acidity was measured by Thomas method (pH meter with glass electrode) (Bower et al 1952, Allison 1975, Farley et al. 2004).

Finally, in order to investigate some soil biological properties, soil microbial basal respiration was measured applying Anderson method (Anderson 1982). In order to measure substrate induced respirations (SIR), 1% glucose was used as a substrate and the amount of released CO_2 was calculated applying Alef and Nannipieri (1955) method then the amount of SIR by substrate was estimated. Finally, soil microbial biomass carbon was measured by chloroform fumigation (gasification) and potassium sulfate solution extraction (extraction) (Jenkinson and Ladd 1984). The microbial biomass carbon (MBC) value was calculated from the difference in carbon content of fumigated and non- fumigated samples.

Data analysis

In order to compare different properties of stand and soil, the normality of the data was evaluated by Kolmogorov-Smirnov test and the homogeneity of variances was evaluated by Leven test.

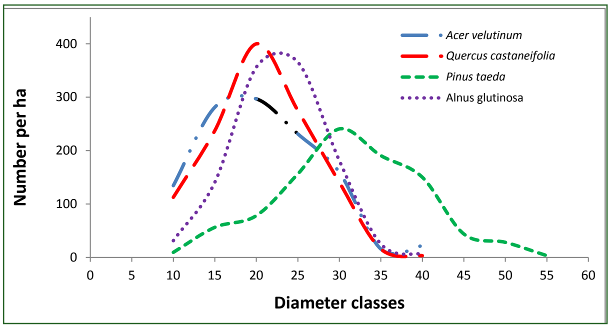
Considering the normality of the data and the homogeneity of variances, we used SPSS-21 and applied analysis of variance (ANOVA) and Duncan test of comparison of means to test the significance of differences in stand and soil properties. The correlation of different soil properties with species in different stands was investigated using principal component analysis (PCA) in Pc-Ord-5 software.

Results

Quantitative characteristics of stands

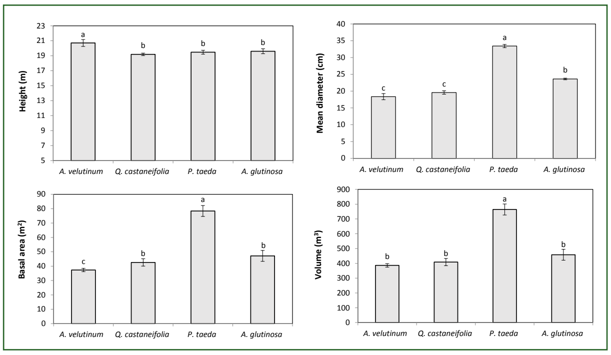
According to the number of trees per hectare chart, afforestation with three broadleaf species of maple, oak and alder has a similar diameter growth (10 to 35 cm). However, the coniferous species of loblolly pine has grown more than the broadleaf species and the diameter of the trees in this stand has reached to 55 cm (Fig. 2).

Figure 2 - Abundance of trees in diameter classes of four studied stands.



Based on the results, the highest average diameter between four stands is related to pine stands (33.42 cm). After that, alder stands had the highest average diameter with 23.63 cm. The alder and oak stands possessed the lowest mean diameter. The highest mean height with 20.7 m was related to maple stands and other stands did not show a significant difference in this regard. Also, the highest basal area and volume per hectare were related to pine stand (78.43 m^2 and 763.98 m^3 per hectare, respectively) (Fig. 3).

Figure 3 - Mean diameter, height, basal area and volume of four studied stands per hectare.



Soil parameters

Based on the results, there is a significant difference between all physical properties of soil in the studied stands. Oak stand soil has the highest percentage of sand; alder stand soil has the highest percentage of silt and pine stand soil has the highest amount of clay. The lowest bulk density and the highest porosity were observed in alder soil. The highest particle density observed to exist in alder soil.

Table 1 - Comparison of soil physical properties in the studied stands (different letters indicate a significant difference between the means).

Soil parameters	Stand			
	Acer velutinum	*Quercus castaneifolia*	*Pinus taeda*	*Alnus glutinosa*
Sand (%)	28.25 ± 3.44 (b)	37 ± 1.51 (a)	21.25 ± 1.88 (c)	13.5 ± 0.62 (d)
Silt (%)	44.25 ± 2.35 (b)	37.50 ± 1.34 (c)	44.75 ± 3.02 (b)	61.25 ± 1.19 (a)
Clay (%)	27.5 ± 1.45 (b)	25.5 ± 0.62 (b)	34 ± 1.60 (a)	25.25 ± 0.83 (b)
Bulk density (g/cm^3)	1.43 ± 0.02 (a)	1.35 ± 0.01 (ab)	1.36 ± 0.05 (ab)	1.27 ± 0.01 (b)
Particle density (g/cm^3)	2.60 ±<0.01 (a)	2.54 ± 0.01 (b)	2.52 ± 0.01 (b)	2.59 ± <0.01 (a)
Porosity (%)	44.89 ± 0.81 (b)	46 ± 94 ± 0.73 (b)	45.99 ± 2.12 (b)	50.78 ± 0.81 (a)
Moisture (%)	64 ± 2.24 (c)	71.5 ± 2.12 (b)	79.5 ± 2.42 (a)	68.37 ± 1.25 (bc)

Table 2 - Comparison of soil chemical properties in the studied stands (different letters indicate a significant difference between the means).

