European Journal of Forest Research (2018) 137:793–805
https://doi.org/10.1007/s10342-018-1140-1

ORIGINAL PAPER

Tree species could have substantial consequences on topsoil fauna: a feedback of land degradation/restoration

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Received: 18 March 2018 / Revised: 10 August 2018 / Accepted: 6 September 2018 / Published online: 10 September 2018

Abstract

The characteristics of the faunal community in the soil are closely related to soil quality and function. Land degradation, which reduces vegetation cover, may affect the soil surface-active fauna because both the above ground and below ground invertebrates depend on complex plant communities. In this study, we evaluated the effect of land degradation/restoration and factors affecting soil fauna in northern Iran. The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF). VNF and ASP enhanced soil earthworm density (2.43 and 2.12 ind. m^{-2}) and dry mass (27.44 and 23.39 mg m^{-2}) with more ratio of epigeic. The activities of acarina (91,851.37 and 85,810.43 ind. m^{-2}), collembola (83,009.50 and 74,996.18 ind. m^{-2}) and protozoa [921.25 and 851.81 ($\times 10^2$ g soil)] were increased under VNF ≈ ASP, respectively. Nematode population (650 in 100 g soil) significantly improved under VNF. In general, good quality forest floor, alkaline soil and accumulation of macro-element nutrients improved biological activities under the VNF and ASP sites, while low-quality forest floor, acidic soil, less macro-elements nutrients decreased biological activities imposed by the QCP, CSP and DNF sites. More activities of the studied soil fauna were found in autumn and spring. The findings of this study support the importance of preserving natural forests. In addition, employing N_2-fixing and suitable native broadleaved species have been proposed in a bid to rehabilitate DNFs.

Keywords Earthworm · Acarina · Collembola · Nematode · Protozoa

Introduction

The land surface affected by anthropogenic degradation is increasing. Approximately 23% of all arable land of the planet has been affected by land degradation, and, at the end of the last century, approximately 910 Mha were under moderate to extreme degradation (Ferreira de Araújo et al. 2015). The growth rate of population caused by urbanization has resulted in changes in population, wealth, social trends and transportation costs. Comparisons of land use projects between 1988 and 2004 in the northern forests of Iran showed an alarming trend—that 12,152 ha of forests was destroyed during this period—in most areas of Mazandaran province (Moghimian et al. 2017). Different human activities can modify landscapes, reducing resilience of the altered areas. This, in some cases, requires human intervention in order to facilitate and accelerate recovery of the ecosystem's functions. Therefore, one of the commonly used practices is to plant trees, which covers the ground via litter, minimizing the effects of erosion (Rocha De Lima et al. 2017). Moreover, these plantations can restart the forest succession process, favoring the nutrient cycling through the input of organic matter and change of soil quality. Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation (Blasi et al. 2013). It can be evaluated through chemical or physical properties and biological indicators. Biotic indices, based on invertebrate

Handling Editor: Dr. Agustín Merino.

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community studies, were recently developed as a promising tool in monitoring soil quality (Bayranvand et al. 2017b). The soil fauna community considered the "engineer of the soil ecosystem" to be large, diverse and with significant ecosystem functions (Madhav et al. 2014). Soil fauna can interact with microorganisms and influence decomposition and nutrient cycling in communities (Li et al. 2014).

Earthworms are probably the most familiar group of soil macro-fauna, and although they probably represent only 1% of the global soil animal diversity (Kooch 2012), they are known to act as ecosystem engineers through their bioperturbational activities, altering soil nutrient dynamics, augmenting plant growth, as well as playing a fundamental role in nutrient cycling (Lavelle et al. 1998; Bayranvand et al. 2017b). Acarina play an important role in the decomposition of plant material. The vast majority are either generalist particle-feeding saprophages, primary decomposers for breakdown of plant debris, or mycophages, secondary decomposers which, through feeding on fungi, release nutrients trapped in the vegetation back into the soil (Schneider et al. 2004). Collembola (springtails) are small (2–4 mm) primitive wingless invertebrates and among the most abundant and widespread organisms in the world that are common in soil. They are believed to be more closely related to crustaceans than insects. They are best recognized by their unique forked jumping organ, or furca, folded under the abdomen, and a ventral tube, which is an abdominal organ used for water balance (Nardi et al. 2003). Nematodes are among the most abundant soil organisms and are an essential part of soil ecology, influencing various aspects such as nutrient mineralization and decomposition. Certain parasitic nematodes also influence plant and animal dynamics. Nematodes are often used as indicators of soil health (Ferris et al. 2012). The protozoa population is known to be one of the most important bacterial feeders in soils, followed by bacteria-feeding nematodes. Due to their size, protozoa are able to move and utilize very small pore spaces unavailable to other soil biota (Mayzlish and Steinberger 2004). Protozoa consume a significant portion (usually > 50%) of bacterial productivity, enhance soil respiration, increase carbon and nitrogen mineralization, and are prey for a large number of microfauna (Lee et al. 2000).

The activity of soil biology in temperate ecosystems is strongly affected by the seasons through changes in biotic and abiotic factors (Kaiser et al. 2010). Unfortunately, studies considering the impact of different land uses on soil organisms through seasonal cycles are rare (Collignon et al. 2011). The Hyrcanian vegetation zone, also called the Caspian forest, is one of the last remnants of natural deciduous forests in the world (Bayranvand et al. 2017a). Despite the importance of the Hyrcanian sites, an earlier study that evaluated the effects of dominated land uses on forest floor quality and also spatiotemporal variability of the soil fauna was not considered. This study aims to investigate: (1) if different land uses affect the following: forest floor quality, soil chemical properties, earthworm density/dry mass (as a soil macro-fauna index), acari, collembola, nematode (as soil meso-fauna indices), and protozoa activity (as a soil microfauna index), (2) seasonal changes in soil fauna activity under different land uses, (3) the factors that determine soil fauna activity in these temperate sites. The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF).

