

Comparison of soil fertility of *Acer insigne*, *Quercus castaneifolia*, and *Pinus brutia* stands in the Hyrcanian forests of Iran

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Abstract Trees species have different effects on soil properties and nutrients. Plantation as a management strategy for soil productivity retention and the prevention of destruction can be effective in the continuity of forest productivity. After 21 years, the effects of the maple (*Acer velutinum* Bioss.), oak (*Quercus castaneifolia* C. A. Mey.), and red pine (*Pinus brutia* Ten.) stands on soil fertility were assessed in the Sari region (northern Iran). Soil was sampled at depths of 0-10, 10-20, 20-30, and 30-40 cm at all stands using a core soil sampler with an 81 cm² cross section. Soil texture, pH, organic carbon (C), total nitrogen (N), available phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) for all samples were measured in the laboratory. Our findings showed that the planted stands significantly affected soil physicochemical properties. Statistical comparisons revealed that the highest and lowest levels of N, P, K, Ca, and Mg in soil occurred in the maple and red pine stands, respectively. Measurements of soil fertility showed that fertility decreased in relation to increased soil depth, with significant differences depending on soil depth. Our results suggest that to rehabilitate degraded natural forests, at least in northern Iran, the plantation of suitable native broad-leaved species can be recommended for forestation plan management.

Keywords plantation; needle-leaved species; broad-leaved species; soil property; depth

The world's supply of high-value timber is becoming more limited due to the over-exploitation of vital resources, the conversion of forests containing species used for timber production to other land uses, and the growing interest in protecting remaining forest areas^[1]. Consequently, over the last few years, interest in establishing and maintaining reforestation projects with native forest species in forest plantations has increased as a means to supplement the existing wood market and to prevent the over-exploitation of natural resources^[2]. The Hyrcanian vegetation zone is a green belt stretching over the northern slopes of the Alborz mountain ranges and covering the southern coast of the Caspian Sea. It has a total area of 1.84 million hm², comprising 15% of Iran's forests and 1.1% of the country's area^[3]. The Hyrcanian or northern forests of Iran stretch up to an altitude of 2 800 m above sea level and encompass different forest types thanks to the 80 tree and shrub species found there^[4].

Today, these forests are being depleted rapidly due to population growth and the associated socio-economic problems, industrial development, urbanism, and, more recently, intensive/irregular tourism^[5]. About 60% of Hyrcanian forests are managed for timber production and the remaining have been degraded by varying degrees^[6]. Threatening the existence of the Caspian forests are such conditions as the existence of different land uses and their increasing alterations (mainly by local communities), the mismanagement of natural resources

over long periods of time, plans for industrial development (e.g., the establishment of industrial towns adjacent to forested areas), public road construction without detailed environmental considerations, and a shortage of human/financial resources for sustainable monitoring and management of forest resources^[5].

It is obvious that the natural forests in this area have been under continuous degradation over the last few decades, 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^[5]. Abandoning agriculture and tree planting for commercial or restoration purposes are also two main methods of forest restoration. There have been many 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^[6].

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^[6], especially those related to soil properties. In fact, the evaluation of afforestation is complex because of the great number of factors involved prior to afforestation (choice of appropriate sites and species), during afforestation (planting techniques, density, interaction with

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natural vegetation of the zone, etc.), and afterwards (changes in the physicochemical properties of the soils, impact on biodiversity, implications for the increase or reduction in erosion, changes in the landscape, etc.). In recent years, some scholarly works have been published on these issues ^[7-14], although few have analyzed changes in soil properties at a basin scale in relation to nearby non-afforested areas (e.g., grassland, scrub, or bare soils) and the intrinsic characteristics of each soil.

In general, some authors have indicated that afforestation increases nutrient content in soil, although on occasion the differences found have been minor or negligible ^[15]. These discrepancies in findings may be due to the species used, their density, and/or the degree of cover, as well as the time since planting. In addition, some topographic and pedological properties should be taken into account, such as slope, orientation, and lithology, as these affect both the characteristics of the vegetation as well as the soil properties ^[16]. Previous studies have reported soil macro-element accumulation ^[17-18], loss ^[19-20], or no net change ^[21-22], resulting from the establishment of trees. Most studies have focused on the quantity of soil organic carbon (SOC) and nitrogen occurring in plantations. Soil fertility is protected by a variety of physical and chemical mechanisms which produce nutrient pools with different residence times.

