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Do soil management practices affect the activity density, diversity, and stability of soil arthropods in vineyards?

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ABSTRACT

Arthropods are important components of the soil fauna in improving soil quality and its structural properties. Arthropods are also very sensitive to soil management practices. Thus, a study was carried out in a vineyard in the Douro Demarcated Region (Northeast Portugal), to investigate the effect of three soil management practices (tillage, ground cover with spontaneous vegetation, and ground cover with sown vegetation) on the activity density, richness and diversity of soil arthropods, as well as on the stability of their communities. Soil-surface arthropods were assessed in 2014 and 2015 using pitfall traps, while soil-living arthropods were assessed in 2016 by collecting soil samples and extracting them through a Berlese-Tullgren funnel. The possibility of using the Soil Biological Quality index (QBS-ar index) as a tool to discriminate soils of vines subject to those management practices was also investigated. Results show that ground cover treatments significantly enhanced the activity density of soil-surface herbivores and of their potential natural enemies in both years and the activity density of detritivores in 2014. The richness of total soil-surface arthropods and potential predators was also increased by ground cover treatments in 2015. In both years, Simpson's diversity index of herbivores was enhanced by ground cover treatments, and in 2015, Simpson's diversity index of the total soil-surface arthropods, potential predators, and omnivores was significantly higher in spontaneous vegetation than in tillage or sown vegetation treatments. The soil-surface arthropods community stability was positively affected by both their activity density and richness in 2015, with that stability being better achieved in the sown vegetation treatment. In soil-living arthropods, activity density, richness and Simpson's diversity index were significantly higher in ground cover treatments than in the tillage treatment. The QBS-ar index was significantly higher in ground cover treatments than in the tillage, suggesting that this index can be a useful tool to discriminate soil management practices in vineyards. In conclusion, our results indicate that the ground cover with vegetation improves the activity density and diversity of soil arthropods in vineyards.

1. Introduction

Soil degradation is a worldwide concern that poses a threat to agricultural production and terrestrial ecosystems (Jie et al., 2002). This degradation is caused by several factors, both natural (e.g. climate, topography, hydrology, and soil characteristics) and anthropogenic (e.g. land use and management, natural resource exploitation) (Comino et al., 2015).

In the Mediterranean Region, vineyards are one of the agricultural systems that cause more soil losses, mainly due to: (a) management practices that keep the soil without plant cover; (b) intense rainfall mainly concentrated in spring and autumn; and (c) the location, frequently on steep-sloping soils and consequently, more susceptible to erosion (Prosdocimi et al., 2016a).

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In the Douro Demarcated Region (DDR) (northeast of Portugal), vineyards occupy 43,500 ha (about 17.6 % of the total area) (IVDP, 2018). The Alto Douro Vinhateiro (ADV), a portion of the DDR with about 24,600 ha, has been in the list of UNESCO World Heritage Sites since 2001 as an evolving and living cultural landscape. Nowadays, the authenticity of the ADV prevails, and sustainable solutions are being implemented according to the condition of scarce resources (water and fertile soil) and steep slopes (Andresen and Rebelo, 2013), aiming to promote environmentally friendly farming practices for the hydrogeological and environmental protection of the territory, ensure the conservation of biodiversity and other natural resources, and protect the landscape features (Biagioli and Vezzosi, 2012).

In this context, government policies support measures which allow a sustainable management of natural resources through the restoration, preservation, and improvement of ecosystems linked to agriculture and forestry (MAM, 2015). Among those measures is the soil conservation through ground cover, a practice that has proved to increase water infiltration, protect the soil surface from the impact of raindrops, facilitate the formation and stabilization of soil aggregates, and reduce soil erosion by enhancing the organic matter and microbiological function of the soil (Prosdocimi et al., 2016b). Additionally, ground cover improves biodiversity by providing habitat and food to many different species below and above ground (Daane et al., 2018).