Materials and methods

Site description

The study area is in the Neirang district of the city of Noshahr in Mazandaran province in northern Iran at 36°30′40″ and 36°37′30″ latitude, 51°28′25″ and 51°26′30″ longitude (Fig. 1a, b). The study site was located at 50 m in altitude with a mild slope of 0–5%. Annual rainfall averages 1300 mm, with wetter months occurring between September and February. The dry season is from April to August, when monthly rainfall averages < 40 mm. Average daily temperatures range from 11.7 °C in February to 29.5 °C in August (Fig. 1c). According to the USDA Soil Taxonomy, soils can be classified as silty-clay-loam Alfisols, developed on dolomite limestones belonging to the upper Jurassic and lower Cretaceous periods. This area is dominated by degraded natural forests containing native tree species including hornbeam (*Carpinus betulus* L.), ironwood (*Parrotia persica* C.A. Meyer) and some individual trees of Caspian zelkova [*Zelkova carpinifolia* (Pall.) Dipp.] and Caspian locust (*Gleditschia caspica* Desf.). While 31 years ago, after clear cutting (in some areas of degraded natural forests), reforestation has been done (within 2 × 2 m spaces) in this area, with some native species including alder (*Alnus subcordata* C.A.M.) with ~ 5 ha, oak (*Quercus castaneifolia* C.A.M.) with ~ 8 ha and Mediterranean cypress [*Cupressus sempervirens* L. var. *horizontalis* (Mill.) Loudon] with ~ 6 ha. The stands were never fertilized. Therefore, in a relatively small homogeneous area natural, reforested and degraded plots can be found (Anonymous 2016). A detailed description of each site is reported in Table 1 (Tavakoli et al. 2018).

Sampling and analysis

In this study, one sample plot, of 4 ha (200 × 200 m); was selected in every plantation as well as in the natural forest. In order to decrease the border effects, surrounding rows of stands were not considered during sampling, which was

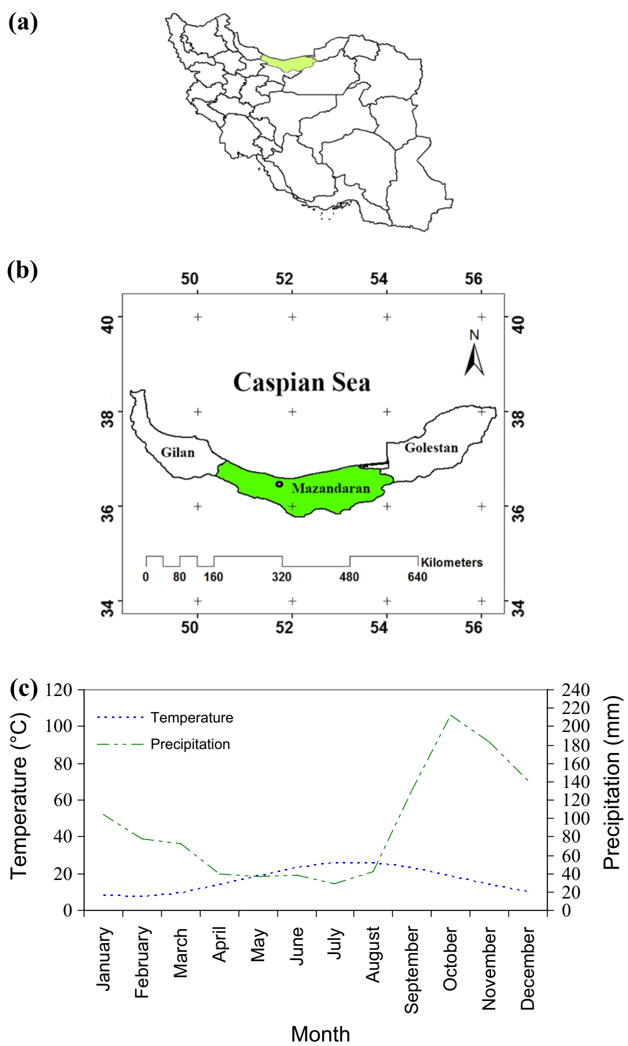

Fig. 1 Geographical location of the study area in north of Iran (**a**), Mazandaran province (**b**) and climate diagram based on Noshahr city metrological station (**c**)

carried out during summer (August) using a systematic random method. The sampling was performed by randomly selecting a location from the area; thereafter, the other soil sample positions were selected systematically. Using this procedure, each location in the areas has a known and equal probability of selection in relation to trees position. Four soil profiles (25 × 25 × 15 cm depth) were dug along the four parallel transects in the central part of each tree plantation, resulting in 16 soil samples for each stand. Also, the same sampling procedure was carried out for the mixed virgin forest dominated by *Carpinus betulus* L.–*Parrotia persica* C.A. Meyer and also degraded natural forest. Forest floor and soil samples were collected from each stand. In total, 80 (i.e., 16 forest floor and soil samples in each land use × 5 land use) samples were taken to measure forest floor and soil features. Forest floors (including L, F and H horizons) thickness was measured with a tape from the forest floor surface to the top of the mineral soil (Dechoum et al. 2015), and the dry mass was determined in the laboratory (Xu and Hirata 2002). Forest floor was stored in bags and transported to the laboratory, washed gently for 30 s to remove mineral soil, and dried at 70 °C for 48 h. Dried forest floor samples were finely grounded and analyzed. Total C and nutrients contents in forest floor samples were determined in quadruplicate using dry combustion with an elemental analyzer (Fisons EA1108, Milan, Italy) calibrated by the BBOT [2,5-bis-(5-*tert*-butyl-benzoxazol-2-yl)-thiophen] standard (Ther moQuest Italia s.p.a.) (Kooch et al. 2017). Soils were air-dried and passed through a 2-mm sieve. (Aggregates were broken to pass through a 2-mm sieve.) Before air-drying, soil water content was measured by drying soil samples at 105 °C for 24 h. Soil pH was determined using an Orion Ionalyzer Model 901 pH meter in a 1:2.5 soil/water solution. EC (electrical conductivity) was determined using an Orion Ionalyzer Model 901 EC meter in a 1:2.5 soil/water solution. The Walkley–Black technique (Allison 1975) was used to determine soil organic carbon. Total N was measured using a semi-micro-Kjeldahl technique (Bremner and Mulvaney 1982). Available P was determined with a spectrophotometer using the Olsen method (Homer and Pratt 1961), and available K, Ca and Mg (by ammonium acetate extraction at pH 9) were determined with an atomic absorption spectrophotometer (Bower et al. 1952).

