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Reaction and fractal description of soil bio-indicator to human disturbance in lowland forests of Iran

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ABSTRACT

Mollaei-Darabi S, Kooch Y, Hosseini SM. 2014. Reaction and fractal description of soil bio-indicator to human disturbance in lowland forests of Iran. Biodiversitas 15: 60-66. Earthworms are expected to be good bio-indicators for forest site quality. The deforestation of land into another function could changes the soil features that could effect on earthworm population. This study was conducted to understand the changes of soil functions, resulting from exploitive management using some soil features and their fractal dimensions. Two sites were selected, consisting of an undisturbed forest site (FS) and a completely deforested site (DS) in lowland part of Khanikan forests located in Mazandaran province, north of Iran. Within each site 50 soil samples were obtained from 0-30cm depth along two sampling lines with 250 meter length for each. Deforestation brought a lower soil quality in the sites under the study. Decreasing silt, clay, moisture, pH, carbon to nitrogen ratio, available Ca, earthworm density and biomass, increasing bulk density and sand were few outcomes of the deforestation. Except for clay, the deforestation affect on fractal dimension of soil features. The fractal dimension of bulk density, silt, moisture, pH, earthworm density and biomass were decreased imposed by deforestation. Our results suggest that deforestation should be regarded as an effective factor on variability of soil features that are tied to forest ecology. This is significant for evaluating forest management policies and practices with respect to effects on soil and also for the use of soils as indicators, especially earthworms as bio-indicator, of forest ecosystems.

Key words: Earthworm, deforestation, fractal dimension, soil feature, top soil

INTRODUCTION

Earthworms are arguably the most important components of the soil biota in formation and maintenance of soil structure and fertility. Earthworms, although not numerically dominant but their large size makes them one of the major contributors to invertebrate biomass in soils (Kooch et al. 2013a). Their activities are important for maintaining soil fertility in a variety of ways in forests, grasslands and agro ecosystems (Palm et al. 2013). Earthworms are also expected to be good bio-indicators for forest site quality (Rahmani 2000). Earthworm's populations are as indicator that is representative of destruction in exploited regions and nature return indicator in reclamation projects (Kooch et al. 2013a). Earthworms are subject to physical, chemical and biological changes in soil, so they have a major role in soil structure and performance, transfer minerals to different horizons and also organics to lower horizons of soil (Rahmani 2000; Palm et al. 2013). Creation of holes in path of earthworms increases water penetration and soil aeration. It has been shown that 60% of earthworm's paths at soil depth of 15 cm and 18% of earthworm's paths at soil depth of 80 cm have been covered by tree roots (Palm et al. 2013). The earthworms cause remarkable increase in soil microorganisms and have an important effect on soil invertebrate's diversity and feed cycle (Groffman et al. 2004).

The year 2011 was ‘The International Year of Forests’. This designation has generated momentum bringing greater attention to the forests worldwide. Forests cover almost a third of the earth’s land surface providing many environmental benefits including a major role in the hydrologic cycle, soil conservation, prevention of climate change and preservation of biodiversity. Forest resources can provide long-term national economic benefits. For example, at least 145 countries of the world are currently involved in wood production (Chakravarty et al. 2012). Sufficient evidence is available that the whole world is facing an environmental crisis on account of heavy deforestation. For years remorseless destruction of forests has been going on and we have not been able to comprehend the dimension until recently. Nobody knows exactly how much of the world forests have already been destroyed and continue to be razed each year. Data is often imprecise and subject to differing interpretations. However, it is obvious that the area of forests is diminishing and the rate of temperate forest destruction is escalating worldwide, despite increased environmental activism and awareness (Chakravarty et al. 2012). Deforestation is the conversion of forest to an alternative permanent non-forested land use such as agriculture, grazing or urban development (Van Kooten and Bulte 2000). Deforestation is primarily a concern for the developing countries (Myers 1994).

Hyrcanian forest ecosystem is considered to be one of the last remnants of natural deciduous forests in the world.