Arthropods have long been recognized as an important asset for the functioning of soil ecosystems by acting as litter transformers and ecosystem engineers, thereby improving soil quality and its structural properties (Culliney, 2013). Besides their role in the ecosystem, arthropods respond to a variety of environmental and ecological factors, habitat disturbance, pollution, being therefore recognized and used as bioindicators in agroecosystems assessment (Madzaric et al., 2018), namely as indicators of soil quality, able to reflect general ecological changes (Yan et al., 2012). Even so, most studies conducted to date to obtain soil quality indices have used microbial biomass, soil respiration and enzymatic activities, while few studies have focused on the soil fauna (Paz-Ferreiro and Fu, 2016). Among these latter, the QBS-ar (acronym for Biological Soil Quality) index, developed by Parisi et al. (2005), has gained great highlight (Blasi et al., 2013; Galli et al., 2014; Menta et al., 2017a, 2017b, 2018; Yan et al., 2012). This index is based on the concept that the number of microarthropod groups morphologically well adapted to the soil is higher in high quality soils than in low quality ones (Parisi et al., 2005). Moreover, it allows overcoming the well-known difficulties of taxonomic analysis to separate arthropods into species. The QBS-ar index joins soil microarthropod biodiversity with soil microarthropod vulnerability, thus providing information on the soil biological quality, which is an indicator of land degradation (Menta et al., 2017a). Nevertheless, some authors have pointed out that the QBS-ar index was not suitable for detecting the impact of soil practices on soil arthropods (Tabaglio et al., 2009; Xin et al., 2018). Menta et al. (2017a) indicate that QBS-ar has good sensitiveness to soil practices, being able to discriminate among different soil uses and different levels of degradation.

Several studies have shown the positive impact of ground cover on the abundance and/or diversity of both soil-surface and canopy arthropods in vineyards (Burgio et al., 2016; Danne et al., 2010; Vogelweith and Thiéry, 2017). However, as far as we know, no assessment has ever been made of its impact on the activity density and diversity of soil-living arthropod in vineyards or on the stability of the soil-surface arthropod community.

The basic hypothesis of this study is that soil management practices affect the activity density, diversity and stability of soil arthropod communities. Specifically it was intended to address the following questions: a) does the activity density and diversity of soil arthropods (both soil-surface and soil-living) differ significantly among three soil management practices (tillage, spontaneous vegetation, and sown vegetation)?; b) which functional groups of soil-surface arthropods (omnivores, herbivores, detritivores, natural enemies) are most affected by soil management practices?; c) do soil management practices influence the stability of soil-surface arthropod communities?; d) does the QBS-ar index differ significantly among the three soil management practices?

2. Material and methods

2.1. Study area

The study was carried out in a commercial vineyard located in Alijó (Lat. 41°14′N, Long. 7°29′W), in the Cima Corgo sub-region of the Douro Demarcated Region. In this sub-region, the total annual rainfall is 914 mm and the annual mean temperature is 13.6 °C (Fraga and Santos, 2017).

The experiment was set up in a flat field (about 2 ha with less than 5% of slope) where vines (*Vitis vinifera* L. var. Moscatel Galego) were spaced 2.10 m apart between rows and 1.00 m apart within rows.

Four blocks of three treatments were established: tilled, sown vegetation, and spontaneous vegetation, the latter actually consisting of a weedy treatment. The treatments will hereafter be referred to as TILL, SOWN, and SPONT, respectively. Each block consisted of five 170 m long rows covering an area of 1428 m^2 and the blocks were separated by about 5 m. In the autumn of 2013, all the inter-rows were plowed and the following procedures were undertaken: in the SOWN treatment, a commercial mixture of Fabaceae species (REVIN® from Fertiprado company with five species: *Ornithopus sativus* Brot., *Trifolium incarnatum* L., *Trifolium michelianum* Savi, *Trifolium resupinatum* ssp. *resupinatum* L., and *Trifolium subterraneum* ssp. *subterraneum* L.) was sown at a rate of 25 kg/ha; in the SPONT treatment, weeds were allowed to develop during the studied period; the soil under the TILL treatment was superficially tilled. The vegetation of the SOWN and SPONT treatments was mowed twice a year (in mid-March and mid-July) and in all treatments, the vegetation within the vine rows was controlled with herbicide (a combined treatment with glyphosate (isopropylamine salt) and oxyfluorfen), applied to a 30 cm wide strip directly underneath the grapevines.

2.2. Data collection

2.2.1. Cover vegetation

Cover vegetation was analyzed in late spring (mid-June) 2014 and 2015, by surveying and identifying vascular plant species in two 10 m^2 sample areas, each located around one of the pitfall traps used in arthropod sampling (see 2.2.2).