Investigations on forest plantation projects in northern Iran have indicated that about 200 000 hm² of degraded forests have been reforested; of which 40 000 hm² consist of needle-leaved species ^[23]. Forest plantation activity is one method of rehabilitating the degraded forests in the Caspian region. Therefore, the evaluation of planted species and their comparison with other natural forests are very important ^[24]. A closer examination of changes in soil properties over time following the establishment of different tree species is necessary to understand the mechanisms responsible for changes in the soil organic matter (SOM) and nutrient availability ^[25], which, in turn, will assist in the development of effective, long-term strategies to maintain soil quality and fertility. The specific objective of this project was to quantify the effects of different tree species on selected soil properties, especially fertility, 21 years after planting in a part of northern Iran.

1 Materials and Methods

1.1 Site characteristics

The study area is located at the Experimental Forest Station of Sari University of Agricultural and Natural Resources in Mazandaran province, north of Iran (between 36°28' to 36°23' latitude North and 52°14' to 52°31' longitude East). The experimental plots, located between 240 and 270 m a.s.l., show very similar climatic conditions and management practices. The area is on flat and uniform terrain with low slope (0-3%). The mean annual precipitation and temperature were 733 mm and

16.8 °C, respectively. The climate is temperate moist and the dry months extend from May to September. The soils are deep, moderately well drained and stone-free with organic matter of 1-3% prior to planting. They have the textures of sandy clay loam and clay loam with a pH of 6.0-7.5 and CaCO₃ of 0-15%. The soil order name is Alfisols. In 1991, the dominant forest types, which were planted at a spacing of 2 × 2 m, included maple (*Acer velutinum* Bioss.), oak (*Quercus castaneifolia* C.A. Mey.), and red pine (*Pinus brutia* Ten.) stands ^[26]. The stands were never fertilized.

1.2 Soil sampling and analysis

In the experimental area, the soil investigations were carried out with the aim of estimating the effect of plantation type on soil fertility. For this purpose, four hectare areas (200 × 200 m) were selected for each stand. In order to decrease the border effects, surrounding rows of stands were not considered during sampling. Soil sampling was dug along the four parallel transects in the central part of each afforested stand. Soils were sampled to a depth of 40 cm in all plantations during the summer time using a 7.6 cm diameter core sampler ($N = 16$ cores/stand using a randomly systematic method) taken at 0-10, 10-20, 20-30, and 30-40 cm depths ^[23]. The same sampling procedure was carried out also for the control area (covered by sparse herbaceous species including *Asperula odorata* L., *Euphorbia amygdaloides* L., *Hypericum androsaemum* L., and *Polystichum* sp). After air drying, soils were passed through a 2.0 mm (20 mesh) sieve to remove roots prior to laboratory analyses. Soil texture was determined by the Bouyoucos hydrometer method ^[27]. pH was measured using an Orion Ionalyzer Model 901 pH meter in a 1:2.5, soil: water solution. SOC was determined using the Walkley-Black technique ^[28]. Total N was determined using the Kjeldhal method ^[29]. Available P was determined with spectrophotometer by using Olsen method ^[30]. Available K, Ca and Mg (by ammonium acetate extraction at pH 9) were determined with Atomic absorption Spectrophotometer ^[31].

1.3 Statistical analyses

Normality of the variables was checked by Kolmogorov-Smirnov test and Levene's test was used to examine the equality of the variances. The soil parameters were analyzed by using two-way analysis (ANOVA) procedure, treating plantation and soil depth as factors with interaction. Duncan tests were used to separate the averages of the dependent variables which were significantly affected by treatment. SPSS v.11.5 software was used for all the statistical analyses.