In comparison to European broad-leaved forests, the Hyrcanian forests seem to have remained from the Tertiary and to be relict ecosystem. In Iran, Hyrcanian (Caspian) forests are located at green strip extending over the Northern Slops of Alborz range of mountains and Southern coasts of the Caspian Sea. This zone has a total area of 1.84 million ha comprising 15% of the total Iranian forests and 1.1% of the country's area. These forests stretch out from sea level up to an altitude of 2800 m and encompass different forest types (Khosroshahi and Ghavvami 2006). Today, these forests are depleting rapidly due to population growth, and associated socioeconomic problems, industrial development, urbanism, and more recently intensive/ irregular tourism. About 60% of Hyrcanian forests are managed for timber production and the remainders are degraded to different intensities. The existence of various land-uses, and their increasing alteration, mainly by local communities, mismanagement of natural resources over long periods of time, plans for industrial development (e.g., establishment of industrial towns adjacent to the forested areas), public road construction without detailed environmental considerations and shortage of human/ financial resources for sustainable monitoring and management of the forest resources are threatening the existence of the Caspian forests (Poorzady and Bakhtiari 2009).

Deforestation has many significant ecological consequences. The removal of vegetation results in increased erosion of soil sediments, which are many times deposited in water bodies, consequently depositing soil particles and nutrients. A decrease in vegetation also corresponds with a decrease in nutrient uptake in the soil, resulting in an increased rate of nutrient leaching from the soil. The effects of deforestation on soil physical, chemical and biological properties have been studied in both temperate and boreal forests around the world (Caruso 2002; Nkongolo and Plassmeyer 2010). Deforestation is known to cause severe disturbances, including changes in microclimatic conditions and light availability that affect plant growth (Xu et al. 2008). It also causes subtle changes in soil structure and nutrient dynamics that are detectable both immediately and or after several years of deforestation (Malgwi and Abu 2011). Soil fauna, especially earthworms as bio-indicator, are responsible for organic matter decomposition, nutrient cycling and maintenance of soil structure and thus have great role in long-term sustainability of forest ecosystems (Duffkova and Macurova 2011). Despite continued focus on the interaction between deforestation and soil processes, relatively little is known about the relationship between deforestation and soil fauna or whether deforestation changes in soil fauna influence soil ecosystem functioning. While forest degradation is rampant in the lowland forests of the northern Iran, no information exists on the effect of these changes on soil features. Such studies are particularly important in view of the role of soil features in the management and reclamation of deforested areas. The present study evaluates the reaction and fractal description of earthworms to variability of soil physico-chemical features imposed by deforestation in a lowland part of northern Iran.

MATERIALS AND METHODS

Study area

With an area of 2807 ha, the Khanikan forests are located in the lowland and midland of Mazandaran province in north of Iran, between 36˚ 33́ 15˝, 36˚ 37΄ 45˝ latitude North, and between 51˚ 23΄ 45˝, 51˚ 27΄ 45˝ longitude East (Figure 1a). The elevation of the forest area ranges between 50 and 1400 m above sea level (asl.). Minimum temperature in December (7.5˚C) and the highest temperature in June (24.6˚C) are recorded, respectively. Mean annual precipitation of the study area were from 47.5 mm to 237.6 mm at the Noushahr city metrological station, which is 10Km far from the study area. The climate is temperate moist and the dry months extend from May to September. The soil is forest brown soil showing a texture that ranges between sandy clay loam to clay loam (Kooch et al. 2007). The dominant forest types included Hornbeam (*Carpinus betulus* L.) and Persian ironwood (*Parrotia persica* C.A. Meyer), respectively (Kooch et al. 2007). A lowland part of these forests, almost 7 ha, were destroyed because of extensive exploitation carried out by local residents about 30 years ago (Figure 1a).

Soil sampling and analysis

Two sites (about 300 m apart from each other) were selected, consisting of an undisturbed forest site (FS) and a completely deforested site (DS). Within each site 50 soil samples were obtained from 0-30cm depth along two sampling lines with 250 meter length for each. The interval between samples along lines and also the distance between lines were selected 10 m (Figure 1b). Soils were air-dried and passed through 2-mm sieve (aggregates were broken to pass through a 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 moisture 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. Total carbon was determined using the Walkey-Black technique (Allison 1975). The nitrogen was measured using a semi Micro-Kjeldhal technique (Bremner and Mulvaney 1982). Available Ca was determined with an atomic absorption spectrophotometer (Burt 2004). Earthworms were collected simultaneously with the soil sampling by hand sorting. Worms were stored on ice and returned to the laboratory. They were then washed in water, dried for 48 hours at 60°C, and massed (Edwards and Bohlen 1996).

Statistical analysis

Kolmogorov-Smirnov test was used for testing normality and Levene test for data homogeneity testing. Independent sample t-test was used to find differences in soil features between the two sites. Analysis of the whole data set was done in SPSS Ver. 13.5. The software package used for detecting fractal dimension of soil features was GS^+ version 9 (Gamma Design Software, LLC, Plain well, MI).

