Journal of Environmental Management 345 (2023) 118657

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

The effect of silvicultural systems on soil function depends on bedrock geology and altitude

Yahya Kooch [a,*], Mohammad Kazem Parsapour [a], Azam Nouraei [b], Zahra Mohmedi Kartalaei [a], Donghui Wu [c,d,e,f], María Gómez-Brandón [g], Manuel Esteban Lucas-Borja [h]

[a] *Faculty of Natural Resources & Marine Sciences, Tarbiat Modares University, 46417-76489, Noor, Mazandaran, Iran*
[b] *Department of Sciences and Forest Engineering, Sari Agricultural Sciences and Natural Resources University, Mazandaran, Iran*
[c] *Key Laboratory of Wetland Ecology and Environment, State Key Laboratory of Black Soils Conservation and Utilization, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun, 130102, China*
[d] *State Environmental Protection Key Laboratory of Wetland Ecology and Vegetation Restoration, School of Environment, Northeast Normal University, Changchun, 130117, China*
[e] *Key Laboratory of Vegetation Ecology, Ministry of Education, Northeast Normal University, Changchun, 130024, China*
[f] *Jilin Provincial Key Laboratory of Animal Resource Conservation and Utilization, Northeast Normal University, Changchun, 130117, China*
[g] *Grupo de Ecoloxía Animal (GEA), Universidade de Vigo, Vigo, E-36310, Spain*
[h] *Escuela Técnica Superior Ingenieros Agrónomos y Montes, Universidad de Castilla-La Mancha, Campus Universitario, E-02071, Albacete, Spain*

ARTICLE INFO

Handling Editor: Raf Dewil

Keywords:
Old-growth stands
Intact forest
Single-tree
Shelterwood
Nutrient cycling

ABSTRACT

Soil quality and function in forest environments are influenced by the interaction of soil-forming parameters and silvicultural systems. Hyrcanian forests were recently accepted as a UNESCO World Heritage Site, which extends across an area of approximately 1.8 million hectares and ascend to an elevation of 2800 m above sea level (m.a.s.l). In these woodlands, Oriental Beech (*Fagus orientalis* Lipsky) is the predominant tree species and could be observed at 700–1500 m.a.s.l., and occur on different parent rocks. Shelterwood and single-tree selection techniques have been the primary management methods for beech forests for the past forty years. Studies investigating the impacts of silvicultural systems have not yet been done on soil and forest floor features on different bedrock geology and altitudes. Therefore, in this study, we examined the influence of single-tree selection and shelterwood methods, 25 years after employing those methods, on soil quality and function compared to control areas (intact forests) in Hyrcanian beech stands. For this purpose, 15 forest floor (30 × 30 cm) and topsoil (0–10 cm depth) samples in each silvicultural systems (i.e., single-tree selection and shelterwood methods and control zones) × 4 regions (including Rasht, Nowshahr, Sari and Gorgan) × 4 altitude levels (with averages of 800, 1000, 1200 and 1400 m.a.s.l.) were considered. According to our findings, the investigated forest regions, forest floor and soil characteristics across various locations spots could be separated by principal component analysis output, and more than 85% of the variance was explained by the first and second axes. The structural equation model showed that the region, altitude and silvicultural systems had an effective role in the changes in soil biological activities by influencing the forest floor, and the soil physicochemical features. Based upon the network model, the C/N ratio, the sand content, the soil aggregate stability, the available K, the fulvic acid, and the Acarina density were found to be prominent factors with regard to soil function. In the control sites, increased soil organic material fractions, microbial/enzyme and biota activities were detected, particularly at the lower altitudes of the Nowshahr site, which had geological formations of dolomite and calcic layers. Taken together, it seems that the single-tree method, commonly referred to as the close-to-nature technique produces more suitable conditions for soil functioning compared to the shelterwood management approach. Silvicultural systems, bedrock geology and altitude can have major detrimental effects on soil function and fertility, over the long-term, impacts may increase with harvest intensity.

---

* Corresponding author.
E-mail addresses: yahya.kooch@modares.ac.ir (Y. Kooch), m.parsapour@modares.ac.ir (M.K. Parsapour), a.noraiy@stu.sanru.ac.ir (A. Nouraei), zahramohmedi@gmail.com (Z.M. Kartalaei), wudonghui@iga.ac.cn (D. Wu), mariagomez@uvigo.es (M. Gómez-Brandón), manuelesteban.lucas@uclm.es (M.E. Lucas-Borja).

https://doi.org/10.1016/j.jenvman.2023.118657
Received 15 March 2023; Received in revised form 3 July 2023; Accepted 15 July 2023

1. Introduction

Soil formation is a long-term process that is partially determined by climatic conditions and the properties of the parent materials (Jenny, 1941). The development of soil and the features of ecosystems are ultimately controlled by five determinant elements that are connected to parental material, topography, biota, climate, and timeframe (Chapin et al., 2002). Inherent soil characteristics, fertility, forest growth, and species distribution are functions of topography and parent material (Kranabetter and Banner, 2000; Babur, 2019). The first stage of soil formation and the materials from which soil is formed are both referred to as bedrock geology (Jenny, 1941). Soil physicochemical properties, soil development, and soil type are influenced by bedrock geology. Soil parent materials are highly variable mineralogically and chemically (Augusto et al., 2017); and they determine the original supply of nutrient elements that are released by weathering and affect the balance between nutrient loss and storage (Anderson, 1988). According to Sutinen et al. (2011) and Ruuhola et al. (2016), the bedrock underlying the soil erodes due to physicochemical processes, and the weathered material combined with organic matter forms the soil. In this regard, indispensable nutrients for plants originate from the bedrock beneath the soil (Ruuhola et al., 2016), and differences in their availability are related to distinct soil parent materials and thus to stand productivity (Moore et al., 2022). The elevation is one of the most important factors affecting both the physicochemical properties of the soil and its biodiversity (Babur et al., 2022). Along elevational gradients, soil properties and processes may vary from one landscape location to another due to differences in soil-forming factors such as climate, parent materials, and topography (Ali et al., 2019). The changes in the altitudinal gradient can be applied for ascertaining how warming affects plant and soil properties (Gerdol et al., 2017). In this regard, elevation determines the stability, productivity and functional properties of forest ecosystems by affecting temperature, precipitation and light intensity. Furthermore, variations in temperature and water content with elevation can impact humification processes and soil functionality (Zhou et al., 2022). The growth rate and nutritional status of mountain plants can also be affected by low temperatures at high altitudes, likely owing to a reduced soil nutrient availability as a result of the direct impact of soil temperature on the nutrient mineralization rates (Gerdol et al., 2017).

In forest ecosystems, different silvicultural systems can influence the composition of tree species, the distribution of tree size and the stand density, ultimately altering forest structure (Zhang et al., 2022a). Although intensive management is a vital strategy for enhancing forest productivity, it may also significantly alter soil physicochemical properties and nutrient turnover, as well as plant disease control and soil biological processes (Wan et al., 2022; Mäkipää et al., 2023); the magnitude of such effect vary with the silvicultural systems (Wan et al., 2022; Povilaitienė et al., 2022; Li et al., 2023). The biogeochemistry of forest soils is very sensitive to silvicultural systems, which may affect the long-term viability and productivity of forest regions, as well as the soil function (Foote et al., 2015). Biological features are known to respond more quickly than other soil properties to forest management practices and disturbances (Babur and Dindaroglu, 2020). Soil functions like plant residue decomposition, organic matter stabilities and nutrient and gas exchanges can be the result of soil biological activities (Mohammadi et al., 2017). Changes in the quantity and quality of organic matter inputs due to the various silvicultural systems can influence the activities and compositions of soil biota (Kooch et al., 2020). Furthermore, soil compaction during forest harvesting modifies soil structure, bulk density, porosity, exchange of gas and infiltration of water, which might have an effect on biogeochemical cycles within disturbed soils (Ampoorter et al., 2007; Cambi et al., 2017). Therefore, sustainable forest management requires identifying, maintaining, or improving soil ecological functions and services (Ma et al., 2022). Forests can be harvested by clear-cutting, shelterwood and single-tree selection methods. Using any of these methods can have different effects on the forest ecosystems' soil function (Roy et al., 2021). In this regard, sylvicultural systems may be based upon partial harvesting (such as group and single tree selection methods) which is a form of uneven-aged management, whereas the shelterwood method is based upon total harvesting of varying form and extent in an even-aged management system (Roy et al., 2021).

Recently accepted on the World Heritage List UNESCO, at approximately 1.8 million ha of area are covered with Hyrcanian forests, which reaches an elevation of 2800 m above sea level (m.a.s.l). Oriental Beech (*Fagus orientalis* Lipsky) covers roughly 17.60% of the forest land, 30% of the stand volume, and 23.60% of the stems in the Hyrcanian forest region. This species has a great capacity for competition and has expanded over the intermediate altitudes of the Hyrcanian woodlands, from Astra in the west (adjacent to Azerbaijan) to the Ziyarat Valley in the eastern part of the Caspian Sea coast (Gorgan). This tree species is the dominant tree in Hyrcanian forests and can be found at 700–1500 m.a.s.l. (Kooch et al., 2020). Based upon Sagheb-Talebi et al. (2014), Fagetum communities can be observed on two primary parent rock types in Iran, which are calcic and acidic igneous and metamorphic rock respectively (sedimentary and metamorphic). In the past forty years, two systems based on single-tree selection and the shelterwood method have mainly been applied to manage these forests (Sagheb-Talebi and Schutz, 2002). The primary and more established method for encouraging the regeneration of trees is the shelterwood method. Nevertheless, reducing people's concerns about adverse environmental effects, such as aesthetical and biological principles and silvicultural attributes, is of great importance. As a result, this traditional cutting system has been replaced by a more environmentally friendly system known as the single-tree selective method for logging Hyrcanian forests. One of the vital objectives of this selection method is that, by applying it, forest managers are able to create uneven and mixed forest stands. This action helps to protect the forest soil layer, wildlife and local habitat maintenance or development and also triggers diversity in forest species along with single-tree productivity (Pourmajidian and Rahmani, 2009; Kooch et al., 2020). Nonetheless, no investigations on the impact of silvicultural systems on the forest floor and soil properties at varied bedrock geology and different altitudes have been conducted so far. Therefore, in this study, we examined the influence of single-tree selection and the shelterwood method on soil function compared to control areas (intact forests) in Hyrcanian beech stands. We strove to generalize soil processes that are influenced by forest management, evaluate forest silvicultural systems in terms of their impact on soil function, and offer ways that can result in enhanced performance characteristics of forest soil function. In the lower altitudes of areas with geological formations of dolomite and calcic layers, we hypothesized that single-tree management techniques and old-growth beech forests will lead to a similar scenario in terms of soil function.

2. Materials and methods

2.1. Study areas

The research areas are scattered along the northern strip of Iran's Hyrcanian forests (Fig. 1) (roughly 800 km in length and 110 km in width) as shown below:

(1) *Rasht region*: This research location is situated in Talesh's Nav Forest at 37° 41′ 22″ and 37° 36′ 28″ latitude, 48° 48′ 04″ and 48° 40′ 22″ longitude. The research area's boundary exhibited a 10–30% slope toward the north. With an average annual precipitation of 819 mm, which falls mostly between September and December, the area has a sub-Mediterranean climate. Summer (June–August) is considered the dry season. In February, the daily average temperature is −2.8, while in August, it is 25.7 °C. The soils are classified as Alfisols (silty-sandy-loam) by the USDA soil classification system. The geological substrates of the

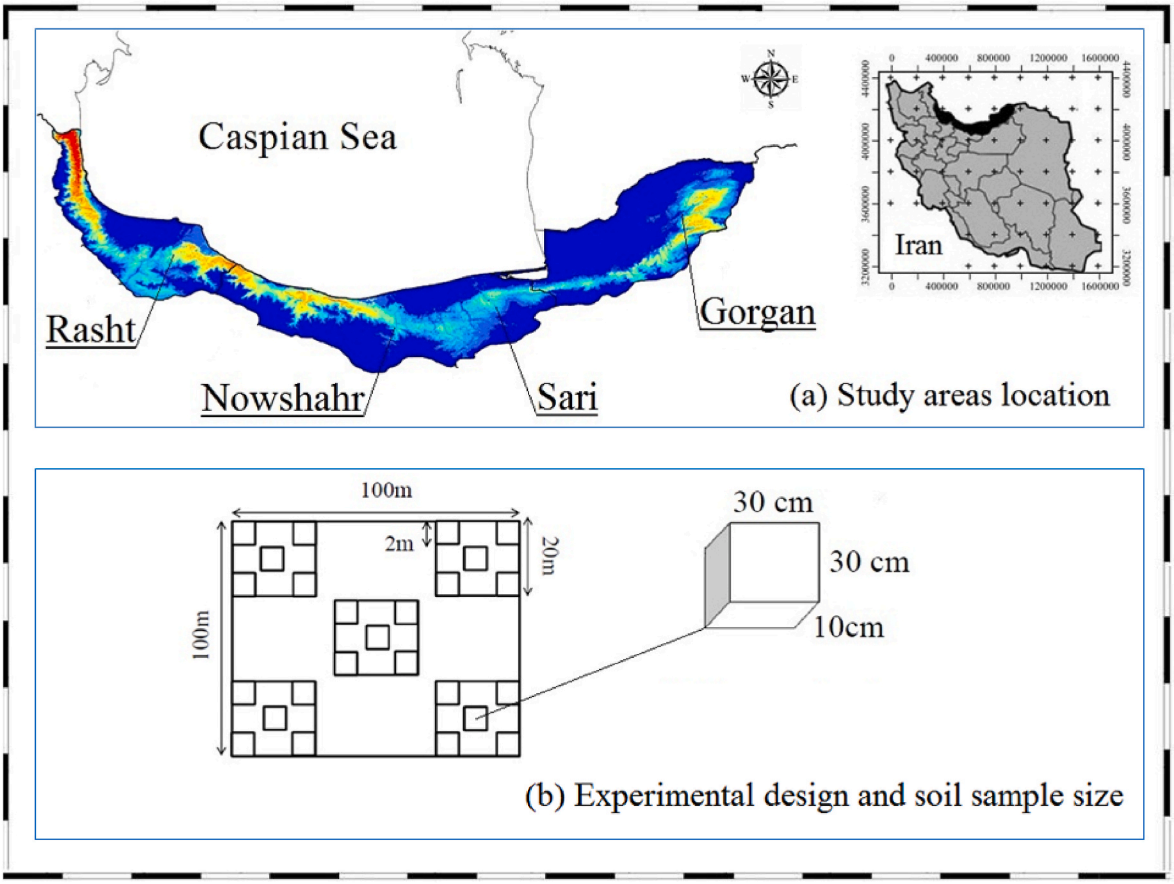

Fig. 1. Location of the study areas in Northern Iran (a), schematic representation of the experimental design and soil sample size (b) (figures not to scale).

research region comprise of granite rocks (acidic igneous), sometimes andesite, alkaline diorite, perfirite, and metamorphic rocks of the early Tertiary, such as quartz schist.

(2) *Nowshahr region*: This research area is situated in the Jamand forest of the town of Nowshahr between 36° 30′ 00″ and 36° 27′ 35″ latitude and 51° 32′ 28″ and 51° 30′ 00″ longitude. The research area was restricted by a slope of 10–30% with northern exposures. The area has a sub Mediterranean climate with an average annual rainfall of 803.4 mm, with the majority of precipitation falling during September and December. Summer (June–August) is the dry season. February average daily temperatures vary from 2.2 to 25.6 °C. According to the USDA soil classification system, these soils are classified as Alfisols (silty-clay-loam). Calcic and dolomite strata are occasionally connected with Paleozoic red sandstones and are bordered by Jurassic, Cretaceous, and Carboniferous calcic layers. At high elevations, alkaline intrusive igneous rocks can also be often seen.

(3) *Sari region*: the Darabkola forest is situated in the southeastern portion of the town of Sari between 36° 28′ and 36° 23′ latitude and 52° 14′ and 52° 31′ longitude. The research area was restricted by a slope of 10–30% with north exposure. According to the Gharakheill Meteorological Station's data processing, the annual mean rainfall and temperature were respectively 732.8 mm and 16.8 °C. The climate is moist and moderate, however, from May to September it is drier than the rest of the year. Soil texture ranges from sandy-clay-loam to clay-loam and it is forest brown. Triassic and Jurassic limestone and dolomite are often found inside geological formations. In some regions, however, late Tertiary metamorphic rocks, often red quartz schist, are also present.

(4) *Gorgan region*: This research area is situated in the Vatana forest in the city of Bandar-e-Gaz between 36° 41′ 50″ and 36° 38′ 00″ in latitude and 54° 00′ 30″ and 53° 55′ 40″ in longitude. The research area was restricted by a slope of 10–30% with northern exposures. The region has on average a sub-Mediterranean climate with 736 mm of annual rainfall, most of which falls during September to December. June through August constitute the dry season. February daily average temperatures are 3 °C and August daily average temperatures are 32.3 °C. The soils are classified as Alfisols (silty-sandy-loam) by the USDA soil classification system. Dolomite, limestone, Devonian sandstones, Jurassic calcic and Carboniferous strata are often found in geological formations. Metamorphic rocks like quartz schist can be observed in such areas as well.

These regions are all inhabited by Oriental Beech (*Fagus orientalis* Lipsky) together with hornbeam (*Carpinus betulus* L.). In various regions of these forests, single-tree and shelterwood methods were utilized in 1998. In addition, a portion of the parcels was maintained unharvested, serving as control zones (Sagheb-Talebi et al., 2014).

2.2. Sampling and laboratory analyses

In August 2021, the four above-mentioned regions with different bedrocks (i.e., Rasht, Nowshahr, Sari and Gorgan) under single-tree selective cutting and shelterwood techniques, together with the control zones, at different altitudes (with averages of 800, 1000, 1200 and 1400 m a.s.l.) were considered for the purpose of the present study. In each of them, three 1-ha (100 × 100 m) plots were set up 4–6 km apart from each other so as to prevent pseudo-replication (Hurlbert, 1984). These experimental plots share the same physiographic characteristics (slopes between 10 and 15 percent and a northern geographical orientation) and previous management. To document the woody and herbaceous flora, 400-m^2 (20 × 20 m) macro plots and 4-m^2 (2 × 2 m) micro plots were considered in every location, respectively (Mesdaghi, 2005) (see Appendix 1). In August 2021, soil layers (0–10 cm) and litter or O-horizon (including layers of L, F, H) were taken in a 30 × 30 cm area from the center of each macro plot and transported to the lab for further evaluation. In parallel, the O-horizon layer was measured by employing a ruler from the litter surface to the top of the mineral soil (Dechoum et al., 2015). A metal frame (20 × 20 cm) was laid out on the ground, and its perimeter was removed with a cutter to determine the O-horizon mass. The O-horizon was obtained within the area of the frame up to the mineral soil's surface. For this purpose, a total of 15 forest floor (30 × 30 cm) and topsoil (0–10 cm depth) samples were considered in each forest silviculture (i.e., single-tree and shelterwood cutting methods and control zones) within four altitudinal gradients (with averages of 800, 1000, 1200 and 1400 m.a.s.l.) and 4 study regions (including Rasht, Nowshahr, Sari, and Gorgan). Each sample was thoroughly cleaned before being dried at 105 °C for 48 h before analysis (Kostel-Hughes et al., 1998). The biomass was turned into mass per square meter (kg/m^{-2}). Total carbon and nutrients were determined in quadruplicate in O-horizon samples by dry combustion using an element analyzer (Fisons EA1108, Milan) standardized by the BBOT [2,5 bis (5 tert-butyl-benzoxazol-2-yl) thiophen] (Thermo-Quest Italia s.p.a) (Kooch et al., 2017).

Air-dried soil samples (broken aggregates) were run through a 2 mm sieve. Before air drying, soil samples were dried overnight at 105 °C to assess the soil moisture content (gravimetric method). A digital thermometer was employed to measure the soil temperature. Utilizing the clod technique (Plaster, 1985) and the pycnometer technique (Blake and Hartge, 1986), the soil's bulk and particle densities were calculated respectively. According to Pires et al. (2014), equation [1−(bulk density/particle density)] was adopted to determine the soil porosity. The Yoder technique (adjusted by Kemper and Rosenau, 1986) was applied to determine the soil aggregate stability; and the Bouyoucos hydrometer technique to assess the soil texture (Bouyoucos, 1962). The aggregate size distribution was performed using the wet sieving method with mesh sizes of 0.25 and 0.50 mm. Micro- and macro-aggregate sizes varied between 0.05 and 0.25 mm and between 0.25 and 0.50 mm, respectively. The biggest screens were used to submerge the soil samples in water for approximately 5 min prior to sifting. The soils were sieved 50 times over 2 min while they were gently lowered into a small pan of water while slowly being moved three mm vertically through the water. The non-sieved materials were dried in an oven (forced air) at 60 °C, and the contents of C and N in the macro and microaggregates were weighed (Cambardella and Elliott, 1992). The Walkly-Black technique was used to determine the soil organic carbon content (Allison, 1975); and total N was measured by utilizing a semi-MicroKjeldahl method (Bremner and Mulvaney, 1982). To ascertain soil C and N stocks at the investigated depth, the sites' bulk densities and concentrations of C and N were utilized. Soil pH and electrical conductivity (EC) were measured in a soil-to-water solution (1:2.5, v/v) using an Orion Ionalyzer Series 901 pH reader and an Orion Ionalyzer Series 901 EC m, respectively. Soil NH_4^+ and NO_3^- contents were colorimetrically measured in 2 M KCl extracts (1:5, w/v) at 645 and 420 nm respectively (Li et al., 2014). N mineralization was assessed following the procedure proposed by Robertson (1999). The amount of available P was assessed using the Olsen method (Homer and Pratt, 1961); while the amounts of K, Ca, and Mg (extracted at pH 9 with ammonium acetate) were performed following the procedure from Bower et al. (1952). The International Humic Substances Society (IHSS) methodology was applied to isolate and purify the humic and fulvic acids from the soil samples (Sparks and Bartels, 1996).

Soil particulate organic matter (POM) was assessed by blending 25 g of soil (equivalent oven dry weight) with 100 ml of sodium hexametaphosphate (5 g L^{-1}). On an end-to-end mixer, the soil solution was mixed for 60 min at 500 rpm before being poured through a sieve (0.05 mm) with numerous washes of deionized water. The sieved soils were backwashed into a weighed metal dish. After 24 h at 60 °C, they were pulverized into a powder and tested for carbon and nitrogen (Cambardella and Elliott, 1992). A 200-ml tube containing 20 g of soil and NaI solution (100 ml; $p = 1.8$ g/ml^{-1}) was maintained for 12 h at 20–22 °C prior to 15 min centrifugation at 3500 rpm to determine the SOM occluded and free light fractions. The supernatant was then filtered through a 0.45 μm-membrane filter prior to being placed in a Millipore vacuum unit. After washing with 200 ml of distilled water and 100 ml of $CaCl_2$ (0.01 mol/l^{-1}), the recovered fraction was poured into a 50 ml beaker that had been pre-weighed. The sediment was centrifuged and filtered in 100 ml NaI. The new fractions were added. Following 72 h of drying at 60 °C, the sediment was weighed and the free light fraction was extracted. The sediment then was shaken and sonicated at 100 W for 15 min after being re-dissolved in NaI (100 ml). The supernatant fraction was termed occluded light fraction after two centrifugations and filtrations (See Wang and Wang, 2011). To calculate the amount of dissolved organic matter (DOM), soil samples (10 g, fresh weight?) were equilibrated in 40 ml of K_2SO_4 (0.5 M) for 60 min after being filtered through a 0.45 μm filter (polyether sulfone) and then acidified using phosphoric acid to reach a pH of 2 (Mikkelson et al., 2016). After dissolving 15 g of dried soil in 150 ml of deionized water, both organic carbon and total nitrogen were recovered in the cold water-soluble extracts. The soil-to-water suspension was then shaken for 30 min, centrifuged for approximately 20 min at 4500 r.p.m, and filtered through a nitrocellulose filter (Ø = 0.45 μm). To determine the cold-water extract, moist soil-filled extraction tubes were weighed (Liang et al., 1997). The residual moist soil was mixed with distilled water up to 150 ml, and the tubes were then submerged for 18 h in a water bath (70 °C) in order to extract the hot water-soluble organic carbon and total nitrogen. Following incubation, the soil was resuspended and filtered through a fiberglass filter (Ø = 0.45 μm) and the purified solutions were cooled to 4 °C prior to measuring organic carbon and total nitrogen (Sparling et al., 1998).

Sample roots with a diameter of fewer than 2 mm were removed and dried at 70 °C to reach a uniform mass (Neatrour et al., 2005). A hand-sorting method was used to collect the earthworms followed by the identification according to their ecological category (e.g., epigeic, anecic, and endogeic) (Jeffery et al., 2010). Acarina and Collembola were extracted using a customized Tullgren funnel as defined by Hutson and Veitch (1987). Nematodes were extracted from the soil samples (100 g) using a customized cotton–wool filtration technique based on Liang et al. (2009). After the extraction technique, soil protozoa were quantified using a microscope (Mayzlish and Steinberger, 2004). Fungi and bacteria were cultured on potato dextrose agar and nutrient agar, respectively. Following a serial dilution from 10^{-1} to 10^{-7} and a week of incubation at 26 °C, the colony-forming units (CFUs) were counted (Wollum, 1983; Asadu et al., 2015). Basal respiration (BR) was measured as CO_2 evolution from soil samples for a three-day incubation period at 25 °C (Alef, 1995). Substrate-induced respiration (SIR) was assessed by mixing the soil samples with 1% (w/w) glucose, and the CO_2 production rate was also determined after three days of incubation (Anderson and Domsch, 1990). Microbial biomass carbon and nitrogen (MBC and MBN) were evaluated by the fumigation-extraction approach (Brookes et al., 1985). The metabolic quotient (qCO_2) was calculated from BR and MBC (Anderson and Domsch, 1990). Microbial ratio (MBC/OC) (Insam and Domsch, 1988) and the C availability index (BR/SIR) (Cheng et al., 1996) were also determined. Urease activity was per utilizing urea (200 mM) at 37 °C for 60 min. Acid phosphatase activity was determined using *p*-Nitrophenyl phosphate disodium (PNP, 15 mM) as a substrate in a customized unified buffer at a pH of 6.5 for 60 min at 37 °C. After incubating the soils with 25 mM *p*-nitrophenyl sulfate for an hour at 37 °C, spectrophotometry was employed to evaluate the activity of arylsulphatase. Using a 1.2% sucrose solution, invertase activity was assessed by incubating it at 50 °C for 3 h and calculating the released reducing sugars using the method of Schinner and von Mersi (1990).

2.3. Statistical analysis

Kolmogorov-Smirnov and Levene's tests were assessed to check data normality and variance homogeneity, respectively. Using ANOVA (one-way analysis of variance), soil data from the different forest management techniques were compared. The variations with regard to the forest floor and the soil properties were compared across zones, elevations, and forest management methods by applying GLM (general linear models) and a three-way analysis of variance. When variables differed substantially ($p < 0.05$), a post hoc test (using Duncan's test) was used to make multiple comparisons of forest floor and soil features. The SPSS v. 20 statistical software program was utilized for statistical analyses. Soil and forest floor data were subjected to PCA (principal component analyses) by using PC-Ord v. 5.0 statistical program (Mc Cune and Mefford, 1999) in order to i) lessen dependent variables, ii) address multi-collinearity difficulties, and iii) soil treatments or samples group and categorize by soil characteristics (Bastida et al., 2006). For further data analysis, the first two components (axis.1 and axis.2) were considered. Furthermore, heat map plots were generated (included in PCA) to illustrate hotspots (islands) of enhanced soil functioning.

Table 1
Properties of forest floor and topsoil properties across different forest management systems. These data are based on mean of studied four regions (i.e., Rasht, Nowshahr, Sari and Gorgan) and four altitudes (i.e., 800, 1000, 1200 and 1400 m above sea level). Data in details is presented in Appendix 2 and 3.

Forest floor and soil properties/forest management systems		Control	Single tree	Shelter wood
Forest floor properties	Mass (kg m^{-2})	19.43 ± 0.39a	16.99 ± 0.33 b	14.39 ± 0.35c
	C (%)	46.74 ± 0.71 b	49.39 ± 0.70a	50.74 ± 0.69
	N (%)	1.70 ± 0.06a	1.54 ± 0.05 b	1.33 ± 0.04c
	C/N ratio	41.08 ± 2.48 b	47.80 ± 2.34a	49.11 ± 1.67a
	P (%)	2.84 ± 0.07a	2.66 ± 0.06 b	2.42 ± 0.05c
	K (%)	1.98 ± 0.05a	1.82 ± 0.05 b	1.66 ± 0.05c
	Ca (%)	1.82 ± 0.05a	1.70 ± 0.05a	1.53 ± 0.05 b
	Mg (%)	0.63 ± 0.01a	0.58 ± 0.01 b	0.54 ± 0.01b
Soil physical properties	Bulk density (g cm^{-3})	1.41 ± 0.01 b	1.44 ± 0.01 ab	1.45 ± 0.01a
	Particle density (g cm^{-3})	2.63 ± 0.01ns	2.64 ± 0.01ns	2.65 ± 0.01ns
	Porosity (%)	46.17 ± 0.53ns	45.36 ± 0.51ns	44.74 ± 0.58ns
	Macro aggregates (%)	32.80 ± 1.34a	28.50 ± 1.19 b	25.81 ± 1.20 b
	Micro aggregates (%)	33.92 ± 1.18a	30.45 ± 1.03 b	26.26 ± 1.06c
	Aggregate stability (%)	56.45 ± 1.01a	53.66 ± 0.86 b	51.39 ± 0.96 b
	Sand (%)	29.76 ± 9.07c	32.77 ± 0.55 b	35.07 ± 0.62a
	Silt (%)	46.90 ± 0.66ns	46.45 ± 0.56ns	46.07 ± 0.51ns
	Clay (%)	23.33 ± 0.58a	10.76 ± 0.54 b	18.85 ± 0.50c
	Water content (%)	42.93 ± 0.63a	39.18 ± 0.62 b	37.40 ± 0.73 b
	Temperature (°C)	16.56 ± 0.26c	17.84 ± 0.26 b	19.14 ± 0.34a
Soil chemical and biochemical properties	pH (1:2.5 H_2O)	6.57 ± 0.03a	6.50 ± 0.03 ab	6.44 ± 0.03 b
	Electrical Conductivity or EC (ds m^{-1})	0.31 ± 0.00a	0.28 ± 0.00 b	0.26 ± 0.00c
	Organic C (%)	6.06 ± 0.17a	4.86 ± 0.16 b	4.02 ± 0.16c
	C in macro aggregates (%)	0.29 ± 0.01a	0.25 ± 0.01 b	0.22 ± 0.01 b
	C in micro aggregates (%)	0.18 ± 0.00a	0.16 ± 0.00 ab	0.14 ± 0.00 b
	Carbon stocks (Mg ha^{-1})	86.42 ± 2.70a	70.19 ± 2.47 b	59.71 ± 2.43c
	Total N (%)	0.38 ± 0.01a	0.33 ± 0.01 b	0.31 ± 0.01 b
	N in macro aggregates (%)	0.28 ± 0.00a	0.26 ± 0.00a	0.23 ± 0.00 b
	N in micro aggregates (%)	0.23 ± 0.00a	0.21 ± 0.00 ab	0.19 ± 0.01 b
	Nitrogen stocks (Mg ha^{-1})	5.51 ± 0.17a	4.98 ± 0.18 b	4.65 ± 0.18 b
	C/N ratio	16.95 ± 0.37a	15.56 ± 0.28 b	14.01 ± 0.28c
	Ammonium (mg kg^{-1})	21.25 ± 1.02a	18.04 ± 0.88 b	15.34 ± 0.89c
	Nitrate (mg kg^{-1})	27.72 ± 0.86a	24.54 ± 0.77 b	22.22 ± 0.90 b
	N mineralization (mg N kg $soil^{-1}$)	21.28 ± 1.09a	16.74 ± 0.88 b	14.11 ± 0.79c
	Available P (mg kg^{-1})	19.87 ± 0.55a	17.23 ± 0.52 b	15.14 ± 0.59c
	Available K (mg kg^{-1})	320.63 ± 7.14a	297.05 ± 6.71 b	271.43 ± 6.84c
	Available Ca (mg kg^{-1})	260.12 ± 7.43a	235.52 ± 6.41 b	203.32 ± 6.82c
	Available Mg (mg kg^{-1})	35.95 ± 0.92a	31.72 ± 0.89 b	28.73 ± 0.99c
	Fulvic acid (mg/100 g)	378.28 ± 11.69a	347.26 ± 13.37 ab	320.57 ± 12.65 b
	Humic acid (mg/100 g)	264.80 ± 11.23a	240.60 ± 8.00a	212.13 ± 9.34 b
Labile soil organic matter	Free light fraction or FLF (g kg^{-1} soil)	5.20 ± 0.12ns	5.04 ± 0.13ns	4.97 ± 0.13ns
	Occluded light fraction or OLF (g kg^{-1} soil)	6.41 ± 0.14ns	6.20 ± 0.17ns	6.10 ± 0.16ns
	Carbon content in free light fraction or CFLF(g kg^{-1} soil)	313.93 ± 8.24a	298.56 ± 7.33 b	261.81 ± 7.99 b
	Carbon content in occluded light fraction or COLF(g kg^{-1} soil)	40.20 ± 1.44a	36.60 ± 1.56 ab	32.87 ± 1.33 b
	Free light fraction carbon as percent of total soil organic carbon or CFLF/C (%)	80.67 ± 10.04 b	94.46 ± 6.75 b	123.78 ± 13.62a
	Occluded light fraction carbon as percent of total soil organic carbon or COLF/C (%)	10.90 ± 1.41ns	14.91 ± 4.23ns	12.14 ± 0.88ns
	Cold-water-soluble organic carbon or CWC (mg kg^{-1})	107.06 ± 3.56a	10.33 ± 3.07 ab	96.91 ± 3.31 b
	Hot-water-soluble organic carbon or HWC (mg kg^{-1})	497.98 ± 14.94a	463.76 ± 16.02 ab	423.76 ± 13.66 b
	Cold-water-soluble total nitrogen or CWN (mg kg^{-1})	7.18 ± 0.33a	6.78 ± 0.32 ab	6.18 ± 0.31 b
	Hot-water-soluble total nitrogen or HWN (mg kg^{-1})	77.78 ± 1.90ns	74.93 ± 2.32ns	72.47 ± 2.70ns
	Particulate organic matter – carbon or POC (g kg^{-1})	2.59 ± 0.07a	2.46 ± 0.07a	2.18 ± 0.08 b
	Particulate organic matter - nitrogen or PON (g kg^{-1})	0.38 ± 0.01a	0.34 ± 0.01a	0.29 ± 0.01 b
	POC/PON	11.29 ± 0.90ns	11.66 ± 0.81ns	12.10 ± 0.84ns
	Dissolved organic matter - carbon or DOC (mg kg^{-1})	59.37 ± 1.48a	56.52 ± 1.28 ab	53.52 ± 1.35 b
	Dissolved organic matter - nitrogen or DON (mg kg^{-1})	23.82 ± 0.72a	21.35 ± 0.73 b	19.22 ± 0.61c
	DOC/DON	3.25 ± 0.17ns	3.78 ± 0.22ns	3.50 ± 0.16ns

Utilizing Amos 20, a structural equation model (SEM) was used to investigate how the surveyed forest sites influenced the forest floor and the soil parameters. Moreover, Gephi 0.9.7 software program was employed to construct and visualize a network model (Bastian et al., 2009; Cherven, K., 2015) and to evaluate its structure by calculating a variety of network topological metrics.

