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Soil quality and mesofauna diversity relationship are modulated by woody species and seasonality in semiarid oak forest

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ABSTRACT

The relationships between woody species, soil biota activity and soil quality were largely ignored in semi-arid areas. This study evaluated the influence of life form and seasonal variation on the mesofauna activity and soil chemical and microbial properties under three tree species (*Quercus brantii* (QU), *Acer monspessulanum* (AC) and *Pistacia atlantica* (PI), and three shrub species (*Crataegus puntica* (CR), *Amygdalus scoparia* (AM) and *Lonicera nummularifolia* (LO)) in a semiarid oak forest in western Iran. Soils were sampled beneath each individual woody species in spring and winter. Soil chemical and biological properties and soil mesofauna diversity were measured and soil quality index (SQI) was produced. The comparison of soil chemical properties under tree and shrub species showed that only soil total nitrogen (Ntot), available potassium (Kava) and soil organic carbon (SOC) were significantly higher under trees than shrubs (respective mean values for spring: 0.31 vs 0.19%; 1304 vs 1103 mg/kg, 3.94 vs 3.16%). In contrast, all of the studied soil biological characteristics including microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), basal respiration (BR), and substrate induced respiration (SIR) were significantly higher under trees than under shrubs (respective mean values for spring in mg/kg soil/day: 603.5 vs 431.2, 49.6 vs 35, 46 vs 35 and 57.6 vs 36.5). Besides, we found clear seasonal and species effects for most soil properties. Values were higher in spring than in winter and were the most similar for QU and AC for tree species (especially due to the higher content of SOC and MBN under these species in spring) and for AM and LO for shrub species. The Shannon-Wiener diversity index and richness of the soil mesofauna were significantly higher under trees than under shrubs (respective mean values for spring: 1.59 vs 1.09 and 6.5 vs 3.8). The Shannon-Wiener diversity and richness indices for soil mesofauna were positively linearly related to the soil quality index (SQI) in spring and winter. These relationships were weaker in winter than in spring and showed an increase of both indices from shrubs (LO, AM and CR) with low SQI values to trees (QU and AC) with higher SQI values. Based on these results, we conclude that these indices can be used as efficient soil bioindicators which can be helpful in restoration or conservation projects in semi-arid areas.

1. Introduction

Many terrestrial organisms, including trees and shrubs, are directly or indirectly dependent on soil's chemical and biological processes (Binkley and Fisher, 2013; Kleiber et al., 2019; Matei et al., 2020). At the same time, trees may also influence soil properties through plant remains and alteration of microclimatic soil conditions (Lucas-Borja et al., 2016). On this context, there is still insufficient basic information on the various soil biological and chemical systems associated with vegetation characteristics in many terrestrial ecosystems. This indicates the need for multiple studies and defining reference values for optimal ecosystem quality under different spatial and temporal environmental conditions (Ratcliffe et al., 2018). Semi-arid lands cover about 15 percent of the world's land area (Safriel et al., 2005). Forests in these

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areas contribute to maintain suitable conditions for human livelihood especially in providing wood and non-wood products. They also provide a shelter for the wildlife and flora and produce a wide range of ecosystem services such as water balancing, mitigation of the microclimate, limitation of erosion, carbon sequestration and soil fertility restoration (e.g. Malagnoux et al. 2008; Conti and Díaz, 2013; de Oliveira Silveira et al., 2019).

In different regions, especially in arid and semiarid regions, the presence of woody species has an undeniable role in creating efficient microclimates with multiple facilitating processes such as surface runoff reduction, seed trapping efficiency (Aerts et al., 2006), creation of fertile islands (Avendaño-Yáñez et al., 2018), facilitation of seedling establishment especially in degraded sites (Heydari et al., 2017a; Xie et al., 2017; Maltoni et al., 2019). Different woody species can have different effects on soil properties, in particular through soil carbon inputs and nutrients, due to differences in crown and root structure as well as differences in the quality and quantity of litter and root exudates (Prescott, 2002; Liu et al., 2019a). Therefore, the spatial distribution of different wood species on the horizontal surface of the forest makes the forest floor conditions heterogeneous in terms of different environmental factors such as moisture, temperature and litter depth. This leads to the creation of various microhabitats (Prescott and Grayston, 2013) that can affect nesting, diversity and activity of organisms within and on soil surface (Tedersoo et al., 2016; Gallé et al., 2017) as well as physical, chemical and biological soil properties (Waring et al., 2016). For example, Prescott and Grayston (2013) stated that the stabilized carbon produced by trees enters the forest ecosystem with different mechanisms and that the chemical differences of these carbon pools between different species greatly determine the composition, diversity and the abundance of soil biota. Vegetation distribution therefore influences soil quality which is defined as the soil's continued capacity in providing life bedding (Karlen et al., 1997) and which depends on soil physical, chemical and biological properties and their interactions (Karlen et al., 2003; Ratcliffe et al., 2018). In fact, in order to implement a sustainable soil management, it is necessary to evaluate soil quality. Soil quality is one of the three ingredients of environmental quality, besides water and air quality (Bunemann, et al. 2018; Nguemezi, et al. 2020). It is broadly defined as "the capacity of a soil to function in ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994). The complexity and site-specificity of the belowground part of forest ecosystems and also connection between soil indicators and soil-based services can be reflected by this definition. At this point, plant and soil properties may be used together in a soil quality index aiming to determine proper semiarid ecosystems characteristics related to a high environmental quality. Biomass and tree growth are common traditional indicators of soil quality (Schoenholtz et al., 2000), but physical and chemical soil properties such as soil bulk density, soil acidity and nutrient levels are increasingly used (Bünemann et al., 2016). However, changes in these properties as indicators of soil quality can be relatively slow over time, and therefore may not reflect short-term changes in soil quality (Kirschbaum, 2000). Therefore, these indicators might not be as efficient as traditional ones to reflect a high temporal and spatial variability (Doran and Zeiss, 2000). However, the close relationships between soil biological properties and soil processes and their high sensitivity to environmental changes as well as their relatively low cost and rapid evaluation explain a growing interest for this category of soil quality indicators (Dhyani et al., 2019; Moghimian et al., 2019).

Soil quality indicators can also be defined using ecological traits of the soil fauna. In fact, the interactions between soil invertebrates and their ecological niches in the soil matrix indicate that these organisms usually have sedentary life and have a certain composition in different habitats and locations, so they can be useful bioindicators to reflect environmental conditions (Madzaric et al., 2018; Elie et al., 2018; Feng et al., 2019). This fact has prompted many scientists to evaluate soil conditions and quality with methods based on such soil bioindicators to monitor different processes such as land degradation, land recovery or and the influence of management actions on the ecosystem (Lima et al., 2017; Pelosi and Römbke, 2018). Thus, the characteristics of the soil faunal community are closely related to soil quality (Yan et al., 2012; Fusaro et al., 2018). Although some taxon groups are commonly used to monitor soil variation and quality (such as Acari and Collembola), the use of bioindicators for many other groups of soil organisms, in particular soil mesofauna, is still largely ignored (Menta and Remelli, 2020). Soil arthropods are an integral part of soils. These organisms are highly dependent on soil and environmental conditions for their nutrition and survival (Yan et al., 2012; Liu et al. 2019b) and represent a major component of the diversity of different terrestrial ecosystems (Majer et al., 2007; Marquart et al., 2020). They also play a major role in important soil processes including displacement, breaking and translocation of organic matter, nutrients cycle, soil structure and consequently water regulation (Yin and Koide, 2019; Menta and Remelli, 2020). Therefore, their contribution is vital in determining soil quality and guaranteeing sustainable production of terrestrial ecosystems (Stork and Eggleton, 1992). Among the soil arthropods, soil mesofauna with sizes ranging from 0.1 to 2 mm and with different diets (such as detritivores and predators) live in litter and the soil surface layer (Dar, 2009). Although this group of arthropods plays an important role in soil function (Morais et al., 2010), its role and relationships with different woody species are still poorly understood in many forest ecosystems (Young et al., 2018; Pressler et al., 2019). The high spatial heterogeneity of the forest in the horizontal dimension, such as the variation in canopy density, and vertical dimension, such as the variation in the quantity and quality of leaves and woody texture, create different microclimatic conditions and various microhabitats for arthropods (O'Brien et al., 2017). It should be noted that the effects of woody species on soil physical and chemical properties are moderated by soil fauna. In fact, soil arthropod fauna through the comminution of plant debris can accelerate and facilitate the effect of plant species on soil physical and chemical properties (Seastedt, 1984; Bagyaraj et al., 2016). For example, litter decomposition is for a part driven by soil arthropod fauna (Tresch et al., 2019) and there is a positive relationship between soil fauna species richness and decomposition (Nielsen et al., 2011) improving soil fertility (Culliney, 2013).