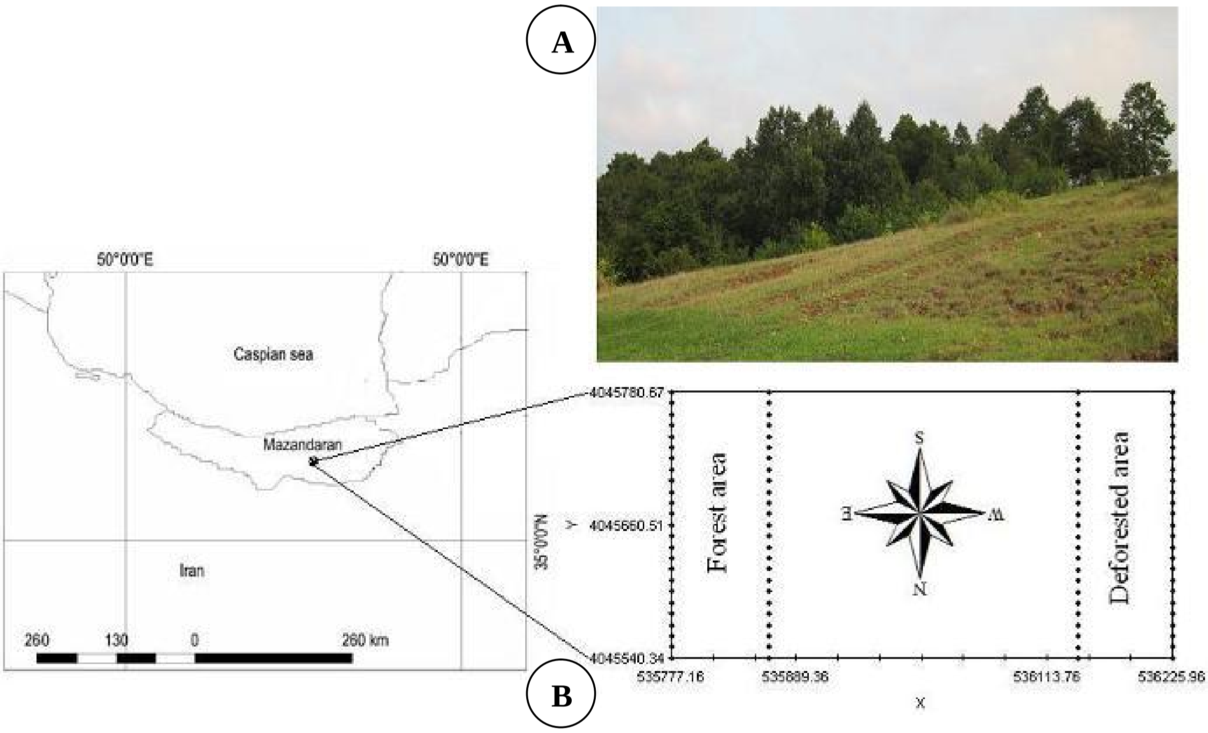

Figure 1. A photo of study area located in Mazandaran province, north of Iran (A). Schematic representation of the experimental design (figure not to scale) adopted for soil sampling pattern in two FS and DS (B).

RESULTS AND DISCUSSION

The changes in soil features and also the fluctuations along sampling lines (fractal dimensions) are presented in Table 1 and Figure 2 respectively. The mean of bulk density was significantly higher at DS (1.01 g cm^{-3}) when compared with FS (0.87 g cm^{-3}) (Table 1). Whereas, fractal dimension of bulk density was more in the FS (1.99) than DS (1.94) (Figure 2). Sand also followed the same trend having significantly higher values at DS (65.10%) than FS (53.24%) (Table 1). A greater amount of fractal dimension was detected in DS (1.95) than FS (1.91) for this character (Figure 2). Mean silt values were significantly higher at the FS (26.43%) than at the DS (22.08%) (Table 1). Higher value of fractal dimension was found at the FS (1.96) than DS (1.93) for silt content (Figure 2). The amounts of clay were significantly higher at the FS (21.27%) than DS (13.13%) (Table 1). The fractal dimension for the clay parameter was same in both of sites (1.97) (Figure 2). Soil moisture observed at the FS (45.89%) greater than at DS (28.72%) (Table 1). FS devoted higher value of fractal dimension (1.97) compared to FS (1.96) for moisture character (Figure 2).