3. Results

3.1. Forest floor characteristics

The control areas had more forest floor (litter or O-horizon) mass (19.43 kg m^{-2}) compared to the habitats with single-tree (16.99 kg m^{-2}) and shelterwood (14.39 kg m^{-2}) cutting systems, and with the increase of altitude above sea level, the forest floor mass also followed an increased trend, especially in the Rasht region. The C content and the C/N ratio had higher values in the forest floor from the shelterwood (50.74% and 49.11%) and the single-tree (49.39% and 47.80%) cutting systems in comparison with that in the control areas (46.74% and 41.08%) at the different altitudes of the studied regions. However, N, P, K, Ca and Mg reached higher contents in the forest floor from the control regions (1.70%, 2.84%, 1.98%, 1.82% and 0.63%, respectively), especially at the low altitudes, whereas the minimum values (i.e., 1.33%, 2.42%, 1.66%, 1.53% and 0.54%, respectively) were observed in the shelterwood system (Table 1; Appendix 2 and 3).

3.2. Soil physico-chemical characteristics

A higher soil bulk density was recorded in the shelterwood system (1.45 g/cm^{-3}) than in the single-tree cutting system (1.44 g/cm^{-3}) and control areas (1.41 g/cm^{-3}), regardless of the altitude and the study region. The forest management systems did not significantly influence the soil particle density and porosity, whereas soil aggregate stability was enhanced in the control areas (56.45%) compared to the single-tree cutting (53.66%) and the shelterwood (51.39%) systems. The soils under sites with shelterwood system were characterized by greater amounts of sand (35.07%), with an increasing trend at higher altitudes, especially in Rasht region; while the control areas had more clay content (23.33%) mainly at the lower altitudes of Nowshahr region. However, the slit content did not differ between the forest management systems regardless of the altitude and the study area. The soil water content and the soil temperature reached its maximum (42.93%) and minimum (16.56 °C) values in the control areas. Soil pH was slightly lower in the shelterwood system (6.44) compared to the single-tree cutting (6.50) and the control (6.57) areas. Wetter and more acidic soil conditions were registered at the high altitudes of Rasht region. Soil organic carbon, carbon stock, EC, total nitrogen, nitrogen stocks, C/N ratio and available nutrients (i.e., P, K, Ca and Mg) were enhanced in the control areas, almost 1–2 times higher, than in the single-tree cutting and shelterwood systems, especially at the low altitudes of Nowshahr region (Table 1; Appendix 2 and 3).

The implementation of the different forest management (i.e., shelterwood and single-tree selection) in the studied forest sites, when compared to the control areas, led to a significant reduction in the amount of soil macro-aggregates, micro-aggregates, C and N contents, fulvic and humic acids, especially in the high altitudes of Rasht region. Ammonium, nitrate and N mineralization were higher in the control areas (21.25 mg/kg^{-1}, 27.76 mg/kg^{-1} and 21.28 mg N/kg $soil^{-1}$) than in the single-tree cutting (18.04 mg/kg^{-1}, 24.54 mg/kg^{-1} and 16.74 mg N/kg $soil^{-1}$) and shelterwood (15.34 mg/kg^{-1}, 22.22 mg/kg^{-1} and 14.11 mg N/kg $soil^{-1}$) systems, respectively. While an increase in soil CWC (cold-water-soluble organic carbon), HWC (hot-water-soluble organic carbon), CWN (cold-water-soluble total nitrogen), CFLF (carbon content in free light fraction), and COLF (carbon content in occluded light fraction) was recorded in the control areas (with maximum values at low altitudes of Nowshahr region), we did not observe significant differences in HWN (hot-water-soluble total nitrogen), FLF (free light fraction), OLF (occluded light fraction) and COLF/C ratio in the study areas. The shelterwood system resulted in an increase of CFLF/C, being almost 1–2 times higher than in the single-tree harvesting system and the control zones. The fractions of POC (particulate organic matter–carbon), PON (particulate organic matter-nitrogen), DOC (dissolved organic matter-carbon) and DON (dissolved organic matter-nitrogen) reached higher levels in the control areas (2.59 g/kg^{-1}, 0.38 g/kg^{-1}, 59.37 mg/kg^{-1} and 23.82 mg/kg^{-1}), followed by the single-tree cutting (2.46 g/kg^{-1}, 0.34 g/kg^{-1}, 56.52 mg/kg^{-1} and 21.35 mg/kg^{-1}), and the shelterwood (2.18 g/kg^{-1}, 0.29 g/kg^{-1}, 53.52 mg/kg^{-1} and 19.22 mg/kg^{-1}) systems. Nonetheless, both the POC/PON and DOC/DON ratios were not significantly affected by the different forest management methods in the studied sites (Table 1; Appendix 2 and 3).

3.3. Soil biological characteristics

An increase in the fine root biomass was recorded in the control areas (46.96 g m^{-2}) compared to the single-tree cutting (40.22 g m^{-2}) and the shelterwood (37 g m^{-2}) systems, with a higher amount in the Nowshahr region, and a decreasing trend from lower to higher altitudes in the study areas. The densities of the different soil faunal groups and the microbial abundances were reduced following the silviculture systems (control area > single-tree selection method > shelterwood method), especially in the higher altitudes of the Rasht region. In the control areas, soil parameters including BR (basal respiration), SIR (substrate-induced respiration), MBC (microbial biomass C) plus MBN (microbial biomass N) showed greater values, whereas the MBC/MMN ratio, qCO_2, and the C availability index were increased in those forest sites subjected to the shelterwood and the single-tree cutting techniques. The activities of urease, acid phosphatase, arylsulfatase and invertase enzymes were almost 1–2 times higher in the control areas, with a maximum value at low altitudes of the Nowahahr region, followed by those with the single-tree cutting and shelterwood systems (Table 2; Appendix 2 and 3).

3.4. Relationship among the studied forest sites with the forest floor and soil characteristics

The principal component analysis revealed distinct locations for the investigated forest areas, forest floor, and soil characteristics with more than 85% of explained variance on the first and second axes (Fig. 2; Table 3). The structural equation and network models were performed on the forest floor and the soil properties that presented a significant correlation (above 0.9) with the PCA components (see Table 3). The structural equation model (Fig. 3) showed that the region, the altitude and the silviculture systems had an effective role in the changes of soil biological activities through their influence on the forest floor and the soil physicochemical properties. Based on the network model (Fig. 4), the role of forest floor C/N, sand content, soil aggregate stability, available K, fulvic acid and acarina density were much more prominent in soil function. Control regions had higher soil organic material fractions, microbial/enzyme activity and biota, particularly in the Nowshahr region's lower altitudes with dolomite and calcic layer geological formations. In comparison to shelterwood method, the single-tree method, which is promoted as being closer to nature, led to an improved situation for soil function (Fig. 2).

4. Discussion

4.1. Forest floor characteristics

Forest harvesting can affect the forest floor properties by altering the inputs from litterfall and litter decomposition and harvesting machines' compaction (Roy et al., 2021). Shortly after logging (such as shelterwood and selective method), part of the litter is removed due to canopy disturbance or reduction, resulting in reduced litterfall. Nevertheless,

Table 2
Soil biological properties across different forest management systems. These data are based on mean of studied four regions (i.e., Rasht, Nowshahr, Sari and Gorgan) and four altitudes (i.e., 800, 1000, 1200 and 1400 m above sea level). Data in details is presented in Appendix 2 and 3.

Soil biological properties/forest management systems		Control	Single tree	Shelter wood
Soil fauna and flora properties	Fine root biomass ($g\ m^{-2}$)	46.96 ± 1.78a	40.22 ± 1.63 b	37.00 ± 1.61 b
	Epigeic density ($n\ m^{-2}$)	2.89 ± 0.11a	2.35 ± 0.09 b	2.08 ± 0.08c
	Epigeic biomass ($mg\ m^{-2}$)	13.95 ± 0.59a	11.18 ± 0.48 b	9.74 ± 0.48 b
	Anecic density ($n\ m^{-2}$)	4.77 ± 0.12a	4.21 ± 0.11 b	3.80 ± 0.11c
	Anecic biomass ($mg\ m^{-2}$)	18.33 ± 0.75a	15.24 ± 0.64 b	13.00 ± 0.58c
	Endogeic density ($n\ m^{-2}$)	0.72 ± 0.06a	0.53 ± 0.04 b	0.44 ± 0.04 b
	Endogeic biomass ($mg\ m^{-2}$)	2.45 ± 0.21a	1.90 ± 0.17 b	1.63 ± 0.16 b
	Earthworm density ($n\ m^{-2}$)	8.38 ± 0.26a	7.10 ± 0.23 b	6.32 ± 0.22c
	Earthworm biomass ($mg\ m^{-2}$)	34.74 ± 1.42a	28.33 ± 1.16 b	26.31 ± 1.07c
	Acarina density ($n\ m^{-2}$)	14258 ± 597a	11691 ± 527 b	10386 ± 552 b
	Collembola density ($n\ m^{-2}$)	4058 ± 109a	3567 ± 197a	2843 ± 194 b
	Total nematode (in 100 gr soil)	365.03 ± 17.20a	320.80 ± 14.33 b	261.60 ± 13.22c
	Protozoa density ($\times 10^2$ g soil)	172.25 ± 10.75a	136.32 ± 8.60 b	122.44 ± 9.35 b
	Total bacteria ($\times 10^7$ g soil)	2.29 ± 0.07a	2.00 ± 0.07 b	1.81 ± 0.06 b
	Total fungi ($\times 10^7$ g soil)	1.16 ± 0.05a	0.94 ± 0.03 b	0.79 ± 0.04c
Soil microbial properties	Basal respiration or BR ($mg\ CO_2\ g^{-1}\ day^{-1}$)	0.25 ± 0.01a	0.24 ± 0.01a	0.20 ± 0.00 b
	Substrate induced respiration or SIR ($mg\ CO_2\ g^{-1}\ day^{-1}$)	1.31 ± 0.02a	1.25 ± 0.02 ab	1.19 ± 0.02 b
	Microbial biomass C or MBC ($mg\ kg^{-1}$)	379.39 ± 11.36a	364.12 ± 10.99a	315.00 ± 11.98 b
	Microbial biomass N or MBN ($mg\ kg^{-1}$)	42.02 ± 1.32a	38.34 ± 1.24 b	33.26 ± 1.27c
	MBC/MBN	9.39 ± 0.14 b	9.86 ± 0.12 ab	10.05 ± 0.23a
	Soil metabolic quotient or qCO_2 (BR:MBC)	0.72 ± 0.03 b	0.66 ± 0.02 ab	0.75 ± 0.03a
	Microbial ratio (MBC:Organic C)	75.11 ± 3.80 b	103.05 ± 7.01a	120.800 ± 10.23a
	Carbon availability index or CAI (BR:SIR)	0.19 ± 0.00ns	0.18 ± 0.00ns	017 ± 0.00ns
Soil enzyme properties	Urease ($\mu g\ NH_4^+–N\ g^{-1}\ 2\ h^{-1}$)	18.56 ± 0.78a	16.10 ± 0.73 b	14.51 ± 0.69 b
	Acid phosphatase (μg PNP $g^{-1}\ h^{-1}$)	434.60 ± 12.15a	398.93 ± 13.48a	352.43 ± 13.71 b
	Arylsulfatase (μg PNP $g^{-1}\ h^{-1}$)	267.88 ± 7.56a	247.22 ± 8.22 ab	227.76 ± 7.73 b
	Invertase (μg Glucose $g^{-1}\ 3\ h^{-1}$)	255.45 ± 6.58a	240.02 ± 6.52a	209.42 ± 7.23 b

this decrease is partially countered by higher litterfall from remaining trees in later years (Trofymow et al., 1991). Based upon Thiffault et al, with alterations to forest management and structure, the varied features of the forest floor may account for the accelerated turnover of nitrogen in the forest floor. According to Bayranvand et al. (2021), forest floor mass increased with tree density in unmanaged areas and this can be related to more plant debris returning to the forest floor. In the present study, the control areas had a higher forest floor mass in the forest stands, especially in the higher altitudes of the Rasht region, which was due to the decrease in temperature, the slower decomposition rate of plant debris decreased and this led to an increase in litter thickness and mass. The combination of tree species in different regions and altitudes along with different forest management systems can affect the quality of the forest floor. The increased density of beech species in the single-tree and shelterwood management systems reduced the quality of the forest floor (high C and C/N). Alternatively, the higher nitrogen concentration in the control zone compared to the harvested stands may be explained by a decreased fraction of N-poor woody litter on the forest floor (Berg and McClaugherty, 2003). However, the presence of species with low C and C/N (e.g., hornbeam) plant residues, has led to an increase in nutrients in the forest floor of the control areas, especially in the low altitudes. According to Hume et al. (2018), the contents of nitrogen and phosphorus (forest floor and minerals) and carbon (forest floor alone) fell rapidly after harvesting and increased slowly with increasing tree age. In the short term, harvesting has the potential to export large amounts of biomass from forests and could significantly degrade coarse wood, carbon, and nutrients in the soil, especially when harvesting intensity is high (Roy et al., 2021). Various long-term consequences of harvesting on C concentration on the forest floor have been reported (Hume et al., 2018), including neutral C reactions and persistent declines (Nave et al., 2010).

4.2. *Soil physical-chemical characteristics*

Using heavy machinery in wood harvesting operations leads to increased soil degradation and disturbances (Horn et al., 2004). The present research assessed a wide range of soil properties to shed light on how soil functions change and interact after forest management on soils from different parent materials and altitudes. Although the shelterwood method led to a considerable increase in the soil bulk density compared to the single-tree selection method and the control areas, various locations and variations in altitude had no significant effect on this attribute. Soil microclimate conditions (i.e., maintenance of soil moisture and temperature by reducing the accumulation of litter on the forest floor) decreased soil fertility and increased the C/N ratio (Chan and Barchia, 2007), while higher machine traffic (Sohrabi et al., 2019) in the shelterwood system led to reduced soil porosity and pore connectivity, increased soil compaction, soil bulk density, and infiltration resistance. A rise in soil strength or bulk density is often accompanied by a decrease in the overall aeration, adversely affecting air-water exchange in the topsoil layer (Ebeling et al., 2017). The forest management systems used at the different altitudes of the study areas did not significantly affect the soil particle density and porosity. In contrast, aggregate stability was elevated in the control areas compared to the single-tree selection and shelterwood methods. Slight increases in soil bulk density and soil strength can lead to significant decreases in soil porosity, especially macro porosity. As soil bulk density increases and air voids fall below 10%, the volume of soil voids decreases, reducing the presence of microarthropod communities (Venanzi et al., 2016).

Additionally, the tested forest management systems had no substantial influence on the soil particle porosity and density, whereas aggregate stability was enhanced in the control areas compared to the single-tree cutting and shelterwood systems. Soil compaction led to heavy machinery in wood harvesting operations causes changes in soil structure, reduction of porosity, disturbance of soil aggregates (Ezzati et al., 2012), and increase of bulk density (Shaheb et al., 2021); furthermore, it decreases soil water content by reducing the space between aggregates (Ebeling et al., 2017). Based on Zhou et al. (2015) and Siebers and Kruse (2019) results, using heavy machinery in silvicultural systems affects soil physical characteristics such as bulk density, aggregate stability, and porosity in the short- and medium-term. The soils under sites with shelterwood systems had greater amounts of sand, with an increasing trend in higher altitudes, especially in the Rasht region, while the controlled habitats had more clay content, especially in

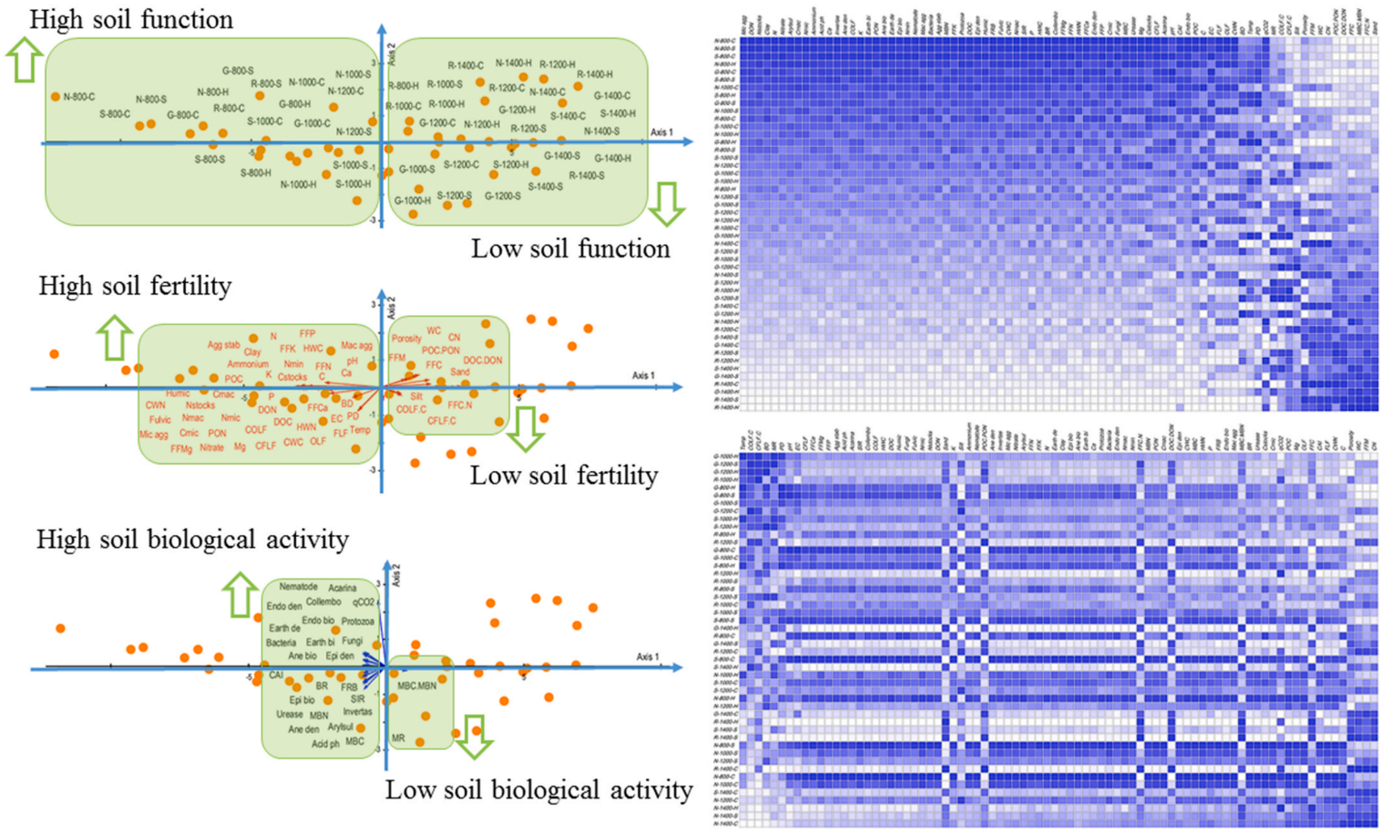

Fig. 2. PCA (axis 1: 84.58% and axis 2: 5.69%) based on the correlation matrix of the forest sites, floor and soil properties (in the left) with heat map plots (in the right).
The full name of abbreviations are presented in Table 3.

the Nowshahr region's lower altitudes. In line with other studies, the influence of factors with regional characteristics such as altitude, temperature, and precipitation on the composition of soil particles was evident (Liu et al., 2022). These varying results reflect the complexity of the effect of the harvesting method on soil texture. Texture is one of the characteristics of soil that remains consistent, however, harvesting processes may alter the types of plants and litter present, leading to long-term changes in the components of soil texture (Meyfroidt et al., 2013). The research also revealed that the sand and clay proportion as soil particles varied as a result of alterations in forest soil properties due to different management practices with higher and lower amounts of sand and clay in the shelterwood methods, respectively. In accordance with these findings, owing to the presence of the canopy in the single selection method, the litter functions as a safeguard cover, blocking the erosive force of raindrops and reducing clay particle detachment. However, in the shelterwood method, due to the reduction of the canopy and litter layer, erosion has increased, which leads to a decrease in clay particles and an increase in sand in the soil texture (Jourgholami and Labelle, 2020). This issue was most likely due to the repeated passes of heavy machinery at the study site which is the line with the results of Cambi et al. (2017).

The soils under the control areas had maximum and minimum values of water content and temperature, respectively, in the shelterwood method compared to single-tree selection method and control zones, along with wetter and more acidic soil in the high altitudes of the Rasht region. According to Ebeling et al. (2017), an augment in bulk density or strength of soil often coincides with a decline in overall aeration, which adversely affects air-water exchange in the topsoil layer. Increasing the bulk density through compaction can reduce overall porosity by almost 50–60% in forest soils (Solgi and Najafi, 2014). Flooding, runoff, and erosion are the result of a severe disruption in oxygen diffusion and soil water balance driven by a decline in total soil porosity (Ampoorter et al., 2007). Altitude plays a vital role in changing climatic and soil properties (Deb et al., 2019). For example, lower mean temperatures and higher precipitation in the highlands of the Rasht region are accompanied by an increase in temperature and water content (Meyfroidt et al., 2013). The shelterwood system led to a drop-in soil pH in comparison with the single-tree cutting and the control regions, along with wetter and more acidic soil in the high altitudes of the Rasht region. The well-developed living moss and litter quality in high altitudes could result in strong eluviation, which might result in lower soil pH values (Liu et al., 2018). However, under shelterwood and single-tree management systems, the formation of a poor-quality litter of beech species led to a low pH ambiance within the soil (Kooijman et al., 2019). Since beech generates acidic litter that decomposes slowly at high altitudes, this feature might be linked to the reduction in soil pH (Guckland et al., 2009). Therefore, it can be assumed that the pH level in the litter is much greater that is prone to decomposition, which explains why, in our study, those stands with a higher soil pH had lower litter thickness (Sohrabi et al., 2022).

Soil chemical properties and available nutrients (P, K, Ca, Mg) reached higher levels in the control areas than in the single-tree cutting and shelterwood systems, especially in the low altitudes of the Nowshahr region. Low temperatures, fluctuating precipitation, reduced air pressure, and soil nutrients have a significant influence on litter quality and type of forest composition in high-altitude ecosystems (Morán-Tejeda et al., 2013). Differences indicating loss of organic C and C stocks (sequestration) are explained by a decrease in above-ground leaf litter input and an increase in mineralization due to changes in abiotic factors after canopy disturbance or reduction at the harvest site. Since total soil N is reciprocally regulated by plant uptake and litter biomass recycling, it is likely that the shelterwood method reduces soil N due to harvesting intensity. The smallest litter C/N ratio of high-quality litter accelerates

Table 3
Correlation of forest floor and soil properties with PCA components.

Forest floor and soil properties (Full name)	Abbreviation	PC1	PC2	Soil properties (Full name)	Abbreviation	PC1	PC2
Forest floor mass	FFM	0.56**	0.30*	Carbon content in free light fraction	CFLF	−0.88**	−0.08 ^{ns}
Forest floor C	FFC	0.81**	0.08^{ns}	Carbon content in occluded light fraction	COLF	−0.96**	−0.03 ^{ns}
Forest floor N	FFN	−0.95**	0.15^{ns}	Free light fraction carbon as percent of total soil organic carbon	CFLF.C	0.47**	−0.27 ^{ns}
Forest floor C/N ratio	FFC.N	0.91**	−0.00 ^{ns}	Occluded light fraction carbon as percent of total soil organic carbon	COLF.C	0.17 ^{ns}	−0.38**
Forest floor P	FFP	−0.92**	0.04 ^{ns}	Cold-water-soluble organic carbon	CWC	−0.95**	−0.13 ^{ns}
Forest floor K	FFK	−0.95**	0.03 ^{ns}	Hot-water-soluble organic carbon	HWC	−0.94**	0.03 ^{ns}
Forest floor Ca	FFCa	−0.92**	−0.00 ^{ns}	Cold-water-soluble total nitrogen	CWN	−0.76**	−0.09 ^{ns}
Forest floor Mg	FFMg	−0.93**	−0.10 ^{ns}	Hot-water-soluble total nitrogen	HWN	−0.93**	−0.14 ^{ns}
Bulk density	BD	−0.56**	−0.34*	Particulate organic carbon	POC	−0.81**	−0.14 ^{ns}
Particle density	PD	−0.50**	−0.51**	Particulate organic nitrogen	PON	−0.97**	−0.11 ^{ns}
Porosity	Porosity	0.53**	0.29*	Particulate organic carbon to Particulate organic nitrogen ratio	POC.PON	0.74**	0.19 ^{ns}
Macro aggregates	Mac agg	−0.97**	0.01 ^{ns}	Dissolved organic carbon	DOC	−0.94**	−0.10 ^{ns}
Micro aggregates	Mic agg	−0.98**	−0.05 ^{ns}	Dissolved organic nitrogen	DON	−0.98**	−0.02 ^{ns}
Aggregate stability	Agg stab	−0.95**	−0.01 ^{ns}	Dissolved organic carbon to Dissolved organic nitrogen ratio	DOC.DON	0.73**	0.28*
Sand	Sand	0.95**	0.10 ^{ns}	Fine root biomass	FRB	−0.97**	−0.00 ^{ns}
Silt	Silt	0.48**	−0.30*	Epigeic density	Epi den	−0.97**	0.00 ^{ns}
Clay	Clay	−0.98**	0.01 ^{ns}	Epigeic biomass	Epi bio	−0.98**	−0.02 ^{ns}
Water content	WC	0.64**	0.35*	Anecic density	Ane den	−0.98**	−0.03 ^{ns}
Temperature	Temp	−0.51**	−0.52**	Anecic biomass	Ane bio	−0.98**	0.00 ^{ns}
pH	pH	−0.86**	−0.14 ^{ns}	Endogeic density	Endo den	−0.95**	0.14 ^{ns}
Electrical Conductivity	EC	−0.77**	−0.17 ^{ns}	Endogeic biomass	Endo bio	−0.89**	0.15 ^{ns}
Organic carbon	C	−0.79**	0.23 ^{ns}	Earthworm density	Ear den	−0.98**	0.00 ^{ns}
C in macro aggregates	Cmac	−0.98**	−0.04 ^{ns}	Earthworm biomass	Ear bio	−0.99**	0.00 ^{ns}
C in micro aggregates	Cmic	−0.94**	−0.03 ^{ns}	Acarina density	Acarina	−0.99**	0.16 ^{ns}
Carbon stocks	Cstocks	−0.90**	0.12 ^{ns}	Collembola density	Collembola	−0.94**	0.07 ^{ns}
Total nitrogen	N	−0.98**	0.05 ^{ns}	Total nematode	Nematode	−0.97**	0.07 ^{ns}
N in macro aggregates	Nmac	−0.95**	−0.15 ^{ns}	Protozoa density	Protozoa	−0.97**	0.13 ^{ns}
N in micro aggregates	Nmic	−0.97**	−0.09 ^{ns}	Total bacteria	Bacteria	−0.96**	0.01 ^{ns}
Nitrogen stocks	N.sto	−0.98**	−0.00 ^{ns}	Total fungi	Fungi	−0.93**	0.06 ^{ns}
C/N ratio	CN	0.65**	0.37**	Basal respiration	BR	−0.96**	−0.02 ^{ns}
Ammonium (NH4)	Ammonium	−0.97**	0.03 ns	Substrate induced respiration	SIR	−0.93**	−0.19 ns
Nitrate (NO3)	Nitrate	−0.98**	−0.12 ns	Microbial biomass carbon	MBC	−0.92**	−0.25 ns
N mineralization	Nmin	−0.98**	0.08 ns	Microbial biomass nitrogen	MBN	−0.96**	−0.17 ns
Available P	P	−0.95**	−0.09 ns	Microbial biomass carbon to Microbial biomass nitrogen ratio	MBC.MBN	0.90**	−0.04 ns
Available K	K	−0.97**	−0.07 ns	Soil metabolic quotient	qCO_2	−0.31**	0.71**
Available Ca	Ca	−0.98**	0.01 ^{ns}	Microbial ratio	MR	0.02 ^{ns}	−0.85**
Available Mg	Mg	−0.91**	−0.05 ^{ns}	Carbon availability index	CAI	−0.88**	0.01 ^{ns}
Fulvic acid	Fulvic	−0.94**	−0.00 ^{ns}	Urease	Urease	−0.93**	−0.07 ^{ns}
Humic acid	Humic	−0.95**	−0.00 ^{ns}	Acid phosphatase	Acid ph	−0.96**	−0.11 ^{ns}
Free light fraction	FLF	−0.77**	−0.17 ^{ns}	Arylsulfatase	Arylsul	−0.97**	−0.10 ^{ns}
Occluded light fraction	OLF	−0.76**	−0.26 ^{ns}	Invertase	Invertase	−0.97**	−0.10 ^{ns}

*$P < 0.05$, **$P < 0.01$, ns = not significant.

decomposition and promotes the natural recovery of compacted soils. This is due to the fact that high-quality litter includes a substantial quantity of nitrogen (Kooijman et al., 2019). Our results revealed that the forest harvesting strategies differently affect soil P, N, and C depending on element concentrations, overstorey composition type, soil layer, harvest intensity, and time after the shelterwood harvesting method (Carpenter et al., 2021). Intensive harvesting practices (such as the shelterwood system) that remove all organic residues by harvesting whole trees can lead to poor organic matter quality, resulting in nutrient-limiting soil conditions (P, K, Ca, and Mg) (Achat et al., 2015).

The labile soil organic matter (SOM) was as follows in control areas > single-tree selection method > shelterwood method of the studied sites (with maximum values in low altitudes of the Nowshahr region). Soil organic matter formation is highly complex (Haynes, 2005); complex interactions of changing litter inputs and abiotic conditions (such as water availability and temperature) are affecting SOM dynamics and consequently nutrient cycling and ecosystem C input, especially along elevation gradients (Ndossi et al., 2020). Management practices can significantly change the fraction of particulate SOM, and alterations in this fraction can be used as indicators of soil C sequestration levels (Durigan et al., 2017). Vegetation is one of the major sources of SOM (Laganière et al., 2022), and the high diversity of understory plants and higher tree density in our study area improved the soil SOM labeling content of the control area. Unstable SOM fractions varied significantly among the forest types considered free and the entrapped light organic matter fractions often have higher turnover periods and react to alterations in management or tree population structure more rapidly than the more stable and mineral-associated fractions (Kooch and Bayranvand, 2019).