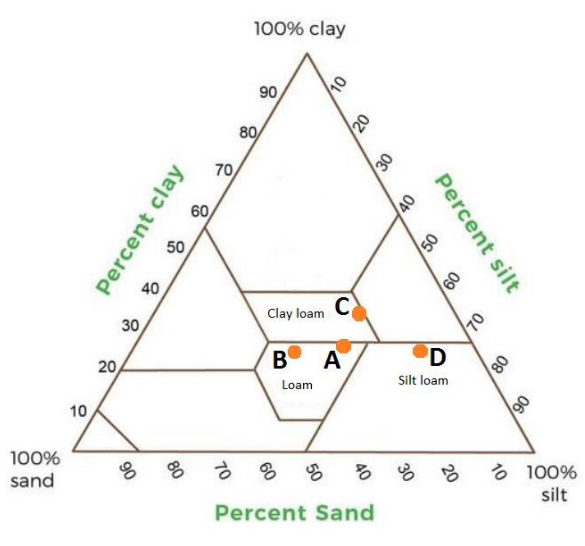
Soil parameters	Stand			
	Acer velutinum	*Quercus castaneifolia*	*Pinus taeda*	*Alnus glutinosa*
pH	6.58 ± 0.07 (a)	6.12 ± 0.03 (b)	5.51 ± 0.02 (d)	5.77 ± 0.05 (c)
OC (%)	2.51 ± 0.21(c)	4.18 ± 0.35 (b)	6.67 ± 0.50 (a)	3.20 ± 0.51 (bc)
TN (%)	0.20 ± 0.01 (b)	0.28 ± 0.01 (a)	0.28 ± 0.01 (a)	0.29 ± 0.01 (a)
P (ppm)	7.18 ± 0.30 (a)	6.21 ± 0.73 (ab)	3.16 ± 0.27 (c)	4.90 ± 0.61 (b)
K (ppm)	165 ± 8.01 (b)	202.5 ± 15.66 (a)	213.75 ± 9.80 (a)	188.75 ± 8.95 (ab)
C/N	14.86 ± 0.79 (b)	14.46 ± 0.85 (b)	21.71 ± 1.10 (a)	13.12 ± 0.42 (b)

OC: Organic carbon, TN: Total nitrogen, P: Phosphorus, K: Potassium

Finally, the highest percentage of soil moisture was obtained from pine stand (Tab. 1).

Based on the results, the alder soil has a high percentage of silt and pine soil has a higher percentage of clay. However, the oak and maple stands contain all three soil particles in the same proportion. The soil texture of the studied stands classified alder soil in silt-loam class, loblolly pine soil in clay-loam class and maple and oak stand soil in loam class (Fig. 4).

Figure 4 - Soil texture of the studied stands (A: maple, B: oak, C: pine and D: alder).



Based on the results, the soils of the four studied stands are located in the acidic range. The most acidic soil was observed in the pine stand. The highest percentage of organic carbon is related to pine stand soil and the lowest carbon content is related to maple stand. Also, the lowest amount of total nitrogen and absorbable potassium was obtained in maple soil. The highest amount of absorbed phosphorus was related to the soil of maple and oak stands. Finally, the highest C/N ratio was related to the soil of loblolly pine (Tab. 2).

Investigation of soil biological properties of studied stands showed that the highest and lowest microbial respiration belonged to maple and alder stands, respectively. Moreover, the highest and lowest values of soil substrate induced respirations were obtained for pine and maple stands, respectively. Finally, the lowest microbial carbon biomass of the soil in the studied populations was related to maple population. The other three stands did not show any significant difference in this regard (Tab. 3).

Table 3 - Comparison of soil biological properties in the studied stands (different letters indicate a significant difference in means).