The pH was slightly acidic at both the sites. The mean pH was lower at the DS (5.70) than FS (6.58) (Table 1). Fractal dimensions presented more value for FS (1.99) than DS (1.81) related to soil pH (Figure 2). The mean values of carbon to nitrogen ratio observed at FS (10.17) were significantly higher than the value at the DS (3.25) (Table 1). The fractal dimension of this soil character was detected a little more in DS (1.97) compared with FS (1.96) (Figure 2). Mean available Ca values were significantly higher at the FS (34.23 mg g^{-1}) than at the DS (20.42 mg g^{-1}) (Table 1). Higher value of fractal dimension for available Ca was found at the DS (1.95) than FS (1.93) (Figure 2). Earthworm density and biomass were significantly higher at the FS (0.60 n m^{-2} and 0.26 mg m^{-2}, respectively) than DS (0.30 n m^{-2} and 0.07 mg m^{-2}, respectively) (Table 1). As the same, the fractal dimensions presented more values for earthworm density and biomass in FS (1.96 and 1.98, respectively) than DS (1.95 and 1.94, respectively) (Figure 2).

Table 1. Mean (±standard error of mean) soil features of FS and DS

Soil features	Site condition		Statistical characters	
	FS	DS	T-value	Sig.
Bulk density (g cm^{-3})	0.87±0.01 b	1.01±0.02 a	-4.57	0.00
Sand (%)	53.24±2.17 b	65.10±2.26 a	-3.77	0.00
Silt (%)	26.43±1.53 a	22.08±1.44 b	2.06	0.04
Clay (%)	21.27±1.59 a	13.13±1.30 b	3.95	0.00
Moisture (%)	45.89±1.23 a	28.72±1.04 b	10.61	0.00
pH	6.58±0.05 a	5.70±0.05 b	12.24	0.00
Carbon to nitrogen ratio	10.17±0.04 a	3.25±0.02 b	13.88	0.00
Available Ca (mg g^{-1})	34.23±0.07 a	20.42±0.07 b	12.47	0.00
Earthworm density (n m^{-2})	0.60±0.13 a	0.26±0.07 b	2.18	0.03
Earthworm biomass (mg m^{-2})	0.30±0.07 a	0.07±0.02 b	3.02	0.00

Note: FS = undisturbed forest site; DS = completely deforested site. N = 50 for FS and N = 50 for DS from 0-30 cm soil depth. Within the same raw the means followed by different letters are statistically different ($P \leq 0.05$).