The preservation, restoration or monitoring of soil quality is an important challenge in arid and semi-arid forests, including Zagros forests in western Iran. These forests present a high heterogeneity in terms of species composition and canopy structure of woody species (Assal et al., 2016; Heydari et al., 2017a) which guarantees diverse ecosystem services and a high biodiversity level. However, these systems have been submitted to a high level of human pressure due to the strong livelihood dependence of people on forest resources. These anthropogenic disturbances, accentuated by climatic and land-use changes, have altered vegetation composition and eliminated many species in the forest habitats (Plieninger, 2006; Vallejo and Alloza, 2019; Moreno-Fernández et al., 2019). Having solid information about soil quality, which could be assessed by mesofauna diversity and composition, would help to correctly manage arid and semiarid environments. In this context, the restoration of habitat diversity depends on a better understanding of mesofauna - soil quality - woody species interactions (Latty et al., 2004; Campbell et al., 2009).

In this study, we have produced soil quality and soil mesofauna diversity indices in various conditions of vegetation and for different seasons in a semi-arid oak forest in western Iran. We have studied the relationships between the soil quality index and the soil mesofauna diversity indices to see to what extent both indicators are correlated. Previous reports have highlighted the close relationship between plant cover and activities of soil organisms in various sites (Bayranvand et al. 2017; Stroud, 2019). In fact, plants can provide different carbon and nutrient sources for soil organisms through the quality and quantity of organic matter as well as through the release of various substrates by roots. Consequently, the density and diversity of soil biota are known to vary widely in habitats with different plant types (Gastine et al. 2003a, b; Errington et al. 2018). In addition to type of vegetation cover, the activities of soil organisms are highly influenced by changes in biotic and abiotic factors due to seasonal changes (Cui et al. 2019). The changes in environmental conditions, i.e. temperature and moisture regimes, can strongly affect the dynamics of soil biological activities directly and, following that, nutrient cycling and site productivity (Ren et al. 2018). Investigations into the relationship between above and below- ground systems is an ambitious and aspiring area of research adding to the study of functional implications of vegetation forms (Bardgett et al. 2005). To the best of the authors' knowledge, to date, no studies have reported on the relationship between above-ground vegetation types and the activities of soil biota and quality at the semiarid areas in Iran.

The objective of this study was to evaluate soil quality and mesofauna diversity relationship in semiarid oak forests of western Iran which are considered as especially fragile and sensitive ecosystems. More specifically our working hypotheses are the following: a) The soil quality index and soil properties are differentially influenced by the life form (tree vs. shrub) and we expect higher values under trees than under shrubs. b) Soil quality index and soil properties values also vary with the season. In particular, the spring season is likely the most favorable for the mesofauna activity, which exerts a positive influence on most soil properties. c) There is a direct relationship between soil mesofauna diversity and soil quality index. It is hoped that the results would improve scientific approaches to further understand the mechanism of plant-soil feedback, and help in optimizing vegetation type management and enhance ecosystem services.

2. Material and methods

2.1. Site description

The study site is located in the Zagros forests (Sirvan city, western Iran) (Fig. 1). It is covered by 60 ha forest dominated by Persian oak (*Quercus brantii* L.) associated with some tree and shrub broadleaved species, such as *Acer monspessulanum* L. subsp. *cinerascens* (Boiss.) Yaltirik., *Pistacia atlantica* Desf., Crataegus puntica C. Koch., L., *Amygdalus scoparia* Spach., and *Lonicera nummularifolia* Jaub & spach. In this forest area, there was a long history of anthropogenic disturbances over the last half-century related to the high dependence of people's livelihood on oak forest services and functions such as grazing and fuelwood demands (Heydari et al., 2012). After the change in national policy in 1963, private administration shifted to governmental management (Sotoudeh Foumani et al., 2017) and the study area was protected by the office of the natural resources. Currently, the vegetation in the area is an opened forest with a discontinuous patchy tree and shrub cover. The ground vegetation is relatively dense and composed of annual and perennial grasses and forbs, such as *Bromus tectorum* L., *Astragalus adscendens* Boiss., *Gundelia turneffortii* L., *Geranium lucidum* L., *Hordeum bulbosum* L., *Alyssum marginatum* Steud. ex Boiss., *Avena wiestii Steud, Medicago radiata* L., *Valerianella vesicaria* Moench and *Neslia apiculata* Fisch. The physiographic conditions are homogenous on the site (slope < 10% and altitude 1900–2000 m a.s.l.). The average annual precipitation is 428.8 mm and the average annual temperature is 18.55 °C (Sarableh climate station, 2009–2018). The dry season is between May and October. Soils are shallow with a sandy clay loam texture. Soils are calcareous with pH = 7.3–7.7 and lime content 20–37%.

2.2. Experimental design

We studied three tree species *Quercus brantii* (hereinafter indicated as QU), *Acer monspessulanum* L. (AC) and *Pistacia atlantica* Desf. (PI), and three shrub species, Crataegus puntica C. Koch. (CR), *Amygdalus scoparia* Spach. (AM) and *Lonicera nummularifolia* Ja ub & spach. (LO). We then sampled five patches (≈ 55–240 m^2 canopy cover) included 4–5 individuals of the same woody species) in each species (total of 30 patches), i.e. small groups of individuals of the same species and of the same size. The minimum distance between two neighboring patches was 40 m.

Between patches of the same species, the size was also kept the less variable as possible. Sampling was done at two seasons, spring (May) and winter (December) 2018 (beginning and end of the growing season), using the same patches. Within each patch, beneath the canopy of the central individual, three soil cores were randomly extracted at 0–25 cm depth using a cylindrical extractor with an area of 314 cm^2. The three soil cores were mixed into a composite sample for the analysis of the mesofauna. Immediately after sampling, the samples were stored in plastic bags for subsequent analyses. Samples were then placed into a Berlese funnel to extract the terrestrial arthropods. Arthropods

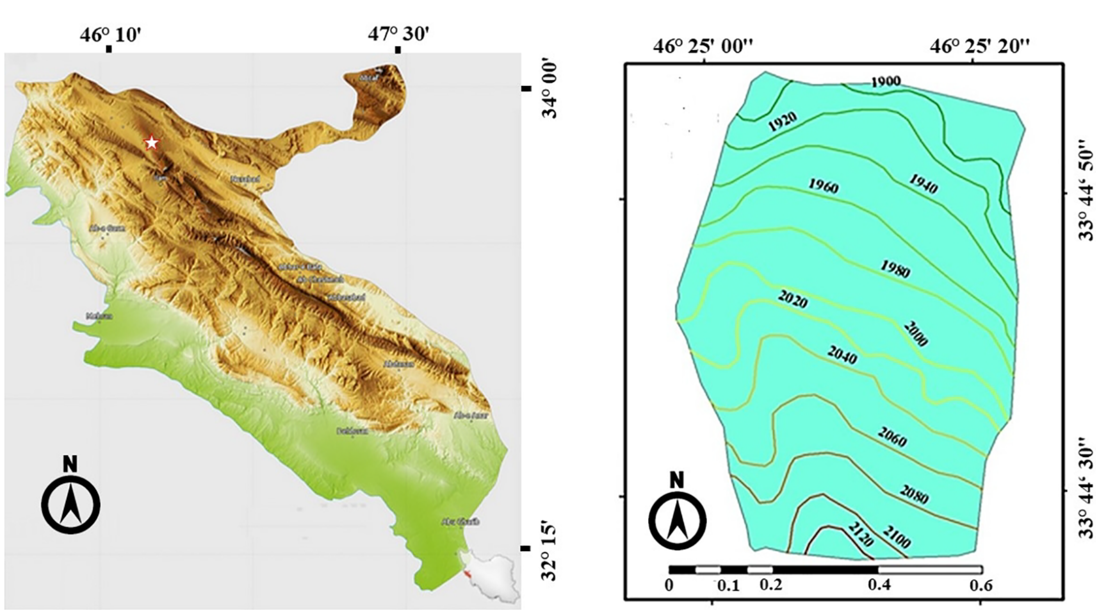


Fig. 1. The location of the study site (☆) in Ilam province in western Iran.