Soil parameters	Stand			
	Acer velutinum	*Quercus castaneifolia*	*Pinus taeda*	*Alnus glutinosa*
Bs (mg CO_2 g^{-1} soil min^{-1})	0.28 ± 0.05 (b)	0.15 ± 0.03 (bc)	0.55 ± 0.05 (a)	0.07 ± 0.02 (c)
SIR (mg $CO_2$$g^{-1}$ soil min^{-1})	1.24 ± 0.17(ab)	0.47 ± 0.06 (b)	1.41 ± 0.11 (a)	1.03 ± 0.45 (c)
MBC (mg in g^{-1})	30.81 ± 4 (b)	40.84 ± 4.49 (b)	64.59 ± 4.46 (a)	30.22 ± 4.42 (b)

Bs: Basal respiration, SIR: Substrate Induced Respirations, MBC: Microbial carbon biomass

PCA analysis

Amounts of eigenvalue, percent and cumulative percent of variance and broken stick eigenvalue of the PCA axes are summarized in Table 4. According to the PCA analysis results among all axes, the 1st and the 2nd axes accounted for about 55.73% of the total variations. Then, these two axes play the main role in explanation of the result of the PCA analysis.

Based on the results of PCA analysis, porosity and silt percentage showed the highest correlation with the positive direction of the second axis. Also, BD, P and pH showed more relationship with the positive direction of axis one and maple stand showed the highest relationship with this group. In addition, C/N ratio, sand percentage, BD, Bs, SIR and clay percentage showed a higher correlation with the negative direction of the second axis. Finally, moisture content, OC and K were ordered in the same group that showed the highest correlation with pine stand. According to the obtained results, oak stand did not show a clear correlation with different soil properties (Fig. 5).

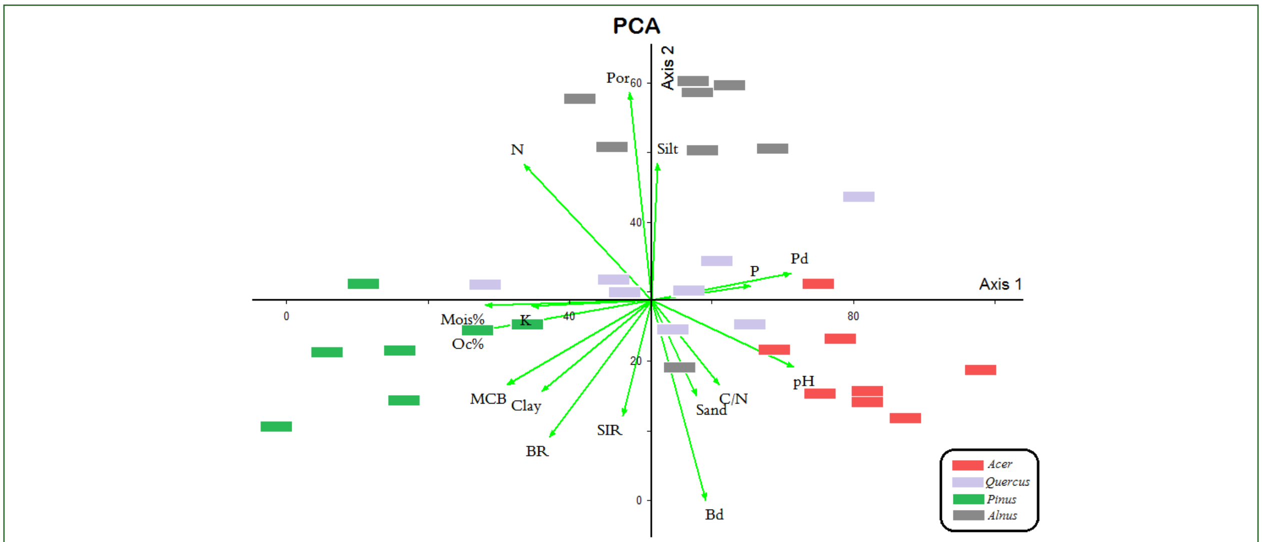
Discussion

According to the results, the highest average diameter between four species was related to loblolly pine that is due to the fast growth of this species (Morris et al. 2006). Among the broad-leaved species, alder has the best growth, which can be related to rapid growth of this species in the first years after planting as a shade-intolerant species (Zare and Amini 2012). Besides, maple species had the most height growth, but due to lower average diameter of this species, its average basal area and volume had the lowest amount. The reason for this could be related to the lower soil fertility of this stand (Rahman et al.

Table 4 - Amounts of eigenvalue, percent and cumulative percent of variance and broken stick eigenvalue of the PCA analyze.

Axis	Eigenvalue	% of Variance	Cum.% of Variance	Broken-stick Eigenvalue
1	5.75	35.98	35.98	3.38
2	3.16	19.75	55.73	2.38
3	1.80	15.96	71.69	1.88
4	1.31	8.19	79.89	1.54

Figure 5 - The results of PCA multivariate test in determining the relationship between different soil properties and the type of tree species (MCB: Microbial carbon biomass, BR: Basal respiration, SIR: substrate induced respiration, K: Potassium, OC%: Percent of carbon biomass, Pd: Particle density, Bd: Bulk density, P: absorbable phosphorus, Mois%: Percent of moisture, Por: porosity, N: Total nitrogen).