The implementation of different silvicultural systems (i.e., shelterwood and single-tree selection methods) in the studied forest sites, in comparison to control areas, significantly reduced fulvic and humic acids, especially at the high altitudes of the Rasht region. Humic and fulvic acids are among the most chemically active components of SOM (De la Rosa et al., 2022). They play a fundamental role in the environment by determining the air-to-water ratio, porosity, temperature, viscosity, buffering capacity, and chemical speciation of micronutrients (Boguta et al., 2017). According to Kooch et al. (2020), SOM labile forms were significantly reduced when forests were harvested, leading to the depletion of humic and fulvic acids in the shelterwood method, which is consistent with our findings. Silvicultural systems influence the content of soil organic matter (Matus, 2021). James et al. (2021), reported that

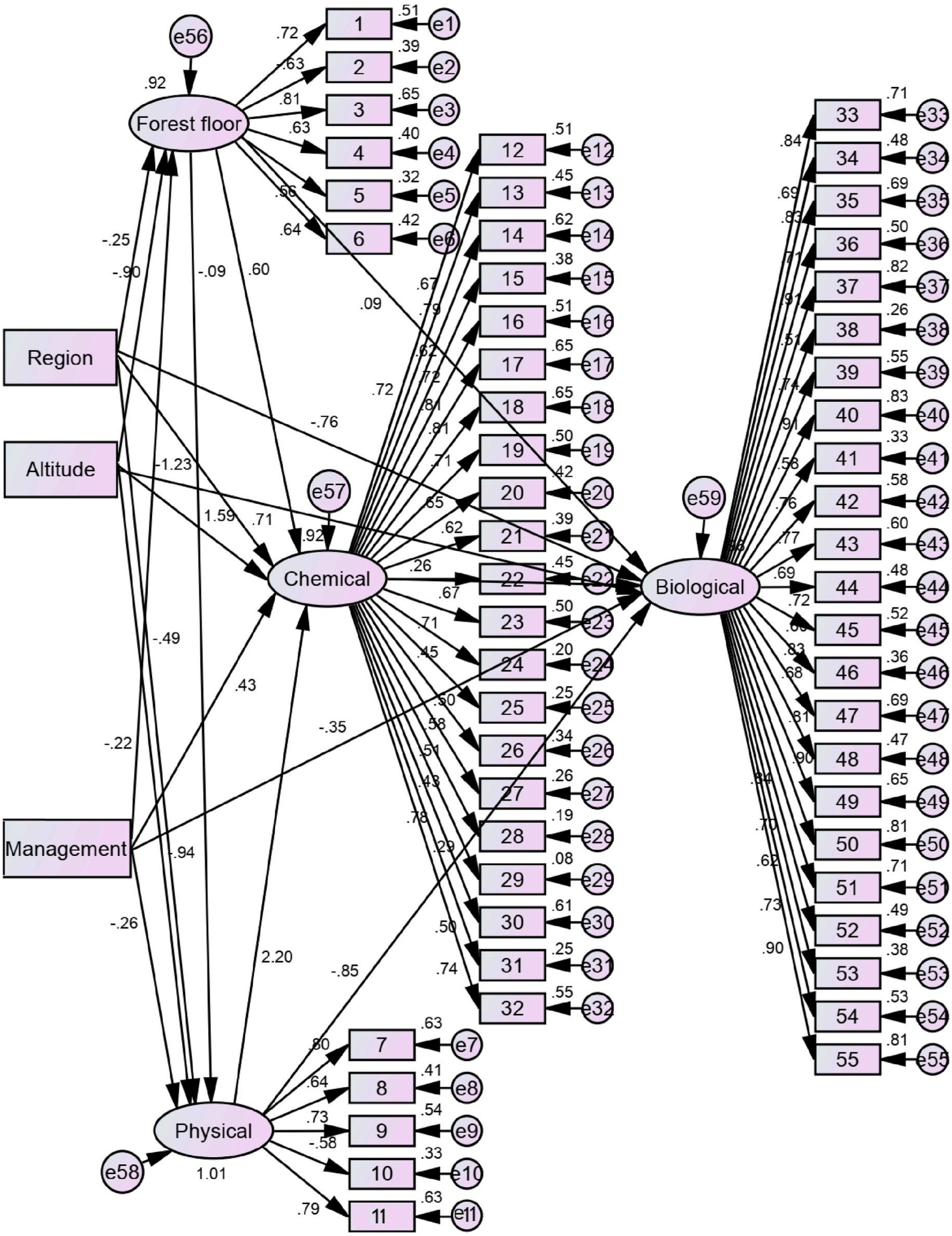

Fig. 3. Structural equation model (SEM) evaluating the direct and indirect effects of Region, Altitude and Management on Forest floor, Chemical, Physical and biological characters. Code numbers: 1: Forest floor N, 2: Forest floor C/N, 3: Forest floor P, 4: Forest floor K, 5: Forest floor Ca, 6: Forest floor Mg, 7: Macro aggregates, 8: Micro aggregates, 9: Aggregate stability, 10: Sand, 11: Clay, 12: C in macro aggregates, 13: C in micro aggregates, 14: Total N, 15: N in macro aggregates, 16: N in micro aggregates, 17: Nitrogen stocks, 18: Ammonium, 19: Nitrate, 20: Available P, 21: Available K, 22: Available Ca, 23: Available Mg, 24: Fulvic acid, 25: Humic acid, 26: Carbon content in occluded light fraction or COLF, 27: Cold-water-soluble organic carbon or CWC, 28: Hot-water-soluble organic carbon or HWC, 29: Hot-water-soluble total nitrogen or HWN, 30: Particulate organic matter - nitrogen or POM-N, 31: Dissolved organic matter - carbon or DOM-C, 32: Dissolved organic matter - nitrogen or DOM-N, 33: Fine root biomass, 34: Epigeic density, 35: Epigeic biomass, 36: Anecic density,37: Anecic biomass, 38: Endogeic density, 39: Earthworm density, 40: Earthworm biomass, 41: Acarina density, 42: Collembola density, 43: Total nematode, 44: Protozoa density, 45: Total bacteria, 46: Total fungi, 47: Basal respiration or BR, 48: Substrate induced respiration or SIR, 49: Microbial biomass C or MBC, 50: Microbial biomass N or MBN, 51: Urease, 52: Acid phosphatase, 53: Arylsulfatase, 54: Invertase, 55: N mineralization.

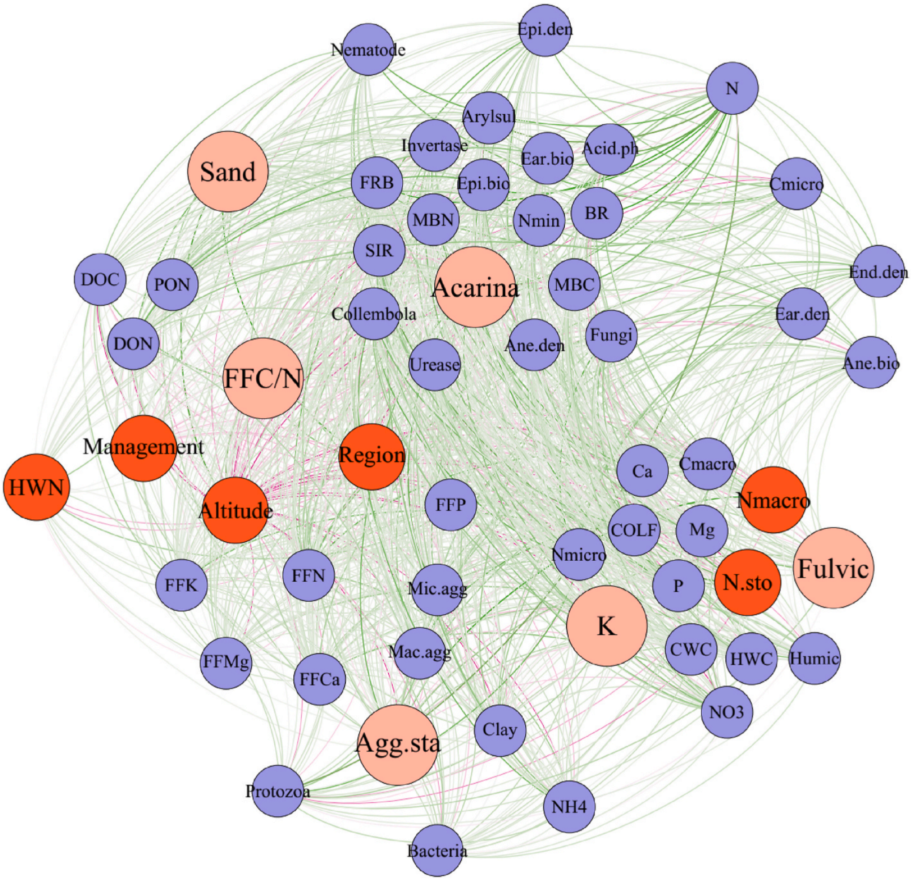

Fig. 4. A network model generated using region, altitude and management and 55 soil properties. Each node (circle) represents a property, and each edge (connection) indicates significant correlations among properties across samples. Node colors reflect the identified modules (groups), and the size and label of each node is proportional to the eigenvector centrality. The thickness of each edge (line) between two nodes is proportional to standardized regression weights. The size and color density of the lines reflects the varying strength of relationship between the soil properties, i.e., thicker lines indicate stronger relationships. Some soil variables are more central and have more connections than others. Abbreviations: FFN: Forest floor N; FFC/N: Forest floor C/N; FFP: Forest floor P; FFK: Forest floor K; FFCa: Forest floor Ca; FFMg: Forest floor Mg; Mac.agg: Macro aggregates; Mic.agg: Micro aggregates; Agg.sta: Aggregate stability; Cmacro: C in macro aggregates; Cmicro: C in micro aggregates; N: Nitrogen; Nmacro: N in macro aggregates; Nmicro: N in micro aggregates; N.sto: Nitrogen stocks; NH4: Ammonium; NO3: Nitrate; Nmin: N mineralization; Fulvic: Fulvic acid; Humic: Humic acid; COLF: Carbon content in occluded light fraction; CWC: Cold-water-soluble organic carbon; HWC: Hot-water-soluble organic carbon; HWN: Cold-water-soluble total nitrogen; PON: Particulate organic matter – nitrogen; DOC: Dissolved organic matter – carbon; DON: Dissolved organic matter – nitrogen; FRB: Fine root biomass; Epi.den: Epigeic density; Epi.bio: Epigeic biomass; Ane.den: Anecic density; Ane.bio: Anecic biomass; Endo.den: Endogeic density; Ear.den: Earthworm density; Ear.bio: Earthworm biomass; Acarina: Acarina density; Collembola: Collembola density; Nematode: Total nematode; Protozoa: Protozoa density; Bacteria: Total bacteria; Fungi: Total fungi; BR: Basal respiration; SIR: Substrate induced respiration; MBC: Microbial biomass C; MBN: Microbial biomass N; Acid.ph: Acid phosphatase; Arylsul: Arylsulfatase. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

SOM labile forms were greatly reduced by forest harvesting, as evidenced by our findings. The layers of litter and humus are the principal suppliers of labile SOM, according to Kalbitz et al. (2000), indicating that plant debris and SOM inputs have a significant effect on the concentration and quantity of labile SOM. Forest floor quality (high C and ratio of C/N) together with SOM decreased as a result of the increased density of beech species in both single-tree selection and shelterwood methods (Kooch et al., 2020). In fact, the high harvesting intensity of the trees in the shelterwood system had a negative impact on organic materials inputs to the soil. Ammonium, nitrate, and N mineralization were elevated under control areas than in the single tree harvesting and shelterwood method, respectively. Nitrification and N mineralization rates showed clear trends among the silvicultural systems. According to Sohrabi et al. (2022), the equilibrium of ammonium and nitrate is significantly impacted by the type of forest management techniques employed. Some researchers argue that the impacts of forest management methods on N mineralization processes are due to changes in the microenvironment (Mylliemngap et al., 2016). The amount and quality of litter and organic materials of the post-harvest tree species composition are other determinants in this regard (Owen et al., 2003).

4.3. Soil biological characteristics

The growth, structure, and activity of soil biota communities in forest soil are affected by abiotic and biotic factors such as nutrient availability, quantity and quality of organic matter, and physical perturbations (Souza et al., 2016). These factors can be influenced by land-use change (such as natural forests and managed plantations) and management techniques. Soil fauna and flora respond differently to environmental factors, with bacteria being more sensitive to ground-level factors such as nutrients and pH, and fungi being more sensitive to plant-related changes (Cheng et al., 2023). However, how intense forest management impacts soil biota populations and interactions is yet unclear (Chen et al., 2019). In our study, the biomass and density of earthworms together with the densities of acarina, nematode, collembola, protozoa, fungi, and bacteria were reduced following intervention in the studied ecosystems (control area > single-tree selection system > shelterwood system), especially in the higher altitudes of the Rasht region. Soil fauna and flora activity and structure are influenced by soil type, temperature, vegetation, and other abiotic and biotic factors (Zhang et al., 2022b). Altitude is an important factor in determining the interactions between soil biota communities and abiotic factors, as various environmental factors vary with changes across an altitude gradient (Feng et al., 2022). Several mechanisms may be involved to reduce the abundance of soil fauna and flora communities and their diversity complexity by intensifying management practices. This can lead to changes in edaphic factors such as organic C, moisture, pH, N, P, and Ca content, which have been shown they are crucial in defining the complexity of biota networks (Wang et al., 2018; Zappelini et al., 2015). Specifically, the soil organisms that depend on labile C inputs are immediately impacted by the elimination of overstory trees (Outerbridge and Trofymow, 2009), which can result in lower abundances of bacteria (Deslippe et al., 2012) and fungi (Lewandowski et al., 2019) owing to changes in the quantity and quality of litter inputs. Moreover, the number of overstory trees eliminated and the quantity of plant debris-maintained influence regimens of temperature and moisture in the soil (Lal, 2005), which could change the metabolism of the soil biota and speed up the mineralization and degradation of organic materials (Wixon and Balser, 2013). Additionally, soil compaction as a major disturbance associated with forest harvesting involves the disintegration of soil structure, which lessens the soil's capability to carry air and water and may destroy several microenvironments that ensure the proliferation and diversity of soil fauna and flora communities (García-Carmona et al., 2021).

Soil BR, SIR, MBC, and MBN reached higher values in the control areas, whereas the MBC/MMN ratio, $qCO_{2,}$ and C availability index were increased in the forest sites with single-tree selection and shelterwood methods. Babur (2021) noticed that the harvesting activities had a statistical effect on the MBC, MBN, and BR. Especially, a significant reduction in organic carbon and microbial biomass was observed in the soils in the harvested areas. Based upon Riutta et al. (2021), forest management strategies limit soil respiration by regulating heterotrophic and autotrophic respiration sources, resulting in an average 8% decrease in carbon retained in soils in forest ecosystems (Nave et al., 2010). According to Chen et al. (2011), autotrophic respiration produced by mycorrhizal fungi and plant roots accounts for more than half of the entire soil respiration, and initial reductions in autotrophic soil respiration are driven by the removal of overstory trees (Lewandowski et al., 2019). Li et al. (2004), observed that MBN was directly correlated with soil C and N throughout harvesting operations. Hassett and Zak (2005), theorized that the drop-in soil microbial biomass is due to reduced litter intake and changes in soil microclimate. MBC and MBN were reported to be more strongly associated with total N than soil organic C, which suggests that it is likely that nitrogen has a higher influence on microbial biomass than carbon in this system (Foote et al., 2015; Babur, 2021). With maximum values at low altitudes of the Nowahahr region, all the studied enzymes activities (i.e., urease, arylsulfatase, invertase, and acid phosphatase) were enhanced under the control areas compared to the single-tree selection and shelterwood methods. Particularly, our findings revealed that decreased values of enzymatic activity were recorded at lower elevations under shelterwood systems where litter thickness, litter quality, and soil nutrient availability were reduced. A plausible explanation could be that enzyme activity is highly correlated with soil pH, total N, and P (Shen et al., 2018). Moreover, it is well-known that climatic conditions (i.e., lower humidity and temperature) are strongly affected by altitude, affecting vegetation distribution/composition, altering litter/soil properties, and the quantity and quality of C loss (Quan et al., 2019). Recent research demonstrates that changes in the composition of the canopy and situation of climatic affect litter degradation rates (Cardelli et al., 2019), activities of soil enzymes (D'Alò et al., 2021; Bayranvand et al., 2021) and various methods of nutrition accumulation (Bello et al., 2015). These fluctuations in enzymatic activity may be due to decreased root activity and altered microbial composition. Moreover, different degrees of soil enzyme utilization of C and N sources may have different impacts on soil enzyme activity under different management strategies.

4.4. *Relationship among studied forest sites with forest floor and soil characteristics*

In the present study, the comparison of soil derived from different parent materials demonstrated how forest management strategies have led to variations in the forest floors and soil function across the altitude gradient. The output of PCA showed apparent differences in the soil properties between plots subjected to different management practices, revealing that the altitude and the management method are key factors determining soil function. The control areas, especially in the low altitudes of the Nowshahr region with geological formations of dolomite and calcic layers, showed an increasing trend in SOM fractions, available nutrients and enzymatic activities. As a 'close-to-nature forestry' or 'retention forestry' management method, SOM content and available nutrients, along with microbial abundances, enzymatic activities and biota were all boosted by the single-tree selection system. Our findings provide evidence that intensive forest management reduces microbial diversity indices and alters community composition, which can directly affect soil function. The present results indicate that soil function is impacted to a larger extent in the order of natural forest < singletree < shelterwood zones after forest harvesting. Therefore, maintaining soil functioning in temperate habitats mainly depends on natural forest protection. Moreover, these results indicate that maintaining soil function may be as important as maintaining terrestrial vegetation diversity for ecosystem resilience and may have important implications for land management and conservation policies.

5. Conclusion

Our study provides further evidence about the role of management practices in soil function in the Hyrcanian forests located in Iran's northern area. Both bedrock geology and altitude appeared to be key factors in determining the interactions between biotic and abiotic factors in the study region. After forest harvesting soil fauna and flora communities were influenced by differences in forest floor and soil physicochemical properties. Moreover, our data showed that the balance of C and N circulations and nutrient availability is highly dependent on the type of management practices. Taken together, the intensity of harvesting adversely affected soil functional indicators, particularly with regards to the shelterwood system when compared to the single-tree selection method, which seeks to balance increased volume and cutting intensity. These results also highlight the long-term effects of forest management strategies and demonstrate the continued utility of long-term field data.

Credit author statement

Yahya Kooch: Statistics, Writing-original draft, Supervision, **Mohammad Kazem Parsapour:** Sampling and laboratory analysis, **Azam Nouraei:** Sampling and laboratory analysis, **Zahra Mohmedi Kartalaei:** Sampling and laboratory analysis, **Donghui Wu:** Writing-revision and editing, **María Gómez Brandón:** Writing-revision and editing, **Manuel Esteban Lucas-Borja:** Writing-revision and editing.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

Acknowledgment

The study described in this paper gained financial assistance from Tarbiat Modares University, for which the authors are appreciative.

Appendix

Appendix 1

Descriptions of study sites located in the north of Iran.

Region	Altitude	Forest management system	Number of trees (ha^{-1})*		Tree basal area (m^2 ha^{-1})		Total canopy cover (%)	Dominant plant (>20%)
			Beech	Hornbeam	Beech	Hornbeam		
Rasht	800 m	Control	385 ± 11	124 ± 9	31.22 ± 3.12	10.09 ± 1.23	92.89 ± 8.78	*Dactylis glomerata* L. (35%), *Bupleurum exaltatum* M. Bieb. (22%)
		Single tree	331 ± 9	109 ± 15	19.89 ± 2.13	8.78 ± 1.11	98.78 ± 11.28	*Laser trilobum* (L.) Borkh. (41%), *Polygonatum orientale* Desf. (32%)
		Shelter wood	295 ± 13	91 ± 11	12.89 ± 3.09	6.98 ± 2.09	70.09 ± 7.78	*Centaurea hyrcanica* Bornm. (36%), *Solidago virgaaurea* L. (25%)
	1000 m	Control	362 ± 14	119 ± 11	28.89 ± 4.23	9.89 ± 2.67	88.78 ± 10.06	*Trifolium pratense* L. (25%), *Campanula lactiflora* M. Bieb. (22%)
		Single tree	310 ± 11	104 ± 13	16.22 ± 3.09	7.23 ± 1.09	90.09 ± 9.89	*Stellaria holostea* L. (40%), *Hypericum perforatum* L. (22%), *Hypericum* androsaemum L. (21%)
		Shelter wood	284 ± 12	83 ± 12	9.95 ± 2.11	5.38 ± 1.23	82.39 ± 9.67	*Carex digitata* L. (33%), *Carex sylvatica* Huds. (29%), *Euphorbia squamosa* Willd. (27%)
	1200 m	Control	359 ± 13	109 ± 15	25.44 ± 5.23	9.23 ± 3.19	83.29 ± 9.39	*Geranium robertianum* L. (31%), *Lamium album* L. (22%), *Laser trilobum* (L.) Borkh. (23%)
		Single tree	307 ± 15	94 ± 11	13.89 ± 2.27	7.09 ± 2.01	80.09 ± 11.04	*Origanum vulgare* L. (41%), *Prunella vulgaris* L. (34%), *Polygonatum orientale* Desf. (25%)
		Shelter wood	280 ± 13	71 ± 15	6.93 ± 1.03	5.12 ± 2.23	77.89 ± 10.02	*Scilla siberica Haw.* (29%), *Bupleurum exaltatum* M. Bieb. (25%)
	1400 m	Control	320 ± 17	89 ± 12	20.04 ± 3.78	7.93 ± 2.11	78.93 ± 10.02	*Circaea lutetiana* L. (38%), *Stellaria holostea* L. (23%), *Laser trilobum* (L.) Borkh. (22%),
		Single tree	270 ± 11	72 ± 9	11.22 ± 3.98	5.23 ± 1.89	74.32 ± 9.67	*Cyclamen coum* Mill. (29%), *Trifolium pratense* L. (27%), *Hypericum perforatum* L. (24%),
		Shelter wood	244 ± 9	50 ± 11	5.23 ± 1.11	3.98 ± 1.02	70.02 ± 11.23	*Carex sylvatica* Huds. (32%), *Polygonatum orientale* Desf. (25%)
Nowshahr	800 m	Control	392 ± 13	132 ± 13	33.49 ± 4.45	12.78 ± 3.78	95.23 ± 13.89	*Ajuga reptans* L. (34%), *Carex sylvatica* L. (25%), *Carpesium cernuum* L. (22%)
		Single tree	342 ± 15	111 ± 18	20.08 ± 4.67	10.03 ± 2.56	87.78 ± 9.22	*Clinopodium vulgare* L. (31%), *Cyclamen coum* Miller. (29%)
		Shelter wood	301 ± 12	90 ± 13	13.88 ± 2.78	8.23 ± 1.29	73.28 ± 4.56	*Fragaria vesca* L. (32%), *Geum urbanum* L. (27%), *Lamium album* L. (22%)
	1000 m	Control	376 ± 15	121 ± 16	29.89 ± 5.87	9.89 ± 1.98	88.67 ± 10.03	*Melisa officinalis* L. (42%), *Ajuga reptans* L. (25%), *Carpesium cernuum* L. (21%)
		Single tree	320 ± 14	105 ± 11	19.33 ± 3.89	7.23 ± 1.36	74.78 ± 4.89	*Fragaria vesca* L. *(29%), Mentha quatic* L. (26%), *Ajuga reptans* L. (23%)
		Shelter wood	295 ± 9	82 ± 18	12.09 ± 1.78	5.32 ± 1.25	62.37 ± 11.56	*Carpesium cernuum* L. *(28%), Mercurialis prennis* L. (22%)
	1200 m	Control	363 ± 13	118 ± 13	26.83 ± 4.78	8.92 ± 2.32	85.37 ± 12.35	*Oxalis corniculata* L. (39%), *Geum urbanum* L. (32%), *Lamium album* L. (26%)
		Single tree	315 ± 19	104 ± 9	15.78 ± 3.56	7.12 ± 2.09	73.29 ± 8.21	*Parietaria officinalis* L. (49%), *Melisa officinalis* L. (32%), *Cyclamen coum* Miller. (21%)
		Shelter wood	291 ± 11	78 ± 12	8.56 ± 2.75	5.04 ± 1.03	60.09 ± 7.21	*Phytoloca quatica* L. (52%), *Melisa officinalis* L. (31%), *Clinopodium vulgare* L. (24%)
	1400 m	Control	345 ± 11	106 ± 11	22.12 ± 6.09	7.82 ± 1.98	80.03 ± 11.27	*Clinopodium vulgare* L. (39%), Plantago major L. (25%), *Mentha quatic* L. (22%)
		Single tree	295 ± 16	91 ± 17	11.78 ± 3.28	5.78 ± 1.12	69.98 ± 8.22	*Prunella vulgaris* L. (39%), *Mentha quatic* L. (29%), *Parietaria officinalis L.* (24%)
		Shelter wood	260 ± 14	79 ± 11	6.34 ± 2.02	3.89 ± 1.03	58.89 ± 7.21	*Melisa officinalis* L. (33%), *Geum urbanum* L. (29%), *Fragaria vesca* L. (22%)
Sari	800 m	Control	295 ± 14	93 ± 13	18.97 ± 3.12	6.45 ± 2.12	77.56 ± 12.56	*Hypericum androsaemum* L. (42%), *Viola odorata* L. (32%), *Ruscus hyrcanus* Woron. (23%)
		Single tree	245 ± 11	81 ± 12	10.02 ± 5.78	4.34 ± 1.22	65.34 ± 8.56	*Cyclamen coum* Miller. (29%), *Fragaria vesca* L. (27%), *Viola alba* Bess. (22%)
		Shelter wood	210 ± 17	61 ± 15	5.78 ± 1.37	2.78 ± 1.23	55.43 ± 3.89	*Asperula odorata* L. (49%), *Hypericum androsaemum* L. (34%), *Fragaria vesca* L. (21%)
	1000 m	Control	302 ± 12	87 ± 11	19.67 ± 3.09	6.12 ± 1.98	80.09 ± 9.78	*Lamium album* L. (39%), *Viola odorata* L. (25%), *Cyclamen coum* Miller. (22%)
		Single tree	253 ± 8	73 ± 7	9.23 ± 2.67	4.23 ± 1.09	69.98 ± 7.45	*Euphorbia amygdaloides* L. (39%), *Asperula odorata* L. (31%), *Geum urbanum* L. (21%)
		Shelter wood	221 ± 15	52 ± 8	5.23 ± 1.56	2.89 ± 1.02	58.78 ± 6.56	*Mercurialis perennis* L. (39%), *Urtica dioica* L. (32%)
	1200 m	Control	283 ± 13	92 ± 13	17.84 ± 1.17	7.02 ± 2.09	83.23 ± 10.04	*Lamium album* L. (42%), *Fragaria vesca* L. (31%), *Hypericum androsaemum* L. (21%)
		Single tree	213 ± 15	80 ± 6	7.89 ± 2.56	5.21 ± 1.27	72.39 ± 6.34	*Fragaria vesca* L. (56%), *Hypericum androsaemum* L. (42%), *Viola odorata* L. (22%)
		Shelter wood	280 ± 18	62 ± 11	4.56 ± 1.34	3.43 ± 1.07	60.09 ± 13.23	*Sambucus ebulus* L. (39%), *Viola odorata* L. (24%)
	1400 m	Control	254 ± 9	79 ± 14	15.66 ± 2.09	6.45 ± 1.11	76.74 ± 9.85	*Viola alba* Bess. (38%), *Asperula odorata* L. (27%), *Geum urbanum* L. (23%)
		Single tree	205 ± 8	65 ± 13	5.89 ± 2.17	4.09 ± 1.04	65.89 ± 5.98	*Fragaria vesca* L. (62%), *Hypericum androsaemum* L. (41%), *Viola odorata* L. (21%)

(*continued on next page*)

Appendix 1 (*continued*)

Region	Altitude	Forest management system	Number of trees (ha^{-1})*		Tree basal area (m^2 ha^{-1})		Total canopy cover (%)	Dominant plant (>20%)
			Beech	Hornbeam	Beech	Hornbeam		
		Shelter wood	176 ± 12	45 ± 16	3.98 ± 1.03	2.89 ± 1.24	50.04 ± 11.23	*Euphorbia amygdaloides* L. (52%), *Hypericum androsaemum* L. (32%)
Gorgan	800 m	Control	236 ± 11	72 ± 11	13.28 ± 1.98	6.12 ± 2.09	79.89 ± 10.02	*Phylitis scolopendrium* L. (39%), *Sanicula europaea* L. (29%)
		Single tree	193 ± 14	62 ± 13	7.89 ± 2.18	4.23 ± 1.07	65.45 ± 10.02	*Mercurialis perennis* L. (39%), *Brachypodium sylvaticum* (Huds.) P. Beauv. (23%)
		Shelter wood	162 ± 18	43 ± 7	3.55 ± 2.09	2.67 ± 1.09	52.34 ± 8.12	*Dryoptris filix-mas* L. (42%), *Pteris cretica* L. (32%), *Circaea lutetiana* L. (23%)
	1000 m	Control	240 ± 13	65 ± 9	14.09 ± 2.11	5.98 ± 1.06	82.23 ± 9.98	*Galium odoratum* L. (53%), *Brachypodium sylvaticum* (Huds.) P. Beauv. (29%)
		Single tree	190 ± 13	51 ± 12	5.78 ± 3.81	4.03 ± 1.36	70.04 ± 9.23	*Brachypodium sylvaticum* (Huds.) P. Beauv. (39%), *Phylitis scolopendrium* L. (24%)
		Shelter wood	155 ± 21	32 ± 6	3.12 ± 1.26	2.12 ± 1.03	59.78 ± 11.43	*Circaea lutetiana* L. (52%), *Brachypodium sylvaticum* (Huds.) P. Beauv. (42%)
	1200 m	Control	211 ± 12	71 ± 11	12.39 ± 3.09	6.12 ± 1.17	79.74 ± 10.05	*Pteris cretica* L. (25%), *Sanicula europaea* L. (22%), *Dryoptris filix-mas* L. (21%)
		Single tree	163 ± 11	55 ± 18	6.45 ± 2.05	4.78 ± 1.45	67.56 ± 9.21	*Lathyrus Laevigatus* (Jacq.) Grake. (49%), *Galium odoratum* L. (32%)
		Shelter wood	132 ± 13	33 ± 9	4.09 ± 2.34	2.98 ± 1.22	53.49 ± 10.04	*Brachypodium sylvaticum* (Huds.) P. Beauv. (39%), *Circaea lutetiana* L. (33%)
	1400 m	Control	203 ± 13	56 ± 13	10.67 ± 2.04	5.03 ± 1.03	84.37 ± 9.33	*Dryoptris filix-mas* L. (46%), *Pteris cretica* L. (32%), *Mercurialis perennis* L. (21%)
		Single tree	153 ± 17	42 ± 17	6.23 ± 1.93	3.87 ± 1.06	72.39 ± 13.24	*Pteris cretica* L. (35%), *Pteris cretica* L. (28%), *Circaea lutetiana* L. (24%)
		Shelter wood	126 ± 9	24 ± 15	3.27 ± 1.03	2.22 ± 1.08	62.47 ± 14.32	*Circaea lutetiana* L. (48%), *Pteris cretica* L. (31%), *Mercurialis perennis* L. (25%)

[*] The other tree species that were observed in these forest sites (number of trees <5 ha^{-1}) include maple (*Acer cappadocicum* rubrum and *Acer velutinum* Boiss.), alder (*Alnus subcordata* C. A. Mey.), oak (*Quercus castaneifolia* C. A. M. *macranthera* F. & M.), ash (*Fraxinus excelsior* L.), elm (*Ulmus glabra* Huds.), wild cherry (*Prunus avium* L.), chequer tree (*Sorbus torminalis* Crantz.), and lime tree (*Tilia platyphyllos* Scop.).