Table 1
Results of GLMs testing for season (SE: spring and winter), species (SP: *Quercus brantii*, *Acer monspessulanum*, *Pistacia atlantica*, *Crataegus pontica*, *Amygdalus scoparia*, *Lonicera nummularifolia*) and growth form (tree and shrub) effects on soil properties. Significant P > -values at P < 0.05 are indicated in bold.

Source	**SQI**				**pH**			**EC (dS/m)**		
	df	*MS*	*F*	*P*	*MS*	*F*	*P*	*MS*	*F*	*P*
SE	1	0.04	11.92	**0.001**	0.091	16.674	< **0.001**	0.254	4.673	0.056
SP	5	0.04	13.01	< **0.001**	0.090	16.354	< **0.001**	0.037	0.671	0.516
GF	1	0.52	168.02	< **0.001**	0.011	2.048	0.159	0.015	0.268	0.607
SE × SP	5	0.003	0.89	0.42	0.003	0.522	0.597	0.023	0.422	0.658
SE × GF	1	0.003	0.84	0.36	0.000	0.019	0.890	0.078	1.434	0.237
SP × GF	5	0.01	2.77	0.07	0.036	6.556	**0.003**	0.041	0.757	0.474
SE × SP × GF	5	0.005	1.75	0.19	0.039	7.190	**0.002**	0.048	0.876	0.423
	Ntot (%)				**SOC (%)**			**Pava (mg/kg dry soil)**		
SE	1	0.23	12.08	< **0.001**	1.87	14.59	< **0.001**	1266.28	240.16	< **0.001**
SP	5	0.31	6.03	**0.002**	30.47	237.59	< **0.001**	145.41	27.59	< **0.001**
GF	1	119.99	16.61	< **0.001**	6.24	48.66	< **0.001**	5.00	0.95	0.335
SE × SP	5	0.05	7.48	**0.001**	0.11	0.87	0.42	26.44	5.02	**0.011**
SE × GF	1	0.74	14.63	< **0.001**	0.27	2.07	0.15	0.43	0.08	0.775
SP × GF	5	0.98	1.24	0.0421	1.78	13.84	< **0.001**	18.59	3.53	**0.037**
SE × SP × GF	5	0.60	6.59	**0.003**	0.07	0.55	0.58	25.79	4.89	**0.012**
	Kava (mg/kg dry soil)				**WC (%)**			**BR ($mg.kgsoil^{-1}.day^{-1}$)**		
SE	1	3638.52	0.23	0.633	1783.84	63.572	< **0.001**	9300.150	929.5	< **0.001**
SP	5	18617.15	1.18	0.316	561.28	20.003	< **0.001**	358.190	35.798	< **0.001**
GF	1	1,139,006	72.11	< **0.001**	2592.62	92.395	< **0.001**	74.951	7.491	**0.009**
SE × SP	5	99049.01	6.27	**0.004**	321.59	11.461	< **0.001**	207.994	20.787	< **0.001**
SE × GF	1	82203.50	5.20	**0.027**	507.29	18.079	< **0.001**	171.501	17.140	< **0.001**
SP × GF	5	330557.8	20.93	< **0.001**	131.03	4.669	**0.014**	55.477	5.544	**0.007**
SE × SP × GF	5	100393.8	6.36	**0.004**	146.13	5.208	**0.009**	13.472	1.346	0.270
	MBC ($mg.kgsoil^{-1}$)				**MBN ($mg.kgsoil^{-1}$)**			**SIR ($mg.kgsoil^{-1}.day^{-1}$)**		
SE	1	375.420	0.07	0.785	480.22	13.76	**0.001**	4034.24	140.9	< **0.001**
SP	5	120426.6	24.03	< **0.001**	220.12	6.31	**0.004**	523.27	18.278	< **0.001**
GF	1	676635.9	135.03	< **0.001**	2096.71	60.07	< **0.001**	3002.91	104.8	< **0.001**
SE × SP	5	17973.7	3.59	**0.035**	67.01	1.92	0.158	226.58	7.915	**0.001**
SE × GF	1	19305.3	3.85	0.055	113.67	3.26	0.077	602.49	21.046	< **0.001**
SP × GF	5	20567.4	4.11	**0.023**	338.40	9.70	< **0.001**	7.79	0.272	0.763
SE × SP × GF	5	60021.0	11.98	< **0.001**	115.16	3.30	**0.045**	126.14	4.406	**0.018**

SQI: soil quality index, pH: Soil acidity, EC: electrical conductivity, SOC: soil organic carbon, Pava: P available phosphorus, Kava: K available potassium, WC: water content, BR: basal respiration, SIR: substrate-induced respiration, MBN: microbial biomass nitrogen, MBC: microbial biomass carbon.

mesofauna were identified at the species level using standard taxonomic keys and reference slides (Mirab-balou et al., 2011; Ramroodi et al., 2014; Nassirkhani et al., 2017).

2.3. Chemical and biological soil properties and soil quality index

Using the same sampling procedure, we also prepared one composite soil sample per patch (0–25 cm depth, 314 cm^2) for chemical and microbial analyses. Soils were placed in hermetic boxes and immediately brought to the laboratory. Soils were sieved through a 2 mm mesh and split into two sub-samples. One subsample was stored at 4 °C at its water content to measure soil microbial activity. The second subsample was air-dried to measure soil chemical properties. Soil water content, soil organic carbon (SOC), total nitrogen (Ntot), soil pH, electrical conductivity (EC), available phosphorus (Pava), available potassium (Kava), microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), basal respiration, substrate induced respiration (SIR) were analyzed base on standard methods (see Heydari et al., 2017b) in Ilam university soil laboratory. These measurements were used as soil indicators affecting soil quality as shown in many previous studies (Mukhopadhyay et al., 2016; Rasouli-Sadaghiani et al., 2018). Because of different indicator units, each indicator was transformed and normalized to a value between 0 and 1.0 using Fuzzy membership function (Liu et al., 2013). The weight for each indicator was assigned by standardized factor analysis based on its communality (Shukla et al., 2006). In factor analysis method, the communality of each indicator was calculated and then the ratio of its communality to cumulative communality of all indicators was considered as weight of each indicator. After computing the weight, the quality index for each soil sample was calculated using weighted additive integrated soil quality index (SQI_{WA}) according to the following equation (Cherubin et al., 2016):

$$SQI_{WA} = \sum_{i=1}^{n} W_i \times N_i$$

where SQI_{wa} is the weighted soil quality index, Wi is the weight of each soil attribute, Ni is the score of each soil attribute and n the number of soil attributes.

2.4. Soil mesofauna composition and diversity

We computed the following indices for the mesofauna: richness (*SR*), diversity (*H’*, Shannon and Wiener, 1949) and evenness (*J’*, Pielou, 1966) using the equations shown below:

$$SR = S \quad (1)$$

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \quad (2)$$

$$E = H'/ln(S) \quad (3)$$

where p_i is the proportion of species ‘*i*’, *N is* the total number of individuals and *S is* the total number of mesofauna species.