2.2.2. Arthropods

Soil-surface arthropods were sampled in 2014 and 2015, namely between June and August 2014 (23rd June, 11th July, 5th and 22nd August) and between April and July 2015 (20th April, 12th May, 5th June, and 27th July). Sampling was conducted by installing two pitfall traps in each of the four blocks allocated to each of the three treatments under study. The traps were placed in the center of the vineyard inter-rows, separated by at least 25 m. Each trap consisted of a plastic cup (16 cm in depth and 9 cm in diameter) filled with about 150 mL of a mixture of water and polypropylene-glycol (3:1). The traps were dug into the ground, uncovered and kept active for 72 h. The arthropod specimens captured were preserved in ethanol 70 % until observation. Then they were counted and sorted into morphospecies and identified until the lowest taxonomic level possible following Triplehorn and Johnson (2005) and Booth et al. (1990). Formicidae specimens were identified by following Collingwood and Prince (1998) and Gómez and Espadaler (2007), while Carabidae specimens were identified by following Aguiar and Serrano (2012), 2013.

Soil-living arthropods were sampled in the autumn of 2016 (26th October and 4th November), after the first rainfall as recommended by Parisi et al. (2005). Soil samples were cut using a 10 cm high and wide spade, and removed with the aid of a hoe; after that, they were transported to the laboratory in plastic containers with the same dimensions. The arthropods were extracted using a Berlese-Tullgren funnel during seven days. An incandescent lamp (60 W) placed 30 cm up the soil dried the soil gradually and created an inhospitable condition for arthropods, which moved into the deeper soil layer until falling into a container with a fixer liquid (mixture of 75 % ethanol and glycerol – ratio 2:1), located under the funnel (Menta et al., 2017a). The collected specimens were counted and sorted into morphospecies and identified until the lowest taxonomic level possible following Triplehorn and Johnson (2005).

2.3. Calculation of response variables

2.3.1. Cover vegetation

The richness and abundance of each plant species and respective cover as well as the total cover vegetation were calculated in each sample area as follows:

$$\text{Richness} = S \tag{1}$$

where S represents the number of different plant species

$$\text{Abundance} = Ni \tag{2}$$

where N represents the number of individuals of species i

$$\text{Percentage of cover vegetation} = (Ai/As) \times 100 \tag{3}$$

where Ai is the area occupied by the species i and As is the sample area

$$\text{Percentage of total cover vegetation} = (At/As) \times 100 \tag{4}$$

where At is the area occupied by all species and As is the sample area

The vegetation structural characterization was performed based on the richness and percentage of cover of each species. One numerical matrix was elaborated with this structural information, and a floristic-structural analysis was applied to describe the information obtained (Crespí et al., 2005; Rocha et al., 2015).

2.3.2. Arthropods

The morphospecies of soil-surface arthropods were assigned to different functional groups based on both taxonomic data and feeding traits. Thus, in accordance with literature, they were grouped into five categories: (1) detritivores; (2) herbivores; (3) omnivores; (4) parasitoids; and (5) predators (Aguiar and Serrano, 2013; Booth et al., 1990; Triplehorn and Johnson, 2005). Since the number of parasitoids collected was very low, this group was combined with that of predators to produce a ‘potential natural enemy’ category. When it was not possible to identify the feeding guild, arthropods were included in an indeterminate group.

The activity density, richness, and Simpson’s diversity index (SDI) of total and different functional groups of the soil-surface arthropods were calculated as follows:

$$\text{Activity density} = N \tag{5}$$

where N represents the number of individuals;

$$\text{Richness} = S \tag{6}$$

where S represents the number of different morphospecies registered.

$$\text{SDI} = 1 - \Sigma\,(n/N)^2 \tag{7}$$

where n is the total number of organisms of a particular morphospecies and N is the total number of organisms observed. The value of SDI ranges between 0 and 1, and represents the probability of two individuals randomly selected from a sample belonging to different species (McCune and Grace, 2002).

The activity density, richness, and Simpson’s diversity index were also calculated for soil-living arthropods as described before. The data collected from 1000 cm^3 samples were extrapolated for 0.1 m^3 (1 m^2 × 0.1 m).

2.3.3. Stability of soil arthropod communities

Based on the data of soil-surface arthropods, four indices of stability were calculated in order to understand the inhibitory effects that potential natural enemies and/or neutral arthropods (omnivores and detritivores) might have on the activity density and richness of herbivores (Wan et al., 2014). Neutral arthropods were included because their role in the stability of arthropod communities has been demonstrated (Wan et al., 2014).

Two of these indices were calculated based on the activity density of functional groups:

$$N_{ne}/N_h \tag{8}$$

$$(N_{ne} + N_n)/N_h \tag{9}$$

where N_{ne}, N_h, and N_n represent the activity density of potential natural enemies, herbivores and neutral arthropods, respectively.