Appendix 2

Summary ANOVA results for properties of forest floor and topsoil properties across different regions (i.e. Rasht, Nowshahr, Sari and Gorgan), altitudes (i.e. 800, 1000, 1200 and 1400 m above sea level) and forest management systems (i.e. control, single tree and shelter wood). Full name of characters are presented in Tables 1 and 2

Forest floor and topsoil properties/summary ANOVA results (F value and Sig.)	Main effects			Interaction effects			
	Region (R)	Altitude (A)	Management systems (MS)	R × A	R × MS	A × MS	R × A × MS
Forest floor mass	28.481 (0.000)	137.701 (0.000)	79.205(0.000)	0.020 (1.000)	0.035 (1.000)	2.654 (0.015)	0.022 (1.000)
Forest floor C	0.124(0.946)	44.370 (0.000)	9.441(0.000)	0.002 (1.000)	0.000 (1.000)	0.354 (0.908)	0.001 (1.000)
Forest floor N	23.135 (0.000)	184.543 (0.000)	19.438(0.000)	1.692 (0.087)	0.053 (0.999)	3.895 (0.001)	0.116 (1.000)
Forest floor C/N ratio	10.587 (0.000)	108.570 (0.000)	5.635(0.004)	1.668 (0.093)	0.032 (1.000)	0.649 (0.691)	0.116 (1.000)
Forest floor P	10.740 (0.000)	384.356 (0.000)	26.291(0.000)	0.262 (0.984)	0.112 (0.995)	2.182 (0.043)	0.173 (1.000)
Forest floor K	23.330 (0.000)	116.373 (0.000)	13.992(0.000)	1.286 (0.241)	0.251 (0.959)	0.623 (0.712)	0.379 (0.991)
Forest floor Ca	2.952(0.032)	91.102 (0.000)	9.944(0.000)	0.134 (0.999)	0.096 (0.997)	0.501 (0.808)	0.162 (1.000)
Forest floor Mg	15.711 (0.000)	137.222 (0.000)	12.295(0.000)	0.788 (0.627)	0.058 (0.999)	0.762 (0.600)	0.097 (1.000)
Bulk density	3.685(0.012)	169.756 (0.000)	5.327(0.005)	0.002 (1.000)	0.001 (1.000)	0.666 (0.677)	0.001 (1.000)
Particle density	3.363(0.018)	2.124(0.096)	0.768(0.464)	0.002 (1.000)	0.001 (1.000)	0.006 (1.000)	0.002 (1.000)
Porosity	0.524(0.666)	114.675 (0.000)	2.473(0.085)	0.006 (1.000)	0.001 (1.000)	0.600 (0.731)	0.001 (1.000)
Macro aggregates	181.342 (0.000)	286.247 (0.000)	23.322(0.000)	0.388 (0.941)	0.044 (1.000)	1.181 (0.315)	0.028 (1.000)
Micro aggregates	32.964 (0.000)	119.429 (0.000)	19.291(0.000)	0.013 (1.000)	0.002 (1.000)	0.757 (0.604)	0.007 (1.000)
Aggregate stability	18.240 (0.000)	274.722 (0.000)	15.430(0.000)	0.464 (0.899)	0.042 (1.000)	0.390 (0.886)	0.048 (1.000)
Sand	33.488 (0.000)	74.618 (0.000)	24.587(0.000)	0.060 (1.000)	0.038 (1.000)	1.417 (0.205)	0.014 (1.000)
Silt	0.264(0.852)	11.976 (0.000)	0.499(0.607)	0.296 (0.976)	0.053 (0.999)	0.621 (0.713)	0.090 (1.000)

(*continued on next page*)

Appendix 2 (*continued*)

Forest floor and topsoil properties/summary ANOVA results (F value and Sig.)	Main effects			Interaction effects			
	Region (R)	Altitude (A)	Management systems (MS)	R × A	R × MS	A × MS	R × A × MS
Clay	85.004 (0.000)	302.332 (0.000)	44.296(0.000)	0.629 (0.773)	0.030 (1.000)	2.249 (0.037)	0.261 (0.999)
Water content	14.590 (0.000)	77.375 (0.000)	23.859(0.000)	0.020 (1.000)	0.139 (0.991)	0.169 (0.985)	0.048 (1.000)
Temperature	19.414 (0.000)	53.025 (0.000)	24.222(0.000)	0.006 (1.000)	0.013 (1.000)	1.679 (0.123)	0.007 (1.000)
pH	2.996(0.031)	43.609 (0.000)	3.451(0.032)	0.035 (1.000)	0.004 (1.000)	0.062 (0.999)	0.004 (1.000)
EC	39.793 (0.000)	71.030 (0.000)	21.936(0.000)	0.000 (1.000)	0.000 (1.000)	2.941 (0.008)	0.000 (1.000)
Organic C	39.645 (0.000)	31.731 (0.000)	47.298(0.000)	0.735 (0.677)	0.288 (0.943)	0.718 (0.635)	0.034 (1.000)
C in macro aggregates	70.423 (0.000)	149.532 (0.000)	16.162(0.000)	0.287 (0.978)	0.052 (0.999)	0.109 (0.995)	0.127 (1.000)
C in micro aggregates	110.589 (0.000)	93.884 (0.000)	10.113(0.000)	1.634 (0.102)	0.132 (0.992)	0.300 (0.937)	0.225 (1.000)
Carbon stocks	35.025 (0.000)	55.152 (0.000)	37.092(0.000)	0.508 (0.869)	0.179 (0.982)	0.386 (0.888)	0.028 (1.000)
Total N	52.730 (0.000)	232.132 (0.000)	21.117(0.000)	0.049 (1.000)	0.059 (0.999)	0.590 (0.738)	0.021 (1.000)
N in macro aggregates	53.822 (0.000)	90.028 (0.000)	16.319(0.000)	0.182 (0.996)	0.191 (0.979)	1.892 (0.080)	0.143 (1.000)
N in micro aggregates	40.311 (0.000)	169.301 (0.000)	5.172(0.006)	0.068 (1.000)	0.051 (0.999)	0.146 (0.990)	0.029 (1.000)
Nitrogen stocks	46.655 (0.000)	276.179 (0.000)	12.853(0.000)	0.305 (0.973)	0.037 (1.000)	0.496 (0.811)	0.013 (1.000)
C/N ratio	35.244 (0.000)	166.135 (0.000)	38.023(0.000)	0.000 (1.000)	0.000 (1.000)	1.057 (0.387)	0.000 (1.000)
Ammonium	53.989 (0.000)	367.458 (0.000)	27.101(0.000)	0.408 (0.931)	0.019 (1.000)	1.078 (0.374)	0.017 (1.000)
Nitrate	57.436 (0.000)	134.088 (0.000)	18.343(0.000)	0.055 (1.000)	0.047 (1.000)	1.050 (0.392)	0.042 (1.000)
N mineralization	250.689 (0.000)	802.320 (0.000)	83.784(0.000)	8.325 (0.000)	0.849 (0.533)	11.024 (0.000)	0.338 (0.996)
Available P	60.630 (0.000)	76.548 (0.000)	27.328(0.000)	0.285 (0.979)	0.081 (0.998)	0.836 (0.543)	0.034 (1.000)
Available K	24.991 (0.000)	118.861 (0.000)	19.697(0.000)	0.000 (1.000)	0.000 (1.000)	1.180 (0.315)	0.000 (1.000)
Available Ca	26.183 (0.000)	105.491 (0.000)	25.376(0.000)	0.000 (1.000)	0.000 (1.000)	0.372 (0.897)	0.000 (1.000)
Available Mg	185.484 (0.000)	115.968 (0.000)	32.771(0.000)	0.268 (0.983)	0.319 (0.927)	0.254 (0.958)	0.061 (1.000)
Fulvic acid	4.201(0.006)	50.477 (0.000)	6.151(0.002)	0.000 (1.000)	0.000 (1.000)	0.439 (0.853)	0.000 (1.000)
Humic acid	5.056(0.002)	66.983 (0.000)	9.382(0.000)	0.000 (1.000)	0.000 (1.000)	1.265 (0.271)	0.000 (1.000)
FLF	121.197 (0.000)	21.743 (0.000)	1.221(0.296)	0.000 (1.000)	0.000 (1.000)	0.178 (0.983)	0.000 (1.000)
OLF	88.162 (0.000)	15.521 (0.000)	1.263(0.283)	0.005 (1.000)	0.005 (1.000)	0.021 (1.000)	0.002 (1.000)
CFLF	2.351(0.071)	78.000 (0.000)	15.018(0.000)	0.000 (1.000)	0.000 (1.000)	2.711 (0.013)	0.000 (1.000)
COLF	13.720 (0.000)	112.055 (0.000)	9.382(0.000)	0.000 (1.000)	0.000 (1.000)	0.470 (0.830)	0.000 (1.000)
CFLF/C	7.226(0.000)	7.120(0.000)	4.500(0.011)	0.878 (0.544)	0.236 (0.965)	1.098 (0.362)	0.329 (0.996)
COLF/C	3.646(0.013)	0.567(0.637)	0.613(0.542)	0.790 (0.626)	0.871 (0.516)	1.078 (0.374)	0.963 (0.502)
CWC	35.467 (0.000)	46.987 (0.000)	2.949(0.053)	0.002 (1.000)	0.001 (1.000)	0.094 (0.997)	0.001 (1.000)
HWC	2.473(0.061)	50.727 (0.000)	7.227(0.001)	0.000 (1.000)	0.000 (1.000)	0.538 (0.779)	0.000 (1.000)
CWN	150.046 (0.000)	22.141 (0.000)	3.999(0.019)	0.118 (0.999)	0.038 (1.000)	0.892 (0.500)	0.058 (1.000)
HWN	12.043 (0.000)	10.764 (0.000)	1.336(0.264)	0.002 (1.000)	0.002 (1.000)	0.046 (1.000)	0.001 (1.000)
POM-C	121.571 (0.000)	49.799 (0.000)	12.718(0.000)	0.657 (0.748)	0.143 (0.990)	5.628 (0.000)	0.078 (1.000)
POM-N	139.015 (0.000)	228.783 (0.000)	22.240(0.000)	1.541 (0.130)	0.419 (0.867)	0.359 (0.905)	0.109 (1.000)
POM-C/POM-N	15.993 (0.000)	28.795 (0.000)	0.292(0.747)	2.503 (0.008)	1.329 (0.242)	3.518 (0.002)	0.902 (0.577)

(*continued on next page*)

Appendix 2 (*continued*)

Forest floor and topsoil properties/summary ANOVA results (F value and Sig.)	Main effects			Interaction effects			
	Region (R)	Altitude (A)	Management systems (MS)	R × A	R × MS	A × MS	R × A × MS
DOM-C	10.030 (0.000)	64.016 (0.000)	5.637(0.004)	0.000 (1.000)	0.000 (1.000)	0.574 (0.751)	0.000 (1.000)
DOM-N	37.093 (0.000)	216.269 (0.000)	22.140(0.000)	0.000 (1.000)	0.000 (1.000)	0.356 (0.907)	0.000 (1.000)
DOM-C/DOM-N	22.540 (0.000)	31.972 (0.000)	21.454(0.087)	5.544 (0.000)	0.395 (0.882)	1.100 (0.361)	0.178 (1.000)
Fine root biomass	238.641 (0.000)	335.106 (0.000)	31.180(0.000)	3.299 (0.001)	0.505 (0.805)	3.533 (0.002)	0.164 (1.000)
Epigeic density	56.367 (0.000)	110.604 (0.000)	29.097(0.000)	0.880 (0.543)	0.566 (0.757)	2.532 (0.020)	0.144 (1.000)
Epigeic biomass	97.431 (0.000)	272.239 (0.000)	42.993(0.000)	1.930 (0.045)	0.527 (0.788)	4.927 (0.000)	0.108 (1.000)
Anecic density	41.520 (0.000)	153.434 (0.000)	29.020(0.000)	0.798 (0.618)	0.310 (0.932)	1.295 (0.257)	0.149 (1.000)
Anecic biomass	206.496 (0.000)	650.659 (0.000)	77.197(0.000)	9.956 (0.000)	1.579 (0.150)	7.633 (0.000)	0.851 (0.639)
Endogeic density	12.828 (0.000)	55.421 (0.000)	8.899(0.000)	0.477 (0.891)	0.175 (0.984)	2.497 (0.021)	0.306 (0.998)
Endogeic biomass	20.024 (0.000)	43.330 (0.000)	6.493(0.002)	3.510 (0.000)	0.866 (0.519)	1.622 (0.138)	0.678 (0.835)
Earthworm density	57.488 (0.000)	169.368 (0.000)	35.547(0.000)	0.902 (0.523)	0.487 (0.818)	2.735 (0.012)	0.154 (1.000)
Earthworm biomass	200.649 (0.000)	596.393 (0.000)	80.642(0.000)	7.158 (0.000)	1.419 (0.205)	9.062 (0.000)	0.341 (0.995)
Acarina density	1.285(0.279)	166.938 (0.000)	20.684(0.000)	0.000 (1.000)	0.000 (1.000)	3.350 (0.003)	0.000 (1.000)
Collembola density	18.810 (0.000)	409.539 (0.000)	26.480(0.000)	0.417 (0.927)	0.062 (0.999)	3.514 (0.002)	0.031 (1.000)
Total nematode	42.368 (0.000)	341.353 (0.000)	30.735(0.000)	0.018 (1.000)	0.011 (1.000)	3.530 (0.002)	0.006 (1.000)
Protozoa density	39.122 (0.000)	181.798 (0.000)	13.495(0.000)	0.804 (0.612)	0.050 (1.000)	1.869 (0.084)	0.029 (1.000)
Total bacteria	68.245 (0.000)	188.102 (0.000)	25.237(0.000)	0.110 (0.999)	0.042 (1.000)	1.558 (0.157)	0.043 (1.000)
Total fungi	5.520(0.001)	124.388 (0.000)	27.357(0.000)	0.013 (1.000)	0.003 (1.000)	4.612 (0.000)	0.007 (1.000)
BR	273.719 (0.000)	306.575 (0.000)	29.728(0.000)	4.435 (0.000)	0.390 (0.885)	1.054 (0.389)	0.122 (1.000)
SIR	37.572 (0.000)	160.151 (0.000)	12.017(0.000)	0.000 (1.000)	0.000 (1.000)	0.653 (0.687)	0.000 (1.000)
MBC	315.489 (0.000)	265.454 (0.000)	29.329(0.000)	1.290 (0.238)	0.230 (0.976)	1.162 (0.325)	0.348 (0.995)
MBN	508.828 (0.000)	681.520 (0.000)	70.360(0.000)	3.269 (0.001)	0.517 (0.796)	0.986 (0.433)	0.328 (0.996)
MBC/MBN	0.292(0.831)	22.304 (0.000)	3.748(0.024)	0.000 (1.000)	0.000 (1.000)	0.351 (0.909)	0.000 (1.000)
qCO_2	5.539(0.001)	2.117(0.097)	2.352(0.096)	0.910 (0.516)	0.142 (0.991)	1.379 (0.220)	0.377 (0.991)
Microbial ratio	10.462 (0.000)	9.154(0.000)	9.869(0.000)	0.727 (0.684)	0.527 (0.788)	1.937 (0.073)	0.262 (0.999)
CAI	72.647 (0.000)	46.608 (0.000)	2.461(0.086)	1.249 (0.262)	0.341 (0.915)	1.066 (0.381)	0.366 (0.993)
Urease	369.351 (0.000)	309.266 (0.000)	30.162(0.000)	9.932 (0.000)	0.732 (0.624)	1.546 (0.161)	0.163 (1.000)
Acid phosphatase	28.687 (0.000)	216.074 (0.000)	19.351(0.000)	0.001 (1.000)	0.001 (1.000)	0.621 (0.714)	0.001 (1.000)
Arylsulfatase	37.475 (0.000)	102.744 (0.000)	10.031(0.000)	0.055 (1.000)	0.031 (1.000)	1.044 (0.395)	0.039 (1.000)
Invertase	65.755 (0.000)	159.459 (0.000)	22.581(0.000)	0.014 (1.000)	0.006 (1.000)	1.955 (0.070)	0.018 (1.000)

Appendix 3

Properties of forest floor and topsoil properties across different forest management systems in studied four regions (i.e. Rasht, Nowshahr, Sari and Gorgan) and four altitudes (i.e. 800, 1000, 1200 and 1400 m above sea level). Full name of characters and units are presented in Tables 1 and 2

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
Forest floor mass	Control	14.97 ± 0.81a	19.13 ± 1.53a	21.11 ± 0.081a	25.82 ± 1.62a	13.17 ± 0.71a	17.78 ± 1.13a	18.64 ± 0.76a	23.91 ± 1.56a	12.22 ± 1.06a	16.27 ± 1.17a	18.46 ± 1.18a	22.68 ± 1.41a	16.25 ± 0.80a	20.27 ± 1.50a	22.26 ± 0.63a	26.89 ± 1.64a
	Single tree	13.41 ± 0.36a	16.51 ± 1.34 ab	19.74 ± 0.066 ab	21.17 ± 1.50 b	12.02 ± 0.48a	15.13 ± 0.90a	16.36 ± 0.65 b	19.59 ± 1.47 b	10.71 ± 0.60a	13.70 ± 0.88a	17.40 ± 1.22 ab	18.40 ± 1.44 b	14.55 ± 0.42a	17.65 ± 1.21 ab	21.09 ± 0.75 ab	22.09 ± 1.46 b
	Shelter wood	11.18 ± 0.039 b	12.87 ± 1.37 b	17.86 ± 0.086 b	19.29 ± 1.48 b	9.49 ± 0.73 b	11.58 ± 1.36 b	13.58 ± 0.67c	17.43 ± 1.29 b	8.12 ± 0.71 b	10.35 ± 1.27 b	14.50 ± 0.76 b	16.15 ± 1.22 b	12.40 ± 0.59 b	14.01 ± 1.46 b	19.05 ± 0.93 b	20.17 ± 1.29 b
Forest floor C	Control	42.88 ± 2.07ns	44.31 ± 2.81ns	47.25 ± 2.80ns	53.14 ± 3.00ns	42.70 ± 2.04ns	44.20 ± 2.85ns	46.67 ± 1.41ns	52.84 ± 3.05ns	42.35 ± 2.25ns	44.03 ± 2.90ns	46.58 ± 2.85ns	52.59 ± 3.11ns	42.99 ± 2.20ns	44.46 ± 2.83ns	47.29 ± 2.85ns	53.22 ± 3.04ns
	Single tree	44.56 ± 3.15ns	47.07 ± 3.50ns	50.53 ± 1.68ns	56.00 ± 2.29ns	44.38 ± 2.64ns	46.80 ± 3.51ns	49.27 ± 1.40ns	55.65 ± 2.36ns	44.11 ± 2.43ns	46.68 ± 3.58ns	50.04 ± 1.79ns	55.41 ± 2.40ns	44.88 ± 2.84ns	47.17 ± 3.54ns	50.61 ± 1.68ns	56.07 ± 2.32ns
	Shelter wood	45.12 ± 2.05ns	47.91 ± 3.28ns	52.05 ± 2.43ns	58.59 ± 2.13ns	44.77 ± 1.98ns	47.85 ± 3.31ns	50.65 ± 1.38ns	58.33 ± 2.13ns	44.47 ± 2.02ns	47.58 ± 3.39ns	51.30 ± 2.30ns	58.25 ± 2.12ns	45.01 ± 2.10ns	47.93 ± 3.39ns	52.13 ± 2.34ns	58.84 ± 2.07ns
Forest floor N	Control	2.92 ± 0.20a	2.13 ± 0.21ns	1.79 ± 0.19ns	1.32 ± 0.15ns	2.84 ± 0.23a	1.88 ± 0.20ns	1.69 ± 0.12ns	0.95 ± 0.10ns	2.77 ± 0.18a	1.63 ± 0.12ns	0.98 ± 0.06ns	0.89 ± 0.07ns	2.68 ± 0.25a	1.60 ± 0.18a	0.92 ± 0.07ns	0.83 ± 0.07ns
	Single tree	2.58 ± 0.17 ab	2.09 ± 0.26ns	1.65 ± 0.22ns	1.16 ± 0.16ns	2.84 ± 0.26 ab	1.74 ± 0.24ns	1.53 ± 0.12ns	0.9 ± 0.10ns	2.41 ± 0.15 ab	1.48 ± 0.20ns	0.95 ± 0.11ns	0.88 ± 0.08ns	2.28 ± 0.20 ab	1.29 ± 0.13 ab	0.86 ± 0.07ns	0.81 ± 0.08ns
	Shelter wood	2.16 ± 0.24 b	1.85 ± 0.21ns	1.49 ± 0.17ns	1.01 ± 0.09ns	2.04 ± 0.26 b	1.49 ± 0.14ns	1.35 ± 0.10ns	0.90 ± 0.04ns	1.94 ± 0.24 b	1.20 ± 0.09ns	0.92 ± 0.13ns	0.85 ± 0.05ns	1.80 ± 0.19 b	1.07 ± 0.03 b	0.84 ± 0.08ns	0.79 ± 0.04ns
Forest floor C/N ratio	Control	15.77 ± 1.43 b	24.66 ± 3.45ns	35.23 ± 6.53ns	50.77 ± 7.26ns	16.50 ± 1.46 b	27.40 ± 3.52ns	40.78 ± 4.53ns	68.33 ± 11.02ns	16.13 ± 1.20 b	29.70 ± 3.30ns	60.14 ± 16.15ns	69.16 ± 11.35ns	17.99 ± 1.69 b	31.43 ± 3.18 b	67.31 ± 16.46ns	75.91 ± 12.49ns
	Single tree	18.46 ± 2.02 b	30.37 ± 5.50ns	42.77 ± 6.80ns	60.64 ± 7.53ns	20.24 ± 1.96 b	35.57 ± 5.79ns	48.26 ± 4.19ns	69.32 ± 7.94ns	19.14 ± 1.61 b	39.15 ± 5.80ns	71.67 ± 14.58ns	73.78 ± 8.49ns	21.13 ± 1.67 b	41.63 ± 5.38 ab	74.12 ± 14.12ns	79.88 ± 9.29ns
	Shelter wood	27.03 ± 4.36a	30.96 ± 3.88ns	42.93 ± 5.97ns	61.64 ± 4.63ns	26.58 ± 2.89a	35.75 ± 3.58ns	47.99 ± 3.22ns	65.63 ± 3.23ns	28.26 ± 3.58a	42.14 ± 4.21ns	64.82 ± 6.48ns	71.36 ± 4.35ns	30.20 ± 3.95a	44.95 ± 3.08a	70.63 ± 7.62ns	78.81 ± 6.39ns
Forest floor P	Control	4.09 ± 0.10a	3.57 ± 0.17a	2.30 ± 0.16ns	1.97 ± 0.23ns	4.04 ± 0.17ns	3.51 ± 0.18a	2.91 ± 0.14a	1.86 ± 0.17ns	3.98 ± 0.19a	3.18 ± 0.23ns	2.15 ± 0.15ns	1.74 ± 0.15ns	3.83 ± 0.10a	3.11 ± 0.21ns	2.14 ± 0.27ns	1.70 ± 0.16ns
	Single tree	3.93 ± 0.16 ab	3.41 ± 0.14a	2.18 ± 0.14ns	1.85 ± 0.10ns	3.79 ± 0.11ns	3.31 ± 0.21a	2.75 ± 0.13 b	1.75 ± 0.11ns	3.57 ± 0.11 ab	3.14 ± 0.18ns	1.93 ± 0.12ns	1.67 ± 0.11ns	3.44 ± 0.13 ab	2.94 ± 0.16ns	1.89 ± 0.14ns	1.52 ± 0.12ns
	Shelter wood	3.70 ± 0.09 b	2.90 ± 0.18 b	1.98 ± 0.13ns	1.81 ± 0.18ns	3.66 ± 0.10ns	2.72 ± 0.19 b	2.50 ± 0.12c	1.73 ± 0.13ns	3.24 ± 0.19 b	2.67 ± 0.15ns	1.83 ± 0.07ns	1.51 ± 0.11ns	3.21 ± 0.17 b	2.59 ± 0.20ns	1.81 ± 0.07ns	1.50 ± 0.11ns
Forest floor K	Control	2.87 ± 0.22a	2.25 ± 0.16ns	2.13 ± 0.21ns	1.96 ± 0.20a	2.72 ± 0.21ns	2.17 ± 0.13ns	2.01 ± 0.09ns	1.45 ± 0.11ns	2.68 ± 0.20ns	2.10 ± 0.16ns	1.49 ± 0.14ns	1.19 ± 0.07ns	2.52 ± 0.22ns	2.03 ± 0.25ns	1.42 ± 0.11a	1.05 ± 0.06ns
	Single tree	2.80 ± 0.16a	2.18 ± 0.17ns	2.10 ± 0.22ns	1.70 ± 0.10a	2.59 ± 0.15ns	1.99 ± 0.20ns	1.87 ± 0.10ns	1.36 ± 0.11ns	2.50 ± 0.12ns	1.66 ± 0.14ns	1.29 ± 0.15ns	1.07 ± 0.07ns	2.43 ± 0.13ns	1.65 ± 0.13ns	1.21 ± 0.12 ab	1.03 ± 0.08ns
	Shelter wood	2.31 ± 0.19a	2.15 ± 0.24ns	2.01 ± 0.27ns	1.22 ± 0.15 b	2.30 ± 0.18ns	1.90 ± 0.18ns	1.72 ± 0.10ns	1.20 ± 0.18ns	2.24 ± 0.20ns	1.65 ± 0.16ns	1.25 ± 0.10ns	1.05 ± 0.18ns	2.18 ± 0.19ns	1.56 ± 0.15ns	1.09 ± 0.08 b	0.98 ± 0.23ns
Forest floor Ca	Control	2.56 ± 0.17ns	2.08 ± 0.26ns	1.54 ± 0.23ns	1.31 ± 0.21ns	2.42 ± 0.18ns	2.13 ± 0.23ns	1.89 ± 0.11a	1.29 ± 0.19ns	2.40 ± 0.16ns	2.15 ± 0.21ns	1.57 ± 0.19ns	1.23 ± 0.18ns	2.27 ± 0.15ns	1.96 ± 0.22ns	1.42 ± 0.19ns	1.08 ± 0.12ns
	Single tree	2.52 ± 0.20ns	1.96 ± 0.20ns	1.44 ± 0.23ns	1.21 ± 0.13ns	2.31 ± 0.22ns	2.16 ± 0.17ns	1.76 ± 0.10 ab	1.21 ± 0.15ns	2.22 ± 0.18ns	2.07 ± 0.14ns	1.32 ± 0.13ns	1.18 ± 0.15ns	2.07 ± 0.17ns	1.87 ± 0.19ns	1.31 ± 0.17ns	1.01 ± 0.11ns

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
	Shelter wood	2.19 ± 0.14ns	1.82 ± 0.20ns	1.43 ± 0.20ns	1.14 ± 0.14ns	2.22 ± 0.18ns	1.71 ± 0.20ns	1.55 ± 0.10 b	0.95 ± 0.12ns	2.16 ± 0.22ns	1.65 ± 0.17ns	1.25 ± 0.20ns	0.92 ± 0.13ns	2.02 ± 0.21ns	1.48 ± 0.16ns	1.18 ± 0.16ns	0.98 ± 0.20ns
Forest floor Mg	Control	0.87 ± 0.02ns	0.79 ± 0.03ns	0.66 ± 0.06ns	0.45 ± 0.02a	0.84 ± 0.05ns	0.71 ± 0.04ns	0.65 ± 0.03ns	0.42 ± 0.03ns	0.81 ± 0.10ns	0.61 ± 0.04ns	0.54 ± 0.05ns	0.41 ± 0.03a	0.78 ± 0.09ns	0.61 ± 0.03ns	0.51 ± 0.04ns	0.38 ± 0.03a
	Single tree	0.82 ± 0.03ns	0.76 ± 0.04ns	0.64 ± 0.06ns	0.38 ± 0.04 ab	0.78 ± 0.04ns	0.70 ± 0.04ns	0.61 ± 0.03ns	0.37 ± 0.04ns	0.71 ± 0.05ns	0.60 ± 0.04ns	0.53 ± 0.06ns	0.36 ± 0.04 ab	0.68 ± 0.05ns	0.57 ± 0.04ns	0.50 ± 0.05ns	0.30 ± 0.04 ab
	Shelter wood	0.80 ± 0.04ns	0.74 ± 0.06ns	0.60 ± 0.05ns	0.31 ± 0.05 b	0.72 ± 0.04ns	0.68 ± 0.04ns	0.56 ± 0.03ns	0.30 ± 0.04ns	0.68 ± 0.05ns	0.56 ± 0.05ns	0.50 ± 0.03ns	0.27 ± 0.04 b	0.62 ± 0.05ns	0.55 ± 0.06ns	0.49 ± 0.04ns	0.24 ± 0.05 b
Bulk density	Control	1.49 ± 0.04ns	1.48 ± 0.03ns	1.46 ± 0.03ns	1.17 ± 0.04ns	1.51 ± 0.04ns	1.50 ± 0.03ns	1.48 ± 0.03ns	1.19 ± 0.04ns	1.52 ± 0.04ns	1.51 ± 0.03ns	1.49 ± 0.03ns	1.20 ± 0.04ns	1.47 ± 0.04ns	1.45 ± 0.03ns	1.44 ± 0.03ns	1.15 ± 0.04ns
	Single tree	1.51 ± 0.04ns	1.49 ± 0.04ns	1.53 ± 0.02ns	1.19 ± 0.04ns	1.53 ± 0.04ns	1.51 ± 0.04ns	1.55 ± 0.02ns	1.21 ± 0.04ns	1.54 ± 0.04ns	1.52 ± 0.04ns	1.56 ± 0.02ns	1.22 ± 0.04ns	1.49 ± 0.04ns	1.47 ± 0.04ns	1.51 ± 0.02ns	1.17 ± 0.04ns
	Shelter wood	1.52 ± 0.03ns	1.50 ± 0.04ns	1.54 ± 0.03ns	1.22 ± 0.04ns	1.54 ± 0.03ns	1.52 ± 0.04ns	1.56 ± 0.03ns	1.24 ± 0.04ns	1.56 ± 0.03ns	1.53 ± 0.04ns	1.58 ± 0.03ns	1.25 ± 0.04ns	1.51 ± 0.03ns	1.47 ± 0.04ns	1.53 ± 0.03ns	1.20 ± 0.04ns
Particle density	Control	2.65 ± 0.03ns	2.62 ± 0.04ns	2.61 ± 0.05ns	2.61 ± 0.05ns	2.67 ± 0.03ns	2.64 ± 0.03ns	2.63 ± 0.05ns	2.63 ± 0.05ns	2.68 ± 0.02ns	2.66 ± 0.03ns	2.64 ± 0.05ns	2.64 ± 0.05ns	2.62 ± 0.03ns	2.60 ± 0.03ns	2.59 ± 0.05ns	2.59 ± 0.05ns
	Single tree	2.66 ± 0.05ns	2.64 ± 0.04ns	2.62 ± 0.03ns	2.62 ± 0.04ns	2.68 ± 0.05ns	2.66 ± 0.04ns	2.64 ± 0.03ns	2.64 ± 0.04ns	2.69 ± 0.04ns	2.67 ± 0.04ns	2.65 ± 0.03ns	2.65 ± 0.04ns	2.63 ± 0.05ns	2.62 ± 0.04ns	2.60 ± 0.03ns	2.59 ± 0.04ns
	Shelter wood	2.66 ± 0.04ns	2.65 ± 0.04ns	2.63 ± 0.05ns	2.62 ± 0.04ns	2.68 ± 0.04ns	2.67 ± 0.04ns	2.65 ± 0.05ns	2.64 ± 0.04ns	2.70 ± 0.04ns	2.68 ± 0.03ns	2.65 ± 0.04ns	2.65 ± 0.04ns	2.64 ± 0.04ns	2.63 ± 0.04ns	2.61 ± 0.05ns	2.60 ± 0.04ns
Porosity	Control	43.36 ± 1.80ns	43.50 ± 1.15ns	43.73 ± 1.74ns	54.49 ± 2.48ns	43.01 ± 1.75ns	43.18 ± 1.14ns	43.43 ± 1.68ns	54.11 ± 2.43ns	42.90 ± 1.76ns	43.08 ± 1.15ns	43.26 ± 1.64ns	53.96 ± 2.40ns	43.59 ± 1.79ns	43.98 ± 1.17ns	44.11 ± 1.69ns	55.02 ± 2.47ns
	Single tree	42.87 ± 1.72ns	43.25 ± 1.82ns	41.40 ± 1.23ns	54.36 ± 1.64ns	42.63 ± 1.70ns	42.92 ± 1.89ns	41.12 ± 1.20ns	53.98 ± 1.57ns	42.51 ± 1.70ns	42.69 ± 1.90ns	40.93 ± 1.18ns	53.74 ± 1.52ns	43.14 ± 1.72ns	43.55 ± 1.85ns	41.82 ± 1.19ns	54.87 ± 1.64ns
	Shelter wood	42.30 ± 1.92ns	43.42 ± 1.52ns	40.67 ± 2.28ns	53.11 ± 2.22ns	42.00 ± 1.95ns	43.11 ± 1.55ns	40.40 ± 2.24ns	52.64 ± 2.21ns	41.91 ± 2.02ns	42.90 ± 1.55ns	40.10 ± 2.23ns	52.46 ± 2.21ns	42.47 ± 1.94ns	43.87 ± 1.53ns	40.90 ± 2.29ns	53.52 ± 2.22ns
Macro aggregates	Control	66.53 ± 2.35ns	54.60 ± 4.52a	39.13 ± 3.87ns	31.46 ± 2.80ns	53.53 ± 2.35ns	41.60 ± 4.52a	26.13 ± 3.87ns	18.46 ± 2.80ns	45.53 ± 2.35ns	33.60 ± 4.52a	18.13 ± 3.87ns	10.46 ± 2.80ns	38.53 ± 2.35ns	26.60 ± 4.52a	13.60 ± 3.28ns	7.13 ± 0.97ns
	Single tree	62.20 ± 2.92ns	47.33 ± 3.04 ab	35.20 ± 1.81ns	29.66 ± 3.16ns	49.20 ± 2.92ns	34.33 ± 3.04 ab	22.20 ± 1.81ns	16.66 ± 3.16ns	41.20 ± 2.92ns	26.33 ± 3.04 ab	14.20 ± 1.81ns	10.26 ± 10.64ns	34.20 ± 2.92ns	19.33 ± 3.04 ab	8.53 ± 1.33ns	5.33 ± 0.81ns
	Shelter wood	59.73 ± 4.16ns	43.33 ± 2.20 b	33.40 ± 2.06ns	25.86 ± 2.31ns	46.73 ± 4.16ns	30.33 ± 2.20 b	20.40 ± 2.06ns	12.86 ± 2.13ns	38.73 ± 4.16ns	22.33 ± 2.20 b	12.40 ± 2.06ns	6.86 ± 1.53ns	31.73 ± 4.16ns	15.93 ± 1.88 b	7.40 ± 1.60ns	4.86 ± 0.57ns
Micro aggregates	Control	55.53 ± 5.04ns	43.13 ± 3.60ns	34.86 ± 3.94ns	29.86 ± 3.04a	50.53 ± 5.04ns	38.13 ± 3.60ns	29.86 ± 3.94ns	24.86 ± 3.04a	46.53 ± 5.04ns	34.13 ± 3.60ns	25.86 ± 3.94ns	20.86 ± 3.04a	41.53 ± 5.04ns	29.13 ± 3.60ns	21.60 ± 3.67ns	16.33 ± 2.87a
	Single tree	50.66 ± 3.84ns	40.46 ± 3.53ns	32.66 ± 2.83ns	25.73 ± 2.58 ab	45.66 ± 3.81ns	35.46 ± 3.53ns	27.66 ± 2.83ns	20.72 ± 2.58 ab	41.66 ± 3.84ns	31.46 ± 3.53ns	23.66 ± 2.83ns	16.73 ± 2.58 ab	36.66 ± 3.84ns	26.80 ± 3.35ns	19.00 ± 2.68ns	12.26 ± 2.42 ab
	Shelter wood	46.33 ± 5.14ns	37.00 ± 3.18ns	30.60 ± 1.41ns	18.53 ± 2.20 b	41.33 ± 5.14ns	32.00 ± 3.18ns	25.60 ± 1.41ns	13.52 ± 2.20 b	37.33 ± 5.14ns	28.00 ± 3.18ns	21.60 ± 1.41ns	9.53 ± 2.20 b	32.33 ± 5.14ns	23.20 ± 3.08ns	16.60 ± 1.41ns	6.73 ± 1.40 b
Aggregate stability	Control	74.15 ± 1.44ns	65.26 ± 3.44ns	57.10 ± 4.12ns	45.00 ± 1.52ns	72.73 ± 1.86ns	60.91 ± 3.36ns	53.67 ± 4.28ns	42.44 ± 1.28ns	71.02 ± 1.87ns	58.15 ± 3.39ns	49.97 ± 4.14ns	41.37 ± 0.91a	69.81 ± 1.97a	54.84 ± 3.31ns	47.22 ± 4.12ns	39.49 ± 0.86a
	Single tree	71.42 ± 1.03ns	62.23 ± 2.84ns	52.83 ± 3.20ns	42.30 ± 1.39ns	68.47 ± 1.01ns	58.36 ± 2.80ns	50.84 ± 3.08ns	40.32 ± 1.29ns	67.18 ± 1.00ns	56.17 ± 2.65ns	47.93 ± 2.78ns	39.03 ± 0.89 ab	64.97 ± 1.02 ab	53.63 ± 2.61ns	45.46 ± 2.72ns	37.55 ± 0.97 ab