2.5. Statistical analysis

The effects of woody species (SP), growth form (GF, tree and shrubs) and seasons (SE, spring and winter) and their interaction on soil properties and diversity indices of soil mesofauna were tested using general linear models (GLMs). Post-hoc Duncan's Multiple Range tests were used to compare the means. The stepwise discriminant analysis (SDA) was applied to achieve linear combinations of the soil properties that best separated the woody species. In order to select the variables that entered in the equation, the Wilks' lambda statistic was used. Entry and removal of soil variables resulted from the tests of the associated F-statistics. Then, a matrix of pairwise F-ratios for each pair of woody species was used according to the selected soil variables after each step. Scores were calculated for each discriminant function (DF) and visualized by plotting DF2 against DF1. The associated classification matrix was used to determine the predictive accuracy of the discriminant functions (Heydari et al., 2017b). Prior to the analyses, the variables were transformed when necessary to satisfy assumptions of normality and homoscedasticity of residuals. Linear regression used for indicting relationships between soil quality index (SQI) and total mesofauna diversity indices. Statistical analyses were carried out in SPSS (version 21.0).

3. Results

3.1. Variation of the soil quality index and soil properties according to the life form and the season

Soil quality index was significantly influenced by species, season and growth form (Table 1). It was higher beneath trees than shrubs with the highest value for QU and the lowest for AM (Fig. 2). Soil quality index value was higher in spring than in winter but was only significant for AM. Soil moisture content under trees was significantly higher than under shrubs. It was also significantly higher in spring than in winter only for *Quercus brantii*, *Acer monspessulanum* and *Crataegus pontica*. Soil pH values did not significantly vary between trees and shrubs but were higher in spring than in winter for some trees (*Acer monspessulanum* and *Pistacia atlantica*) and for some shrubs (*Crataegus pontica*). Similarly, Ntot, organic carbon, and potassium were higher under trees than under shrubs. In contrast, the other chemical properties (except phosphorus) did not show a significant difference between the two seasons whatever the woody species. Phosphorus content was higher in spring than in winter for all species. Soil biological indices (BR, SIR, MBN and MBC) were significantly higher under tree species than shrubs and higher in spring than in winter particularly for BR. In contrast, we found no difference under shrubs for SIR (except for CR) and MBN and under trees for MBC (Fig. 2 and Table 1).

3.2. Classifying the woody species based on soil properties

The results of SDA (stepwise discriminant analysis) showed that the set of soil properties including WC, SOC, Ntot, Kava, BR, SIR, MBC and MBN best separated woody species in both seasons (Table 2). Examination of the pairwise *F*-ratio matrices for each pair of woody species showed that these species were significantly separated at step 1 and step 2 in both seasons. Based on the selected variables, two significant functions were obtained in spring with respective eigenvalues of ($\lambda_1 =$) 9.19 and ($\lambda_2 =$) 4.11, which explained 73.8% and 17.1% of the total variance, respectively. In winter, eigenvalues were ($\lambda_1 =$) 8.13 and ($\lambda_2 =$) 3.15 which explained 59.8% and 19.23% of the total variance, respectively. According to the standardized coefficients of each variable, the best functions to separate the woody species in spring included WC, SOC, Ntot, SIR, and MBN in function 1, and Kava, SOC, Ntot, BR, SIR and MBC in function 2, (Table 2). In winter, Kava and MBC in function 1, versus WC, SOC, Ntot, BR and SIR in function 2, were best able to separate woody species (Table 2). According to almost a similar pattern, QU and AC were effectively separated from the shrubs (AM and LO) along DF1, while PI and CR separated along DF2 in both seasons (Fig. 3). QU and AC were closer to each other in the discriminant ordination in spring compared to winter, indicating similar understory soil conditions (Fig. 3). Besides, shrubs AM and LO were gathered in both seasons especially in winter. Totally, the pattern is similar in both seasons, but it is clearer in winter.

3.3. Influence of the species, life form and the season on the soil mesofauna diversity indices

The Shannon-Wiener diversity and richness indices of top soil mesofauna were significantly influenced by species identity (six woody species), growth forms (tree vs. shrubs) and the interaction between species identity, growth forms and sampling seasons while the Pielou evenness was only significantly ($P < 0.05$) influenced by the interaction between seasons, species identity and growth forms (Table 3). The Shannon-Wiener diversity index and richness of the soil mesofauna were significantly higher under trees than under shrubs (Fig. 4). In addition, in both seasons, the Shannon-Wiener diversity index and the richness were significantly higher under both trees QU and AC than under shrubs and PI. Significant differences between both seasons were only observed under AC and PI with higher values in spring than in winter except for richness under PI (Fig. 4).

3.4. Relationships between soil quality index (SQI) and mesofauna diversity indices

The Shannon-Wiener diversity and richness indices for soil mesofauna were positively related to the soil quality index in spring and winter. These relationships were weaker in winter than in spring (Fig. 5). They showed an increase of both indices from shrubs (LO, AM and CR) with low SQI values to trees (QU and AC) with higher SQI values. In contrast, we did not find any significant relationship between Pielou's evenness index and the soil quality index in both seasons (Fig. 5).

4. Discussion

4.1. Influence of vegetation life form and species on soil properties

The life form of vegetation types plays a prominent role for ecosystem functions, determining primary production, organic matter decomposition, and nutritional cycles (Gastine et al. 2003a, b; Balvanera et al. 2006). In addition, changes in vegetation types can cause variability of soil properties that in further consequence can strongly influence abundance and activities of soil biota (Decaëns et al. 2004; Cui et al. 2019). The impact of plant covers on soil properties can be assigned to both the quantity and quality of organic matter input into a soil ecosystem (Zhang et al. 2015). Actually, soils are the most diverse components of the biosphere and have distinguishing features and processes within them at the nano- and macro-scales. The spatial and temporal variability of organic matter input into soil, due to the presence of different plants, causes hotspot areas of different soil properties, especially biota activities, in terrestrial ecosystems (Zhang et al. 2015).

Comparison of soil properties under tree and shrub species showed that among the chemical soil properties only Ntot, Kava, and SOC were significantly higher under trees than shrubs. In contrast, all of the studied soil biological characteristics including MBC, MBN, BR and SIR were significantly higher under trees than under shrubs. These modifications of soil properties can be mainly explained by the differences in the quantity and the quality of the litter production (Kerdraon et al., 2019) resulting in contrasted patterns and rates of decomposition of the organic matter (De Groote et al., 2018; Mao et al., 2018). In fact, the current results emphasize the importance of the type, or source of organic inputs in the maintenance of soil biota providing various ecosystem functions (Bayranvand et al. 2017).