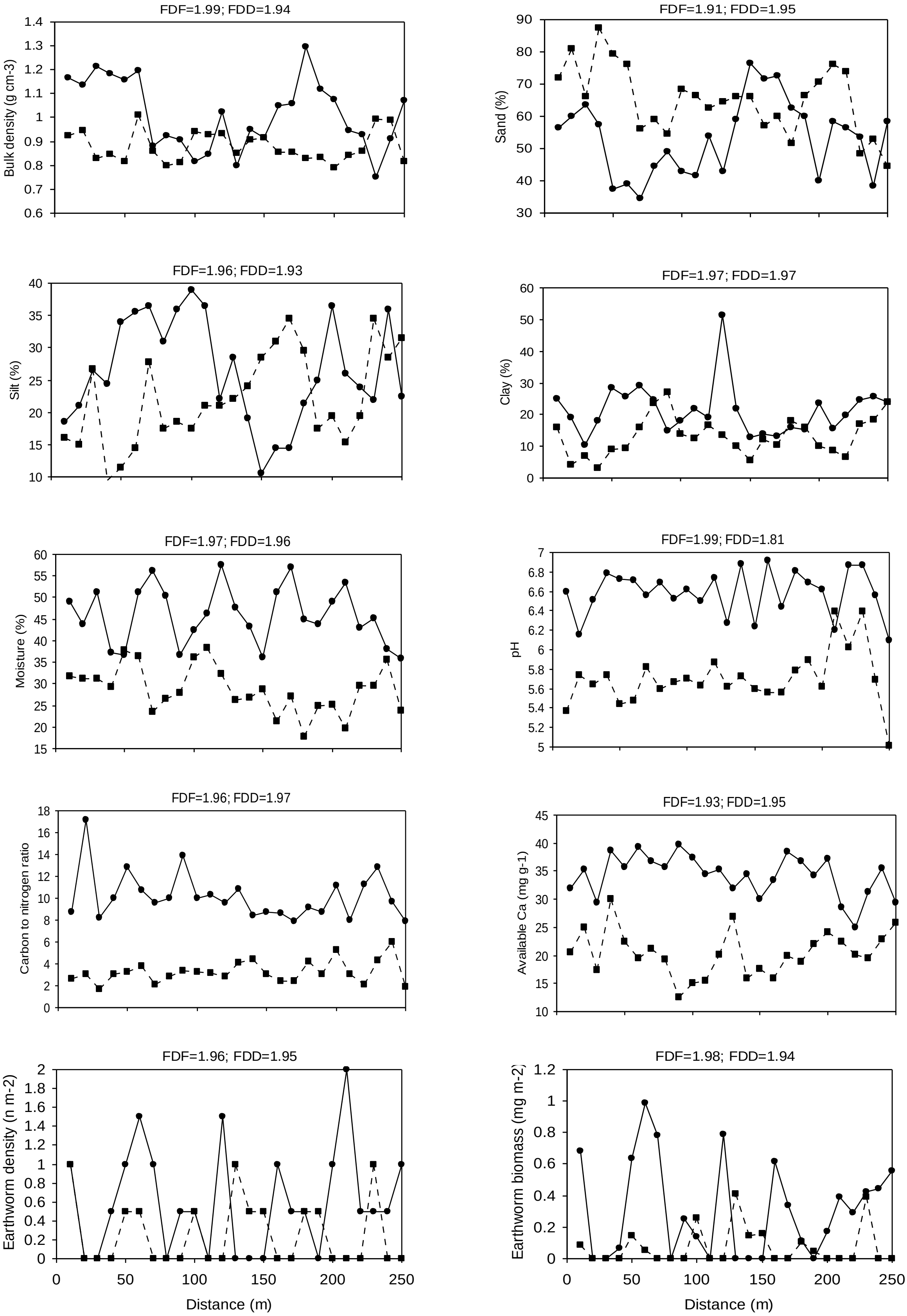

Figure 2. Variability of soil features along the sampling line in study area. Fillers circle with continues line represent values on every sampling of FS. Filled square with discrete line represent values on every sampling of DS. FDF means Fractal Dimension of intact Forest. FDD means Fractal Dimension of Deforested area.

Deforestation in the temperate regions has long been considered to lead to the degradation of the soil features related to soil fertility. Earthworm is one of the important organism in the soil that a susceptible to the faint changes of environmental, especially moisture, temperature and the amount of litter supply (Yusnaini et al. 2002). According to researchers findings (e.g., Brady and Weil 2002) erosion rates appear to have increased in DS compared to the FS. The increased erosion then acted as an important driver, which affected other soil features and nutrient levels. Erosion could have increased the bulk density of the DF (Brady and Weil 2002). It is important to note, however, that compaction due to local residents and also livestock in the DS and potentially lower amounts of vegetative residue inputs into the soil leading to lower levels of soil organic matter in DS as compared to the FS could also have contributed in creating the differences in the soils' relative bulk densities (Abbasi et al. 2007; Khresat et al. 2008). In agreement with the bulk density levels found in the DS and FS in the current study, many other studies have also found bulk density to be higher in disturbed sites compared to natural forests, especially in highly degraded or overgrazed pasture lands (Abril and Bucher 2001; Celik 2005; Basaran et al. 2008).

In addition, a greater amount of bulk density at the DS can be related to soil texture. Kooch (2007) found that bulk density has a negative correlation with content of clay and positive correlation with sand, thus the bulk density tended to be less in clay soils compared with sandy soils. Lower values of bulk density may be due to presence of high organic matter content at the FS because OM had a significant effect on the bulk density of soils (Handayani et al. 2012). The components of soil texture are influenced by canopy cover in the forest ecosystems (Kooch et al. 2013b). With degradation of forest and opening of canopy cover rainfall will effect on these components as direct. Clays and silts with considering smaller size transferring to beneath layers whereas sands are stable in upper soil. This status can be regarded in this research also. As, greater amounts of sand contents were found at the DS compared to FS. Increase in absorption of solar radiation by mineral soil due to removal of forest cover by deforestation has led to the warming of the soil which in turn caused increased air and soil temperature and following reduce of soil moisture (Hashimoto and Suzuki 2004) in our research. Soil acidification often occurs with NO^{3-} leaching and nitrification (Kooch et al. 2010). We are suspect that the leaching in DS is due to reduction of soil pH values. Further differences in available Ca between two sites could be due to soil pH. As FS had higher pH than DS the availability of base cations like Ca increases with increase in pH (Onweremadu 2007).