2 Results

2.1 Soil physicochemical properties

Sand was significantly greater in the red pine (19.18%) stand compared with the oak (10.67%), control (10.54%), and maple (9.88%) stands. Sand was significantly higher at 0 - 10 cm (19.56%)

depths than at depths of 10 - 20 (12.50%), 20 - 30 (10.05%), and 30 - 40 cm (8.16%) (Table 1). Silt was significantly greater in the red pine (58.08%) stand compared with the oak (51.17%), control (51.06%), and maple (48.25%) stands. Silt was significantly higher at 0 - 10 cm (61.56%) depths than at depths of 10 - 20 (51.79%), 20 - 30 (50.66%), and 30 - 40 cm (44.55%) (Table 1). Clay was significantly greater in the maple (42.36%) stand compared with the control (38.39%), oak (38.15%), and red pine (25.75%) stands. Clay was significantly more at 30 - 40 cm (47.28%) depths than at depths of 20 - 30 (39.78%), 10 - 20 (37.78%), and 0 - 10 cm (18.87%) (Table 1). Soil pH was significantly higher in the oak (6.57) stand than in the control (6.55), maple (6.46), and red pine (5.69) stands, whereas soil pH did not differ with depth (Table 1). SOC was significantly greater in the red pine (3.36%) stand compared with the oak (2.40%), maple (1.98%), and control (1.38%). SOC was greatest at the 0 - 10 cm (4.38%) depth and decreased as depth increased (Table 1).

2.2 Soil fertility properties

Total N in soil was greater at the maple (0.19%) stand compared to that of the red pine (0.16%), oak (0.15%), and control (0.10%) stands. Nitrogen at depths of 30 - 40 cm (0.08%) was significantly less than at depths of 20 - 30, 10 - 20, and 0 - 10 cm (0.10%, 0.14% and 0.26% respectively) (Fig. 1a). Soil P, K, Ca, and Mg were significantly higher in maple (23.53 mg/kg, 242.31 mg/kg, 16.50 mg/kg and 2.47 mg/kg, respectively) compared with oak (16.29 mg/kg, 153.75 mg/kg, 15.39 mg/kg and 2.45 mg/kg

respectively), control (15.56 mg/kg, 125.90 mg/kg, 10.23 mg/kg, 2.44 mg/kg, respectively), and red pine (14.56 mg/kg, 121.12 mg/kg, 10.20 mg/kg and 2.13 mg/kg, respectively) stands (Fig. 1b, c, d). Soil P and K were significantly greater at depths of 0 - 10 cm (22.74 mg/kg and 242.31 mg/kg, respectively) than at 10 - 20 cm (18.29 mg/kg and 152.15 mg/kg, respectively), 20 - 30 cm (15.20 mg/kg and 125.57 mg/kg, respectively), and 30 - 40 cm (13.70 mg/kg and 122.75 mg/kg, respectively) depths (Fig. 1b, c). Soil Ca was greater at the 30 - 40 cm (14.36 mg/kg) depth compared with depths of 20 - 30 cm (13.77 mg/kg), 10 - 20 cm (12.64 mg/kg) and 0 - 10 cm (11.55 mg/kg) (Fig. 1d). Soil Mg was significantly greater at 0 - 10 cm (3.15 mg/kg) depths than at 10 - 20 cm (2.50 mg/kg), 20 - 30 cm (1.95 mg/kg), and 30 - 40 cm (1.89 mg/kg) depths (Fig. 1e).

3 Discussion

Globally, the scope of afforestation has rapidly increased in recent decades. As of 2005, roughly 140 million hm^2 were grown as afforested plantations, and ~2.8 million more hectares are afforested per year^[32]. The afforestation rate is likely to increase, since many plantations typically produce greater economic returns than native forests, particularly those of non-native *Pinus* and *Eucalyptus*^[33]. With a potential 34 million more hectares afforested by 2020, managers need to understand the long-term effects of plantation establishment on soils and how they could

Table 1 Mean (standard error of mean) soil physico-chemical features in stands and depths ($N = 16$)