Seasonal (May, August, November and February) measurements were taken under studied land uses (i.e., 16 soil sample × 5 land use × 4 seasons; resulting in 320 soil samples) to find temporal pattern of the soil biological activities. Simultaneously with the soil sampling, the earthworms were collected, in soil volume of 25 × 25 × 15 cm, by hand sorting. For this, an iron frame (25 × 25 cm in size) was placed on the ground at the sampling site, and the vegetation on the soil surface inside the frame was cut and cleared. The soil was dug and carefully searched for earthworms. The worms were picked up and placed separately in polythene bags along with a little parent soil (Vikram Reddy et al. 1995). Each was washed clean of adhering soil particles, placed on blotting paper, and identified based on ecological categories (i.e., epigeic, anecic and endogeic) by external characteristics (See Table 2; Edwards and Bohlen 1996; Jeffery et al. 2010). Earthworms were counted in the field and brought to the laboratory, washed in water, and then they were oven-dried at 60 °C for 24 h. Earthworm dry mass was determined after drying (Vikram Reddy et al. 1995; Rahmani 2000; Rahmani and Saleh-Rastin 2000; Mohammadnezhad Kiasari et al. 2009; Salehi et al. 2013; Heydari et al. 2014). Acarina and collembolan, in soil volume of 5 × 5×15 cm, were extracted with the help of modified Tullgren funnel as described by Hutson and Veitch (1987). Nematodes were extracted from 100 g soil sample (fresh weight) by a modified cotton–wool

Table 1 Land uses properties (mean ± standard error) in the study area

Land use	Main species	Tree density (N ha^{-1})	D.b.h. (cm)	Height (m)	Tree coverage (%)	Coverage (%) of dominant herbaceous species[a]
VNF	*Carpinus betulus* L.	195	63.15 ± 4.22	25.24 ± 0.83	60	*Asperula odorata* L. (10) *Euphorbia amygdaloides* L. (10)
	Parrotia persica C.A. Meyer	112	59.45 ± 3.78	20.89 ± 0.62	30	
ASP	*Alnus subcordata* C.A.M.	545	29.41 ± 0.39	18.33 ± 0.31	80	*Oplismenus undulatifolius* (Ard.) Roem. & Schult. (15) *Carex sylvativa* Huds. (10) *Rubus hyrcanus* Juz. (10)
QCP	*Quercus castaneifolia* C.A. Mey	540	27.62 ± 0.42	16.13 ± 0.25	80	*Microstegium vimineum* (Trin.) A. Camus (15) *Carex sylvativa* Huds. (10) *Oplismenus undulatifolius* (Ard.) Roem. & Schult. (10)
CSP	*Cupressus sempervirens* var. horizontalis	455	24.38 ± 0.29	14.29 ± 0.38	85	*Tamus communis* L. (10) *Oplismenus undulatifolius* (Ard.) Roem. & Schult. (10) *Microstegium vimineum* (Trin.) A. Camus (10)
DNF	*Carpinus betulus* L.	20	60.56 ± 3.94	22.33 ± 0.69	20	*Asperula odorata* L. (30) *Rubus hyrcanus* Juz. (20) *Euphorbia amygdaloides* L. (10) *Hypericum androsaemum* L. (10) *Polystichum* sp. (10)
	Parrotia persica C.A. Meyer	9	58.63 ± 4.04	19.83 ± 0.61	10	

The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF)

The reported data of tree and herbaceous coverage are recorded in August 2017

[a]Most of these species are found in the growing seasons under the different land uses

Table 2 Ecological categories of earthworms

Category	Epigeic	Anecic	Endogeic
External characteristics	Generally small, being 1–5 cm in length, and are dark red in color	Generally the longest earthworms being 10–110 cm in length, and are variable in color, being either red, dark gray or brown	Generally medium to large, being 1–20 cm in length, and are usually slightly colored, being pink to light gray
Photograph			

filter method (Liang et al. 2009). Following extraction method, 25 g soil was stirred with 85 ml water, and protozoa population densities were counted under a microscope (See Mayzlish and Steinberger 2004).

Statistical analysis

Normality of the variables was checked by Kolmogorov–Smirnov test, and Levene's test was used to examine the equality of the variances. One-way analysis of variance (ANOVA) was used to compare forest floor and soil features data among the land uses. Two-way ANOVA and general linear models (GLM) were used to compare changes of soil biological data among land uses and seasons. Duncan's multiple comparison test was further employed to test for differences at the $P = 0.05$ level. All statistical analyses were conducted using the SPSS v. 20 statistical software packages. Factor analysis is a statistical tool for exploring complex relationships among variables. For this purpose, we used principal component analyses (PCA) to examine relationships in the multivariate data. Multivariate correlations were used to identify significant relationships among variables and principal components using PC-Ord version 5.0 (Mc Cune and Mefford 1999).

Results

Effect of forest degradation and reclamation on forest floor and soil quality

Our findings showed that forest floor features were significantly affected by land uses. Forest floor mass was found in the order of CSP ≈ QCP > VNF > DNF ≈ ASP with almost twofold more under *C. sempervirens* compared to *A. subcordata* plantation. Forest floor C was significantly highest under QCP and went on decreasing in the order CSP > VNF > DNF > ASP, whereas the establishment of ASP plantation resulted in an increase in forest floor N concentration, which was higher than all the other studied sites. Forest floor C/N ratio was significantly different among different land uses, and the lowest value of this character was observed in ASP ≈ VNF ecosystems. VNF had the highest value of forest floor P and Ca, whereas VNF ≈ ASP had higher K and Mg concentrations than all the other studied forest types (Table 3). Following forest degradation, the values of soil water content and organic C significantly decreased. Soil pH, EC, available Ca and Mg were significantly higher in VNF ≈ ASP when compared with the other studied sites while greater amounts of the soil's total N and available P and K were enhanced under VNF land use. Soil C/N ratio was significantly different among the land uses, and QCP had the highest value (Table 4).