Contrary to our findings, previous reports (Gastine et al. 2003b; Salamon et al. 2004; Wardle et al. 2006) claimed that the type of aboveground vegetation has no remarkable effect on the soil properties and the activities of soil biota. Literature reviews suggest that there are

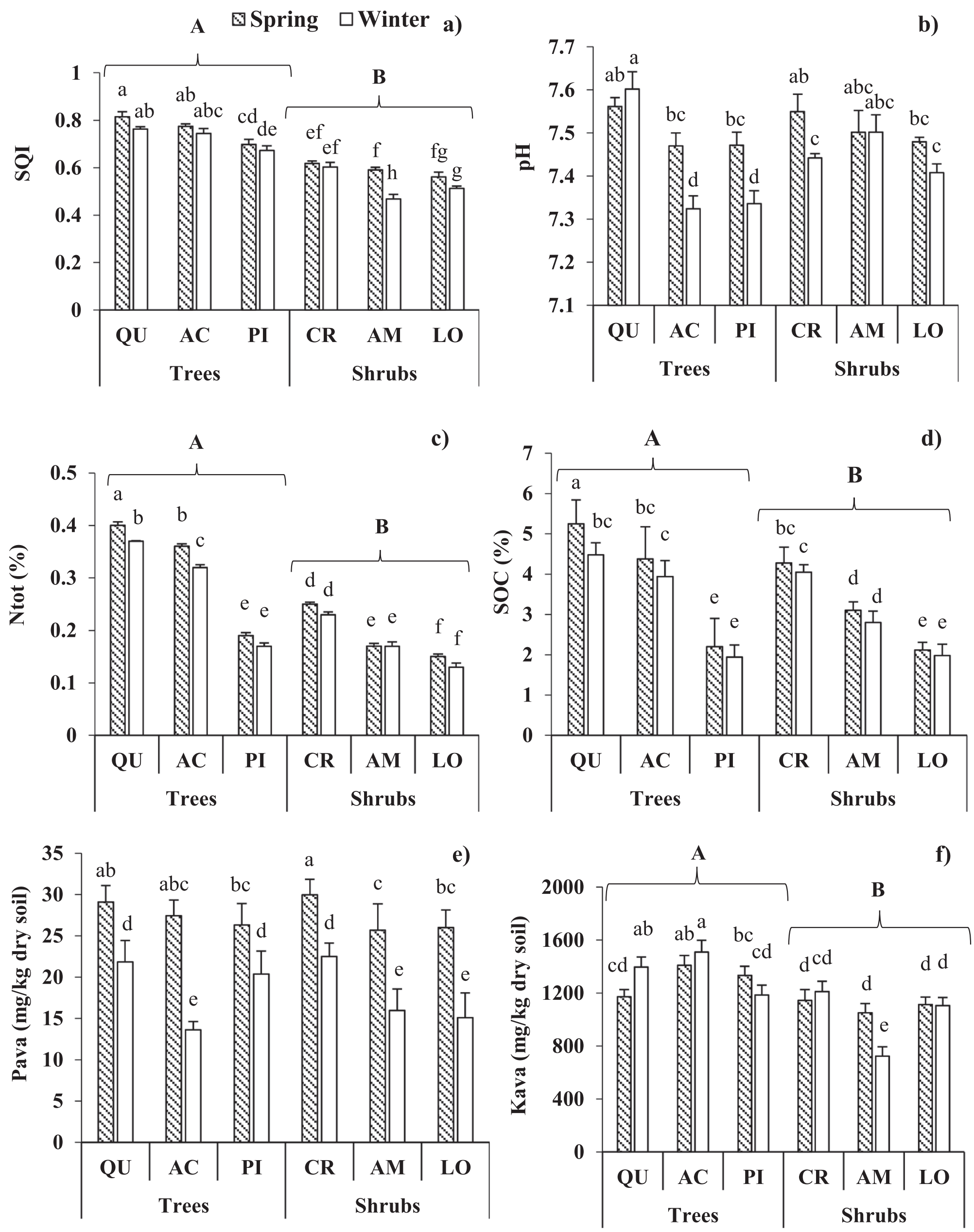


Fig 2. Differences in soil properties (mean ± standard error) according to the different woody species (QU: *Quercus brantii*, AC: *Acer monspessulanum*, PI: *Pistacia atlantica, CR: Crataegus pontica*, AM: *Amygdalus scoparia*, LO: *Lonicera nummularifolia*) and growth forms (tree vs. shrub) in the two seasons (spring and winter). Lowercase letters indicate significant differences between woody species based on Duncan's multiple range test ($p < 0.05$) while uppercase letters indicate differences between shrubs and trees; SQI: soil quality index (a), pH (b), Ntot: total nitrogen (c), SOC: soil organic carbon (d), Pava: P available phosphorus (e), Kava: K available potassium (f), WC: water content (g), BR: basal respiration (h), SIR: substrate-induced respiration (i), MBN: microbial biomass nitrogen (j), MBC: microbial biomass carbon (k).

contradictory records about the variability of soil properties and food preferences of soil organisms. Wardle et al. (2006) claimed that soil biota consume all kinds of plant residues and thus do not show reactions on different litter quality. Tiunov and Scheu (2004) emphasized that carbon availability is a limiting factor for the presence of soil organisms, while Martin and Lavelle (1992) suggested that nitrogen availability plays a decisive role. It is therefore, not exactly clear which components or fractions of the soil organic matter plays a more prominent role in promoting the activity of soil organisms (Briones et al., 2005). Consequently, predicting whether the life form of vegetation cover could affect the soil properties and activity of soil biota remains a complex and difficult task.

In the semi-arid Zagros forest ecosystem, large tree species such as QU and AC with their thick and broad crowns produced a larger quantity of litter than the shrubs. Soil biological activity has a direct relationship with soil organic carbon storage due to the high dependence of soil microbial activity on substrate carbon availability (DeForest, 2009). Therefore, with higher carbon storage under tree species than under shrubs, the basal respiration and the microbial biomass are enhanced. In addition, soil processes are also influenced by a large set of microclimatic factors, such as light availability, throughfall, air and soil temperature (e.g. Zhang et al., 2016; Hardiman et al., 2018; Giesbrecht et al., 2017) which are controlled for a part by the canopy architecture and phenophase of the species (Xu et al., 2019; Raddi and Magnani, 2019). For instance, soil temperature and humidity play an important role in the activity and metabolism of soil