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
	Shelter wood	70.89 ± 2.74ns	60.81 ± 4.23ns	49.40 ± 1.67ns	41.45 ± 1.62ns	67.41 ± 2.60ns	56.52 ± 4.14ns	46.60 ± 1.63ns	38.65 ± 1.44ns	66.05 ± 2.51ns	53.09 ± 4.16ns	43.47 ± 1.60ns	37.35 ± 1.46 b	63.53 ± 2.00 b	49.33 ± 3.83ns	41.70 ± 1.19ns	36.05 ± 1.46 b
Sand	Control	18.93 ± 0.92 b	22.53 ± 1.62 b	25.86 ± 1.72ns	34.60 ± 4.07ns	22.20 ± 0.81 b	26.40 ± 1.57 b	28.93 ± 1.87ns	37.60 ± 4.12ns	24.06 ± 0.70 b	28.66 ± 1.61 b	31.06 ± 1.76ns	39.33 ± 4.14ns	27.13 ± 0.86 b	31.80 ± 1.69c	34.46 ± 1.64ns	42.60 ± 3.98ns
	Single tree	23.60 ± 0.94a	24.73 ± 0.88 ab	30.40 ± 2.70ns	35.26 ± 2.42ns	27.01 ± 0.96a	28.33 ± 0.96 ab	33.86 ± 2.51ns	38.66 ± 2.30ns	29.53 ± 0.98a	30.33 ± 0.87 ab	35.86 ± 2.41ns	40.20 ± 2.24ns	32.46 ± 1.01a	33.46 ± 0.91 ab	38.04 ± 2.34ns	42.26 ± 2.07ns
	Shelter wood	25.46 ± 1.72a	28.26 ± 2.17a	31.86 ± 2.79ns	36.80 ± 2.59ns	29.06 ± 1.63a	22.66 ± 2.01a	34.80 ± 2.64ns	40.06 ± 2.37ns	31.46 ± 1.41a	34.02 ± 1.84a	37.46 ± 2.59ns	42.26 ± 2.11ns	35.00 ± 1.36a	37.86 ± 1.86a	40.53 ± 2.76ns	44.60 ± 2.39ns
Silt	Control	44.06 ± 1.18ns	47.00 ± 2.78ns	49.80 ± 2.02ns	45.33 ± 3.88ns	43.26 ± 1.34ns	48.06 ± 2.18ns	50.26 ± 2.23ns	46.33 ± 4.02ns	43.53 ± 1.18ns	49.46 ± 2.04ns	50.80 ± 2.15ns	41.46 ± 4.27ns	42.13 ± 1.63ns	48.33 ± 2.13ns	49.80 ± 2.09ns	45.80 ± 4.15ns
	Single tree	44.26 ± 2.95ns	46.86 ± 1.14ns	47.46 ± 2.61ns	46.33 ± 2.45ns	43.66 ± 2.95ns	47.53 ± 1.08ns	48.22 ± 2.69ns	45.32 ± 2.40ns	42.73 ± 2.61ns	41.11 ± 1.17ns	48.51 ± 2.51ns	41.80 ± 2.28ns	41.80 ± 2.38ns	48.72 ± 1.36ns	47.20 ± 2.50ns	48.001.90ns
	Shelter wood	44.20 ± 2.15ns	46.13 ± 2.18ns	48.46 ± 2.54ns	45.66 ± 1.96ns	43.26 ± 1.80ns	47.33 ± 2.27ns	48.86 ± 2.26ns	45.93 ± 1.74ns	43.46 ± 1.47ns	45.86 ± 2.06ns	48.13 ± 2.22ns	42.32 ± 1.22ns	42.33 ± 1.22ns	44.86 ± 2.09ns	47.00 ± 2.47ns	47.93 ± 2.21ns
Clay	Control	37.00 ± 0.97a	3.46 ± 2.78ns	24.33 ± 1.03a	20.06 ± 1.16ns	34.53 ± 1.02a	25.53 ± 1.92a	20.80 ± 0.86a	16.06 ± 1.03ns	32.40 ± 0.89a	21.86 ± 1.65ns	18.13 ± 0.75a	14.20 ± 1.15a	30.73 ± 1.01a	19.86 ± 1.49ns	15.73 ± 0.93a	11.60 ± 1.16a
	Single tree	32.13 ± 2.64 ab	28.40 ± 1.17ns	22.13 ± 1.19 ab	18.40 ± 1.12ns	29.33 ± 2.57 b	24.13 ± 0.91 ab	17.80 ± 1.15 ab	16.00 ± 1.18ns	27.73 ± 2.23 b	20.53 ± 0.82ns	15.60 ± 0.92 ab	12.26 ± 0.93 ab	25.73 ± 1.92 b	17.92 ± 0.74ns	14.33 ± 1.01 ab	9.73 ± 0.86 ab
	Shelter wood	30.33 ± 1.34 b	25.60 ± 1.45ns	19.66 ± 1.49 b	17.53 ± 1.27ns	27.66 ± 1.11 b	21.00 ± 1.49 b	16.33 ± 1.12 b	14.00 ± 1.35ns	25.06 ± 0.96 b	20.13 ± 1.79ns	14.40 ± 1.04 b	10.00 ± 0.86 b	22.66 ± 0.78 b	17.26 ± 1.58ns	12.46 ± 0.94 b	7.46 ± 0.42 b
Water content	Control	36.33 ± 2.70ns	39.87 ± 1.85ns	46.68 ± 2.26ns	50.23 ± 1.96ns	35.46 ± 2.77ns	37.96 ± 1.79ns	45.23 ± 2.00a	48.55 ± 1.90ns	34.58 ± 2.52ns	36.45 ± 1.70ns	44.16 ± 1.91a	47.40 ± 1.76ns	40.75 ± 2.58ns	42.20 ± 1.68a	49.32 ± 2.19ns	51.80 ± 2.10ns
	Single tree	34.01 ± 1.65ns	36.72 ± 2.14ns	42.74 ± 1.98ns	47.27 ± 2.82ns	31.93 ± 1.41ns	34.59 ± 2.06ns	40.65 ± 1.93 ab	44.84 ± 2.64ns	28.53 ± 1.29ns	33.45 ± 2.00ns	38.31 ± 1.72 ab	42.91 ± 2.63ns	36.45 ± 1.50ns	39.59 ± 2.10 ab	45.54 ± 1.91ns	49.40 ± 2.73ns
	Shelter wood	32.55 ± 2.28ns	35.05 ± 2.05ns	40.43 ± 2.55ns	44.80 ± 3.84ns	30.69 ± 2.11ns	32.96 ± 1.85ns	38.24 ± 2.53 b	43.67 ± 3.66ns	29.15 ± 2.05ns	31.38 ± 2.62ns	36.99 ± 2.47 b	41.47 ± 3.62ns	34.29 ± 2.36ns	36.35 ± 1.76 b	42.85 ± 2.44ns	47.58 ± 3.81ns
Temperature	Control	18.12 ± 0.90ns	17.71 ± 0.60ns	15.37 ± 1.21ns	13.09 ± 1.01ns	19.00 ± 0.84ns	18.58 ± 0.61ns	16.39 ± 1.20ns	14.19 ± 1.00ns	19.91 ± 0.79ns	19.65 ± 0.61ns	17.44 ± 1.20ns	15.28 ± 0.95ns	17.00 ± 0.88ns	16.70 ± 0.61ns	14.34 ± 1.18ns	12.17 ± 0.98ns
	Single tree	19.03 ± 0.84ns	17.70 ± 1.19ns	17.51 ± 0.80ns	14.79 ± 1.04ns	20.38 ± 0.62ns	18.83 ± 1.18ns	18.66 ± 0.83ns	15.97 ± 1.03ns	21.39 ± 0.61ns	19.75 ± 1.12ns	19.64 ± 0.82ns	16.78 ± 1.01ns	18.24 ± 0.83ns	16.64 ± 1.19ns	16.40 ± 0.77ns	13.63 ± 0.94ns
	Shelter wood	20.38 ± 1.17ns	20.86 ± 1.44ns	18.44 ± 1.14ns	14.89 ± 1.28ns	21.42 ± 1.16ns	21.89 ± 1.40ns	19.45 ± 1.16ns	16.08 ± 1.04ns	22.29 ± 1.13ns	22.73 ± 1.39ns	20.41 ± 1.19ns	17.14 ± 1.04ns	19.24 ± 1.18ns	19.84 ± 1.44ns	17.37 ± 1.11ns	13.83 ± 1.26ns
pH	Control	6.85 ± 0.11ns	6.67 ± 0.15ns	6.50 ± 0.13ns	6.21 ± 0.14ns	6.92 ± 0.10ns	6.72 ± 0.15ns	6.50 ± 0.13ns	6.26 ± 0.14ns	6.95 ± 0.10ns	6.75 ± 0.15ns	6.58 ± 0.13ns	6.29 ± 0.14ns	6.78 ± 0.11ns	6.60 ± 0.15ns	6.43 ± 0.13ns	6.14 ± 0.14ns
	Single tree	6.77 ± 0.14ns	6.60 ± 0.10ns	6.39 ± 0.16ns	6.15 ± 0.15ns	6.89 ± 0.14ns	6.65 ± 0.10ns	6.44 ± 0.16ns	6.20 ± 0.15ns	6.92 ± 0.14ns	6.68 ± 0.10ns	6.47 ± 0.16ns	6.23 ± 0.15ns	6.73 ± 0.14ns	6.53 ± 0.10ns	6.32 ± 0.16ns	6.08 ± 0.15ns

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
	Shelter wood	6.69 ± 0.11ns	6.53 ± 0.14ns	6.32 ± 0.18ns	6.11 ± 0.14ns	6.82 ± 0.09ns	6.58 ± 0.14ns	6.37 ± 0.18ns	6.16 ± 0.14ns	6.87 ± 0.09ns	6.61 ± 0.14ns	6.40 ± 0.18ns	6.19 ± 0.14ns	6.64 ± 0.12ns	6.46 ± 0.14ns	6.25 ± 0.18ns	6.04 ± 0.14ns
EC	Control	0.40 ± 0.20a	0.30 ± 0.01ns	0.26 ± 0.02ns	0.25 ± 0.01ns	0.43 ± 0.02a	0.33 ± 0.01ns	0.29 ± 0.02ns	0.28 ± 0.01ns	0.45 ± 0.02a	0.35 ± 0.01ns	0.31 ± 0.02ns	0.30 ± 0.01ns	0.36 ± 0.02a	0.26 ± 0.01ns	0.22 ± 0.02ns	0.21 ± 0.01ns
	Single tree	0.35 ± 0.01 ab	0.28 ± 0.01ns	0.24 ± 0.02ns	0.22 ± 0.02ns	0.38 ± 0.10 ab	0.31 ± 0.01ns	0.27 ± 0.02ns	0.25 ± 0.02ns	0.40 ± 0.01 ab	0.33 ± 0.01ns	0.29 ± 0.02ns	0.27 ± 0.02ns	0.31 ± 0.01 ab	0.24 ± 0.01ns	0.20 ± 0.02ns	0.18 ± 0.02ns
	Shelter wood	0.30 ± 0.01 b	0.25 ± 0.02ns	0.23 ± 0.02ns	0.21 ± 0.01ns	0.33 ± 0.01 b	0.28 ± 0.02ns	0.26 ± 0.02ns	0.24 ± 0.01ns	0.35 ± 0.01 b	0.30 ± 0.02ns	0.28 ± 0.02ns	0.26 ± 0.01ns	0.36 ± 0.01 b	0.21 ± 0.02ns	0.19 ± 0.02ns	0.17 ± 0.01ns
Organic C	Control	8.36 ± 0.65ns	8.11 ± 0.51a	6.98 ± 0.85a	7.58 ± 0.73a	6.76 ± 0.58ns	6.47 ± 0.46a	5.35 ± 0.76a	5.70 ± 0.64a	5.64 ± 0.53ns	5.35 ± 0.43a	4.26 ± 0.68a	4.42 ± 0.57a	7.02 ± 0.50ns	6.16 ± 0.53a	4.53 ± 0.78ns	4.27 ± 0.61ns
	Single tree	7.62 ± 0.67ns	6.36 ± 0.55 ab	5.75 ± 0.72 ab	5.80 ± 0.56 ab	6.13 ± 0.60ns	4.91 ± 0.50 ab	4.24 ± 0.67 ab	4.12 ± 0.51 ab	5.10 ± 0.55ns	3.93 ± 0.45 ab	3.27 ± 0.62 ab	3.00 ± 0.47 ab	6.45 ± 0.59ns	4.54 ± 0.52 ab	3.56 ± 0.72ns	3.03 ± 0.45ns
	Shelter wood	6.71 ± 0.50ns	5.48 ± 0.76 b	4.32 ± 0.56 b	4.72 ± 0.69 b	5.30 ± 0.44ns	4.20 ± 0.67 b	3.00 ± 0.52 b	3.30 ± 0.62 b	4.33 ± 0.60ns	3.34 ± 0.60 b	2.10 ± 0.44 b	2.50 ± 0.53 b	5.50 ± 0.45ns	3.92 ± 0.69 b	2.75 ± 0.68ns	2.65 ± 0.56ns
C in macro aggregates	Control	0.55 ± 0.06ns	0.46 ± 0.03ns	0.35 ± 0.04ns	0.25 ± 0.03a	0.46 ± 0.06ns	0.37 ± 0.03ns	0.26 ± 0.04ns	0.16 ± 0.03a	0.38 ± 0.06ns	0.30 ± 0.03ns	0.19 ± 0.04ns	0.10 ± 0.03ns	0.36 ± 0.05ns	0.24 ± 0.02ns	0.15 ± 0.03ns	0.06 ± 0.01a
	Single tree	0.50 ± 0.03ns	0.41 ± 0.05ns	0.32 ± 0.03ns	0.21 ± 0.01 ab	0.41 ± 0.03ns	0.32 ± 0.05ns	0.23 ± 0.03ns	0.12 ± 0.01 ab	0.34 ± 0.02ns	0.24 ± 0.05ns	0.16 ± 0.03ns	0.06 ± 0.01ns	0.29 ± 0.02ns	0.20 ± 0.04ns	0.12 ± 0.02ns	0.05 ± 0.00 ab
	Shelter wood	0.49 ± 0.03ns	0.37 ± 0.03ns	0.28 ± 0.01ns	0.16 ± 0.01 b	0.40 ± 0.03ns	0.28 ± 0.03ns	0.19 ± 0.01ns	0.07 ± 0.01 b	0.33 ± 0.03ns	0.21 ± 0.03ns	0.12 ± 0.01ns	0.05 ± 0.00ns	0.27 ± 0.03ns	0.19 ± 0.02ns	0.07 ± 0.01ns	0.03 ± 0.00 b
C in micro aggregates	Control	0.37 ± 0.04ns	0.31 ± 0.02ns	0.25 ± 0.02ns	0.18 ± 0.02ns	0.29 ± 0.04ns	0.23 ± 0.02ns	0.17 ± 0.02ns	0.10 ± 0.02ns	0.25 ± 0.02ns	0.15 ± 0.02ns	0.10 ± 0.01ns	0.07 ± 0.01ns	0.18 ± 0.02ns	0.10 ± 0.02ns	0.07 ± 0.01ns	0.04 ± 0.00ns
	Single tree	0.36 ± 0.03ns	0.28 ± 0.02ns	0.22 ± 0.03ns	0.16 ± 0.02ns	0.28 ± 0.03ns	0.20 ± 0.02ns	014 ± 0.03ns	0.09 ± 0.02ns	0.19 ± 0.03ns	0.13 ± 0.02ns	0.09 ± 0.01ns	0.05 ± 0.01ns	0.15 ± 0.03ns	0.09 ± 0.01ns	0.05 ± 0.00ns	0.04 ± 0.00ns
	Shelter wood	0.33 ± 0.02ns	0.27 ± 0.02ns	0.19 ± 0.02ns	0.13 ± 0.02ns	0.25 ± 0.02ns	0.19 ± 0.02ns	0.12 ± 0.02ns	0.07 ± 0.02ns	0.16 ± 0.02ns	0.11 ± 0.02ns	0.07 ± 0.01ns	0.04 ± 0.00ns	0.12 ± 0.02ns	0.07 ± 0.02ns	0.05 ± 0.01ns	0.03 ± 0.00ns
Carbon stocks	Control	126.74 ± 12.12ns	124.18 ± 5.84a	102.20 ± 12.83ns	86.18 ± 8.97a	104.09 ± 10.82ns	96.75 ± 7.10a	79.55 ± 9.51ns	68.62 ± 8.35a	87.57 ± 9.81ns	80.43 ± 6.64a	63.70 ± 8.48ns	53.67 ± 7.36a	104.68 ± 9.26ns	89.17 ± 7.95a	65.71 ± 9.75ns	40.43 ± 7.31ns
	Single tree	111.52 ± 8.35ns	96.03 ± 9.53 ab	84.13 ± 11.19ns	69.64 ± 7.57 ab	93.04 ± 8.38ns	75.21 ± 8.52 ab	65.24 ± 7.15ns	50.30 ± 6.70 ab	77.75 ± 7.69ns	60.66 ± 7.73 ab	50.56 ± 9.42ns	36.99 ± 6.07 ab	95.22 ± 7.88ns	67.88 ± 8.62 ab	53.22 ± 10.63ns	35.68 ± 5.45ns
	Shelter wood	101.51 ± 6.34ns	85.27 ± 12.91 b	68.42 ± 10.06ns	60.57 ± 6.73 b	81.09 ± 5.69ns	66.11 ± 6.28 b	48.59 ± 8.15ns	39.41 ± 7.19 b	66.60 ± 5.19ns	53.09 ± 10.03 b	37.83 ± 7.76ns	29.81 ± 6.19 b	83.32 ± 5.98ns	59.96 ± 11.30 b	43.26 ± 8.24ns	30.54 ± 6.28ns
Total N	Control	0.63 ± 0.02ns	0.51 ± 0.03a	0.39 ± 0.03ns	0.33 ± 0.02ns	0.56 ± 0.02ns	0.44 ± 0.03a	0.32 ± 0.03ns	0.26 ± 0.02ns	0.51 ± 0.02ns	0.39 ± 0.03a	0.27 ± 0.03ns	0.21 ± 0.02ns	0.47 ± 0.02ns	0.30 ± 0.03a	0.23 ± 0.03ns	0.17 ± 0.02ns
	Single tree	0.61 ± 0.02ns	0.44 ± 0.02 ab	0.34 ± 0.04ns	0.28 ± 0.02ns	0.54 ± 0.02ns	0.37 ± 0.03 ab	0.27 ± 0.04ns	0.21 ± 0.02ns	0.41 ± 0.02ns	0.32 ± 0.03 ab	0.23 ± 0.04ns	0.16 ± 0.02ns	0.45 ± 0.02ns	0.18 ± 0.03 ab	0.19 ± 0.03ns	0.12 ± 0.01ns
	Shelter wood	0.58 ± 0.02ns	0.41 ± 0.03 b	0.31 ± 0.04ns	0.25 ± 0.03ns	0.51 ± 0.02ns	0.34 ± 0.03 b	0.24 ± 0.04ns	0.18 ± 0.03ns	0.46 ± 0.02ns	0.29 ± 0.03 b	0.20 ± 0.03ns	0.15 ± 0.03ns	0.42 ± 0.02ns	0.25 ± 0.03 b	0.18 ± 0.03ns	0.13 ± 0.02ns
N in macro aggregates	Control	0.44 ± 0.03ns	0.37 ± 0.03ns	0.34 ± 0.02ns	0.28 ± 0.02a	0.38 ± 0.03ns	0.31 ± 0.03ns	0.28 ± 0.02ns	0.22 ± 0.02a	0.34 ± 0.03ns	0.27 ± 0.03ns	0.24 ± 0.02ns	0.18 ± 0.02a	0.29 ± 0.03ns	0.22 ± 0.03ns	0.19 ± 0.02ns	0.13 ± 0.02ns
	Single tree	0.43 ± 0.03ns	0.36 ± 0.01ns	0.32 ± 0.02ns	0.26 ± 0.02a	0.37 ± 0.03ns	0.30 ± 0.01ns	0.26 ± 0.02ns	0.20 ± 0.02a	0.33 ± 0.03ns	0.26 ± 0.01ns	0.22 ± 0.02ns	0.16 ± 0.02a	0.28 ± 0.03ns	0.21 ± 0.01ns	0.17 ± 0.02ns	0.11 ± 0.02ns
	Shelter wood	0.39 ± 0.03ns	0.35 ± 0.03ns	0.30 ± 0.03ns	0.14 ± 0.02 b	0.33 ± 0.03ns	0.29 ± 0.03ns	0.24 ± 0.03ns	0.09 ± 0.02 b	0.29 ± 0.03ns	0.25 ± 0.03ns	0.20 ± 0.03ns	0.08 ± 0.01 b	0.26 ± 0.03ns	0.20 ± 0.02ns	0.16 ± 0.02ns	0.08 ± 0.00ns
N in micro aggregates	Control	0.41 ± 0.03ns	0.34 ± 0.02ns	0.25 ± 0.02ns	0.16 ± 0.01ns	0.36 ± 0.03ns	0.29 ± 0.02ns	0.20 ± 0.02ns	0.11 ± 0.01ns	0.32 ± 0.03ns	0.25 ± 0.02ns	0.16 ± 0.02ns	0.07 ± 0.01ns	0.29 ± 0.03ns	0.21 ± 0.02ns	0.13 ± 0.02ns	0.05 ± 0.01ns
	Single tree	0.39 ± 0.03ns	0.33 ± 0.02ns	0.24 ± 0.03ns	0.15 ± 0.01ns	0.34 ± 0.03ns	0.28 ± 0.02ns	0.19 ± 0.03ns	0.10 ± 0.01ns	0.30 ± 0.03ns	0.24 ± 0.02ns	0.15 ± 0.03ns	0.06 ± 0.01ns	0.27 ± 0.03ns	0.20 ± 0.02ns	0.11 ± 0.02ns	0.04 ± 0.00ns
	Shelter wood	0.37 ± 0.03ns	0.31 ± 0.04ns	0.22 ± 0.02ns	0.14 ± 0.04ns	0.32 ± 0.03ns	0.26 ± 0.04ns	0.17 ± 0.02ns	0.06 ± 0.02ns	0.28 ± 0.03ns	0.23 ± 0.04ns	0.13 ± 0.02ns	0.04 ± 0.01ns	0.25 ± 0.03ns	0.20 ± 0.04ns	0.10 ± 0.02ns	0.04 ± 0.01ns

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
Nitrogen stocks	Control	9.51 ± 0.35ns	7.62 ± 0.47ns	5.82 ± 0.64ns	3.92 ± 0.30ns	8.58 ± 0.35ns	6.67 ± 0.48ns	4.86 ± 0.64ns	3.14 ± 0.29ns	7.87 ± 0.35ns	5.96 ± 0.48ns	4.14 ± 0.64ns	2.56 ± 0.28ns	7.02 ± 0.33ns	5.16 ± 0.47ns	3.43 ± 0.61ns	1.99 ± 0.27ns
	Single tree	9.33 ± 0.33ns	6.67 ± 0.52ns	5.29 ± 0.65ns	3.36 ± 0.31ns	8.37 ± 0.32ns	5.78 ± 0.52ns	4.26 ± 0.65ns	2.57 ± 0.30ns	7.66 ± 0.31ns	5.06 ± 0.51ns	3.55 ± 0.65ns	1.98 ± 0.30ns	6.81 ± 0.30ns	4.30 ± 0.48ns	2.96 ± 0.59ns	1.58 ± 0.22ns
	Shelter wood	8.89 ± 0.44ns	6.35 ± 0.62ns	5.00 ± 0.70ns	2.99 ± 0.43ns	7.91 ± 0.43ns	5.37 ± 0.60ns	3.97 ± 0.70ns	2.26 ± 0.42ns	7.19 ± 0.43ns	4.64 ± 0.59ns	3.39 ± 0.64ns	1.82 ± 0.39ns	6.36 ± 0.40ns	3.89 ± 0.57ns	2.89 ± 0.54ns	1.51 ± 0.32ns
C/N ratio	Control	13.34 ± 1.15ns	15.90 ± 0.65a	17.72 ± 1.39ns	22.51 ± 1.49a	12.17 ± 1.15ns	14.72 ± 0.65a	16.55 ± 1.39ns	21.34 ± 1.49a	11.19 ± 1.15ns	13.75 ± 0.65a	15.57 ± 1.39ns	20.36 ± 1.49a	15.00 ± 1.15ns	17.56 ± 0.65a	19.83 ± 1.39ns	24.17 ± 1.49a
	Single tree	12.12 ± 0.75ns	14.40 ± 0.83 ab	16.93 ± 0.70ns	20.44 ± 0.66 ab	10.95 ± 0.75ns	13.23 ± 0.83 ab	15.76 ± 0.70ns	19.27 ± 0.66 ab	9.97 ± 0.75ns	12.25 ± 0.83 ab	14.78 ± 0.70ns	18.29 ± 0.66 ab	13.78 ± 0.75ns	16.06 ± 0.83 ab	18.59 ± 0.70ns	22.10 ± 0.66 ab
	Shelter wood	11.55 ± 0.67ns	12.49 ± 0.94 b	14.74 ± 1.12ns	18.91 ± 0.47 b	10.38 ± 0.67ns	11.32 ± 0.94 b	13.57 ± 1.12ns	17.74 ± 0.47 b	9.40 ± 0.67ns	10.34 ± 0.94 b	12.59 ± 1.12ns	16.76 ± 0.47 b	13.21 ± 0.67ns	14.15 ± 0.94 b	16.40 ± 1.12ns	20.57 ± 0.47 b
Ammonium	Control	43.18 ± 3.76ns	31.92 ± 2.75ns	20.97 ± 2.73a	12.41 ± 0.96a	39.42 ± 3.76ns	28.16 ± 2.75ns	17.21 ± 2.73a	8.65 ± 0.96a	34.33 ± 3.76ns	23.07 ± 2.75ns	12.12 ± 2.73a	3.56 ± 0.96a	31.35 ± 3.76ns	20.09 ± 2.75ns	10.37 ± 2.43a	3.24 ± 0.61a
	Single tree	40.59 ± 2.00ns	21.73 ± 2.70ns	17.01 ± 1.22 ab	10.23 ± 0.23 b	36.83 ± 2.00ns	23.97 ± 2.70ns	13.25 ± 1.22 ab	6.47 ± 0.23 b	31.74 ± 2.00ns	18.88 ± 2.70ns	8.16 ± 1.22 ab	1.38 ± 0.23 b	28.76 ± 2.00ns	16.07 ± 2.63ns	5.58 ± 1.11 b	2.04 ± 0.19 b
	Shelter wood	36.95 ± 3.32ns	24.12 ± 2.71ns	13.91 ± 1.03 b	8.80 ± 0.85 b	33.80 ± 3.32ns	20.36 ± 2.71ns	10.15 ± 1.03 b	5.44 ± 0.70 b	28.10 ± 3.32ns	15.27 ± 2.71ns	5.06 ± 1.03 b	1.14 ± 0.13 b	25.12 ± 3.32ns	12.29 ± 2.71ns	3.63 ± 0.80 b	1.90 ± 0.23 b
Nitrate	Control	45.20 ± 2.71ns	35.59 ± 2.79ns	30.03 ± 3.23ns	25.72 ± 2.00a	41.21 ± 2.71ns	31.60 ± 2.79ns	26.04 ± 3.23ns	21.73 ± 2.00a	37.17 ± 2.71ns	27.56 ± 2.79ns	22.00 ± 3.23ns	17.69 ± 2.00a	31.41 ± 2.71ns	21.80 ± 2.79ns	16.84 ± 3.01ns	11.93 ± 2.00a
	Single tree	40.77 ± 2.21ns	33.47 ± 2.01ns	28.81 ± 3.00ns	20.50 ± 1.35 ab	36.78 ± 2.21ns	29.48 ± 2.01ns	24.82 ± 3.00ns	16.51 ± 1.35 ab	32.74 ± 2.21ns	25.44 ± 2.01ns	20.78 ± 3.00ns	12.47 ± 1.35 b	26.98 ± 2.21ns	19.68 ± 2.01ns	15.80 ± 2.71ns	7.51 ± 1.03 b
	Shelter wood	38.94 ± 3.36ns	31.71 ± 3.36ns	26.81 ± 2.31ns	15.90 ± 2.11 b	34.95 ± 3.36ns	27.72 ± 3.36ns	22.82 ± 2.31ns	11.91 ± 1.11 b	30.91 ± 3.36ns	23.68 ± 3.36ns	18.78 ± 2.31ns	8.20 ± 2.03 b	25.38 ± 3.24ns	18.41 ± 3.19ns	13.21 ± 2.24ns	6.19 ± 1.36 b
N mineralization	Control	54.25 ± 2.46a	33.14 ± 2.39a	20.13 ± 1.42a	15.83 ± 0.95a	47.16 ± 2.46a	26.05 ± 2.39a	13.04 ± 1.42a	8.74 ± 0.95a	40.13 ± 2.46a	19.02 ± 2.39a	10.62 ± 1.73a	3.58 ± 0.56a	31.09 ± 2.46a	9.98 ± 2.39ns	5.91 ± 0.79a	1.80 ± 0.16a
	Single tree	44.31 ± 2.26 b	28.76 ± 1.49 ab	18.31 ± 0.94 ab	11.17 ± 0.70 b	37.22 ± 2.26 b	21.67 ± 1.49 ab	11.22 ± 0.94 ab	4.08 ± 0.70 b	30.19 ± 2.26 b	15.31 ± 1.32 ab	8.28 ± 0.71 ab	2.82 ± 0.42 ab	21.15 ± 2.26 b	8.57 ± 1.46ns	3.17 ± 0.76 b	1.54 ± 0.24 ab
	Shelter wood	39.85 ± 2.23 b	24.27 ± 1.46 b	16.31 ± 1.07 b	9.92 ± 0.28 b	32.76 ± 2.23 b	17.18 ± 1.46 b	9.22 ± 1.07 b	2.83 ± 0.28 b	25.75 ± 2.23 b	11.33 ± 1.39 b	6.56 ± 0.55 b	1.75 ± 0.30 b	16.69 ± 2.23 b	7.50 ± 1.07ns	2.83 ± 0.61 b	0.98 ± 0.23 b
Available P	Control	31.20 ± 2.02a	24.27 ± 1.46ns	21.22 ± 1.98ns	19.93 ± 1.62a	29.07 ± 2.02a	22.14 ± 1.46ns	19.34 ± 1.87ns	17.80 ± 1.62a	25.85 ± 2.02a	18.92 ± 1.46ns	16.14 ± 1.86ns	14.74 ± 1.55a	20.68 ± 2.02a	14.25 ± 1.17ns	11.67 ± 1.71ns	10.66 ± 1.19a
	Single tree	27.46 ± 1.18 ab	22.42 ± 1.43ns	19.39 ± 2.70ns	16.49 ± 1.16 ab	25.33 ± 1.18 ab	20.29 ± 1.43ns	17.26 ± 2.70ns	14.36 ± 1.16 ab	22.11 ± 1.18 ab	17.07 ± 1.43ns	14.04 ± 2.70ns	11.44 ± 1.12 ab	16.94 ± 1.18 ab	11.90 ± 1.43ns	11.24 ± 2.23ns	8.01 ± 0.80 b
	Shelter wood	25.08 ± 1.89 b	20.95 ± 2.84ns	17.32 ± 2.25ns	13.38 ± 0.79 b	22.95 ± 1.89 b	18.82 ± 2.84ns	15.47 ± 2.19ns	11.25 ± 0.79 b	19.73 ± 1.89 b	15.60 ± 2.84ns	12.25 ± 2.19ns	8.03 ± 0.79 b	14.56 ± 1.89 b	10.90 ± 2.75ns	10.07 ± 1.48ns	5.93 ± 0.32 b
Available K	Control	446.46 ± 28.06ns	350.20 ± 27.88ns	316.26 ± 12.99ns	291.60 ± 23.26a	433.46 ± 28.06ns	337.20 ± 27.88ns	303.26 ± 12.99ns	278.60 ± 23.26a	410.46 ± 28.06ns	314.20 ± 27.88ns	280.26 ± 12.99ns	255.60 ± 23.26a	373.46 ± 28.06ns	277.20 ± 27.88ns	243.26 ± 12.99ns	218.60 ± 23.26a