	Maple	Oak	Red pine	Control	Statistic description
Sand (w/%)					
D1 ($\pm$ SE)	16.92 ($\pm$ 0.42)	15.60 ($\pm$ 0.64)	29.81 ($\pm$ 0.52)	15.90 ($\pm$ 0.30)	Stand: $F = 319.14$, $P = 0.000$ (Red pine ^a > Oak ^b > Control ^{bc} > Maple ^c); Depth: $F = 405.45$, $P = 0.000$ (D1 ^a > D2 ^b > D3 ^c > D4 ^d); Stand $\times$ Depth: $F = 21.93$, $P = 0.000$.
D2 ($\pm$ SE)	6.84 ($\pm$ 0.61)	11.88 ($\pm$ 0.41)	19.77 ($\pm$ 0.40)	11.52 ($\pm$ 0.46)	
D3 ($\pm$ SE)	9.24 ($\pm$ 0.41)	8.59 ($\pm$ 0.44)	14.96 ($\pm$ 0.46)	7.41 ($\pm$ 0.51)	
D4 ($\pm$ SE)	6.51 ($\pm$ 0.28)	6.60 ($\pm$ 0.47)	12.20 ($\pm$ 0.85)	7.32 ($\pm$ 0.40)	
Silt (w/%)					
D1 ($\pm$ SE)	55.74 ($\pm$ 0.43)	63.72 ($\pm$ 0.67)	62.01 ($\pm$ 0.73)	64.77 ($\pm$ 0.63)	Stand: $F = 80.42$, $P = 0.000$ (Red pine ^a > Oak ^b , Control ^b > Maple ^c); Depth: $F = 227.85$, $P = 0.000$ (D1 ^a > D2 ^b > D3 ^b > D4 ^c); Stand $\times$ Depth: $F = 13.51$, $P = 0.000$.
D2 ($\pm$ SE)	47.65 ($\pm$ 0.48)	50.36 ($\pm$ 0.77)	57.39 ($\pm$ 2.70)	51.75 ($\pm$ 0.26)	
D3 ($\pm$ SE)	46.59 ($\pm$ 0.44)	48.53 ($\pm$ 0.82)	60.42 ($\pm$ 0.71)	47.10 ($\pm$ 0.87)	
D4 ($\pm$ SE)	43.03 ($\pm$ 0.56)	42.07 ($\pm$ 0.23)	52.49 ($\pm$ 1.15)	40.62 ($\pm$ 0.48)	
Clay (w/%)					
D1 ($\pm$ SE)	27.34 ($\pm$ 0.39)	20.67 ($\pm$ 0.71)	8.17 ($\pm$ 1.05)	19.32 ($\pm$ 0.71)	Stand: $F = 17.06$, $P = 0.000$ (Maple ^a , Control ^a , Oak ^a > Red pine ^b); Depth: $F = 48.44$, $P = 0.000$ (D4 ^a > D3 ^b , D2 ^b > D1 ^c); Stand $\times$ Depth: $F = 1.25$, $P = 0.285$.
D2 ($\pm$ SE)	45.50 ($\pm$ 0.86)	37.75 ($\pm$ 0.75)	34.93 ($\pm$ 1.39)	36.72 ($\pm$ 0.38)	
D3 ($\pm$ SE)	46.15 ($\pm$ 2.24)	42.86 ($\pm$ 0.70)	24.61 ($\pm$ 1.03)	45.49 ($\pm$ 1.23)	
D4 ($\pm$ SE)	50.45 ($\pm$ 0.83)	51.32 ($\pm$ 0.52)	35.30 ($\pm$ 1.28)	52.05 ($\pm$ 0.85)	
pH					
D1 ($\pm$ SE)	6.36 ($\pm$ 0.08)	6.52 ($\pm$ 0.01)	5.58 ($\pm$ 0.25)	6.49 ($\pm$ 0.01)	Stand: $F = 33.86$, $P = 0.000$ (Oak ^a , Control ^a , Maple ^a > Red pine ^b); Depth: $F = 1.08$, $P = 0.366$ (D4 ^a , D3 ^a , D2 ^a , D1 ^a); Stand $\times$ Depth: $F = 0.054$, $P = 1.000$.
D2 ($\pm$ SE)	6.43 ($\pm$ 0.08)	6.55 ($\pm$ 0.01)	5.64 ($\pm$ 0.24)	6.51 ($\pm$ 0.00)	
D3 ($\pm$ SE)	6.47 ($\pm$ 0.09)	6.59 ($\pm$ 0.01)	5.77 ($\pm$ 0.30)	6.60 ($\pm$ 0.00)	
D4 ($\pm$ SE)	6.59 ($\pm$ 0.04)	6.62 ($\pm$ 0.02)	5.78 ($\pm$ 0.30)	6.61 ($\pm$ 0.00)	
Organic C (w/%)					
D1 ($\pm$ SE)	3.82 ($\pm$ 0.31)	5.01 ($\pm$ 0.26)	6.25 ($\pm$ 0.38)	2.44 ($\pm$ 0.03)	Stand: $F = 100.53$, $P = 0.000$ (Red pine ^a > Oak ^b > Maple ^c > Control ^d); Depth: $F = 312.38$, $P = 0.000$ (D1 ^a > D2 ^b > D3 ^c > D4 ^d); Stand $\times$ Depth: $F = 16.05$, $P = 0.000$.
D2 ($\pm$ SE)	1.62 ($\pm$ 0.20)	2.29 ($\pm$ 0.03)	3.48 ($\pm$ 0.15)	1.20 ($\pm$ 0.00)	
D3 ($\pm$ SE)	1.37 ($\pm$ 0.14)	1.19 ($\pm$ 0.05)	2.41 ($\pm$ 0.11)	0.95 ($\pm$ 0.10)	
D4 ($\pm$ SE)	1.10 ($\pm$ 0.03)	1.11 ($\pm$ 0.03)	1.29 ($\pm$ 0.11)	0.94 ($\pm$ 0.01)	