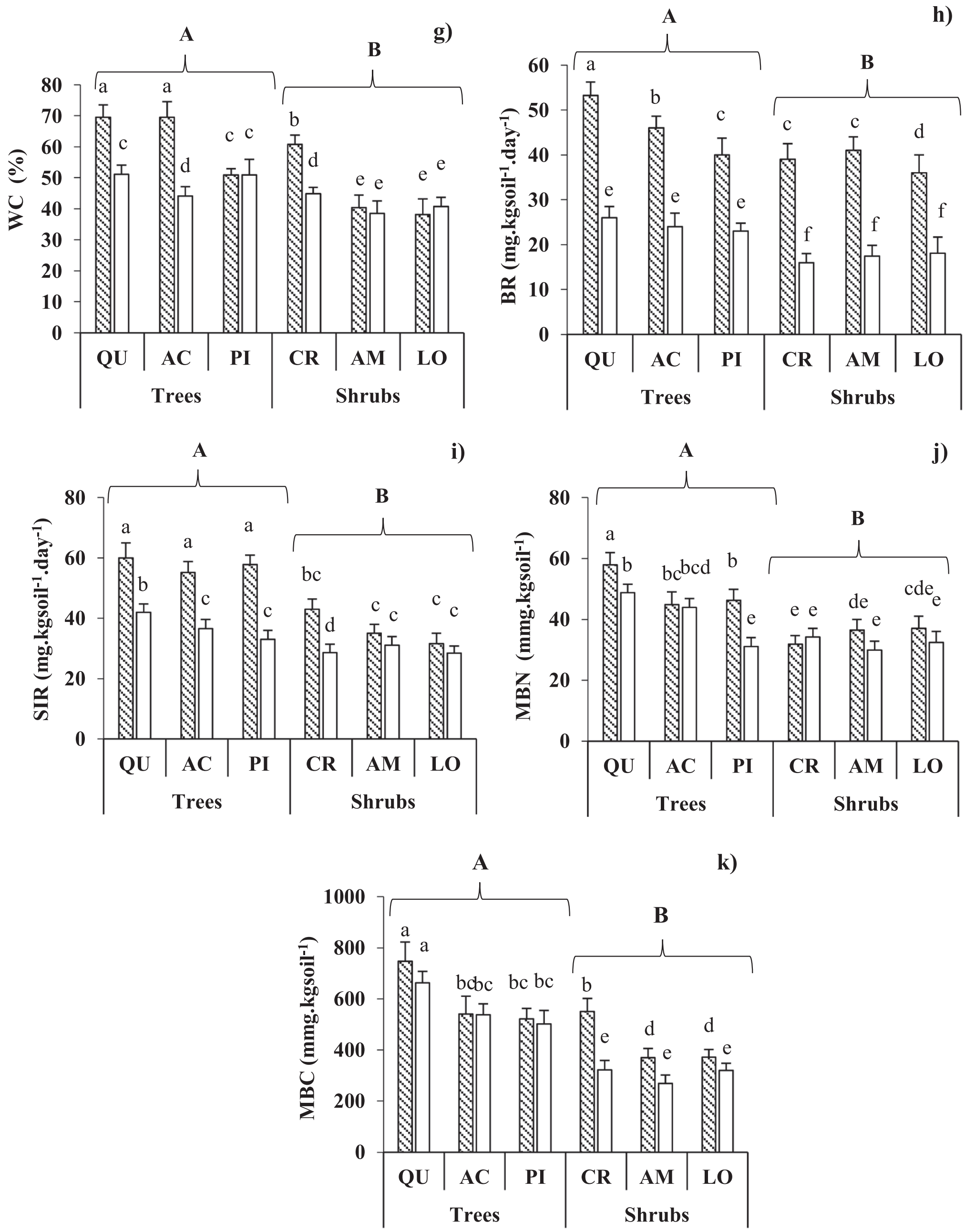


Fig 2. (*continued*)

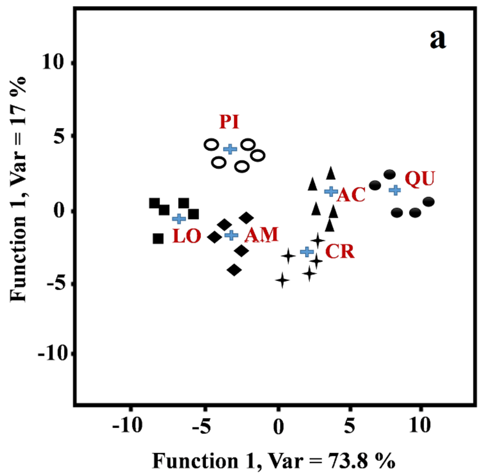
Table 2
Standardized canonical coefficient of soil attributes in each function.

Soil attributes	Function (spring)		Function (winter)	
	1	2	1	2
WC	**0.334**	− 0.282	0.041	**0.322**
SOC	**0.774**	**− 0.394**	0.276	**0.511**
Kava	0.051	**0.379**	**0.359**	− 0.050
Ntot	**0.520**	**−0.421**	0.171	**0.601**
MBC	0.303	**0.569**	**0.365**	0.101
MBN	**0.547**	0.215	0.070	0.147
BR	0.120	**0.401**	0.013	**0.347**
SIR	**0.351**	**0.488**	0.071	**0.344**

Abbreviations: SOC: soil organic carbon, Ntot: total nitrogen, Kava: available potassium, WC: water content, BR: basal respiration, SIR: substrate-induced respiration, MBN: microbial biomass nitrogen, MBC: microbial biomass carbon; bold significant coefficients ($P < 0.05$).

decomposer community, controlling the rate of decomposition of the litter and the release of nutrients such as carbon, nitrogen and phosphorus (Moore et al., 2006; Bayranvand et al., 2017). For the same reasons mentioned above, trees are likely to create more stable and suitable microclimate conditions than shrub species in terms of temperature and humidity beneath their canopy (Heydari et al., 2017b). Besides, tree canopy can more efficiently reduce the rainfall intensity during intense events and therefore can prevent the erosion of organic matter and fine particles such as clay. In these conditions, the rate of litter decomposition under trees is enhanced and thus the organic carbon content of the soil as the main substrate for the activity of microorganisms is increased (Xu et al., 2014).

It is noteworthy that soil characteristics among the different woody species based on SDA were the most similar for QU and AC for tree species (especially due to the higher content of SOC and MBN under these species in spring) and for AM and LO for shrub species. The



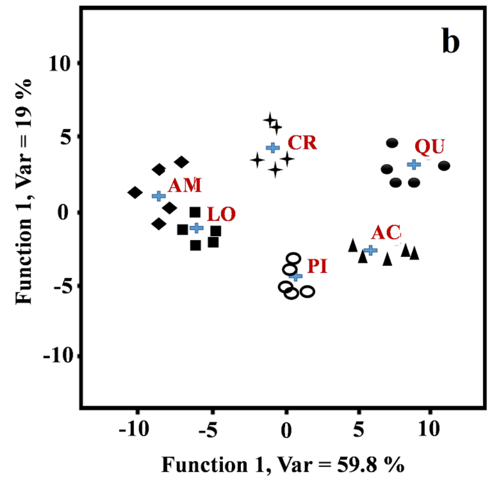


Fig. 3. Distribution of the plots along the first two discriminant function values according to the different woody species including QU: *Quercus brantii*, AC: *Acer monspessulanum*, PI: *Pistacia atlantica, CR: Crataegus pontica*, AM: *Amygdalus scoparia*, LO: *Lonicera nummularifolia* in spring (a) and winter (b).

Table 3
Results of GLMs for woody species (SP: *Quercus brantii*, *Acer monspessulanum*, *Pistacia atlantica, Crataegus pontica*, *Amygdalus scoparia*, *Lonicera nummularifolia*), growth form (GF, tree and shrubs) and seasons (SE, spring and winter) effects on diversity indices (Shannon–Wiener diversity, richness (number of species) and Pielou's evenness) of soil mesofauna.

Source	Shannon–Wiener diversity				Richness (No. of species)			Pielou's evenness		
	df	Mean square	*F*-value	*P*-value	Meansquare	*F*-value	*P*-value	Meansquare	*F*-value	*P*-value
SE	1	0.075	1.697	0.199	0.267	0.340	0.562	0.008	0.922	0.342
SP	5	0.986	22.430	**0.000**	23.617	30.149	**0.000**	0.014	1.679	0.197
GF	1	2.289	52.054	**0.000**	96.267	122.894	**0.000**	0.019	2.305	0.136
SE × SP	5	0.110	2.505	0.092	6.317	8.064	**0.001**	0.019	2.312	0.110
SE × GF	1	0.131	2.989	0.090	0.267	0.340	0.562	0.005	0.657	0.422
SP × GF	5	0.243	5.520	**0.007**	8.517	10.872	**0.000**	0.010	1.261	0.293
SE × SP × GF	5	0.144	3.272	**0.047**	9.817	12.532	**0.000**	0.030	3.612	**0.035**

Bold p-values indicate significant statistical differences at $p < 0.05$.

coefficient of organic carbon in the DA was higher than the other soil characteristics in spring (0.774) and winter (0.511). This confirms the importance of a species effect in changes in soil organic carbon stocks. Consistent with our results, previous studies have shown that differences in plant species characteristics, such as leaf area, quantity and quality of the litter can induce temporal and spatial heterogeneity of soil characteristics (Boeger et al., 2004; Yang et al., 2005; Scherer-Lorenzen et al., 2007).

4.2. Seasonal effect on soil properties

We found a significant effect of the season on most soil chemical and biological variables, although the interaction of season and species or growth form has clearer trend on soil biological variables. This result reflects the fact that plant species or plant life form can be mediator of the changes of the chemical soil properties with seasons. For example, higher SIR and MBC in spring compared to winter depended on the presence of tree and shrub vegetative forms, respectively. Therefore, studying the biological characteristics of soil in forests of arid and semi-arid Mediterranean regions can be a better indicator than the soil chemical properties to reflect the effect of seasonal changes on soil conditions under different types of woody species. Bastida et al. (2006) also emphasized the good performance of soil biological properties in reflecting soil conditions in different seasons and in different canopy cover conditions. Previous studies (Suthar, 2012; Song et al. 2016) emphasized that the microclimate conditions during sampling (i.e. sampling season) and the availability of resources affected soil biota communities. Soil conditions are known to depend on season providing either favorable conditions for the activity of soil organisms (Bayranvand et al. 2017) or reducing the activity of soil biota (Hackenberger and Hackenberger, 2014) during the cold or warm seasons. Similar to our findings, Uvarov et al. (2011) reported that soil moisture and temperature are the main factors explaining variations in soil biota under different vegetation types. Parallel to the current findings in these study sites, previous research (Suthar, 2012; Xu et al. 2012; Crumsey et al. 2013; Ren et al. 2018) already declared that soil fauna activities increased during the spring season.