Effect of forest degradation and reclamation on soil fauna

The higher values of soil earthworm density/dry mass were detected under VNF ≈ ASP when compared with the other land uses, with more activities seen during autumn and spring (Table 4; Fig. 2a, b). The ecological group of epigeic had more ratio than anecic and endogeic earthworms (Fig. 2a, b). Replacement of native forest by QCP, CSP and forest degradation resulted in a shift from a high soil acarina density to less activity under DNF (Table 4), especially in autumn and spring (Fig. 3a). Activities of soil collembola were enhanced, especially in autumn, under the VNF and ASP sites (Table 4; Fig. 3b). Soil nematode population was found to be significantly higher under VNF than in ASP > QCP > CSP ≈ DNF sites, especially during autumn (Table 4; Fig. 3c). Soil protozoa was significantly higher in order of VNF ≈ ASP > QCP > CSP > DNF ecosystems and also during autumn (Table 4; Fig. 4). Two-way ANOVA test showed that the land cover was the more dominating factor for explaining variations of earthworm density/dry mass (52.11 and 52.67%, respectively), acarina density (57.24%), total nematode (40.44%) and protozoa density (51.30%), while collembola activity (46.73%) was more affected by the seasonal factor in the area under study (Fig. 5). From the PCA output, the first component explained more than 90% of the variance in forest floor and soil features under the studied land uses (Fig. 6). The left PC1 shows good quality of forest floor, alkaline soil, accumulation of macro-element nutrients and more biological activities, and this can be attributed to the VNF and ASP sites while the right PC1 and left PC2 (explained variance of less than 10%) presented positions of low-quality forest floor, acidic soil, less macro-element nutrients and low biological activities imposed by QCP, CSP and DNF sites (Fig. 6).

Table 3 Mean (± SE; $n = 16$) of forest floor features under different land uses

Forest floor features	Land use					Summary ANOVA results	
	VNF	ASP	QCP	CSP	DNF	*F* test	*P* value
Mass (kg m^{-2})	12.89 ± 0.39b	11.03 ± 0.40c	20.09 ± 0.60a	20.93 ± 0.53a	11.29 ± 0.61c	85.464	0.000
Carbon (%)	45.78 ± 1.37bc	42.10 ± 1.85c	53.64 ± 1.36a	48.13 ± 2.62b	47.53 ± 1.52bc	5.013	0.001
Nitrogen (%)	2.26 ± 0.08b	2.73 ± 0.24a	0.74 ± 0.03c	0.71 ± 0.02c	0.71 ± 0.03c	67.101	0.000
C/N ratio	20.59 ± 1.03b	17.66 ± 1.89b	73.94 ± 2.37a	68.74 ± 4.75a	69.02 ± 4.17a	79.378	0.000
Phosphorus (%)	3.92 ± 0.10a	3.48 ± 0.13b	2.18 ± 0.16c	2.11 ± 0.13c	2.27 ± 0.13c	37.687	0.000
Potassium (%)	1.96 ± 0.06a	1.96 ± 0.12a	1.17 ± 0.06bc	1.06 ± 0.08c	1.38 ± 0.10b	22.507	0.000
Calcium (%)	2.23 ± 0.12a	1.44 ± 0.14b	0.59 ± 0.05c	0.73 ± 0.03c	0.74 ± 0.04c	55.795	0.000
Magnesium (%)	0.71 ± 0.04a	0.68 ± 0.03a	0.35 ± 0.01c	0.43 ± 0.02c	0.56 ± 0.04b	20.229	0.000

The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF)

Different letters in each line indicate significant differences ($P < 0.05$ by Duncan test) between land uses

Table 4 Mean (±SE; $n=16$) of the soil physicochemical and biological features analyzed

Soil features	Land use					Summary ANOVA results	
	VNF	ASP	QCP	CSP	DNF	*F* test	*P* value
Physicochemical features							
Water content (%)	38.33±1.80a	36.32±1.95a	42.50±2.68a	41.80±2.51a	29.46±1.28b	6.180	0.000
pH (1:2.5 H_2O)	7.22±0.05a	7.07±0.07a	6.16±0.10b	6.48±0.20b	6.45±0.17b	10.820	0.000
EC (ds/m)	0.30±0.00a	0.28±0.00a	0.17±0.00b	0.19±0.02b	0.19±0.01b	17.446	0.000
Organic C (%)	4.39±0.24a	4.00±0.26a	4.59±0.55a	4.12±0.72a	2.20±0.13b	4.659	0.002
Total N (%)	0.47±0.02a	0.39±0.03b	0.24±0.02c	0.24±0.03c	0.23±0.01c	14.801	0.000
C/N ratio	9.20±0.18c	10.54±0.43c	18.29±0.77a	16.30±0.86ab	14.88±1.01b	28.520	0.000
Available P (mg kg^{-1})	28.71±1.56a	22.61±1.42b	13.48±0.86c	15.73±2.71c	12.65±0.63c	18.082	0.000
Available K (mg kg^{-1})	422.50±20.99a	319.03±15.90b	173.83±11.61d	224.56±28.26 cd	242.56±18.86c	23.640	0.000
Available Ca (mg kg^{-1})	241.00±16.44a	227.59±13.34a	124.10±9.29c	185.12±22.02b	178.12±10.64b	9.393	0.000
Available Mg (mg kg^{-1})	59.56±1.21a	53.75±3.41a	37.34±2.36b	38.06±4.47b	37.75±1.45b	13.679	0.000
Biological features							
Earthworm density (N m^{-2})	2.43±0.42a	2.12±0.46a	0.18±0.10b	0.18±0.08b	0.06±0.01b	16.349	0.000
Earthworm dry mass (mg m^{-2})	27.44±6.07a	23.39±4.81a	1.76±1.02b	1.72±0.96b	0.53±0.09b	14.132	0.000
Acarina density (N m^{-2})	91,851.37±2264.55a	85,810.43±1394.74a	66,551.06±60,985.18b	50,457.37±45,631.59c	22,331.56±17,020.11d	157.351	0.000
Collembola density (N m^{-2})	83,009.50±2516.37a	74,996.18±3047.51a	60,821.25±5469.19b	42,722.75±4447.59c	18,569.25±1926.21d	48.733	0.000
Total nematode (in 100 g soil)	650.00±41.86a	470.93±19.56b	205.75±17.26c	113.56±5.52d	85.62±3.56d	121.729	0.000
Protozoa density (×10^2 g soil)	921.25±23.37a	851.81±26.90a	657.93±38.54b	476.25±34.77c	261.85±37.07d	68.806	0.000