Contrasting letters a, b, c refer to significant differences between different stands (Maple, Oak, Red pine, Control) and or soil depths ($D_1 = 0 - 10$ cm, $D_2 = 10 - 20$ cm, $D_3 = 20 - 30$ cm, $D_4 = 30 - 40$ cm).

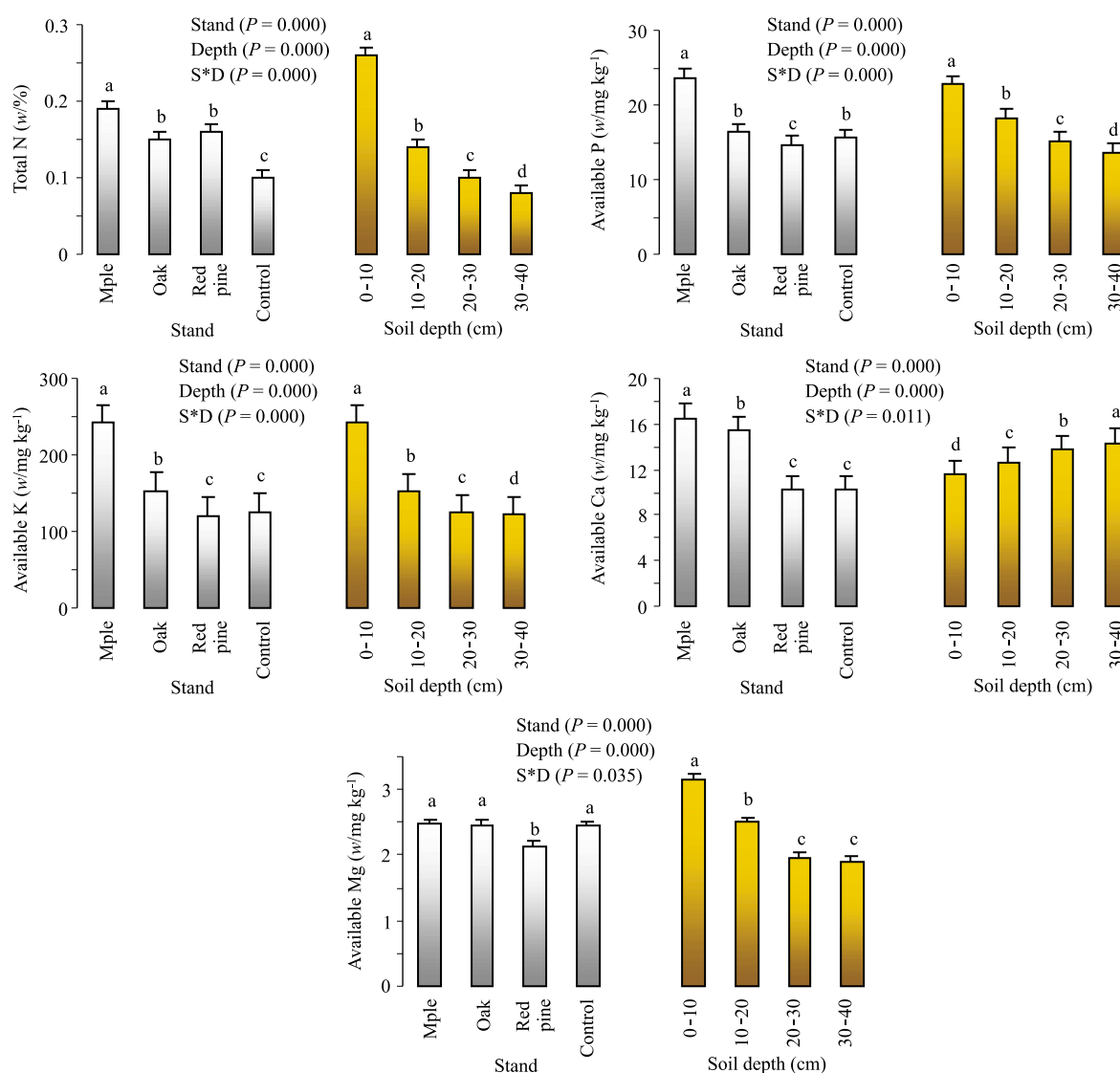


Fig. 1 Average values of total N (a), available P (b), K (c), Ca (d) and Mg (e) in different stands and soil depths.

affect long-term productivity. Our study showed that all three plantation stands had great effects on soil physicochemical properties, especially available soil nutrients. Most nutrients were significantly increased in soil after the establishment of plantations. These findings, however, were similar to those obtained by Lemenih *et al.* [34] who claimed that species dependent differences in soil properties are probably on account of differences in biomass production and nutrient cycle via litter fall and root turnover between the species.

Soil texture showed statistically significant differences both in stands vs. the control and with depth. This suggests a different evolution of the soil profile when covered by forest, especially in terms of erosion. Soil texture plays a huge role in determining the majority of chemical soil properties, namely the movement and retention of exchangeable base cations [35]. Compared to clay particles (< 0.002 mm), sand particles (0.02 - 2 mm) within a soil

consequently create large pore spaces, resulting in little capability to retain water or nutrients [36-37]. Exchangeable base cations are, therefore, often easily leached out of a soil, contributing to the low nutrient content of sandy soils [36, 38]. This is evident in red pine stands, which consist of more sand particles and have the lowest concentration of soil fertility. Sandy, well-drained and aerated soil is often prone to erosion as well [38]. Clay particles, on the other hand, are much more compactable than sand particles due to their small size, and so create