4.3. Variation of the SQI

Among the species under study, QU and then AC exhibited higher SQI values than the other species. These two tree species are dominant in the region and belong to the climax species in the forest ecosystem of the Zagros region. As already mentioned, the high and wide crown of AC and QU produces a large quantity of litter as a source of soil nutrients and attenuates more efficiently the variations of air temperature and humidity, which leads to favorable conditions for the activity of microorganisms under these species. This also explains increasing SQI values under tree species than under the small-sized canopy shrub species. This crown size effect seems more important than a species effect as we did not record any significant difference in SQI values between shrub species. Similarly, Liu et al. (2014) showed that important determinants of SQI, including soil respiration, were significantly higher under large-sized canopies than under small-sized canopies in both dry and wet soil conditions. This result suggests that managers and decision makers should focus primarily on tree species in conservation, rehabilitation or afforestation projects in semi-arid areas. The richness and diversity of the soil mesofauna species were

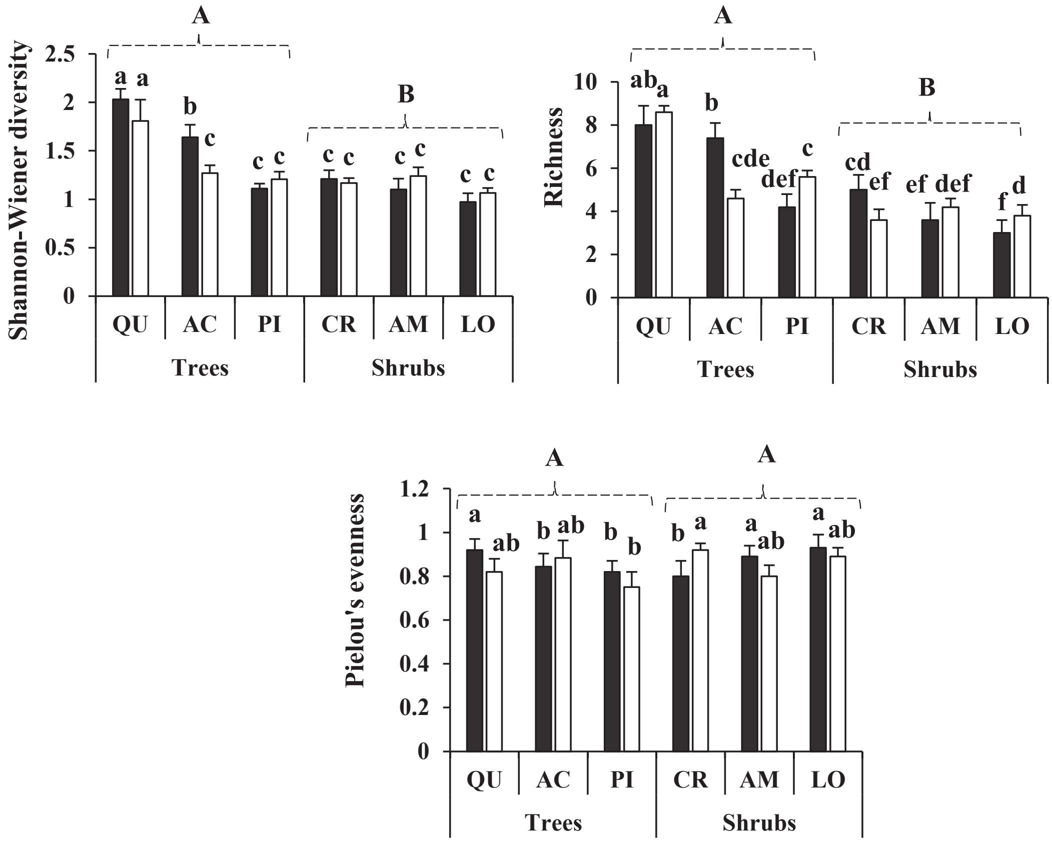


Fig 4. Effects of woody species (QU: *Quercus brantii*, AC: *Acer monspessulanum*, PI: *Pistacia atlantica, CR: Crataegus pontica*, AM: *Amygdalus scoparia*, LO: *Lonicera nummularifoli*a), seasons (spring; black and winter: white) and growth forms (tree and shrub) on topsoil mesofauna diversity (mean ± SE) indices.

influenced by the life form as they were higher under trees than under shrubs. In fact, the higher contents in soil nutrients, organic matter, moisture under trees were beneficial to the soil fauna activity. This result is consistent with the findings of Prescott and Grayston (2013) and Bayranvand et al. (2017) who reported that various woody species can differently modify soil moisture, carbon substrate availability, temperature, and nutrient regimes through root turnover, shading, and litter accumulation this affecting in turn the distribution of soil arthropods (see also Sayad et al., 2012; Korboulewsky et al., 2016).

There is also a close relationship between the change in canopy cover of different woody species and the litter depth (e.g. Binkley and Fisher, 2013). Due to the dependence of the soil mesofauna to the forest floor litter as a shelter and source of nutrition (Wissuwa et al., 2012; Wu and Wang, 2019), it makes sense to find a greater diversity and richness of mesofauna beneath tree species (with more litter depth) than beneath shrub species. Thus, in this study the mean litter depth increases from tree species to shrub species according to the following order: QU (5.30 ± 0.53), AC (3.15 ± 0.61) and PI (2.75 ± 0.33), CR (2.08 ± 0.35), AM (0.81 ± 0.18) and LO (0.90 ± 0.26). We found a significant variation of soil mesofauna richness and diversity indices under tree species but not under shrub species (excepted for CR in spring). Similarly, Peterson et al. (2001), reported comparable soil arthropods richness under different types of shrubs for both the spring and the winter seasons in the Mediterranean region. However, other studies have shown that the presence of shrub species (compared to the open space) can affect the distribution and assembly of soil arthropods (Doblas-Miranda et al., 2009). Among the shrub species, a higher mesofauna richness was found for CR in spring. This result maybe explained by the large crown and the high fruit and debris production of this shrub, characteristics which are likely to attract a more abundant mesofauna (Mazía et al., 2006). Among the tree species, the highest values of the diversity and richness indices of soil mesofauna were observed according to the following order PI < AC < QU. This result can be explained by an increase in litter inputs (from PI to QU) which leads to an amelioration of soil properties (such as soil moisture and organic matter) and thicker organic layers more favorable to the soil fauna (Bardgett and Van Der Putten, 2014; Coyle et al., 2017; Qiu et al., 2019). In this study, the richness, diversity and evenness indices under most studied species did not vary with the season. This can be due to the modulating role of the physical environment (microclimate, soil nutrient and water availability) by the canopy of the woody species e.g, (Doblas-Miranda et al., 2009; Zhao and Liu, 2013). In particular, the accumulation of litter under the canopy acting as a hermal insulator, can provide suitable conditions for mesofauna activity even in winter (Parmenter et al., 1989).