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
	Single tree	411.00 ± 22.06ns	343.33 ± 15.40ns	295.07 ± 26.99ns	260.80 ± 22.20 ab	398.00 ± 22.06ns	330.33 ± 15.40ns	282.07 ± 26.99ns	247.80 ± 22.20 ab	375.00 ± 22.06ns	307.33 ± 15.40ns	259.07 ± 26.99ns	248.80 ± 22.20 ab	338.00 ± 22.06ns	270.33 ± 15.40ns	222.07 ± 26.99ns	187.80 ± 22.20 ab
	Shelter wood	396.00 ± 29.05ns	326.53 ± 19.60ns	271.33 ± 14.47ns	213.87 ± 15.53 b	383.00 ± 29.05ns	313.53 ± 19.60ns	258.33 ± 14.47ns	200.80 ± 15.55 b	360.00 ± 29.05ns	210.51 ± 21.60ns	235.33 ± 14.47ns	177.87 ± 15.55 b	323.00 ± 29.05ns	253.53 ± 19.60ns	198.33 ± 14.47ns	140.87 ± 15.55 b
Available Ca	Control	389.06 ± 22.71a	311.73 ± 25.33ns	260.37 ± 29.48ns	223.33 ± 20.18ns	372.06 ± 27.71a	296.73 ± 28.33ns	243.37 ± 20.48ns	206.33 ± 20.18ns	335.06 ± 22.71a	257.73 ± 25.33ns	206.37 ± 29.48ns	169.33 ± 20.18ns	316.06 ± 22.71a	238.73 ± 25.33ns	187.37 ± 29.48ns	150.33 ± 20.18ns
	Single tree	357.87 ± 18.17 ab	293.26 ± 22.82ns	230.40 ± 20.22ns	204.53 ± 17.51ns	340.87 ± 18.17 ab	276.27 ± 22.82ns	213.40 ± 19.22ns	187.53 ± 17.51ns	303.87 ± 18.17 ab	239.27 ± 23.82ns	176.40 ± 20.22ns	150.53 ± 17.51ns	284.87 ± 18.17 ab	220.27 ± 22.82ns	157.40 ± 2022ns	131.53 ± 17.51ns
	Shelter wood	320.20 ± 26.65 b	248.87 ± 25.11ns	209.73 ± 20.03ns	178.47 ± 19.92ns	303.20 ± 26.65 b	23187 ± 25.11ns	192.93 ± 19.03ns	161.47 ± 19.92ns	266.20 ± 26.65 b	194.87 ± 25.11ns	155.73 ± 20.03ns	124.41 ± 19.92ns	247.20 ± 26.65 b	175.81 ± 25.11ns	136.73 ± 20.03ns	105.47 ± 19.92ns
Available Mg	Control	59.06 ± 1.29a	48.53 ± 2.84ns	44.13 ± 2.86ns	41.33 ± 2.66a	50.06 ± 1.29a	39.52 ± 2.84ns	35.12 ± 2.86ns	32.33 ± 2.66a	43.06 ± 1.29a	32.53 ± 2.84ns	28.13 ± 2.86ns	25.33 ± 2.66a	34.06 ± 1.29a	23.53 ± 2.84ns	20.80 ± 2.17ns	17.60 ± 2.23a
	Single tree	55.33 ± 1.74 ab	45.00 ± 2.27ns	40.00 ± 2.90ns	35.80 ± 1.17 ab	46.33 ± 1.74 ab	36.00 ± 2.27ns	31.00 ± 2.90ns	26.80 ± 1.17 ab	39.33 ± 1.74 ab	29.00 ± 2.27ns	24.00 ± 2.90ns	19.80 ± 1.17 ab	30.33 ± 1.74 ab	20.00 ± 2.27ns	15.93 ± 2.62ns	12.93 ± 1.11 ab
	Shelter wood	51.00 ± 3.61 b	42.66 ± 2.07ns	36.00 ± 3.72ns	31.53 ± 3.37 b	42.00 ± 3.61 b	36.66 ± 2.07ns	27.00 ± 3.72ns	22.51 ± 3.37 b	35.06 ± 3.58 b	26.66 ± 2.07ns	20.66 ± 3.46ns	16.40 ± 3.10 b	27.66 ± 1.82 b	17.66 ± 2.07ns	17.20 ± 1.89ns	12.00 ± 1.63 b
Fulvic acid	Control	510.73 ± 32.09ns	459.73 ± 45.57ns	382.20 ± 58.21ns	308.46 ± 28.42ns	475.73 ± 32.09ns	424.73 ± 47.57ns	347.20 ± 58.21ns	273.46 ± 28.42ns	462.73 ± 32.09ns	411.73 ± 47.57ns	334.20 ± 58.21ns	260.46 ± 28.42ns	445.71 ± 32.09ns	394.73 ± 47.57ns	317.20 ± 58.21ns	243.46 ± 28.42ns
	Single tree	501.80 ± 61.73ns	403.20 ± 51.60ns	342.73 ± 40.89ns	289.33 ± 46.15ns	466.80 ± 61.73ns	368.20 ± 51.60ns	307.72 ± 40.89ns	254.33 ± 46.15ns	453.80 ± 61.73ns	355.20 ± 51.60ns	294.70 ± 40.89ns	241.33 ± 46.15ns	436.80 ± 61.83ns	338.20 ± 51.60ns	277.73 ± 40.89ns	224.33 ± 46.15ns
	Shelter wood	490.47 ± 51.58ns	388.40 ± 57.11ns	314.73 ± 35.66ns	236.73 ± 32.65ns	455.47 ± 51.58ns	353.40 ± 57.11ns	279.70 ± 35.66ns	201.73 ± 32.65ns	424.47 ± 51.58ns	340.40 ± 57.11ns	266.70 ± 15.66ns	188.73 ± 32.65ns	425.47 ± 51.58ns	323.40 ± 57.11ns	249.73 ± 35.66ns	171.73 ± 32.65ns
Humic acid	Control	418.86 ± 51.14ns	308.33 ± 35.55ns	242 ± 37.47ns	202 ± 36.06ns	395.86 ± 51.14ns	285.33 ± 35.55ns	219.00 ± 37.47ns	179.00 ± 36.06ns	382.86 ± 51.14ns	272.33 ± 35.55ns	206 ± 37.47ns	166.38 ± 36.06ns	365.86 ± 35.98ns	255.33 ± 35.55ns	189.00 ± 37.47ns	149 ± 36ns
	Single tree	359.87 ± 19.51ns	292.53 ± 35.17ns	233 ± 27.83ns	189 ± 26.44ns	336.87 ± 19.51ns	269.51 ± 35.17ns	210.00 ± 27.83ns	166.00 ± 26.44ns	323.87 ± 19.51ns	256.53 ± 35.17ns	197 ± 27.83ns	153 ± 26.44ns	306.87 ±	239.53 ± 35.17ns	180.00 ± 27.83ns	136 ± 26.44ns
	Shelter wood	316.80 ± 43.44ns	289.93 ± 42.07ns	208.27 ± 20.14ns	145 ± 21.92ns	293.80 ± 43.44ns	266.93 ± 42.07ns	185.27 ± 20.14ns	122.53 ± 21.92ns	280.80 ± 43.44ns	253.93 ± 42.07ns	172.27 ± 20.14ns	109.53 ± 21.92ns	263.30 ±	236.93 ± 42.07ns	155.27 ± 20.14ns	92 ± 21.92ns
FLF	Control	7.61 ± 0.55ns	7.04 ± 0.40ns	6.32 ± 0.20ns	6.18 ± 0.35ns	6.58 ± 0.55ns	6.01 ± 0.40ns	5.29 ± 0.20ns	5.15 ± 0.35ns	5.47 ± 0.55ns	4.90 ± 0.40ns	4.18 ± 0.20ns	4.04 ± 0.35ns	4.44 ± 0.55ns	3.87 ± 0.40ns	3.15 ± 0.20ns	3.01 ± 0.35ns
	Single tree	7.32 ± 0.46ns	6.82 ± 0.45ns	6.24 ± 0.39ns	6.13 ± 0.43ns	6.29 ± 0.46ns	5.79 ± 0.45ns	5.21 ± 0.39ns	5.10 ± 0.43ns	5.18 ± 0.46ns	4.68 ± 0.45ns	4.10 ± 0.39ns	3.99 ± 0.43ns	4.15 ± 0.46ns	3.65 ± 0.45ns	3.07 ± 0.39ns	2.96 ± 0.43ns
	Shelter wood	7.27 ± 0.40ns	6.63 ± 0.36ns	6.21 ± 0.36ns	6.11 ± 0.62ns	6.24 ± 0.40ns	5.60 ± 0.36ns	5.18 ± 0.36ns	5.08 ± 0.62ns	5.13 ± 0.40ns	4.49 ± 0.36ns	4.07 ± 0.36ns	3.97 ± 0.62ns	4.10 ± 0.40ns	3.46 ± 0.36ns	3.04 ± 0.36ns	2.94 ± 0.62ns
OLF	Control	8.76 ± 0.38ns	8.37 ± 0.39ns	8.05 ± 0.61ns	7.32 ± 0.50ns	7.68 ± 0.38ns	7.29 ± 0.39ns	6.97 ± 0.61ns	6.24 ± 0.50ns	6.51 ± 0.38ns	6.12 ± 0.39ns	5.80 ± 0.61ns	5.07 ± 0.50ns	5.24 ± 0.38ns	4.85 ± 0.39ns	4.57 ± 0.59ns	3.80 ± 0.50ns

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
	Single tree	8.64 ± 0.41ns	8.16 ± 0.51ns	7.79 ± 0.69ns	7.10 ± 0.79ns	7.56 ± 0.41ns	7.08 ± 0.51ns	6.71 ± 0.69ns	6.02 ± 0.79ns	6.39 ± 0.41ns	5.91 ± 0.51ns	5.54 ± 0.69ns	4.85 ± 0.79ns	5.12 ± 0.41ns	4.66 ± 0.51ns	4.28 ± 0.68ns	3.51 ± 0.77ns
	Shelter wood	8.50 ± 0.43ns	8.12 ± 0.57ns	7.71 ± 0.66ns	7.02 ± 0.66ns	7.42 ± 0.43ns	7.04 ± 0.57ns	6.63 ± 0.66ns	5.94 ± 0.66ns	6.25 ± 0.43ns	5.87 ± 0.57ns	5.46 ± 0.66ns	4.77 ± 0.66ns	4.98 ± 0.43ns	4.61 ± 0.57ns	4.10 ± 0.60ns	3.20 ± 0.44ns
CFLF	Control	399.26 ± 38.37ns	356.06 ± 15.44ns	301.06 ± 46.07ns	261.33 ± 12.75a	386.26 ± 38.37ns	343.06 ± 15.44ns	288.06 ± 44.07ns	248.33 ± 12.75a	379.26 ± 38.37ns	336.06 ± 15.44ns	281.06 ± 44.07ns	241.33 ± 12.75a	370.26 ± 38.37ns	327.06 ± 15.44ns	272.06 ± 44.07ns	232.33 ± 12.75a
	Single tree	380.60 ± 32.42ns	344.07 ± 27.25ns	289.00 ± 26.84ns	242.40 ± 21.08a	367.60 ± 34.42ns	331.07 ± 27.25ns	276.00 ± 24.84ns	229.60 ± 21.08a	360.60 ± 32.42ns	324.07 ± 27.25ns	269.00 ± 24.84ns	222.26 ± 21.08a	351.60 ± 32.42ns	315.07 ± 27.25ns	260.00 ± 24.84ns	213.60 ± 21.08a
	Shelter wood	369.40 ± 20.77ns	311.07 ± 35.00ns	278.33 ± 21.99ns	150.47 ± 18.83 b	356.40 ± 20.77ns	298.07 ± 35.06ns	265.33 ± 21.99ns	137.47 ± 18.83 b	349.40 ± 20.77ns	291.07 ± 35.00ns	258.33 ± 21.99ns	130.47 ± 18.83 b	340.40 ± 20.77ns	282.07 ± 35.00ns	249.33 ± 21.99ns	121.47 ± 18.83 b
COLF	Control	65.00 ± 4.26ns	48.20 ± 7.01ns	39.73 ± 2.70ns	27.86 ± 3.15ns	62.00 ± 4.26ns	45.20 ± 7.01ns	36.73 ± 2.70ns	24.86 ± 3.15ns	60.60 ± 4.26ns	43.20 ± 7.01ns	34.73 ± 2.70ns	22.86 ± 3.15ns	53.00 ± 4.26ns	36.20 ± 7.01ns	27.73 ± 2.70ns	15.86 ± 3.15ns
	Single tree	59.66 ± 5.86ns	46.80 ± 7.57ns	33.33 ± 3.26ns	26.60 ± 3.51ns	56.66 ± 5.86ns	43.80 ± 7.57ns	30.33 ± 3.26ns	23.60 ± 3.51ns	54.66 ± 5.86ns	41.80 ± 7.57ns	28.33 ± 3.26ns	21.60 ± 3.51ns	47.66 ± 5.86ns	34.80 ± 7.57ns	21.33 ± 3.26ns	14.60 ± 3.51ns
	Shelter wood	55.66 ± 3.75ns	40.46 ± 6.47ns	31.53 ± 3.54ns	23.93 ± 2.75ns	52.66 ± 3.75ns	37.46 ± 6.47ns	28.53 ± 3.54ns	20.93 ± 3.75ns	50.66 ± 3.75ns	35.46 ± 6.47ns	26.53 ± 3.54ns	18.93 ± 2.75ns	43.66 ± 3.75ns	28.46 ± 6.47ns	19.53 ± 3.54ns	11.53 ± 1.75ns
CFLF/C	Control	52.87 ± 6.80ns	47.12 ± 4.09ns	56.80 ± 14.74ns	40.96 ± 5.77ns	64.32 ± 8.64ns	59.46 ± 7.07ns	84.99 ± 26.83ns	55.69 ± 9.41ns	77.03 ± 5.79ns	76.38 ± 13.64ns	180.16 ± 75.80ns	78.40 ± 16.57ns	57.01 ± 7.11ns	80.53 ± 27.06ns	177.63 ± 1.27ns	101.32 ± 33.71ns
	Single tree	55.33 ± 7.00ns	62.27 ± 7.92ns	65.17 ± 11.58ns	49.88 ± 7.34ns	68.02 ± 9.26ns	81.49 ± 12.07ns	113.40 ± 32.90ns	79.40 ± 11.20ns	82.31 ± 8.87ns	106.48 ± 18.99ns	195.45 ± 56.66ns	96.35 ± 17.68ns	61.77 ± 9.20ns	98.47 ± 23.91ns	190.86 ± 1.59ns	104.76 ± 19.90ns
	Shelter wood	58.24 ± 4.18ns	86.23 ± 11.12ns	81.41 ± 11.34ns	46.18 ± 8.63ns	72.08 ± 5.23ns	127.43 ± 10.06ns	162.56 ± 37.43ns	110.90 ± 17.20ns	87.80 ± 7.10ns	201.02 ± 18.36ns	214.69 ± 54.77ns	159.69 ± 78.81ns	65.67 ± 5.17ns	253.20 ± 15.30ns	167.76 ± 11.76ns	85.61 ± 18.09ns
COLF/C	Control	8.42 ± 0.85ns	7.26 ± 1.86ns	7.73 ± 1.37ns	4.17 ± 0.58ns	10.09 ± 1.10ns	9.49 ± 3.07ns	11.51 ± 2.89ns	5.30 ± 0.93ns	11.89 ± 1.38ns	13.08 ± 5.54ns	30.21 ± 17.35ns	7.10 ± 1.66ns	8.13 ± 0.93ns	15.22 ± 9.68ns	17.76 ± 5.95ns	7.10 ± 3.08ns
	Single tree	8.77 ± 1.13ns	7.78 ± 1.28ns	7.50 ± 1.34ns	5.39 ± 0.93ns	10.61 ± 1.47ns	9.70 ± 1.74ns	12.39 ± 3.31ns	7.69 ± 1.60ns	12.64 ± 1.86ns	12.02 ± 2.31ns	22.48 ± 7.61ns	78.17 ± 6.56ns	8.45 ± 1.32ns	9.02 ± 2.13ns	16.74 ± 5.55ns	9.27 ± 4.22ns
	Shelter wood	8.78 ± 0.79ns	9.32 ± 1.81ns	8.39 ± 0.90ns	6.83 ± 1.31ns	10.67 ± 1.05ns	12.56 ± 1.84ns	14.26 ± 2.63ns	18.30 ± 2.12ns	12.77 ± 1.35ns	17.67 ± 4.86ns	19.15 ± 4.96ns	14.25 ± 2.95ns	8.48 ± 0.96ns	15.83 ± 6.43ns	9.98 ± 1.90ns	7.15 ± 1.93ns
CWC	Control	155.9351.14ns	142.40 ± 8.31ns	117.73 ± 12.69ns	103 ± 4.64ns	142.93 ± 20.15ns	129.40 ± 8.31ns	104.73 ± 12.69ns	90.20 ± 4.64ns	123.93 ± 20.13ns	110.40 ± 8.31ns	85.73 ± 12.69ns	71.20 ± 4.64ns	109.93 ± 20.13ns	96.40 ± 8.31ns	71.73 ± 12.69ns	57.20 ± 4.64ns
	Single tree	151.60 ± 29.51ns	136.80 ± 9.44ns	109.93 ± 3.32ns	101 ± 9.26ns	138.60 ± 16.38ns	123.80 ± 9.44ns	96.93 ± 3.32ns	88.46 ± 9.26ns	119.60 ± 16.38ns	104.80 ± 9.44ns	77.93 ± 3.32ns	70.53 ± 8.17ns	105.60 ± 16.38ns	90.80 ± 9.44ns	63.93 ± 3.32ns	56.53 ± 8.17ns
	Shelter wood	147.20 ± 43.44ns	129.60 ± 13.82ns	105.13 ± 6.83ns	96 ± 11.56ns	134.20 ± 13.65ns	116.60 ± 13.82ns	92.13 ± 6.83ns	83.26 ± 9.56ns	115.20 ± 13.65ns	97.60 ± 13.82ns	73.13 ± 6.83ns	64.80 ± 11.34ns	101.20 ± 13.65ns	83.60 ± 13.82ns	59.13 ± 6.83ns	52.50 ± 10.59ns
HWC	Control	677.20 ± 49.37ns	575.86 ± 74.49ns	456.60 ± 50.97ns	404.26 ± 36.32ns	654.20 ± 49.37ns	552.86 ± 74.41ns	433.60 ± 50.97ns	381.26 ± 36.32ns	637.20 ± 49.37ns	535.86 ± 74.49ns	416.60 ± 50.97ns	364.26 ± 36.32ns	618.20 ± 49.37ns	516.86 ± 74.99ns	397.60 ± 50.97ns	345.26 ± 36.30ns

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
	Single tree	641.40 ± 67.25ns	492.53 ± 84.72ns	450.40 ± 27.18ns	392.73 ± 40.45ns	618.40 ± 67.25ns	469.53 ± 84.72ns	427.40 ± 27.18ns	369.73 ± 50.45ns	601.40 ± 67.25ns	452.53 ± 86.72ns	410.40 ± 27.18ns	352.73 ± 50.45ns	582.40 ± 67.25ns	433.53 ± 84.72ns	391.40 ± 27.18ns	333.73 ± 50.45ns
	Shelter wood	594.87 ± 36.20ns	484.73 ± 80.77ns	416.27 ± 33.84ns	321.20 ± 28.02ns	571.87 ± 36.20ns	461.73 ± 80.77ns	393.27 ± 33.84ns	298.20 ± 28.02ns	554.87 ± 36.20ns	444.73 ± 80.77ns	376.27 ± 13.84ns	281.20 ± 28.02ns	535.87 ± 36.20ns	425.73 ± 80.77ns	357.27 ± 33.84ns	292.20 ± 28.02ns
CWN	Control	14.36 ± 1.08ns	11.30 ± 1.20ns	11.06 ± 0.93ns	10.02 ± 1.37ns	11.19 ± 1.08ns	8.13 ± 1.20ns	7.13 ± 0.70ns	6.85 ± 1.37ns	8.10 ± 1.08ns	5.47 ± 1.10ns	4.04 ± 0.70ns	3.70 ± 0.58ns	5.35 ± 1.08ns	3.77 ± 0.82ns	2.38 ± 0.52ns	2.02 ± 0.42ns
	Single tree	12.91 ± 1.09ns	11.19 ± 1.37ns	10.95 ± 1.25ns	9.59 ± 1.20ns	9.74 ± 1.09ns	8.02 ± 1.37ns	7.78 ± 1.25ns	6.42 ± 1.20ns	6.65 ± 1.09ns	5.17 ± 0.91ns	3.88 ± 0.83ns	3.56 ± 0.27ns	4.93 ± 0.68ns	3.59 ± 0.27ns	2.30 ± 0.33ns	1.81 ± 0.34ns
	Shelter wood	11.76 ± 1.00ns	10.54 ± 1.71ns	10.23 ± 0.70ns	9.51 ± 1.45ns	8.59 ± 1.00ns	7.37 ± 1.71ns	7.05 ± 0.70ns	6.34 ± 1.45ns	5.50 ± 1.00ns	4.88 ± 0.60ns	3.96 ± 0.70ns	3.40 ± 0.48ns	3.79 ± 0.98ns	2.40 ± 0.57ns	2.94 ± 0.63ns	1.56 ± 0.25ns
HWN	Control	99.56 ± 5.07ns	92.07 ± 5.90ns	85.71 ± 9.55ns	79.26 ± 7.89ns	89.69 ± 5.07ns	82.20 ± 5.90ns	75.84 ± 9.55ns	69.39 ± 7.89ns	86.62 ± 5.07ns	79.13 ± 5.90ns	72.77 ± 9.55ns	66.32 ± 7.89ns	76.79 ± 5.07ns	69.30 ± 5.90ns	62.94 ± 9.55ns	56.85 ± 7.70ns
	Single tree	96.88 ± 5.28ns	88.79 ± 9.81ns	81.83 ± 7.31ns	77.30 ± 12.91ns	87.01 ± 5.28ns	78.92 ± 9.81ns	71.96 ± 7.31ns	67.47 ± 9.73ns	83.94 ± 5.28ns	75.85 ± 9.81ns	68.89 ± 7.31ns	64.96 ± 12.71ns	74.11 ± 5.28ns	66.93 ± 9.37ns	59.06 ± 7.31ns	54.95 ± 11.93ns
	Shelter wood	93.62 ± 8.83ns	87.88 ± 12.10ns	80.78 ± 13.45ns	72.30 ± 8.09ns	83.75 ± 8.83ns	78.01 ± 12.10ns	70.91 ± 9.45ns	62.42 ± 8.09ns	80.68 ± 8.83ns	74.94 ± 12.10ns	67.84 ± 11.28ns	59.36 ± 8.09ns	70.85 ± 8.83ns	66.69 ± 10.49ns	58.01 ± 13.45ns	51.51 ± 7.17ns
POM-C	Control	4.03 ± 0.22ns	3.76 ± 0.21ns	3.48 ± 0.22ns	3.18 ± 0.27a	3.17 ± 0.22ns	2.90 ± 0.21ns	2.62 ± 0.22ns	2.32 ± 0.27a	2.54 ± 0.22ns	2.27 ± 0.21ns	1.99 ± 0.22ns	1.85 ± 0.22a	2.15 ± 0.22ns	1.88 ± 0.21ns	1.60 ± 0.22ns	1.68 ± 0.17a
	Single tree	3.94 ± 0.23ns	3.71 ± 0.21ns	3.27 ± 0.32ns	2.85 ± 0.26a	3.08 ± 0.23ns	2.85 ± 0.21ns	2.41 ± 0.32ns	1.99 ± 0.26a	2.45 ± 0.23ns	2.22 ± 0.21ns	2.02 ± 0.23ns	1.58 ± 0.22a	2.06 ± 0.23ns	1.83 ± 0.21ns	1.70 ± 0.21ns	1.41 ± 0.20a
	Shelter wood	3.80 ± 0.19ns	3.58 ± 0.20ns	3.25 ± 0.34ns	1.89 ± 0.27 b	2.94 ± 0.19ns	2.72 ± 0.20ns	2.30 ± 0.34ns	1.03 ± 0.22 b	2.31 ± 0.19ns	2.09 ± 0.20ns	2.05 ± 0.26ns	0.82 ± 0.15 b	1.92 ± 0.19ns	1.70 ± 0.20ns	1.87 ± 0.23ns	0.55 ± 0.14 b
POM-N	Control	0.72 ± 0.03ns	0.62 ± 0.04ns	0.45 ± 0.03ns	0.32 ± 0.02a	0.63 ± 0.03ns	0.53 ± 0.04ns	0.36 ± 0.03ns	0.23 ± 0.02a	0.51 ± 0.03ns	0.41 ± 0.04ns	0.24 ± 0.03ns	0.13 ± 0.01a	0.38 ± 0.03ns	0.28 ± 0.04ns	0.13 ± 0.03ns	0.07 ± 0.00ns
	Single tree	0.68 ± 0.04ns	0.57 ± 0.05ns	0.41 ± 0.04ns	0.28 ± 0.01a	0.59 ± 0.04ns	0.48 ± 0.05ns	0.32 ± 0.04ns	0.19 ± 0.01a	0.47 ± 0.04ns	0.36 ± 0.05ns	0.23 ± 0.03ns	0.09 ± 0.01 ab	0.34 ± 0.04ns	0.25 ± 0.04ns	0.12 ± 0.01ns	0.06 ± 0.00ns
	Shelter wood	0.63 ± 0.04ns	0.50 ± 0.03ns	0.35 ± 0.05ns	0.20 ± 0.02 b	0.54 ± 0.04ns	0.41 ± 0.03ns	0.26 ± 0.05ns	0.13 ± 0.01 b	0.42 ± 0.04ns	0.29 ± 0.03ns	0.18 ± 0.04ns	0.07 ± 0.01 b	0.31 ± 0.03ns	0.17 ± 0.03ns	0.11 ± 0.01ns	0.05 ± 0.00ns
POM-C/POM-N	Control	5.70 ± 0.40ns	6.64 ± 0.72ns	7.99 ± 0.54ns	11.04 ± 1.72ns	5.16 ± 0.45ns	6.23 ± 0.83ns	7.62 ± 0.65ns	13.59 ± 3.70ns	5.21 ± 0.58ns	6.97 ± 1.23ns	9.14 ± 1.00 b	23.07 ± 7.45ns	6.29 ± 0.95ns	12.37 ± 3.37ns	27.72 ± 4.76ns	30.35 ± 7.18a
	Single tree	6.14 ± 0.61ns	7.35 ± 0.83ns	10.06 ± 1.84ns	9.96 ± 0.84ns	5.68 ± 0.69ns	7.11 ± 1.07ns	12.41 ± 3.35ns	10.11 ± 1.25ns	6.02 ± 0.95ns	9.43 ± 2.51ns	12.80 ± 2.77 b	20.40 ± 4.36ns	8.41 ± 2.02ns	11.47 ± 2.27ns	24.71 ± 8.23ns	24.46 ± 3.15a
	Shelter wood	6.40 ± 0.64ns	7.61 ± 0.73ns	12.25 ± 2.21ns	10.94 ± 1.81ns	5.98 ± 0.80ns	7.31 ± 0.90ns	19.04 ± 6.88ns	10.49 ± 2.69ns	6.92 ± 1.64ns	9.03 ± 1.64ns	22.90 ± 4.88a	19.33 ± 5.47ns	7.23 ± 1.01ns	16.27 ± 4.06ns	21.97 ± 3.63	9.79 ± 1.86 b
DOM-C	Control	75.96 ± 4.81ns	69.18 ± 6.34ns	62.29 ± 5.84ns	52.86 ± 5.19ns	71.57 ± 4.81ns	64.79 ± 6.34ns	57.90 ± 5.84ns	48.47 ± 5.19ns	67.79 ± 4.81ns	61.01 ± 6.34ns	54.12 ± 5.84ns	44.69 ± 5.19ns	65.72 ± 4.81ns	58.94 ± 6.34ns	52.05 ± 5.84ns	42.62 ± 5.19ns
	Single tree	74.75 ± 4.64ns	66.26 ± 4.62ns	59.86 ± 4.82ns	48.01 ± 3.96ns	70.36 ± 4.64ns	61.87 ± 4.62ns	55.47 ± 4.82ns	43.62 ± 3.96ns	66.58 ± 4.64ns	58.09 ± 4.62ns	51.69 ± 4.82ns	39.84 ± 3.96ns	64.51 ± 4.64ns	56.02 ± 4.62ns	49.62 ± 4.82ns	37.77 ± 3.96ns
	Shelter wood	71.92 ± 4.11ns	65.81 ± 3.99ns	57.43 ± 5.31ns	41.73 ± 4.88ns	67.53 ± 4.11ns	61.42 ± 3.90ns	53.04 ± 5.31ns	37.34 ± 4.88ns	63.75 ± 4.11ns	57.64 ± 3.99ns	49.26 ± 5.31ns	33.56 ± 4.88ns	61.68 ± 4.11ns	55.57 ± 3.99ns	47.19 ± 5.31ns	22.49 ± 4.88ns

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
DOM-N	Control	38.78 ± 1.73ns	29.99 ± 2.43ns	24.36 ± 2.01ns	8.20 ± 2.11ns	35.61 ± 1.73ns	26.82 ± 2.43ns	21.19 ± 2.01ns	15.49 ± 2.11ns	33.64 ± 1.73ns	24.85 ± 2.43ns	19.22 ± 2.01ns	13.52 ± 2.11ns	30.58 ± 1.73ns	21.79 ± 2.43ns	16.16 ± 2.01ns	10.46 ± 2.11ns
	Single tree	35.94 ± 2.33ns	28.36 ± 2.07ns	21.60 ± 1.95ns	8.14 ± 2.10ns	32.77 ± 2.33ns	25.19 ± 2.07ns	18.43 ± 1.95ns	12.85 ± 2.10ns	30.80 ± 2.33ns	23.22 ± 2.07ns	16.46 ± 1.95ns	10.88 ± 2.10ns	27.74 ± 2.33ns	20.16 ± 2.07ns	13.40 ± 1.95ns	7.82 ± 2.10ns
	Shelter wood	32.77 ± 1.99ns	26.04 ± 1.24ns	19.70 ± 1.45ns	6.58 ± 1.70ns	29.60 ± 1.99ns	22.87 ± 1.24ns	16.53 ± 1.45ns	11.70 ± 1.70ns	27.63 ± 1.99ns	20.90 ± 1.24ns	14.56 ± 1.45ns	9.73 ± 1.70ns	24.57 ± 1.99ns	17.84 ± 1.24ns	1.50 ± 1.45ns	6.67 ± 1.70ns
DOM-C/DOM-N	Control	1.99 ± 0.14ns	2.49 ± 0.25ns	2.73 ± 0.29ns	3.24 ± 0.38ns	2.05 ± 0.16ns	2.68 ± 0.31ns	2.99 ± 0.35ns	3.87 ± 0.55ns	2.06 ± 0.17ns	2.79 ± 0.35ns	3.16 ± 0.40ns	4.46 ± 0.74ns	2.21 ± 0.20ns	3.33 ± 0.53ns	3.94 ± 0.59ns	7.97 ± 1.98ns
	Single tree	2.19 ± 0.18ns	2.67 ± 0.40ns	3.14 ± 0.47ns	3.33 ± 0.29ns	2.29 ± 0.21ns	2.95 ± 0.52ns	3.63 ± 0.65ns	4.06 ± 0.43ns	2.33 ± 0.23ns	3.15 ± 0.65ns	4.04 ± 0.54ns	4.78 ± 0.60ns	2.56 ± 0.28ns	3.99 ± 1.14ns	5.88 ± 1.59ns	9.56 ± 1.75ns
	Shelter wood	2.34 ± 0.22ns	2.61 ± 0.20ns	3.17 ± 0.46ns	2.98 ± 0.27ns	2.46 ± 0.25ns	2.80 ± 0.24ns	3.65 ± 0.63ns	3.54 ± 0.37ns	2.52 ± 0.28ns	2.90 ± 0.26ns	4.04 ± 0.81ns	4.02 ± 0.48ns	2.82 ± 0.35ns	3.34 ± 0.33ns	5.82 ± 1.60ns	7.00 ± 1.12ns
Fine root biomass	Control	98.94 ± 2.74a	70.22 ± 3.36ns	59.82 ± 5.26a	40.60 ± 1.91ns	85.66 ± 2.74a	56.94 ± 3.36ns	46.54 ± 5.26a	27.32 ± 1.91ns	68.44 ± 2.74a	39.72 ± 3.36ns	31.03 ± 4.68ns	12.52 ± 1.49ns	54.46 ± 2.74a	25.74 ± 3.36ns	21.81 ± 3.52ns	11.60 ± 1.08ns
	Single tree	85.79 ± 2.92 b	65.97 ± 4.73ns	52.87 ± 4.04 ab	35.97 ± 2.70ns	72.51 ± 2.93 b	52.69 ± 4.73ns	39.59 ± 4.04 ab	22.69 ± 2.70ns	55.28 ± 2.92 b	35.47 ± 4.73ns	22.37 ± 4.04ns	10.75 ± 1.58ns	41.31 ± 2.92 b	25.48 ± 2.83ns	14.46 ± 2.95ns	10.25 ± 0.39ns
	Shelter wood	80.69 ± 3.50 b	61.10 ± 5.90ns	45.28 ± 5.01 b	32.63 ± 4.68ns	67.41 ± 3.50 b	47.82 ± 5.90ns	32.00 ± 5.01 b	23.38 ± 3.52ns	50.19 ± 3.50 b	30.60 ± 5.90ns	21.65 ± 3.17ns	13.65 ± 2.10ns	36.21 ± 3.50 b	22.54 ± 4.41ns	15.75 ± 1.54ns	11.10 ± 0.79ns
Epigeic density	Control	5.60 ± 0.44a	4.13 ± 0.33a	3.20 ± 0.22ns	2.53 ± 0.36a	4.60 ± 0.34a	3.13 ± 0.38ns	2.33 ± 0.27ns	1.73 ± 0.28a	4.00 ± 0.48ns	2.93 ± 0.34ns	2.26 ± 0.24ns	1.60 ± 0.25ns	3.66 ± 0.41a	2.20 ± 0.26a	1.26 ± 0.11ns	1.06 ± 0.06ns
	Single tree	4.26 ± 0.48 b	3.53 ± 0.30 ab	2.93 ± 0.33ns	2.13 ± 0.23 ab	3.46 ± 0.38 b	2.53 ± 0.32ns	1.93 ± 0.26ns	1.40 ± 0.16 ab	3.40 ± 0.53ns	2.60 ± 0.28ns	1.93 ± 0.26ns	1.40 ± 0.16ns	2.40 ± 0.34 b	1.66 ± 0.33 ab	1.13 ± 0.09ns	1.00 ± 0.00ns
	Shelter wood	3.93 ± 0.46 b	3.13 ± 0.30 b	2.53 ± 0.38ns	1.53 ± 0.19 b	3.00 ± 0.41 b	2.33 ± 0.23ns	1.86 ± 0.29ns	1.13 ± 0.09 b	2.93 ± 0.41ns	2.26 ± 0.28ns	1.80 ± 0.27ns	1.13 ± 0.09ns	2.26 ± 0.34 b	1.40 ± 0.16 b	1.06 ± 0.06ns	1.00 ± 0.00ns
Epigeic biomass	Control	28.52 ± 2.29a	19.45 ± 0.76ns	13.45 ± 1.08a	10.09 ± 0.76a	27.35 ± 2.29a	18.28 ± 0.76ns	12.28 ± 1.08a	8.92 ± 0.76a	23.37 ± 2.29a	14.30 ± 0.76ns	8.30 ± 1.08a	4.49 ± 3.48ns	17.92 ± 2.12a	8.53 ± 0.76ns	5.38 ± 0.63ns	2.57 ± 0.23a
	Single tree	22.22 ± 1.93 b	17.10 ± 1.36ns	11.16 ± 0.92 ab	8.27 ± 0.88 ab	21.05 ± 1.93 b	15.93 ± 1.36ns	9.99 ± 0.92 ab	7.10 ± 0.88 ab	17.07 ± 1.93 b	11.95 ± 1.36ns	6.01 ± 0.92 ab	3.91 ± 2.55ns	12.84 ± 1.39 ab	7.17 ± 0.12ns	5.29 ± 0.69ns	1.86 ± 0.22 b
	Shelter wood	20.30 ± 1.86 b	15.60 ± 1.85ns	9.13 ± 0.46 b	7.05 ± 0.87 b	19.13 ± 1.86 b	14.41 ± 1.85ns	7.96 ± 0.46 b	5.88 ± 0.87 b	15.12 ± 1.86 b	10.45 ± 1.85ns	4.71 ± 0.58 b	3.24 ± 2.20ns	9.73 ± 1.75 b	6.83 ± 0.50ns	4.40 ± 0.33ns	1.82 ± 0.16 b
Anecic density	Control	7.86 ± 0.35a	6.06 ± 0.37ns	5.06 ± 0.30ns	4.00 ± 0.39a	6.80 ± 0.55a	5.06 ± 0.26ns	3.93 ± 0.30ns	3.20 ± 0.31a	6.26 ± 0.43ns	5.00 ± 0.43ns	4.06 ± 0.39ns	3.40 ± 0.30a	5.73 ± 0.45a	4.20 ± 0.26ns	3.26 ± 0.26ns	2.46 ± 0.27ns
	Single tree	6.53 ± 0.44 b	5.60 ± 0.34ns	4.66 ± 0.31ns	3.26 ± 0.37 ab	5.60 ± 0.44 ab	4.66 ± 0.50ns	3.86 ± 0.25ns	2.86 ± 0.29 ab	5.80 ± 0.45ns	4.46 ± 0.49ns	3.86 ± 0.27ns	2.86 ± 0.21 ab	4.66 ± 0.38 ab	3.73 ± 0.40ns	2.66 ± 0.31ns	2.26 ± 0.24ns
	Shelter wood	6.20 ± 0.48 b	5.13 ± 0.51ns	4.26 ± 0.37ns	2.53 ± 0.30 b	5.13 ± 0.44 b	4.33 ± 0.28ns	3.40 ± 0.25ns	2.13 ± 0.27 b	5.06 ± 0.43ns	4.13 ± 0.36ns	3.66 ± 0.34ns	2.46 ± 0.21 b	4.33 ± 0.33 b	3.53 ± 0.37ns	2.60 ± 0.25ns	1.86 ± 0.23ns
Anecic biomass	Control	40.75 ± 1.96a	28.97 ± 1.06a	17.66 ± 1.32a	10.30 ± 1.55ns	35.41 ± 1.95a	23.48 ± 1.07a	15.02 ± 1.04a	9.71 ± 0.61a	30.36 ± 1.88a	18.87 ± 0.80a	10.98 ± 0.70a	5.97 ± 0.73ns	22.93 ± 1.74a	10.59 ± 0.72ns	8.03 ± 0.5a	4.32 ± 0.49a
	Single tree	32.11 ± 1.77 b	26.78 ± 1.49a	14.93 ± 0.99 ab	8.71 ± 1.33ns	30.81 ± 1.86 b	21.65 ± 1.20 ab	13.22 ± 0.92 ab	7.78 ± 0.99 ab	22.41 ± 2.03 b	13.88 ± 0.96 b	8.60 ± 0.45 b	5.32 ± 0.71ns	18.46 ± 1.24 b	10.32 ± 0.91ns	5.63 ± 0.66 b	3.30 ± 0.40 ab
	Shelter wood	31.29 ± 1.68 b	20.96 ± 1.57 b	12.56 ± 1.26 b	8.20 ± 0.65ns	24.11 ± 1.41 b	18.87 ± 0.98 b	11.07 ± 0.93 b	5.47 ± 1.21 b	19.99 ± 1.77 b	11.81 ± 1.00 b	6.40 ± 0.78c	4.81 ± 0.75ns	14.50 ± 1.59 b	9.80 ± 1.25ns	5.31 ± 0.68 b	2.82 ± 0.40 b