considerably smaller pore spaces, which pose poor drainage [36]. This, combined with their large surface area and electrical charge, make clay particles particularly good at absorbing water and nutrients, which accounts for clay-dominated soils being rich in nutrients [39]. This was observed at the maple stand which had clay-dominated soil comprising high concentrations of soil fertility.

Soil acidity can play a significant role in the amount of

available nitrogen present in a soil. Usually the more acidic a soil is, the lower the macro-nutrient supply will be^[37]. Again, the more acidic the soil is, the more hydrogen ions there are expected to be present, thus leading to an increase in exchangeable aluminum ions likely dominating cation exchange sites. The presence of a coniferous tree canopy, e.g., red pine, has led to considerable acidification and long-term changes in soil chemistry due to the capture of atmospheric pollutants^[39]. The widespread input of highly acidic red pine needles onto the forest floor creates an extremely acidic litter, aiding soil acidification^[38]. Usually the more acidic the soil is, the lower the supply of macro-nutrients will be^[37, 40]. The red pine stand also featured slightly, but significantly, lower pH values. In fact, it is well known that conifer litter is more acidic than deciduous leaf litter^[38, 41-42], thus giving substance to the theory that litter pH affects soil pH. These results are in agreement with previous works carried out by several other authors, including Sariyildiz *et al.*^[43] and Marcos *et al.*^[44]. Higher amounts of soil pH in deeper soil layers, although non-significant, can be related to lower values of organic matter in soil beneath depths as indicated by the inverse relationship found between these characters^[45-46]. This was found to be true in a study by Smal and Olszewska^[42], in which it was reported that soil pH increased as organic matter content decreased.