The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF)

Different letters in each line indicate significant differences ($P<0.05$ by Duncan test) between land uses

Discussion

Plants can affect soil food webs through the resources they provide for decomposers and other root-associated organisms (Bayranvand et al. 2017a). In addition, the density of a canopy cover can have an effect on soil fauna as seen in our data. This might indicate that the assemblage of the studied fauna (i.e., earthworm, acari, collembola, nematode and protozoa) is more likely under shady conditions, presumably because of the better microclimate created by the tree shade (Sarlo 2006; Sabrina et al. 2009) in summer. Accordingly, forest degradation, following decreased canopy cover, created inappropriate climate for activity of these soil organisms under the DNF site. Forest types and tree species affect forest floor thickness, thereby affecting soil fauna density also. The forest floor layer is essential for soil organisms as it functions as both habitat and food resource (Erdmann et al. 2012). However, plant species vary in palatability to consumers as well as quality and quantity of the forest floor they produce (Maharning et al. 2009), influencing the soil food web (Wardle 2002). Forest floor quality, which is one of the several drivers of nutrient cycling in forests, has an important role in soil fauna activities (Holly et al. 2009). In the present study, earthworms, micro-arthropods (acarina and collembola), nematodes and protozoa population were decreased under QCP, DNF and CSP sites, influenced by forest floor chemistry including lower N (Salamon et al. 2004), higher C and C/N ratio (Rodríguez-Arrieta and Retana-Salazar 2010) and less nutrient elements (Salamon et al. 2004). The presence of N-fixing bacteria associated with *A. subcordata* is believed to enhance decomposition (Milcu et al. 2008; McLaren and Turkington 2010), soil fertility

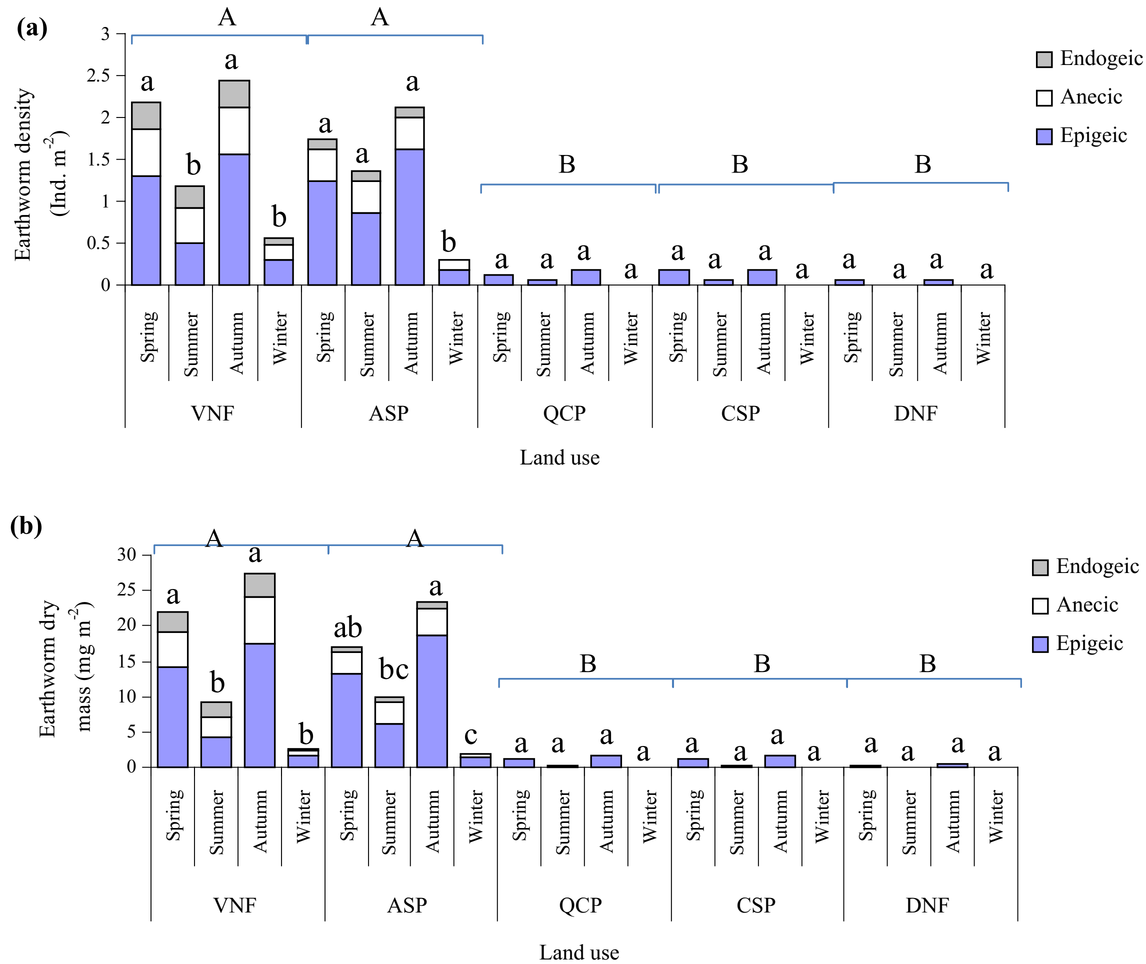

Fig. 2 Mean values of epigeic, anecic and endogeic density (**a**) and dry mass (**b**) in different seasons under five land uses. The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF). For earthworm density, land use ($F=48.170$; $P=0.000$), season ($F=13.442$; $P=0.000$) and Lu × S ($F=3.553$; $P=0.000$). For earthworm dry mass, land use ($F=38.955$; $P=0.000$), season ($F=17.566$; $P=0.000$) and Lu × S ($F=5.081$; $P=0.000$). Different capital and lowercase letters indicate significant differences ($P<0.05$ by Duncan test) between land uses and seasons, respectively

(Taleshi et al. 2009) and fauna feeding activity (Birkhofer et al. 2011). Soil fauna like earthworms (Milcu et al. 2008) and collembola (Salamon et al. 2004) benefited from the presence of N-fixing bacteria. Similar to collembola, acarina mainly feeds on plant material and microorganisms (Behan-Pelettier 1999) and are therefore likely to be affected by resource quality pertaining to plant functional groups or single plant species. According to our findings, based on PCA output (Fig. 6), forest floor quantity and chemistry can generate microhabitat variability, in different land uses, which may affect the demographic pattern of edaphic fauna assemblages (Ilieva-Makulec et al. 2006; de Moraes et al. 2011; Wissuwa et al. 2013; Sigurdsson and Gudleifsson 2013).