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
Endogeic density	Control	2.13 ± 0.32a	0.93 ± 0.28ns	0.66 ± 0.18ns	0.46 ± 0.16ns	1.33 ± 0.15a	0.66 ± 0.28ns	0.46 ± 0.16ns	0.20 ± 0.09ns	1.33 ± 0.31ns	0.80 ± 0.22ns	0.33 ± 0.09ns	0.13 ± 0.06ns	1.26 ± 0.28ns	0.40 ± 0.16ns	0.26 ± 0.09ns	0.13 ± 0.09ns
	Single tree	1.33 ± 0.27 b	0.86 ± 0.21ns	0.60 ± 0.16ns	0.40 ± 0.13ns	1.00 ± 0.21 ab	0.60 ± 0.19ns	0.33 ± 0.12ns	0.20 ± 0.08ns	1.13 ± 0.29ns	0.40 ± 0.16ns	0.26 ± 0.08ns	0.13 ± 0.05ns	0.66 ± 0.25ns	0.33 ± 0.12ns	0.20 ± 0.08ns	0.13 ± 0.09ns
	Shelter wood	1.00 ± 0.16 b	0.80 ± 0.22ns	0.53 ± 0.23ns	0.33 ± 0.12ns	0.73 ± 0.18 b	0.53 ± 0.16ns	0.26 ± 0.11ns	0.13 ± 0.04ns	0.93 ± 0.33ns	0.43 ± 0.23ns	0.20 ± 0.06ns	0.06 ± 0.01ns	0.60 ± 0.21ns	0.33 ± 0.12ns	0.13 ± 0.05ns	0.06 ± 0.01ns
Endogeic biomass	Control	9.30 ± 1.08a	3.57 ± 0.90ns	2.03 ± 0.67ns	1.66 ± 0.73ns	4.97 ± 0.72ns	2.07 ± 0.79ns	1.56 ± 0.68ns	1.14 ± 0.09ns	2.65 ± 0.58ns	2.16 ± 0.57ns	1.17 ± 0.59ns	0.97 ± 0.11ns	2.62 ± 0.57ns	1.63 ± 0.70ns	1.00 ± 0.09ns	0.63 ± 0.09ns
	Single tree	5.19 ± 0.81 b	3.03 ± 0.75ns	1.87 ± 0.54ns	1.45 ± 0.58ns	3.62 ± 0.80ns	1.76 ± 0.56ns	1.36 ± 0.64ns	0.90 ± 0.13ns	2.50 ± 0.67ns	1.72 ± 0.65ns	1.16 ± 0.64ns	0.69 ± 0.15ns	2.10 ± 0.73ns	1.53 ± 0.61ns	0.97 ± 0.08ns	0.50 ± 0.08ns
	Shelter wood	4.56 ± 0.83 b	2.75 ± 0.75ns	1.69 ± 0.72ns	1.14 ± 0.53ns	2.84 ± 0.73ns	1.70 ± 0.54ns	1.20 ± 0.69ns	0.61 ± 0.22ns	2.32 ± 0.75ns	1.33 ± 0.59ns	1.02 ± 0.55ns	0.49 ± 0.13ns	2.00 ± 0.80ns	1.12 ± 0.45ns	0.94 ± 0.07ns	0.25 ± 0.07ns
Earthworm density	Control	15.60 ± 0.91a	11.13 ± 0.66ns	8.93 ± 0.50ns	7.00 ± 0.71a	12.73 ± 0.93a	8.86 ± 0.70ns	6.73 ± 0.65ns	5.13 ± 0.56a	11.60 ± 1.09ns	8.73 ± 0.82ns	6.66 ± 0.68ns	5.13 ± 0.54a	10.66 ± 0.92a	6.80 ± 0.61ns	4.80 ± 0.35ns	3.66 ± 0.31ns
	Single tree	12.13 ± 0.98 b	10.00 ± 0.66ns	8.20 ± 0.73ns	5.80 ± 0.51 ab	10.06 ± 0.85 b	7.80 ± 0.86ns	6.13 ± 0.51ns	4.46 ± 0.43 ab	10.33 ± 1.11ns	7.46 ± 0.65ns	6.06 ± 0.57ns	4.40 ± 0.25 ab	7.73 ± 0.91 b	5.73 ± 0.52ns	4.00 ± 0.40ns	3.40 ± 0.25ns
	Shelter wood	11.13 ± 0.98 b	9.06 ± 0.88ns	7.33 ± 0.88ns	4.40 ± 0.46 b	8.88 ± 0.98 b	7.20 ± 0.53ns	5.53 ± 0.43ns	3.40 ± 0.34 b	8.93 ± 1.13ns	6.86 ± 0.77ns	5.66 ± 0.58ns	3.66 ± 0.25 b	7.20 ± 0.75 b	5.26 ± 0.45ns	3.80 ± 0.26ns	2.29 ± 0.22ns
Earthworm biomass	Control	78.58 ± 3.80a	51.99 ± 1.66a	33.15 ± 2.10a	22.06 ± 1.60a	67.73 ± 4.12a	43.83 ± 1.98a	28.87 ± 1.18a	19.77 ± 0.92a	56.39 ± 4.40a	35.33 ± 1.58a	20.47 ± 7.21a	11.44 ± 1.13ns	43.49 ± 3.72a	20.76 ± 1.70ns	14.43 ± 1.08a	6.53 ± 0.09a
	Single tree	59.52 ± 3.98 b	46.92 ± 2.68a	27.97 ± 1.79 ab	18.43 ± 1.87 ab	55.48 ± 3.85 b	39.36 ± 2.57 ab	24.58 ± 1.28 b	15.79 ± 1.63 ab	41.99 ± 3.24 b	27.56 ± 2.13 b	15.78 ± 3.60 b	9.93 ± 1.35ns	33.42 ± 2.48 b	19.02 ± 1.41ns	11.89 ± 1.02 ab	5.67 ± 0.07 b
	Shelter wood	56.16 ± 3.45 b	39.32 ± 3.21 b	23.38 ± 1.58 b	16.40 ± 1.08 b	46.08 ± 3.21 b	35.01 ± 2.49 b	20.23 ± 1.09c	11.97 ± 1.60 b	37.47 ± 3.47 b	23.60 ± 2.54 b	12.15 ± 1.44c	8.58 ± 0.87ns	26.23 ± 3.31 b	17.75 ± 2.79ns	10.66 ± 0.94 b	4.90 ± 0.06 b
Acarina density	Control	26387 ± 2309a	15462 ± 1482ns	10286 ± 135ns	7837 ± 612ns	25789 ± 2309a	14864 ± 1482ns	9688 ± 1355ns	7239 ± 612ns	25402 ± 209a	14477 ± 148ns	9301 ± 135ns	6852 ± 612ns	25030 ± 230a	14105 ± 148ns	8929 ± 135ns	6480 ± 612ns
	Single tree	20188 ± 1743 ab	1283 ± 2213ns	9955 ± 165ns	6659 ± 107ns	19590 ± 1743 ab	12265 ± 2213ns	9357 ± 1654ns	60615 ± 107ns	19204 ± 174 ab	11878 ± 221ns	9022 ± 163ns	5674 ± 107ns	18832 ± 174 ab	11506 ± 221ns	8696 ± 161ns	5302 ± 107ns
	Shelter wood	18526 ± 2405 b	11522 ± 1769ns	8220 ± 199ns	6118 ± 130ns	17928 ± 2405 b	10924 ± 1769ns	7622 ± 1997ns	55205 ± 130ns	17542 ± 240 b	10537 ± 176ns	7363 ± 196ns	5133 ± 130ns	17170 ± 240 b	10256 ± 173ns	6991 ± 196ns	4801 ± 129ns
Collembola density	Control	8813 ± 245a	5695 ± 577a	3042 ± 323ns	1583 ± 249ns	8300 ± 245a	5182 ± 577a	2529 ± 323ns	1070 ± 249ns	7925 ± 245a	4807 ± 577a	2154 ± 323ns	796 ± 22a	7136 ± 245a	4018 ± 577a	1379 ± 319ns	506 ± 133 ab
	Single tree	8216 ± 494 ab	4464 ± 496 ab	2723 ± 563ns	1369 ± 358ns	7703 ± 494 ab	3951 ± 496 ab	2210 ± 563ns	1121 ± 297ns	7328 ± 494 ab	357 ± 496 ab	1835 ± 563ns	949 ± 25a	6539 ± 494 ab	2787 ± 496 ab	1381 ± 511ns	594 ± 165a
	Shelter wood	6794 ± 733 b	3900 ± 481 b	2527 ± 818ns	885 ± 109ns	6281 ± 733 b	3387 ± 481 b	2014 ± 818ns	457 ± 81ns	5906 ± 733 b	3012 ± 481 b	1328 ± 626ns	210 ± 65 b	5117 ± 733 b	2239 ± 476 b	1244 ± 549ns	180 ± 14 b
Total nematode	Control	752 ± 50a	520.60 ± 52.88ns	329 ± 48ns	219 ± 22ns	677 ± 50a	455 ± 52ns	254 ± 48.07ns	144 ± 22.26ns	611 ± 50.05a	379 ± 52.88ns	195 ± 46.17ns	96.73 ± 15.71ns	592.46 ± 50.05a	360.20 ± 52.88ns	181.40 ± 45.45a	76.46 ± 15.16a
	Single tree	651 ± 27 ab	509.40 ± 51.13ns	288 ± 24ns	20.3 ± 14ns	576 ± 27 ab	434 ± 51ns	213 ± 24.33ns	133 ± 23.37ns	510 ± 27.58 ab	368 ± 51.13ns	147 ± 24.33ns	70.93 ± 12.13ns	491.93 ±	349.40 ± 51.13ns	128.1 ±	55.20 ± 11.12 ab

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
														27.58 ab		24.33 ab	
	Shelter wood	566 ± 36 b	412.26 ± 54.10ns	240 ± 15ns	194 ± 26ns	491 ± 36 b	337 ± 54ns	165 ± 15.81ns	130 ± 21.90ns	425 ± 36.43 b	271 ± 56.10ns	102 ± 13.98ns	60.40 ± 10.10ns	406.87 ± 36.43 b	252.20 ± 54.10ns	86.33 ± 13.06 b	41.40 ± 10.10 b
Protozoa density	Control	414 ± 48ns	300.33 ± 38.94a	172 ± 9.71ns	109 ± 10.88a	325.73 ± 48.47ns	214 ± 38.94a	86.26 ± 9.71ns	40.93 ± 5.29ns	293 ± 48.47ns	186 ± 36.62a	61.20 ± 5.29ns	40.73 ± 3.76a	274.73 ± 48.47ns	167.93 ± 36.62a	42.20 ± 5.29ns	21.73 ± 3.76ns
	Single tree	367 ± 38ns	223.93 ± 25.71 ab	148 ± 11.63ns	89 ± 3.58 ab	281.93 ± 38.58ns	142 ± 23.94 ab	62.46 ± 10.63ns	38.60 ± 6.13ns	246.93 ± 38.58ns	115.60 ± 21.39 ab	50.13 ± 6.39ns	37.80 ± 2.18a	227.93 ± 38.58ns	96.60 ± 21.39 ab	31.13 ± 6.39ns	19.80 ± 1.91ns
	Shelter wood	339 ± 56ns	215.80 ± 11.49 b	138 ± 19.07ns	68 ± 17.15 b	253.60 ± 36.43ns	129 ± 11.49 b	57.60 ± 10.83ns	30.20 ± 4.31ns	225.80 ± 54.21ns	94.80 ± 11.49 b	47.86 ± 7.41ns	27.73 ± 2.53 b	209.20 ± 53.63ns	75.80 ± 11.49 b	28.86 ± 7.41ns	14.66 ± 1.16ns
Total bacteria	Control	3.97 ± 0.23ns	3.15 ± 0.17ns	2.75 ± 0.21a	2.09 ± 0.18a	3.20 ± 0.23ns	2.38 ± 0.17ns	1.98 ± 0.21a	1.32 ± 0.18a	3.01 ± 0.23ns	2.19 ± 0.17ns	1.79 ± 0.21a	1.13 ± 0.18ns	2.88 ± 0.23ns	2.06 ± 0.17ns	1.66 ± 0.21ns	1.14 ± 0.14a
	Single tree	3.51 ± 0.30ns	3.05 ± 0.21ns	2.37 ± 0.15 ab	1.85 ± 0.21a	2.74 ± 0.30ns	2.28 ± 0.21ns	1.60 ± 0.15 ab	1.08 ± 0.21 ab	2.55 ± 0.30ns	2.09 ± 0.21ns	1.41 ± 0.15a	0.89 ± 0.09ns	2.42 ± 0.30ns	1.96 ± 0.21ns	1.28 ± 0.15ns	0.87 ± 0.19 ab
	Shelter wood	3.40 ± 0.15ns	2.96 ± 0.12ns	2.21 ± 0.17 b	1.24 ± 0.19 b	2.63 ± 0.15ns	2.31 ± 0.12ns	1.44 ± 0.17 b	0.75 ± 0.16 b	2.44 ± 0.15ns	2.00 ± 0.12ns	1.25 ± 0.17 b	0.57 ± 0.08ns	2.31 ± 0.15ns	1.87 ± 0.12ns	1.19 ± 0.15ns	0.46 ± 0.07 b
Total fungi	Control	2.08 ± 0.20a	1.26 ± 0.15ns	0.97 ± 0.16ns	0.81 ± 0.08a	1.99 ± 0.20a	1.17 ± 0.15ns	0.88 ± 0.16ns	0.72 ± 0.08a	1.91 ± 0.20a	1.09 ± 0.15ns	0.82 ± 0.16a	0.64 ± 0.08a	1.84 ± 0.20a	1.02 ± 0.15ns	0.76 ± 0.15ns	0.57 ± 0.07a
	Single tree	1.60 ± 0.14 b	1.12 ± 0.13ns	0.91 ± 0.17ns	0.62 ± 0.06 b	1.51 ± 0.14 b	1.03 ± 0.13ns	0.84 ± 0.16ns	0.53 ± 0.06 b	1.43 ± 0.14 b	0.95 ± 0.13ns	0.79 ± 0.15 b	0.45 ± 0.06 b	1.36 ± 0.14 b	0.88 ± 0.13ns	0.74 ± 0.15ns	0.38 ± 0.06 b
	Shelter wood	1.34 ± 0.13 b	1.09 ± 0.16ns	0.87 ± 0.14ns	0.30 ± 0.05c	1.25 ± 0.13 b	1.00 ± 0.16ns	0.79 ± 0.14ns	0.22 ± 0.05c	1.17 ± 0.13 b	0.92 ± 0.16ns	0.72 ± 0.14 b	0.16 ± 0.05c	1.10 ± 0.13 b	0.85 ± 0.16ns	0.66 ± 0.13ns	0.14 ± 0.04c
BR	Control	0.55 ± 0.01a	0.43 ± 0.01a	0.23 ± 0.03ns	0.24 ± 0.02ns	0.46 ± 0.01a	0.34 ± 0.01a	0.23 ± 0.03ns	0.15 ± 0.02ns	0.25 ± 0.01a	0.23 ± 0.01a	0.14 ± 0.02ns	0.07 ± 0.01ns	0.26 ± 0.01a	0.14 ± 0.01ns	0.09 ± 0.01ns	0.06 ± 0.00ns
	Single tree	0.53 ± 0.02 ab	0.40 ± 0.03 ab	0.30 ± 0.02ns	0.23 ± 0.02ns	0.44 ± 0.02 ab	0.31 ± 0.03 ab	0.21 ± 0.02ns	0.14 ± 0.02ns	0.33 ± 0.02 ab	0.20 ± 0.03 ab	0.12 ± 0.02ns	0.07 ± 0.01ns	0.24 ± 0.02 ab	0.13 ± 0.02ns	0.08 ± 0.01ns	0.06 ± 0.00ns
	Shelter wood	0.47 ± 0.01 b	0.36 ± 0.01 b	0.26 ± 0.02ns	0.19 ± 0.01ns	0.38 ± 0.01 b	0.27 ± 0.01 b	0.17 ± 0.02ns	0.10 ± 0.01ns	0.27 ± 0.01 b	0.16 ± 0.01 b	0.09 ± 0.01ns	0.05 ± 0.00ns	0.18 ± 0.01 b	0.11 ± 0.01ns	0.07 ± 0.01ns	0.05 ± 0.00ns
SIR	Control	1.70 ± 0.04ns	1.53 ± 0.07ns	1.41 ± 0.06ns	1.14 ± 0.06a	1.62 ± 0.04ns	1.45 ± 0.07ns	1.33 ± 0.06ns	1.06 ± 0.06a	1.51 ± 0.04ns	1.34 ± 0.07ns	1.22 ± 0.06ns	0.95 ± 0.06a	1.42 ± 0.04ns	1.25 ± 0.07ns	1.13 ± 0.06ns	0.86 ± 0.06a
	Single tree	1.62 ± 0.06ns	1.50 ± 0.07ns	1.38 ± 0.06ns	1.04 ± 0.06 ab	1.54 ± 0.06ns	1.42 ± 0.07ns	1.30 ± 0.06ns	0.96 ± 0.06 ab	1.43 ± 0.06ns	1.31 ± 0.03ns	1.19 ± 0.05ns	0.85 ± 0.06 ab	1.34 ± 0.06ns	1.22 ± 0.07ns	1.10 ± 0.06ns	0.76 ± 0.06 ab
	Shelter wood	1.57 ± 0.08ns	1.46 ± 0.08ns	1.33 ± 0.07ns	0.94 ± 0.05 b	1.49 ± 0.08ns	1.38 ± 0.08ns	1.25 ± 0.07ns	0.86 ± 0.05 b	1.38 ± 0.08ns	1.27 ± 0.01ns	1.14 ± 0.04ns	0.75 ± 0.05 b	1.29 ± 0.08ns	1.18 ± 0.08ns	1.05 ± 0.07ns	0.66 ± 0.05 b
MBC	Control	614.29 ± 29.17ns	555.11 ± 16.96ns	483.24 ± 33.57a	359.42 ± 30.01 ab	578.30 ± 27.84ns	512.53 ± 16.26ns	435.34 ± 32.75a	308.43 ± 25.54a	475.61 ± 24.52ns	395.19 ± 15.52a	306.39 ± 30.65a	173.48 ± 16.74ns	354.73 ± 21.10a	258.15 ± 16.05a	169.80 ± 22.78a	90.18 ± 10.68ns
	Single tree	608.54 ± 22.18ns	543.52 ± 22.48ns	442.60 ± 31.08 ab	376.63 ± 25.48a	568.48 ± 21.01ns	499.36 ± 21.65ns	393.70 ± 30.19 ab	320.99 ± 22.42a	456.35 ± 18.40ns	378.15 ± 19.77 ab	262.90 ± 27.88 ab	174.52 ± 16.75ns	324.94 ± 16.31 ab	237.61 ± 18.36a	142.88 ± 14.67 ab	94.39 ± 10.61ns
	Shelter wood	584.93 ± 34.55ns	498.48 ± 35.63ns	386.92 ± 27.96 b	275.73 ± 39.97 b	543.84 ± 32.02ns	451.40 ± 32.24ns	337.09 ± 26.84 b	218.92 ± 34.17 b	429.60 ± 26.01ns	324.01 ± 25.05 b	204.60 ± 26.09 b	125.39 ± 21.21ns	295.92 ± 20.26 b	175.86 ± 21.24 b	99.80 ± 15.52 b	88.20 ± 16.32ns
MBN	Control	76.49 ± 1.83a	62.14 ± 2.34a	49.00 ± 2.71a	36.13 ± 1.75a	71.21 ± 1.83a	56.86 ± 2.34a	43.72 ± 2.71a	30.85 ± 1.75a	57.92 ± 1.83a	43.57 ± 2.34a	30.43 ± 2.71a	17.56 ± 1.75a	42.83 ± 1.83a	28.48 ± 2.34a	16.65 ± 2.08a	8.68 ± 0.63ns

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
	Single tree	70.54 ± 2.11 b	58.74 ± 1.82 ab	44.28 ± 2.53 ab	34.71 ± 1.61a	65.26 ± 2.11 b	53.46 ± 1.82 ab	39.00 ± 2.53 ab	29.43 ± 1.61a	51.97 ± 2.11 b	40.17 ± 1.82 ab	25.71 ± 2.53 ab	16.14 ± 1.61a	36.88 ± 2.11 b	25.08 ± 1.82 ab	14.00 ± 1.40 ab	8.31 ± 0.56ns
	Shelter wood	66.93 ± 2.09 b	52.72 ± 2.46 b	39.63 ± 2.77 b	25.21 ± 2.19 b	61.65 ± 2.09 b	47.44 ± 2.46 b	34.25 ± 2.77 b	19.93 ± 2.19 b	48.36 ± 2.09 b	34.15 ± 2.45 b	21.06 ± 2.77 b	11.19 ± 1.34 b	33.27 ± 2.09 b	19.06 ± 2.46 b	10.15 ± 1.67 b	7.12 ± 0.67ns
MBC/MBN	Control	8.02 ± 0.31ns	9.03 ± 0.33ns	9.81 ± 0.32ns	10.18 ± 1.00ns	8.11 ± 0.31ns	9.12 ± 0.33ns	9.90 ± 0.32ns	10.27 ± 1.00ns	8.20 ± 0.31ns	9.21 ± 0.33ns	9.99 ± 0.33ns	10.36 ± 1.00ns	8.27 ± 0.31ns	9.28 ± 0.33ns	10.06 ± 0.32ns	10.43 ± 1.00ns
	Single tree	8.69 ± 0.31ns	9.27 ± 0.28ns	9.92 ± 0.30ns	11.03 ± 0.77ns	8.78 ± 0.31ns	9.36 ± 0.28ns	10.01 ± 0.30ns	11.12 ± 0.77ns	8.87 ± 0.31ns	9.45 ± 0.28ns	10.10 ± 0.44ns	11.21 ± 0.77ns	8.94 ± 0.31ns	9.52 ± 0.28ns	10.17 ± 0.30ns	11.29 ± 0.77ns
	Shelter wood	8.83 ± 0.54ns	9.72 ± 0.81ns	10.02 ± 0.71ns	11.09 ± 1.46ns	8.92 ± 0.54ns	9.81 ± 0.81ns	10.11 ± 0.71ns	11.18 ± 1.46ns	9.01 ± 0.54ns	9.90 ± 0.81ns	10.20 ± 0.67ns	11.27 ± 1.46ns	9.08 ± 0.54ns	9.97 ± 0.81ns	10.27 ± 0.71ns	11.34 ± 1.46ns
qCO_2	Control	0.94 ± 0.06ns	0.79 ± 0.03ns	0.73 ± 0.11ns	0.74 ± 0.08ns	0.83 ± 0.06ns	0.68 ± 0.03ns	0.60 ± 0.12ns	0.55 ± 0.08ns	0.78 ± 0.06ns	0.61 ± 0.04ns	0.72 ± 0.09ns	0.44 ± 0.10ns	0.80 ± 0.09ns	0.61 ± 0.08ns	0.80 ± 0.26ns	0.85 ± 0.12ns
	Single tree	0.89 ± 0.05ns	0.75 ± 0.06ns	0.72 ± 0.06ns	067 ± 0.07ns	0.79 ± 0.05ns	0.63 ± 0.06ns	0.57 ± 0.06ns	0.49 ± 0.07ns	0.74 ± 0.06ns	0.53 ± 0.08ns	0.59 ± 0.04ns	0.43 ± 0.10ns	0.76 ± 0.08ns	0.59 ± 0.10ns	0.65 ± 0.14ns	0.70 ± 0.09ns
	Shelter wood	0.84 ± 0.05ns	0.77 ± 0.06ns	0.76 ± 0.11ns	1.06 ± 0.22ns	0.73 ± 0.05ns	0.64 ± 0.06ns	0.60 ± 0.13ns	0.75 ± 0.20ns	0.66 ± 0.05ns	0.53 ± 0.06ns	0.71 ± 0.04ns	0.67 ± 0.07ns	0.64 ± 0.06ns	0.83 ± 0.15ns	1.03 ± 0.22ns	0.81 ± 0.14ns
Microbial ratio	Control	77.14 ± 4.62ns	74.88 ± 9.31c	83.44 ± 9.94ns	54.13 ± 6.60ns	90.86 ± 5.88ns	91.69 ± 15.92ns	110.32 ± 16.44ns	66.03 ± 9.56ns	90.60 ± 6.35ns	93.56 ± 22.88ns	120.47 ± 23.86ns	54.90 ± 11.38ns	52.34 ± 3.15ns	65.30 ± 25.50ns	46.23 ± 9.36ns	34.21 ± 7.78ns
	Single tree	88.03 ± 8.05ns	93.87 ± 9.13 b	97.29 ± 14.15ns	77.82 ± 10.49ns	104.48 ± 10.42ns	116.31 ± 13.87ns	150.05 ± 31.72ns	110.42 ± 21.26ns	103.15 ± 11.20ns	117.13 ± 15.19ns	122.91 ± 14.22ns	83.03 ± 18.83ns	55.64 ± 5.53ns	70.11 ± 16.21ns	121.64 ± 15.75ns	46.96 ± 10.40ns
	Shelter wood	92.83 ± 7.50ns	132.39 ± 28.21a	112.28 ± 16.44ns	63.85 ± 7.70ns	110.87 ± 9.43ns	184.16 ± 12.43ns	202.84 ± 10.64ns	128.48 ± 22.86ns	108.96 ± 9.78ns	208.64 ± 77.55ns	182.31 ± 9.93ns	91.93 ± 22.63ns	57.53 ± 5.13ns	143.73 ± 17.77ns	70.29 ± 12.86ns	42.59 ± 11.69ns
CAI	Control	0.33 ± 0.01ns	0.29 ± 0.02ns	0.23 ± 0.02ns	0.22 ± 0.02ns	0.29 ± 0.01ns	0.24 ± 0.02ns	0.17 ± 0.02ns	0.15 ± 0.02ns	0.23 ± 0.01ns	0.18 ± 0.02ns	0.12 ± 0.02ns	0.07 ± 0.02ns	0.18 ± 0.01ns	0.12 ± 0.02ns	0.09 ± 0.02ns	0.08 ± 0.00ns
	Single tree	0.33 ± 0.02ns	0.28 ± 0.02ns	0.22 ± 0.01ns	0.23 ± 0.02ns	0.29 ± 0.02ns	0.23 ± 0.02ns	0.16 ± 0.01ns	0.16 ± 0.02ns	0.23 ± 0.02ns	0.16 ± 0.03ns	0.10 ± 0.01ns	0.09 ± 0.01ns	0.18 ± 0.02ns	0.11 ± 0.02ns	0.07 ± 0.02ns	0.08 ± 0.01ns
	Shelter wood	0.31 ± 0.01ns	0.25 ± 0.01ns	0.22 ± 0.03ns	0.21 ± 0.01ns	0.26 ± 0.01ns	0.20 ± 0.01ns	0.16 ± 0.03ns	0.11 ± 0.01ns	0.20 ± 0.01ns	0.12 ± 0.01ns	0.09 ± 0.01ns	0.10 ± 0.03ns	0.14 ± 0.01ns	0.09 ± 0.01ns	0.08 ± 0.02ns	0.16 ± 0.06ns
Urease	Control	41.11 ± 1.36a	32.78 ± 1.16ns	24.60 ± 2.80ns	18.05 ± 0.97a	33.88 ± 1.36a	25.55 ± 1.16ns	17.37 ± 2.80ns	10.82 ± 0.97a	24.82 ± 1.36a	16.49 ± 1.16ns	10.45 ± 2.27ns	5.46 ± 0.77ns	17.04 ± 1.36a	8.72 ± 1.16ns	6.01 ± 0.93ns	4.17 ± 0.57ns
	Single tree	36.53 ± 1.77 b	30.83 ± 2.13ns	22.06 ± 1.70ns	16.24 ± 1.45a	29.30 ± 1.77 b	23.60 ± 2.13ns	14.83 ± 1.70ns	9.01 ± 1.45a	20.24 ± 1.77 b	15.14 ± 1.79ns	6.88 ± 1.36ns	4.68 ± 0.54ns	12.46 ± 1.77 b	7.30 ± 0.88ns	4.76 ± 0.50ns	3.81 ± 0.28ns
	Shelter wood	34.56 ± 1.41 b	28.97 ± 1.84ns	20.01 ± 2.11ns	12.61 ± 1.29 b	27.33 ± 1.41 b	21.74 ± 1.84ns	12.78 ± 2.11ns	5.38 ± 1.29 b	18.27 ± 1.41 b	14.14 ± 1.24ns	6.64 ± 1.44ns	4.30 ± 0.30ns	10.49 ± 1.41 b	6.95 ± 0.90ns	4.47 ± 0.54ns	3.50 ± 0.21ns
Acid phosphatase	Control	686.13 ± 26.72ns	554.33 ± 30.82ns	419 ± 39.76ns	315.8 ± 23.95a	649.13 ± 26.72ns	517.33 ± 30.82ns	382.80 ± 39.76ns	278.80 ± 23.95a	623.13 ± 26.72ns	491.33 ± 30.82ns	356.80 ± 39.76ns	252.80 ± 23.95a	548.13 ± 26.72ns	416.33 ± 30.82ns	283.20 ± 39.04ns	177.80 ± 23.95a
	Single tree	632.40 ± 63.53ns	509.73 ± 45.27ns	400 ± 30.56ns	291.4 ± 8.60a	595.40 ± 63.53ns	472.73 ± 45.42ns	363.20 ± 30.56ns	254.40 ± 8.60a	569.40 ± 63.53ns	446.73 ± 45.27ns	337.20 ± 30.58ns	228.40 ± 8.60a	494.40 ± 63.53ns	371.73 ± 45.27ns	262.20 ± 30.58ns	153.40 ± 8.60a
	Shelter wood	605.67 ± 46.70ns	477.46 ± 54.07ns	357 ± 19.28ns	205 ± 22.62 b	568.97 ± 46.70ns	440.47 ± 44.07ns	320.00 ± 19.28ns	168.00 ± 22.62 b	542.96 ± 46.70ns	414.47 ± 54.07ns	294.00 ± 19.28ns	142.00 ± 12.46 b	467.67 ± 46.70ns	341.27 ± 53.25ns	219.00 ± 19.28ns	75.60 ± 10.60 b

(*continued on next page*)

Appendix 3 (*continued*)

forest floor and topsoil properties/ studied areas	Forest management system	Nowshahr				Sari				Gorgan				Rasht			
		800 m	1000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m	800 m	110000 m	1200 m	1400 m	800 m	1000 m	1200 m	1400 m
Arylsulfatase	Control	395.73 ± 32.27ns	354.73 ± 24.96ns	286.86 ± 23.37ns	234.13 ± 11.62ns	366.73 ± 32.27ns	325.73 ± 24.96ns	257.86 ± 23.37ns	205.13 ± 11.62ns	333.73 ± 32.27ns	292.73 ± 24.96ns	224.86 ± 23.37ns	172.13 ± 11.62ns	286.73 ± 32.27ns	245.73 ± 24.96ns	178.20 ± 23.20ns	125.13 ± 11.62ns
	Single tree	385.33 ± 28.79ns	321.00 ± 35.85ns	246.27 ± 22.34ns	230.93 ± 24.73ns	356.33 ± 28.79ns	292.00 ± 35.85ns	217.27 ± 22.34ns	201.93 ± 24.72ns	323.33 ± 28.79ns	259.00 ± 35.85ns	184.27 ± 23.34ns	168.93 ± 24.73ns	276.33 ± 28.79ns	222.53 ± 32.18ns	139.47 ± 21.47ns	130.80 ± 21.44ns
	Shelter wood	381.67 ± 32.18ns	296.93 ± 27.32ns	241.33 ± 14.67ns	182.20 ± 15.98ns	352.57 ± 32.18ns	267.93 ± 22.32ns	212.33 ± 14.67ns	153.20 ± 15.98ns	319.67 ± 32.18ns	234.93 ± 27.32ns	179.33 ± 14.67ns	120.20 ± 15.98ns	272.67 ± 32.18ns	187.93 ± 27.32ns	132.33 ± 14.67ns	108.87 ± 15.02ns
Invertase	Control	392.33 ± 17.99ns	319.80 ± 26.32ns	299.93 ± 18.87a	213.60 ± 10.90a	363.33 ± 17.99ns	290.80 ± 24.32ns	270.93 ± 18.87a	184.60 ± 10.90a	324.33 ± 17.99ns	251.80 ± 24.32ns	231.93 ± 18.87a	145.60 ± 10.90ns	283.33 ± 17.99ns	219.40 ± 19.27ns	190.93 ± 18.87a	104.60 ± 10.90ns
	Single tree	370.47 ± 20.22ns	316.53 ± 14.44ns	266.47 ± 25.18a	210.80 ± 15.25a	341.47 ± 20.22ns	287.53 ± 14.44ns	237.41 ± 25.18 ab	181.80 ± 15.25a	302.47 ± 20.22ns	248.53 ± 14.44ns	198.47 ± 25.14 ab	142.80 ± 15.25ns	261.47 ± 20.22ns	207.50 ± 14.44ns	161.80 ± 23.56 ab	104.87 ± 14.15ns
	Shelter wood	339.87 ± 29.16ns	307.27 ± 24.92ns	222.60 ± 12.68 b	167.73 ± 17.76 b	310.87 ± 29.16ns	278.23 ± 24.92ns	193.60 ± 12.68 b	13.73 ± 17.76 b	271.87 ± 29.16ns	239.27 ± 24.92ns	154.60 ± 12.68 b	106.60 ± 15.44ns	230.87 ± 29.16ns	200.40 ± 23.78ns	113.60 ± 12.68 b	75.13 ± 12.48ns

References

Achat, D.L., Deleuze, C., Landmann, G., Pousse, N., Ranger, J., Augusto, L., 2015. Quantifying consequences of removing harvesting residues on forest soils and tree growth–A meta-analysis. For. Ecol. Manag. 348, 124–141. https://doi.org/10.1016/j.fore.