Plants play an important role in regulating the biogeochemistry of ecosystems by fixing SOC and N and preventing the loss of nutrients^[47]. SOC is very important in terrestrial ecosystems since it plays a crucial role in the formation and maintenance of soil structure, fertility, and nutrient and water availability^[48-49]. Nitrogen is an essential macronutrient required in large quantities by plants, which is why coniferous afforestation is known for the depletion of available nitrogen reserves within the soil^[36]. Since SOC and N are indices of soil fertility, the loss of N from soil under red pine plantation, compared with maple and oak, may indicate a general loss in soil fertility^[50]. Soil CEC, and available P, Ca, and K are linked to mineral weathering, so it is reasonable that Ca and K increased in stands with greater amounts of silt and clay^[51-53]. At all stands; the upper soil layers had greater amounts of organic carbon, N, P, and K, likely due to plant restitution^[52, 54-56]. Upper layers had more available P and K, whereas available Ca increased with depth. These findings are similar to those of Habibi Kaseb and Lesani^[57]. Soil acidification may increase at the rate of dissolution of soil minerals beneath trees, and it has been shown to reduce soil structural stability and fertility^[58-59]. The soil under the red pine stand had lower fertility compared to that of the maple stand, and these changes may have contributed to the observed decreased pH. Soil acidity increases Al and Fe solubility, which removes base cations (available P, K, and Ca) from the exchange complex^[60]. Therefore, under red pine stands, base cations are likely to be displaced from the CEC to the soil solution where they are leached from the upper soil layer.

On the other hand, nutrient retention is dependent upon the balance between inputs (atmospheric deposition, gas adsorption/fixation), transformations (mineral weathering, mineralization of SOM), and outputs (soil leaching and volatilization)^[61]. Leaching is the process most responsible for the loss of exchangeable base cations from a soil, with 'cations with the least affinity for exchange sites' being lost most easily^[38]. Precipitation levels play a significant role in the leaching of a soil^[35], and with no forest canopy to intercept precipitation, exchangeable base cations will be frequently washed out. This could create distinct nutrient rich horizons lower down in the soil profile^[35]. As well as leaching, soil erosion can reduce exchangeable base cation concentrations, predominantly in the topsoil where a high majority of exchangeable base cations are concentrated^[35]. Leaching is known to aid the acidification of soil^[42]. Again, like in the forest soil, a reduction in exchangeable base cations would suggest an increase in soil acidification, exchangeable aluminum and exchangeable hydrogen ions dominating the exchange complex^[62]. Trees tend to enhance nutrient concentrations of incident precipitation^[59] with regard to canopy cover sizes. In broad-leaved forest stands (maple and oak), the expanded canopy cover resulted in less soil leaching than in the red pine stand or the control area.

In addition, coniferous afforestation, e.g., red pine, leads to a reduction in base cations from the soil as they are readily taken up by trees where they are stored in leaf litter and plant biomass^[39]. Soil K and Ca decreased after coniferous afforestation, suggesting their rapid uptake by coniferous trees. Decreases in Ca, Mg, and K were found after afforestation in studies by Smal and Olszewska^[42] and Berthrong *et al.*^[39] under the afforestation of *Pinus* species. The decrease in soil Ca and K could also be explained by the increase in soil acidity. Exchangeable base cation concentrations would decrease as exchangeable aluminum and exchangeable hydrogen ions would likely dominate cation exchange sites^[36]. This was also found to be true by Adriano and Havas^[63] who concluded that the decrease in exchangeable base cations was due to an increase in soil acidity via acid deposition. In general, according to the results of the current research, within 21 years of establishment, these plantations showed positive influences on most soil properties.

4 Conclusion

The goal of our study was to quantify the effects of plantation on soil fertility and to suggest forestry practices that can ameliorate any negative impacts of afforestation. Our findings showed that all three plantation stands had great effects on soil physicochemical properties, especially available soil nutrients. Most nutrients were significantly increased after the plantations were established. According to our results, the highest and lowest soil N, P, K, Ca and Mg levels occurred in maple and red

pine stands, respectively. Measurements of soil fertility showed a decrease in fertility in relation to increased soil depth, with significant differences depending on soil depth. Our research recommends plantation with suitable native broad-leaved species and forestation plan management to rehabilitate degraded natural forests, at least in the northern part of Iran.

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