Our results revealed an increase in soil fauna activities where soil pH was higher under the VNF and ASP sites while this amount declined when soil pH was lower under the other studied sites. According to Korboulewsky et al. (2016) report, earthworms are less density and mass where a soil is acidity. Several studies have shown that microarthropod communities are related to soil acidity (Cassagne et al. 2003; Migge-Kleian et al. 2006; Erdmann et al. 2012) in forest ecosystems. In a study conducted in Iowa and Wisconsin (USA), it was demonstrated that nematode population densities are often the highest in soils with pH 7.0 or higher as compared to soil with pH between 5.9 and 6.5 (Matute 2013), thus confirming our data. A similar conclusion was reached by Rqnn et al. (2001), who found evidence that soil pH had a direct effect on soil protozoa. The differences in soil fauna activities in the present study can also be related to differences in soil fertility (Sabrina et al. 2009; Mariappan et al. 2013; Crumsey

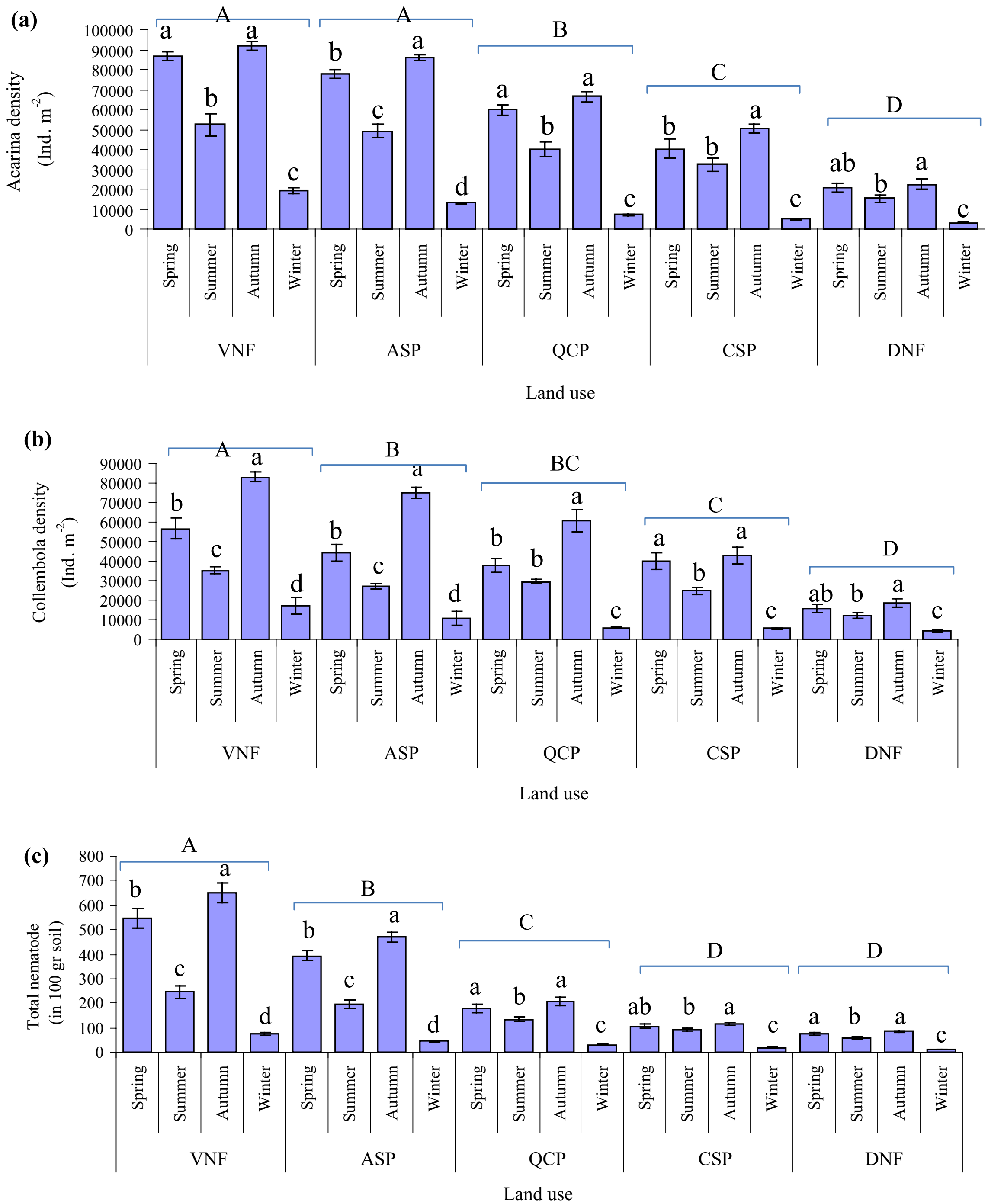

Fig. 3 Mean values (±SE; $n=16$) of acarina (**a**), collembola (**b**) and nematode (**c**) population in different seasons under five land uses. The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF). For acarina density, land uses ($F=210.838$; $P=0.000$), season ($F=426.011$; $P=0.000$) and Lu × S ($F=16.877$; $P=0.000$). For collembola density, land use ($F=73.523$; $P=0.000$), season ($F=209.948$; $P=0.000$) and Lu × S ($F=10.362$; $P=0.000$). For total nematode, land use ($F=243.677$; $P=0.000$), season ($F=236.875$; $P=0.000$) and Lu × S ($F=35.400$; $P=0.000$). Different capital and lowercase letters indicate significant differences ($P<0.05$ by Duncan test) between land uses and seasons, respectively