Augusto, L., Achat, D.L., Jonard, M., Vidal, D., Ringeval, B., 2017. Soil parent material—a major driver of plant nutrient limitations in terrestrial ecosystems. Global Change Biol. 23 (9), 3808–3824.

Alef, K., 1995. Estimating of soil respiration. In: Alef, K., Nannipieri, P. (Eds.), Methods in Soil Microbiology and Biochemistry. Academic Press, New York, pp. 464–470.

Ali, S., Hussain, I., Hussain, S., Hussain, A., Ali, H., Ali, M., 2019. Effect of altitude on forest soil properties at Northern Karakoram. Eurasian Soil Sci. 52, 1159–1169. https://doi.org/10.1134/S1064229319100120.

Allison, L.E., 1975. Organic carbon. In: Black, C.A. (Ed.), Methods of Soil Analysis. Madison, W. I, vol. 2. American Society of Agronomy, pp. 1367–1378. Part.

Ampoorter, E., Goris, R., Cornelis, W.M., Verheyen, K., 2007. Impact of mechanized logging on compaction status of sandy forest soils. For. Ecol. Manag. 241 (1–3), 162–174. https://doi.org/10.1016/j.foreco.2007.01.019.

Anderson, T.H., Domsch, K.H., 1990. Application of eco-physiological quotients (qCO_2 and qD) on microbial biomasses from soils of different cropping histories. Soil Biol. Biochem. 22 (2), 251–255.

Anderson, D.W., 1988. The effect of parent material and soil development on nutrient cycling in temperate ecosystems. Biogeochemistry 5, 71–97.

Asadu, C.L.A., Nwafor, I.A., Chibuike, G.U., 2015. Contributions of microorganisms to soil fertility in adjacent forest, fallow and cultivated land use types in Nsukka, Nigeria. Int. J. Agric. For. 5, 199–204.

Babur, E., Dindaroglu, T., 2020. Seasonal changes of soil organic carbon and microbial biomass carbon in different forest ecosystems. Environ. Factors Affect. Human Health 1, 1–21.

Babur, E., 2021. Short-term monitoring of the winching and skidding effects on soil microbial biomass in Turkish red pine in the Mediterranean Region. Eurasian J. Forest Sci. 9 (3), 107–121.

Babur, E., 2019. Effects of parent material on soil microbial biomass carbon and basal respiration within young afforested areas. Scand. J. For. Res. 34 (2), 94–101.

Babur, E., Dindaroglu, T., Danish, S., Häggblom, M.M., Ozlu, E., Gozukara, G., Uslu, O.S., 2022. Spatial responses of soil carbon stocks, total nitrogen, and microbial indices to post-wildfire in the Mediterranean red pine forest. J. Environ. Manag. 320, 115939.

Bastian, M., Heymann, S., Jacomy, M., 2009. March. Gephi: an open source software for exploring and manipulating networks. In: Proceedings of the international AAAI conference on web and social media, 3, pp. 361–362. No. 1.

Bastida, F., Moreno, J.L., Hernández, T., García, C., 2006. Microbiological degradation index of soils in a semiarid climate. Soil Biol. Biochem. 38 (12), 3463–3473.

Bayranvand, M., Akbarinia, M., Salehi Jouzani, G., Gharechahi, J., Baldrian, P., 2021. Distribution of soil extracellular enzymatic, microbial, and biological functions in the C and N-cycle pathways along a forest altitudinal gradient. Front. Microbiol. 12, 660603.

Bello, C., Galetti, M., Pizo, M.A., Magnago, L.F.S., Rocha, M.F., Lima, R.A., Peres, C.A., Ovaskainen, O., Jordano, P., 2015. Defaunation affects carbon storage in tropical forests. Sci. Adv. 1 (11), e1501105 https://doi.org/10.1126/sciadv.1501105.

Berg, B., McClaugherty, C., 2003. Plant Litter: Decomposition, Humus Formation, Carbon Sequestration. Springer-Verlag, Berlin and Heidelberg, Germany.

Blake, G.R., Hartge, K.H., 1986. Particle density. In: Klute, A. (Ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, second ed. SSSA Book Ser. 5. ASA and SSSA, Madison, WI, pp. 377–382.

Boguta, P., Sokołowska, Z., Skic, K., 2017. Use of thermal analysis coupled with differential scanning calorimetry, quadrupole mass spectrometry and infrared spectroscopy (TG-DSC-QMS-FTIR) to monitor chemical properties and thermal stability of fulvic and humic acids. PLoS One 12 (12), e0189653. https://doi.org/10.1371/journal.pone.0189653.

Bouyoucos, G.J., 1962. Hydrometer method improved for making particle size analyses of soils. Agron. J. 54 (5), 464–465.

Bower, C.A., Reitemeier, R.F., Fireman, M., 1952. Exchangeable cation analysis of saline and alkali soils. Soil Sci. 73, 251–262.

Bremner, J.M., Mulvaney, C.S., 1982. Nitrogen-total. Methods of soil analysis. Part 2. Chemical Microbiol. Properties 595–624 (methodsofsoilan2).

Brookes, P.C., Landman, A., Pruden, G., Jenkinson, D.S., 1985. Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol. Biochem. 17, 837–842.

Cambardella, C.A., Elliott, E.T., 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56 (3), 777–783.

Cambi, M., Paffetti, D., Vettori, C., Picchio, R., Venanzi, R., Marchi, E., 2017. Assessment of the impact of forest harvesting operations on the physical parameters and microbiological components on a Mediterranean sandy soil in an Italian stone pine stand. Eur. J. For. Res. 136, 205–215. https://doi.org/10.1007/s10342-016-1020-5.

Cardelli, V., De Feudis, M., Fornasier, F., Massaccesi, L., Cocco, S., Agnelli, A., Weindorf, D.C., Corti, G., 2019. Changes of topsoil under Fagus sylvatica along a small latitudinal-altitudinal gradient. Geoderma 344, 164–178. https://doi.org/10.1016/j.geoderma.2019.01.043.

Carpenter, R., Ward, E.B., Wikle, J., Duguid, M.C., Bradford, M.A., Ashton, M.S., 2021. Soil nutrient recovery after shelterwood timber harvesting in a temperate oak hardwood forest: insights using a twenty-five-year chronosequence. For. Ecol. Manag. 499, 119604 https://doi.org/10.1016/j.foreco.2021.119604.

Chan, K.Y., Barchia, I., 2007. Soil compaction controls the abundance, biomass and distribution of earthworms in a single dairy farm in south-eastern Australia. Soil Tillage Res. 94 (1), 75–82. https://doi.org/10.1016/j.still.2006.07.006.

Chapin, F.S., Matson, P.A., Mooney, H.A., 2002. Geology and Soils. *Principles of Terrestrial Ecosystem Ecology*, pp. 46–67.

Chen, G.S., Yang, Y.S., Guo, J.F., Xie, J.S., Yang, Z.J., 2011. Relationships between carbon allocation and partitioning of soil respiration across world mature forests. Plant Ecol. 212, 195–206. https://doi.org/10.1007/s11258-010-9814-x.

Chen, J., Wu, Q., Li, S., Ge, J., Liang, C., Qin, H., Xu, Q., Fuhrmann, J.J., 2019. Diversity and function of soil bacterial communities in response to long-term intensive management in a subtropical bamboo forest. Geoderma 354, 113894. https://doi.org/10.1016/j.geoderma.2019.113894.

Cheng, C., Zhang, T., Yang, F., Li, Q., Wang, Q., Xu, M., Li, S., Wang, H., 2023. Effects of thinning on forest soil and stump respiration in a subtropical pine plantation. For. Ecol. Manag. 531, 120797.

Cheng, W., Zhang, Q., Coleman, D.C., Carroll, C.R., Hoffman, C.A., 1996. Is available carbon limiting microbial respiration in the rhizosphere? Soil Biol. Biochem. 28 (10–11), 1283–1288.

Cherven, K., 2015. Mastering Gephi Network Visualization. Packt Publishing, UK.

D'Alò, F., Odriozola, I., Baldrian, P., Zucconi, L., Ripa, C., Cannone, N., Malfasi, F., Brancaleoni, L., Onofri, S., 2021. Microbial activity in alpine soils under climate change. Sci. Total Environ. 783, 147012 https://doi.org/10.1016/j.scitotenv.2021.147012.

De la Rosa, J.M., Santa-Olalla, A., Campos, P., López-Núñez, R., González-Pérez, J.A., Almendros, G., Knicker, H.E., Sánchez-Martín, Á., Fernández-Boy, E., 2022. Impact of biochar amendment on soil properties and organic matter composition in trace element-contaminated soil. Int. J. Environ. Res. Publ. Health 19 (4), 2140. https://doi.org/10.3390/ijerph19042140.

Deb, P., Debnath, P., Denis, A.F., Lepcha, O.T., 2019. Variability of Soil Physicochemical Properties at Different Agroecological Zones of Himalayan Region: Sikkim, India, vol. 21. Environment, Development and Sustainability, pp. 2321–2339. https://doi.org/10.1007/s10668-018-0137-8.

Dechoum, M.S., Zenni, R.D., Castellani, T.T., Zalba, S.M., Rejmánek, M., 2015. Invasions across secondary forest successional stages: effects of local plant community, soil, litter, and herbivory on Hovenia dulcis seed germination and seedling establishment. Plant Ecol. 216, 823–833.

Deslippe, J.R., Hartmann, M., Simard, S.W., Mohn, W.W., 2012. Long-term warming alters the composition of Arctic soil microbial communities. FEMS Microbiol. Ecol. 82 (2), 303–315. https://doi.org/10.1111/j.1574-6941.2012.01350.x.

Durigan, M.R., Cherubin, M.R., De Camargo, P.B., Nunes Ferreira, J., Berenguer, E., Gardner, T.A., Barlow, J., dos Santos Dias, C.T., Signor, D., de Oliveira Junior, R.C., Pellegrino Cerri, C.E., 2017. Soil organic matter responses to anthropogenic forest disturbance and land use change in the Eastern Brazilian Amazon. Sustainability 9 (3), 379. https://doi.org/10.3390/su9030379.

Ebeling, C., Fründ, H.C., Lang, F., Gaertig, T., Ebeling, C., Fründ, H.C., Lang, F., Gaertig, T., 2017. Evidence for increased P availability on wheel tracks 10 to 40 years after forest machinery traffic. Geoderma 297, 61–69. https://doi.org/10.1016/j.geoderma.2017.03.003.

Ezzati, S., Najafi, A., Rab, M.A., Zenner, E.K., 2012. Recovery of soil bulk density, porosity and rutting from ground skidding over a 20-year period after timber harvesting in Iran. Silva Fenn. 46 (4), 521–538. https://www.cabdirect.org/cabdirect/abstract/20133010644.

Feng, H., Wang, Z., Jia, P., Gai, J., Chen, B., Wang, S., 2022. Diversity and distribution of CO2-fixing microbial community along elevation gradients in meadow soils on the Tibetan Plateau. Sci. Rep. 12 (1), 9621.

Foote, J.A., Boutton, T.W., Scott, D.A., 2015. Soil C and N storage and microbial biomass in US southern pine forests: influence of forest management. For. Ecol. Manag. 355, 48–57. https://doi.org/10.1016/j.foreco.2015.03.036.

García-Carmona, M., García-Orenes, F., Mataix-Solera, J., Roldán, A., Pereg, L., Caravaca, F., 2021. Salvage logging alters microbial community structure and functioning after a wildfire in a Mediterranean forest. Appl. Soil Ecol. 168, 104130.

Gerdol, R., Marchesini, R., Iacumin, P., 2017. Bedrock geology interacts with altitude in affecting leaf growth and foliar nutrient status of mountain vascular plants. J. Plant Ecol. 10 (5), 839–850.

Guckland, A., Jacob, M., Flessa, H., Thomas, F.M., Leuschner, C., 2009. Acidity, nutrient stocks, and organic-matter content in soils of a temperate deciduous forest with different abundance of European beech (Fagus sylvatica L.). J. Plant Nutr. Soil Sci. 172 (4), 500–511. https://doi.org/10.1002/jpln.200800072.

Hassett, J.E., Zak, D.R., 2005. Aspen harvest intensity decreases microbial biomass, extracellular enzyme activity, and soil nitrogen cycling. Soil Sci. Soc. Am. J. 69 (1), 227–235.

Haynes, R.J., 2005. Labile organic matter fractions as central components of the quality of agricultural soils: an overview. Adv. Agron. 85, 221–268.

Homer, C.D., Pratt, P.F., 1961. Methods of Analysis for Soils, Plants and Waters. University of California, Agricultural Sciences Press, Berkeley, p. 309.

Horn, R., Vossbrink, J., Becker, S., 2004. Modern forestry vehicles and their impacts on soil physical properties. Soil Tillage Res. 79 (2), 207–219. https://doi.org/10.1016/j.still.2004.07.009.

Hume, A.M., Chen, H.Y., Taylor, A.R., 2018. Intensive forest harvesting increases susceptibility of northern forest soils to carbon, nitrogen and phosphorus loss. J. Appl. Ecol. 55 (1), 246–255. https://doi.org/10.1111/1365-2664.12942.

Hurlbert, S.H., 1984. Pseudo-replication and the design of ecological field experiments. Ecol. Monogr. 54, 187–211.

Hutson, B.R., Veitch, L.G., 1987. Densities of Collembola and Acarina in the soil and litter of three indigenous South Australian forests related to layer, site and seasonal differences. Aust. J. Ecol. 12, 239–261.

Insam, H., Domsch, K.H., 1988. Relationship between soil organic carbon and microbial biomass on chronosequences of reclamation sites. Microb. Ecol. 15, 177–188.

James, J., Page-Dumroese, D., Busse, M., Palik, B., Zhang, J., Eaton, B., Slesak, R., Tirocke, J., Kwon, H., 2021. Effects of forest harvesting and biomass removal on soil carbon and nitrogen: two complementary meta-analyses. For. Ecol. Manag. 485, 118935 https://doi.org/10.1016/j.foreco.2021.118935.

Jeffery, S., Gardi C Jones, A., Montanarella, L., Marmo, L., Miko, L., Ritz, K., Peres, G., Römbke, J., Putten, WH van der (Eds.), 2010. European Atlas of Soil Biodiversity. European Commission, Publications Office of the European Union, Luxembourg.

Jenny, H., 1941. Factors of Soil Formation. McGraw-Hill, New York.

Jourgholami, M., Labelle, E.R., 2020. Effects of plot length and soil texture on runoff and sediment yield occurring on machine-trafficked soils in a mixed deciduous forest. Ann. For. Sci. 77 (1), 1–11. https://doi.org/10.1007/s13595-020-00938-0.

Kalbitz, K., Solinger, S., Park, J.H., Michalzik, B., Matzner, E., 2000. Controls on the dynamics of dissolved organic matter in soils: a review. Soil Sci. 165 (4), 277–304.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution. In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, second ed. American Society of Agronomy, Madison, Wisconsin, pp. 383–411.

Kooch, Y., Bayranvand, M., 2019. Labile soil organic matter changes related to forest floor quality of tree species mixtures in Oriental beech forests. Ecol. Indicat. 107, 105598 https://doi.org/10.1016/j.ecolind.2019.105598.

Kooch, Y., Moghimian, N., Wirth, S., Haghverdi, K., 2020. Effects of shelterwood and single-tree cutting systems on topsoil quality and functions in northern Iranian forests. For. Ecol. Manag. 468, 118188 https://doi.org/10.1016/j.foreco.2020.118188.

Kooch, Y., Samadzadeh, B., Hosseini, S.M., 2017. The effects of broad-leaved tree species on forest floor quality and soil properties in a plain forest stand. Catena 150, 223–229.

Kooijman, A.M., Weiler, H.A., Cusell, C., Anders, N., Meng, X., Seijmonsbergen, A.C., Cammeraat, L.H., 2019. Litter quality and microtopography as key drivers to topsoil properties and understorey plant diversity in ancient broadleaved forests on decalcified marl. Sci. Total Environ. 684, 113–125. https://doi.org/10.1016/j.scitotenv. 2019.05.285.

Kostel-Hughes, F., Young, T.P., Carreiro, M.M., 1998. Forest leaf litter quantity and seedling occurrence along an urban-rural gradient. Urban Ecosyst. 2, 263–278.

Kranabetter, J.M., Banner, A., 2000. Selected biological and chemical properties of forest floors across bedrock types on the north coast of British Columbia. Can. J. For. Res. 30 (6), 971–981. https://doi.org/10.1139/x00-018.

Laganière, J., Augusto, L., Hatten, J.A., Spielvogel, S., 2022. Vegetation effects on soil organic matter in forested ecosystems. Vegetation Effects Soil Organ. Matter Forest. Ecosyst. 4. https://doi.org/10.3389/ffgc.2021.828701.

Lal, R., 2005. Forest soils and carbon sequestration. For. Ecol. Manag. 220 (1–3), 242–258. https://doi.org/10.1016/j.foreco.2005.08.015.

Lewandowski, T.E., Forrester, J.A., Mladenoff, D.J., D'Amato, A.W., Fassnacht, D.S., Padley, E., Martin, K.J., 2019. Do biological legacies moderate the effects of forest harvesting on soil microbial community composition and soil respiration. For. Ecol. Manag. 432, 298–308.

Li, M., Zhou, X., Zhang, Q., Cheng, X., 2014. Consequences of Afforestation for Soil Nitrogen Dynamics in Central China, vol. 183. Agriculture, ecosystems & environment, pp. 40–46.

Li, Q., Allen, H.L., Wollum II, A.G., 2004. Microbial biomass and bacterial functional diversity in forest soils: effects of organic matter removal, compaction, and vegetation control. Soil Biol. Biochem. 36 (4), 571–579.

Li, X., Zhang, Q., Feng, J., Jiang, D., Zhu, B., 2023. Forest Management Causes Soil Carbon Loss by Reducing Particulate Organic Carbon in Guangxi. Southern China. Forest Ecosystems, 100092.

Liang, B.C., MacKenzie, A.F., Schnitzer, M., Monreal, C.M., Voroney, P.R., Beyaert, R.P., 1997. Management-induced change in labile soil organic matter under continuous corn in eastern Canadian soils. Biol. Fertil. Soils 26, 88–94.

Liang, W., Lou, Y., Li, Q., Zhong, S., Zhang, X., Wang, J., 2009. Nematode faunal response to long-term application of nitrogen fertilizer and organic manure in Northeast China. Soil Biol. Biochem. 41 (5), 883–890.

Liu, D., Liu, G., Chen, L., Wang, J., Zhang, L., 2018. Soil pH determines fungal diversity along an elevation gradient in Southwestern China. Sci. China Life Sci. 61 (6), 718–726. https://doi.org/10.1007/s11427-017-9200-1.

Liu, Y., Wu, X., Wu, T., Zhao, L., Li, R., Li, W., Hu, G., Zou, D., Ni, J., Du, Y., Wang, M., 2022. Soil texture and its relationship with environmental factors on the Qinghai–Tibet plateau. Rem. Sens. 14 (15), 3797.

Ma, Z., Chen, S., Shahi, C., Chen, H.Y., Chen, H., 2022. Trade-offs between economic gains and carbon stocks across a range of management alternatives in boreal forests. Forests 13 (11), 1777. https://doi.org/10.3390/f13111777.

Mäkipää, R., Abramoff, R., Adamczyk, B., Baldy, V., Biryol, C., Bosela, M., Casals, P., Yuste, J.C., Dondini, M., Filipek, S., Garcia-Pausas, J., 2023. How Does Management Affect Soil C Sequestration and Greenhouse Gas Fluxes in Boreal and Temperate Forests?–A Review, vol. 529. Forest Ecology and Management, 120637.

Matus, F.J., 2021. Fine silt and clay content is the main factor defining maximal C and N accumulations in soils: a meta-analysis. Sci. Rep. 11 (1), 6438. https://doi.org/10.1038/s41598-021-84821-6.

Mayzlish, E., Steinberger, Y., 2004. Effects of chemical inhibitors on soil protozoan dynamics in a desert ecosystem. Biol. Fertil. Soils 39, 415–421.

Mc Cune, B., Mefford, M., 1999. Multivariate Analysis of Ecological Data Version 4.17. MJM Software. Gleneden Beach, Oregon, USA, p. 233.

Mesdaghi, M., 2005. Plant Ecology. Mashhad University Press, Mashhad.

Meyfroidt, P., Lambin, E.F., Erb, K.H., Hertel, T.W., 2013. Globalization of land use: distant drivers of land change and geographic displacement of land use. Curr. Opin. Environ. Sustain. 5 (5), 438–444. https://doi.org/10.1016/j.cosust.2013.04.003.

Mikkelson, K.M., Lozupone, C.A., Sharp, J.O., 2016. Altered edaphic parameters couple to shifts in terrestrial bacterial community structure associated with insect-induced tree mortality. Soil Biol. Biochem. 95, 19–29.

Mohammadi, M.F., Jalali, S.G., Kooch, Y., Said-Pullicino, D., 2017. The effect of landform on soil microbial activity and biomass in a Hyrcanian oriental beech stand. Catena 149, 309–317.

Moore, J.A., Kimsey, M.J., Garrison-Johnston, M., Shaw, T.M., Mika, P., Poolakkal, J., 2022. Geologic soil parent material influence on forest surface soil chemical characteristics in the inland northwest, USA. Forests 13 (9), 1363. https://doi.org/10.3390/f13091363.

Morán-Tejeda, E., López-Moreno, J.I., Beniston, M., 2013. The changing roles of temperature and precipitation on snowpack variability in Switzerland as a function of altitude. Geophys. Res. Lett. 40 (10), 2131–2136. https://doi.org/10.1002/grl.50463.

Mylliemngap, W., Nath, D., Barik, S.K., 2016. Changes in vegetation and nitrogen mineralization during recovery of a montane subtropical broadleaved forest in North-eastern India following anthropogenic disturbance. Ecol. Res. 31 (1), 21–38.

Nave, L.E., Vance, E.D., Swanston, C.W., Curtis, P.S., 2010. Harvest impacts on soil carbon storage in temperate forests. For. Ecol. Manag. 259 (5), 857–866. https://doi.org/10.1016/j.foreco.2009.12.009.

Ndossi, E.M., Becker, J.N., Hemp, A., Dippold, M.A., Kuzyakov, Y., Razavi, B.S., 2020. Effects of land use and elevation on the functional characteristics of soil enzymes at Mt. Kilimanjaro. Eur. J. Soil Biol. 97, 103167 https://doi.org/10.1016/j.ejsobi.2020.103167.

Neatrour, M.A., Jones, R.H., Golladay, S.W., 2005. Correlations between soil nutrient availability and fine-root biomass at two spatial scales in forested wetlands with contrasting hydrological regimes. Can. J. For. Res. 35 (12), 2934–2941.

Outerbridge, R.A., Trofymow, J.T., 2009. Forest management and maintenance of ectomycorrhizae: a case study of green tree retention in south-coastal British Columbia. J. Ecosyst. Manag. 10, 59–39.

Owen, J.S., Wang, M.K., Wang, C.H., King, H.B., Sun, H.L., 2003. Net N mineralization and nitrification rates in a forested ecosystem in northeastern Taiwan. For. Ecol. Manag. 176 (1–3), 519–530.

Pires, L.F., Brinatti, A.M., Saab, S.C., Cássaro, F.A., 2014. Porosity distribution by computed tomography and its importance to characterize soil clod samples. Appl. Radiat. Isot. 92, 37–45.

Plaster, E.J., 1985. Soil Science and Management. Delmar Publishers Inc, Albany, N.Y., p. 124

Pourmajidian, M.R., Rahmani, A., 2009. The influence of single-tree selection cutting on silvicultural properties of a northern hardwood forest in Iran. Am.-Eurasian J. Agric. Environ. Sci. 5 (4), 526–532.

Povilaitienė, A., Gedminas, A., Varnagirytė-Kabašinskienė, I., Marčiulynienė, D., Marčiulynas, A., Lynikienė, J., Mishcherikova, V., Menkis, A., 2022. Changes in chemical properties and fungal communities of mineral soil after clear-cutting and reforestation of Scots pine (*Pinus sylvestris* L.) sites. Forests 13 (11), 1780.

Quan, Q., Tian, D., Luo, Y., Zhang, F., Crowther, T.W., Zhu, K., Chen, H.Y., Zhou, Q., Niu, S., 2019. Water scaling of ecosystem carbon cycle feedback to climate warming. Sci. Adv. 5 (8), eaav1131. https://doi.org/10.1126/sciadv.aav1131.

Riutta, T., Kho, L.K., Teh, Y.A., Ewers, R., Majalap, N., Malhi, Y., 2021. Major and persistent shifts in below-ground carbon dynamics and soil respiration following logging in tropical forests. Global Change Biol. 27 (10), 2225–2240. https://doi.org/10.1111/gcb.15522.

Robertson, G.P., 1999. Standard Soil Methods for Long-Term Ecological Research, vol. 2. Oxford University Press on Demand.

Roy, M.È., Surget-Groba, Y., Delagrange, S., Rivest, D., 2021. Legacies of forest harvesting on soil properties along a chronosequence in a hardwood temperate forest. For. Ecol. Manag. 496, 119437 https://doi.org/10.1016/j.foreco.2021.119437.

Ruuhola, T., Nikula, A., Nivala, V., Nevalainen, S., Matala, J., 2016. Effects of Bedrock and Surficial Deposit Composition on Moose Damage in Young Forest Stands in Finnish Lapland.

Sagheb-Talebi, K., Schütz, J.P., 2002. The structure of natural oriental beech (Fagus orientalis) forests in the Caspian region of Iran and potential for the application of the group selection system. Forestry 75 (4), 465–472.

Sagheb-Talebi, Kh, Sajedi, T., Pourhashemi, M., 2014. Forests of Iran: a treasure from the past, a hope for the future. https://doi.org/10.1007/978-94-007-7371-4.

Schinner, F., Von Mersi, W., 1990. Xylanase-, CM-cellulase-and invertase activity in soil: an improved method. Soil Biol. Biochem. 22 (4), 511–515.

Shaheb, M.R., Venkatesh, R., Shearer, S.A., 2021. A review on the effect of soil compaction and its management for sustainable crop production. J. Biosyst. Eng. 1–23. https://doi.org/10.1007/s42853-021-00117-7.

Shen, Y., Cheng, R., Xiao, W., Yang, S., Guo, Y., Wang, N., Zeng, L., Lei, L., Wang, X., 2018. Labile organic carbon pools and enzyme activities of Pinus massoniana plantation soil as affected by understory vegetation removal and thinning. Sci. Rep. 8 (1), 1–9. https://doi.org/10.1038/s41598-017-18812-x.

Siebers, N., Kruse, J., 2019. Short-term impacts of forest clear-cut on soil structure and consequences for organic matter composition and nutrient speciation: a case study. PLoS One 14 (8), e0220476. https://doi.org/10.1371/journal.pone.0220476.

Sohrabi, H., Jourgholami, M., Labelle, E.R., 2022. The effect of forest floor on soil microbial and enzyme indices after forest harvesting operations in Hyrcanian deciduous forests. Eur. J. For. Res. 141 (6), 1013–1027. https://doi.org/10.1007/s10342-022-01486-0.

Sohrabi, H., Jourgholami, M., Tavankar, F., Venanzi, R., Picchio, R., 2019. Post-harvest evaluation of soil physical properties and natural regeneration growth in steep-slope terrains. Forests 10 (11), 1034. https://doi.org/10.3390/f10111034.

Solgi, A., Najafi, A., 2014. The impacts of ground-based logging equipment on forest soil. J. For. Sci. 60 (1), 28–34.

Souza, G.P.D., Figueiredo, C.C.D., Sousa, D.M.G.D., 2016. Relationships between labile soil organic carbon fractions under different soil management systems. Sci. Agric. 73, 535–542. https://doi.org/10.1590/0103-9016-2015-0047.

Sparks, D.L., Bartels, J.M., 1996. Pt. 3: Chemical Methods (No. 5-3). Soil Science Society of America, Madison ([etc.]).

Sparling, G., Vojvodić-Vuković, M., Schipper, L.A., 1998. Hot-water-soluble C as a simple measure of labile soil organic matter: the relationship with microbial biomass C. Soil Biol. Biochem. 30 (10–11), 1469–1472.

Sutinen, R., Kuoppamaa, M., Hänninen, P., Middleton, M., Närhi, P., Vartiainen, S., Sutinen, M.L., 2011. Tree species distribution on mafic and felsic fells in Finnish Lapland. Scand. J. For. Res. 26 (1), 11–20.

Trofymow, J.A., Barclay, H.J., McCullough, K.M., 1991. Annual rates and elemental concentrations of litter fall in thinned and fertilized Douglas-fir. Can. J. For. Res. 21 (11), 1601–1615.

Venanzi, R., Picchio, R., Piovesan, G., 2016. Silvicultural and logging impact on soil characteristics in Chestnut (*Castanea sativa* Mill.) Mediterranean coppice. Ecol. Eng. 92, 82–89. https://doi.org/10.1016/j.ecoleng.2016.03.034.

Wan, P., He, R., Wang, P., Cao, A., 2022. Implementation of different forest management methods in a natural forest: changes in soil microbial biomass and enzyme activities. For. Ecol. Manag. 520, 120409 https://doi.org/10.1016/j.foreco.2022.120409.

Wang, Q., Wang, S., 2011. Response of labile soil organic matter to changes in forest vegetation in subtropical regions. Appl. Soil Ecol. 47 (3), 210–216.

Wang, S., Wang, X., Han, X., Deng, Y., 2018. Higher precipitation strengthens the microbial interactions in semi-arid grassland soils. Global Ecol. Biogeogr. 27 (5), 570–580. https://doi.org/10.1111/geb.12718.

Wixon, D.L., Balser, T.C., 2013. Toward conceptual clarity: PLFA in warmed soils. Soil Biol. Biochem. 57, 769–774.

Wollum, A.G., 1983. Cultural methods for soil microorganisms. Methods of soil analysis: part 2 chemical and microbiological properties, 9, pp. 781–802.

Zappelini, C., Karimi, B., Foulon, J., Lacercat-Didier, L., Maillard, F., Valot, B., Blaudez, D., Cazaux, D., Gilbert, D., Yergeau, E., Greer, C., 2015. Diversity and complexity of microbial communities from a chlor-alkali tailings dump. Soil Biol. Biochem. 90, 101–110. https://doi.org/10.1016/j.soilbio.2015.08.008.

Zhang, L., Feng, H., Du, M., Wang, Y., Lai, G., Guo, J., 2022a. Dynamic effects of structure-based forest management on stand spatial structure in a platycladus orientalis plantation. Forests 13 (6), 852. https://doi.org/10.3390/f13060852.

Zhang, R., Tian, X., Xiang, Q., Penttinen, P., Gu, Y., 2022b. Response of soil microbial community structure and function to different altitudes in arid valley in Panzhihua, China. BMC Microbiol. 22 (1), 1–11.

Zhou, X., Zhou, Y., Zhou, C., Wu, Z., Zheng, L., Hu, X., Chen, H., Gan, J., 2015. Effects of cutting intensity on soil physical and chemical properties in a mixed natural forest in southeastern China. Forests 6 (12), 4495–4509. https://doi.org/10.3390/f6124383.

Zhou, Y., Wang, L., Chen, Y., Zhang, J., Xu, Z., Guo, L., Wang, L., You, C., Tan, B., Zhang, L., Chen, L., 2022. Temporal dynamics of mixed litter humification in an alpine treeline ecotone. Sci. Total Environ. 803, 150122 https://doi.org/10.1016/j.scitotenv.2021.150122.