4.4. Relationships between soil mesofauna indices and SQI

Our results showed that the increase in soil quality from tree species to shrub species coincided with an increase in richness and diversity of soil mesofauna with a similar pattern in both seasons. This can reflect the large influence of tree species on soil factors and microclimate in semiarid areas (Heydari et al., 2017a). It also indicates that soil mesofauna arthropods can be very effective in expressing soil quality under different woody species in Zagros semi-arid forest ecosystem. This positive relationship between soil mesofauna diversity and richness indices with soil quality index provides a new evidence supporting the niche complementarity hypothesis. This hypothesis suggests that most of the ecosystem functions (such as MBC and BR in our study) should increase with soil mesofauna diversity in relation with a greater capacity to exploit the resources available in the ecosystem (Schnitzer et al., 2011; Lamb et al., 2011). In contrast, there was no significant relationship between soil mesofauna evenness and soil quality index, which indicates that the change in soil mesofauna evenness has no

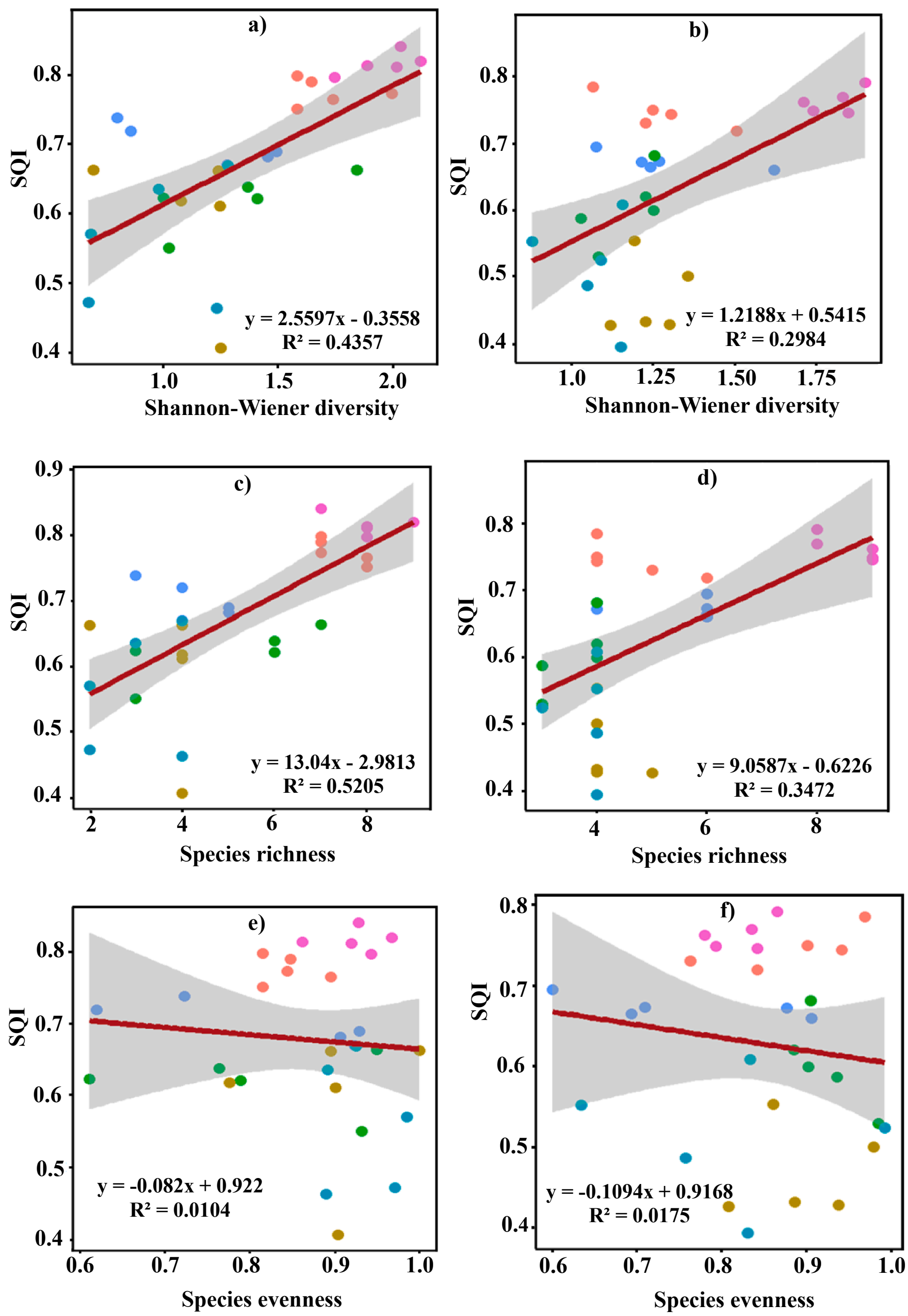


Fig. 5. Linear regressions between the Shannon-Wiener diversity index of soil mesofauna and the soil quality index in spring (a) and winter (b), richness (number of species) in spring (c) and winter (d) and Pielou's evenness index in spring (e) and winter (f); (QU●: *Quercus brantii*, AC●: *Acer monspessulanum*, PI●: *Pistacia atlantica*, CR●: *Crataegus pontica*, AM●: *Amygdalus scoparia*, LO ●: *Lonicera nummularifolia*).

effect on soil quality changes. We hope that these results will be tested in a replicated study to determine whether our findings can be generalized. We believe that such a study in different natural forest ecosystems could be conducted using the set of measurements and the analytical tools we have presented, which revealed that soil mesofauna indices and SQI is tied to forest ecology and management.

5. Conclusion and implications for soil management

Semiarid Mediterranean ecosystems present a discontinuous patchy vegetation cover composed of trees or shrubs of various species. These types of vegetation play a crucial role in mitigating the harsh climatic conditions prevailing in these areas and in creating spots of high soil fertility. In this study, we showed that most of the chemical and biological soil properties and SQI were influenced by the life form of the vegetation and were more favorable under trees than under shrubs, thus confirming our first hypothesis. Moreover, we detected a clear seasonal effect as anticipated in our second hypothesis. After the life form, the species identity plays an important role and modification of soil fertility is likely to be linked to a size-canopy effect: species with a large and dense crown being more favorable than species with a less developed crown (typically *Quercus brantii* for trees and *Crataegus puntica* for shrubs in this study). Finally, in line with our third hypothesis, we show that the diversity and richness of soil mesofauna are closely related with soil properties and SQI. This finding therefore indicates that these indices can be used as efficient soil bioindicators. By identifying the most valuable microhabitats in terms of soil characteristics and soil mesofauna diversity and by defining the relationships between these two components, we hope that these results will be useful in defining sustainable soil management practices in semiarid systems. Such practices are in fact crucial to optimize a large set of soil functions such as primary productivity, carbon management, nutrient cycling, water regulation and habitat for biodiversity. Soil organisms has a lead role to play in promoting these functions through the mineralization of nutrients or decomposition of organic matter in soils. Therefore, land managers should consider the effects of their actions on the health and function of the soil biological community. All soils have the capacity to deliver all functions, but the landscape, land management strongly influence which soils deliver which functions at an optimum capacity. Therefore, by selecting the right management practices, we can optimize these functions, rather than the traditional focus on primary production alone. Despite the well-known importance of soil biological processes, the development of monitoring and management guidelines is in its infancy. However, land managers can learn the general principles of how their choices affect biological processes and can monitor changes in soil function. In semi-arid areas, as for other systems, soil biological health generally improves when the following management practices are applied as (1) regularly adding adequate organic matter, (2) diversifying the type of plants across the landscape and though time, (3) keeping the ground covered with living plants and residue, (4) avoiding excessive levels of disturbances including soil mixing or tillage, compaction, pesticides, heavy grazing, and catastrophic wildfires.

CRediT authorship contribution statement

Mehdi Heydari: Conceptualization, Methodology, Data curation, Resources, Formal analysis, Software, Visualization, Funding acquisition, Project administration, Supervision, Writing -original draft, Writing -review & editing. **Parasto Eslaminejad:** Data curation, Writing - original draft. **Fatemeh Valizadeh Kakhki:** Data curation, Investigation. **Majid Mirab-balou:** Data curation, Investigation. **Reza Omidipour:** Formal analysis, Software, Writing -original draft, Writing -review & editing. **Bernard Prévosto:** Writing -review & editing. **Yahya Kooch:** Investigation, Writing -review & editing. **Manuel Esteban Lucas-Borja:** Writing -review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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