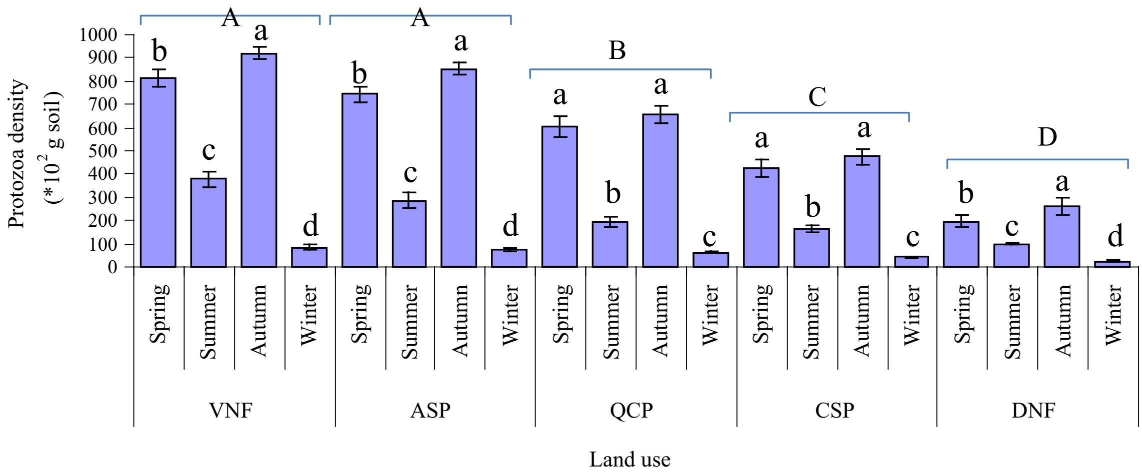

Fig. 4 Mean values (±SE; $n=16$) of soil protozoa density in different seasons under five land uses. The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF). For protozoa density, land use ($F=139.511$; $P=0.000$), season ($F=492.444$; $P=0.000$) and Lu×S ($F=19.140$; $P=0.000$). Different capital and lowercase letters indicate significant differences ($P<0.05$ by Duncan test) between land uses and seasons, respectively

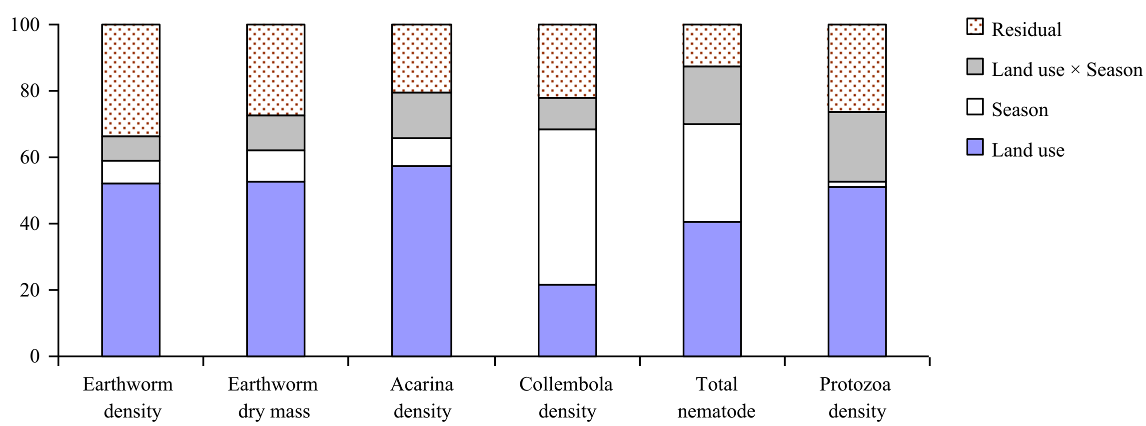

Fig. 5 Contribution (%) of independent single factors "land use," "season" and the combination of both "land use + season" to variation of soil fauna by application of two-way ANOVA test

et al. 2013). The VNF and ASP sites with good quality of forest floor improved soil fertility (Fig. 6). This can boost soil fauna activities. Based on Erdmann et al. (2012) and Kohyt and Skubała (2013) reports, acarina can reach high densities in fertile soils. Our results showed a positive relationship between collembola and basic cations (K, Ca and Mg) as already stated by Cassagne et al. (2003). In addition, more assemblage of nematodes in forest sites, in our study under VNF ecosystem, can be related to higher amounts of soil nutrient elements (Li et al. 2010; Sun et al. 2013). Hasegawa (2001) and Bedano et al. (2006) stated that soil organic matter is a limiting factor in forest soils with low organic resources where most plant residues are removed through degradation. Hence, there is no food resource for soil organisms. Our findings showed that forest degradation reduces the litter mass as well as soil fertility sources. This tends to make the soil quality poorer.

Input of residues is the key factor affecting the soil biota's population density (Elfstrand et al. 2008). The abundance of fresh forest floor reaches a peak in late autumn and decomposes rapidly during the first 4 months despite the fact that the mean temperature at the soil surface is low (Šnajdr et al. 2011). More resource inputs could lead to greater soil organic N concentration, microbial activity and fauna population (Ge et al. 2014). Soil water conditions have been recognized as one of the most important factors in the soil environment and affects survival, virulence and persistence of different soil biota such as earthworms, micro-arthropods, nematodes and protozoa (Grant and Villani 2003; Choi et al. 2006; Franco et al. 2017). In the present study (Fig. 6), drier