2017). The oak species had a low volume growth. However, due to the limited annual growth of *Quercus castaneifolia* C.A. Mey. it could be a normal yield for this species (Rahmati et al. 2021).

Among the soil characteristics, soil texture has a direct effect on other soil properties. In the present study, increasing the porosity of silt filled soil in alder stands has reduced the bulk density of this soil. Also, the results showed that the highest percentage of soil moisture is related to loblolly pine stands. It can be related to the slow decomposition of conifer litters and its accumulation in forest soil. This litter acts like a sponge and prevents the loss of soil moisture (Mijangos et al. 2014, Torreano and Morris 1998, Morris et al. 2006).

Between the chemical characteristics, higher acidity of pine soil can be related to acidic compounds of its litter, slow decomposition of litter, subsequent production of organic acid and delay in the return of base cation's to the soil as the main characteristics of the coniferous species (Chandran et al. 1987, Hagen-Thorn et al. 2004). Also, higher percentage of soil organic carbon in loblolly pine stand in comparison to other broadleaf species can be related to lower growth of trees, weaker canopy, limited litter volume, and rapid decomposition of litter of broadleaf stands, which results in rapid release of carbon into the atmosphere and reduced soil carbon content in this study (Badehian 2007, Hashemi et al. 2017). Otherwise, less soil total nitrogen in the broadleaf stands such as maple compared with loblolly pine could be related to more nitrogen leaching in this stand which is due to the lighter soil texture and thinner canopy cover of maple stands (Hashemi et al. 2017, Nobakht et al. 2011, Ghazanshahi 2006).

Hence, the high percent of organic carbon and low total nitrogen in the loblolly pine soil created the highest ratio of C/N for this stand while low C/N ratio in alder afforestation can be related to the coexistence of Frankia actinomycetes with this species and the nitrogen fixation in the soil of alder soil, which increases the soil fertility of this stand (Motaghikhah et al. 2021). Also, absorbable potassium cannot be considered as a reason for the lack of fertility of maple stand, because amounts of absorbable potassium in four stands is more than 160 ppm, which is a normal level of potassium in the forests soil (Montagnini 2000, Simard et al. 1993). On the other hand, high volume of base cations in the litter of broadleaf stands and its shorter decomposition period can be considered as factors in increasing the phosphorus in the soil of these stands (Hagen-Thorn 2004). In the case of alder stands, lighter soil texture caused more leaching of phosphorus from the soil (Niu et al. 2009).

Based on the results, investigation of basal and substrate induced respiration and microbial biomass carbon of the soil in the study area indicates more microbial activity in the soil of loblolly pine stand. The percentage of organic carbon can be considered as one of the most important factors in increasing the microbial population and increasing microbial respiration in the soil (Aletta et al. 2010, Moscatteli et al. 2007). Percentage of soil moisture is one of the other factors affecting biological characteristics of soil because it has a significant effect on inlet carbon of litter in heterotrophic respiration (Jenkinson and Ladd 1984, Alef and Nannipieri 1995). Therefore, due to higher soil moisture in pine stand, microbial respiration and microbial biomass carbon have increased in this stand. Kooch and Bayranvand (2017) reported that increasing the soil moisture, carbon and nitrogen are the main factors that can enhance soil microbial population, which is consistent with the results of the present study.

Finally, results of PCA test shows that variability explained by the two first axes is not very high (55% of the total variability) because oak stand did not create a significant relationship with different soil properties. However, most correlation with the amount of silt and soil porosity was related to alder stand. This is because alder species usually prefers porous and alluvial soils (Zare and Amini 2012). Also, absorbable phosphorus, pH and particle density were highly correlated with maple stand, which is consistent with the results of Hashemi et al. (2017) study. Finally, loblolly pine was highly correlated with organic carbon content, moisture, microbial biomass carbon and clay.

Conclusion

Proper management of manmade forests requires recognizing the effects of different tree species on various soil conditions. Given the two million hectares area of Hyrcanian forests and the environmental concerns about this area as a UNESCO world heritage site, selection of suitable species for afforestation in this area is very important. Results of the present study proved the success of afforestation with non-native species of loblolly pine and native species of alder in Hyrcanian region. In addition to Hyrcanian region of Iran and Azerbaijan, the results of the present study can be used in management of western Asia forests, such as forests of Turkey. Due to the high production per hectare and the lack of negative effects of pine and alder species on soil characteristics, afforestation with the introduced species can lead to the restoration of degraded forest areas and control of the degradation trend of these forests in the mentioned areas. However, additional studies in this area are also suggested.

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