Regarding to higher carbon to nitrogen ratio in FS compared DS; the greater amounts of carbon and nitrogen were detected in FS (Unpublished data). Deforestation can impact soils in multiple ways including reducing organic carbon and nitrogen (Pennock and Kessel 1997). It has also been shown to reduce the cation exchange capacity of the soil and the levels of soil nutrients such as calcium (Eden et al. 1991). Organic carbon and organic matter are added to the soil primarily from decomposing vegetative residues such as leaves, litter, and roots and a decrease in these inputs can lead to a decrease in soil organic carbon and matter (Bernoux et al. 1998). Also, organic matter and organic carbon often accumulate at the top of the soil profile and therefore their abundance in a soil can be reduced by erosion (Abbasi and Rasool 2005; Zheng et al. 2005). The higher levels of organic carbon in the FS compared to the DS could be attributed to these factors. Deforestation and the essential removal of all tree biomass for use as fuel wood removed organic material high in nutrients (Khresat et al. 2008). Therefore, following the cut, the DS soils would have had fewer inputs of vegetative residues than the FS soils.

Higher erosion rates after the removal of the overstorey in the forest ecosystems could also be removing decomposable vegetative material as well as the upper levels of soil where organic matter would accumulate. The removal of the overstorey vegetation have increased the solar radiation reaching the soil surface and raised daytime temperatures. This would decrease organic matter by increasing organic matter mineralization rates in the soil (Zou et al. 2007). Zheng et al. (2005) found erosion to result in a loss of 69% of organic matter seven years after deforestation. Nitrogen can enter the soil through organic matter, precipitation, and also through biological nitrogen fixation. Nitrogen leaves the soil through leaching, volatilization, and biological uptake (Wachendorf et al. 2008). The higher levels of total nitrogen in the FS compared to the DS can be explained by the higher amounts of organic matter in the forest soils. In addition, removing the overstorey in the DS could have caused increased organic matter decomposition and nitrogen transformation rates resulting in more nitrogen being leached out of the soil (Khresat et al. 2008). In another study where erosion was an important driver of site characteristics, Zheng et al. (2005) reported that erosion following deforestation resulted in a 46.7% decrease in total nitrogen.

The accurate information on earthworm ecology and population is very important for maintaining the sustainability of forest productivity. The use of this information can be directed toward maximizing beneficial effects and contributing to richness of the concerned lands. According to our findings in present research, whole of studied soil features were significantly imposed by deforestation. Also, our data showed that FS has more appropriate position for earthworm living. Greater amounts of moisture (Saleh Rastin 1978; Londo 2001; Nachtergale et al. 2002; Whalen and Costa 2003; Valckx et al. 2009), pH (Neirynck et al. 2000; Deleporte 2001; Decaëns and Rossi 2001; Jiménez et al. 2001; Whalen and Costa 2003) and Ca (Kooch and Jalilvand 2008) in FS creates good conditions for gathering of earthworms. Our results suggest that deforestation should be regarded as an effective factor on variability of soil features that are tied to forest ecology. This is significant for evaluating forest management policies and practices with respect to effects on soil and also for the use of soils as indicators, especially earthworms as bio-indicator, of forest ecosystems.

A fractal dimension is a ratio providing a statistical index of complexity comparing how detail in a pattern (strictly speaking, a fractal pattern) changes with the scale at which it is measured. It has also been characterized as a measure of the space-filling capacity of a pattern that tells how a fractal scales differently than the space it is embedded in; a fractal dimension does not have to be an integer (Kenneth 2003). In the present research the fluctuation and fractal dimension of soil features were studied in FS and DS. The analysis of spatial dependence presented different spatial distribution and spatial dependence for whole of soil features. Bulk density, silt, moisture, pH, earthworm density and biomass presented shorter variability amplitude in FS compared to DS. Whereas sand, carbon to nitrogen ratio and Ca showed shorter variability amplitude in DS. In general, our finding implied that soil features have weak spatial correlation in both of studied sites, especially FS.

CONCLUSION

Lowland forests in the northern Iran have been influenced by humans for centuries, mainly through activities such as timber extraction and grazing. The present structure and composition of these forests are largely a result of these past activities. Deforestation brought a lower soil quality in the sites under the study. Soil quality was examined through determination and comparing of some soil physico-chemical and biological. Decreasing silt, clay, moisture, pH, carbon to nitrogen ratio, available Ca, earthworm density and biomass, increasing bulk density and sand were few outcomes of the deforestation. Except for clay, the deforestation affect on fractal dimension of soil features. The fractal dimension of bulk density, silt, moisture, pH, earthworm density and biomass were decreased imposed by deforestation.

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