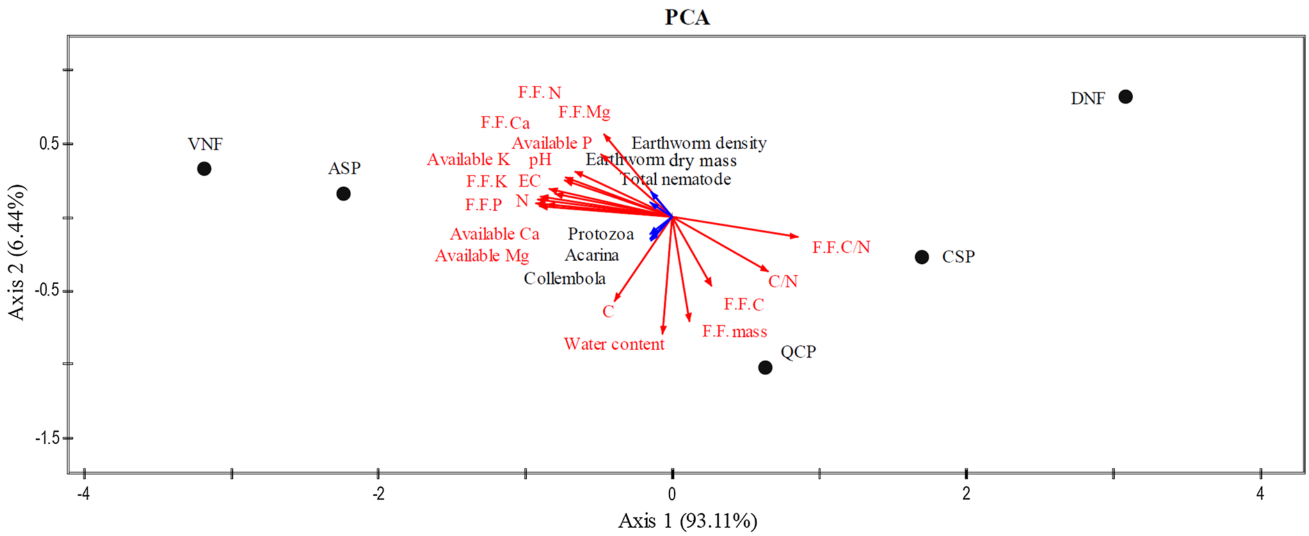

Fig. 6 PCA based on the correlation matrix of the land use, forest floor (F.F.), soil physicochemical and biological features. The studied land uses were virgin natural forest (VNF), *Alnus subcordata* C.A.M. plantation (ASP), *Quercus castaneifolia* C.A. Mey plantation (QCP), *Cupressus sempervirens* var. horizontalis plantation (CSP) and degraded natural forest (DNF)

soils in the DNF site significantly had less soil fauna population, whereas enhanced soil water availability under the natural vegetation and plantations could have provided better microenvironments for soil organisms (Song et al. 2016). Similarly, to our findings, Mohammadnezhad Kiasari et al. (2009) and Suthar (2012) showed that earthworm numbers is highest in autumn and declines sharply in winter. Low physiological activity and winter temperatures are likely to limit earthworm activity. In the subsequent spring, earthworms reappeared and showed a moderate population density, and the number again declined in early summer and virtually disappeared in winter. In the rainy season, earthworms reappeared in the topsoil layers and newly hatched sub-adults were also seen during the period. The population abundances observed during the rainy season showed continuous increase of earthworms up to autumn (Suthar 2012). Among the factors responsible for earthworm distribution in this study, soil moisture content seems to be of major importance as it has been observed in other studies (Crumsey et al. 2013). Soil moisture and soil temperature are usually inversely correlated in this climatic zone and act synergistically to influence earthworm activity (Day and Chaudhur 2014). Indeed, maximum earthworm activity was recorded in autumn and spring, when the soil moisture and soil temperature were favorable, whereas in summer, the driest and warmest period, earthworm population reduce. Crumsey et al. (2013) also showed that soil water content had significant effects on the number of earthworm species and was a stronger driver of earthworm ecological groups as well as pH or soil organic carbon. Furthermore, we also observed differences in earthworm diversity with higher presence of the epigeic variety compared to anecic and endogeic earthworms. This may be related to the deep burrowing ability of anecic and endogeic earthworms, a hypothesis supported by previous studies (Jégou et al. 2001; Uvarov 2009). This could also partly explain the low dispersal rates by these anecic and endogeic earthworms in the top soil (0–15 cm) under different tree species and seasons, because of their activity in the lower layers of the soil.

According to Rodríguez-Arrieta and Retana-Salazar (2010) report, there was an increase in the micro-arthropods (acarina and collembola) population in the rainy season and a fall in the driest months; this increase again started in the beginning of the forthcoming rainy season. In agreement with our results, Paul et al. (2011) and Kooch (2012) indicated that soil moisture gradient and changes in soil temperature play a significant role in seasonal fluctuation and distribution of soil protozoa and nematode densities in forest sites, with population increased during autumn and spring but decreased in summer and winter. Kuikman and Van Veen (1989) emphasized that protozoa are aquatic organisms. Hence, their mobility, feeding and growth in terrestrial ecosystems will depend upon their ability to cope with the fluctuating moisture conditions. Generally, it seems that the abundance of all faunal groups decreases with drought. Changes in the soil fauna also influence the functions of an ecosystem, e.g., decomposition and nitrogen cycling (Xu et al. 2012). It can be concluded that environmental factors such as high soil organic matter, proper soil moisture conditions throughout the year, soil temperature without extreme heat during summer, near neutral pH levels, and low incident of radiation due to plant cover are favorable conditions for soil fauna development. It is well known and documented that a high quality of litter layer is usually beneficial for most soil animal groups (Bandyopadhyaya et al. 2002) and that biodiversity is relatively strongly linked to available energy resources and essential nutrients (Bedano et al. 2005).

Conclusion

Our results indicate that land degradation strongly decreases the density of earthworms, acarina, collembolas, nematodes and protozoa, but land restoration practices, especially the use of *Alnus subcordata*, may increase the density of soil surface-active fauna similar to a virgin forest. The rapid assessment of these invertebrate groups may become a powerful tool to evaluate the biological status of degraded and restored lands. As a consequence, the findings of this study suggest that protection of a natural forest is of utmost importance. In addition, *A. subcordata* which is an N-fixing species and growth of suitable native broadleaved species have been proposed to rehabilitate degraded natural forests.

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