The other two indices were calculated based on the richness of functional groups:

$$S_{ne}/S_h \tag{10}$$

$$(S_{ne} + S_n)/S_h \tag{11}$$

where S_{ne}, S_h, and S_n represent the richness of potential natural enemies, herbivores and neutral arthropods, respectively.

Eq.s 8 and 10 were used to assess the stability of arthropod communities and measure the inhibitory effects of natural enemies on herbivores (Wan et al., 2014). Eq.s 9 and 11 were proposed by Wan et al. (2014) in order to include the role of neutral species in the stability of arthropod communities, as well as the antagonistic and regulatory relationships among the three groups (natural enemies, herbivores, and neutral arthropods). According to the authors, an existing predator-prey relationship between natural enemies and neutral arthropods should also be taken into consideration, as it contributes directly to the population increase of natural enemies and indirectly to the stability of arthropod communities.

2.3.4. Biological soil quality index

The biological soil quality index (QBS-ar) was calculated using the data on soil-living arthropods and following Parisi et al. (2005). This index uses a biological form approach to separate the arthropods into eco-morphological groups according to their levels of adaptation to the soil environment (Parisi et al., 2005). Each eco-morphological group received a score (EMI – Ecological-Morphological Index) ranging from 1 to 20, according to its adaptation level to the edaphic conditions. As a general rule, each form achieves a value that is proportionate to its degree of soil specialization, ranging between an EMI = 20 for eu-edaphic forms (i.e., deep soil-living) and EMI = 1 for epi-edaphic forms (surface-living) (Parisi et al., 2005). When two eco-morphological forms are present for one same group, the final score is decided by the highest EMI (Parisi et al., 2005). For each sample, the QBS-ar index corresponds to the sum of individual EMI values.

2.4. Statistical analysis

Analyses were performed with R (version 3.4.2) (R Development Core Team, 2015) and IBM SPSS v20 (SPSS Inc. IBM Company, 2010).

In order to identify plant species that were indicative of a particular treatment, an indicator species analysis was performed in R using the *IndVal* function in the “*labdsv*” package (Roberts, 2019). This analysis combines the specificity of a species in a treatment (i.e., its relative abundance) and the species fidelity (i.e., relative frequency of occurrence of the species within a treatment) (Dufrêne and Legendre, 1997). It also allows identifying species that are present in the majority of samples from one group and absent in the majority of samples from

Table 1
General linear model analysis comparing the effect of management practices on the richness and percentage of the total cover vegetation. Data are presented as mean (S.E.).

	2014					2015				
	SPONT	SOWN	TILL	$F_{(2,15)}$	*p*-value	SPONT	SOWN	TILL	$F_{(2,15)}$	*p*-value
Richness (S)	11.00 (1.29)ab	15.00 (1.32)b	9.00 (1.63)a	4.62	< 0.05	13.33 (0.80)	12.67 (1.20)	12.33 (0.61)	0.32	> 0.05
Total cover vegetation (%)	65.83(4.90)b	76.67 (2.79)b	35.00 (2.24)a	26.00	< 0.01	56.50 (3.12)b	54.33 (4.97)b	21.83 (3.02)a	38.09	< 0.01

SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage.

other groups. Indicator values were tested for significance with Monte Carlo (based on 1000 permutations).

General linear models (GLM) were performed in R using the "*MASS*" package (Venables and Ripley, 2002) in order to evaluate differences between treatments regarding both the richness of plants and the total cover vegetation. A multifactorial (Pearson's correlation matrices described by Principal Components Analysis, PCA) description of the numerical matrix obtained by sampling works was also conducted in IBM SPSS, which allowed comparing the vegetation structural characterization.

With respect to arthropods, the differences between treatments were checked in terms of activity density, richness, Simpson's diversity index and stability indices, the number of eco-morphological groups and the QBS-ar index, all by means of generalized linear models (GzLM), using the "*MASS*" package in R. For activity density, richness, number of eco-morphological groups and QBS-ar, we used a Poisson error distribution with a log link function or a negative binomial distribution to account for overdispersion. Meanwhile, Gaussian distribution was used for SDI and stability indices.

GLM and GzLM assumptions were inspected by visualizing residual plots. Interaction effects were evaluated but discarded due to the small sample sizes. For the data analysis of soil-surface arthropods, different models were obtained for the two-year data set (Global models) and also for each year separately (Annual models).

The models were described as follows:

$$\text{Global models} = \text{constant} + \text{treatment} + \text{year} \tag{12}$$

$$\text{Annual models} = \text{constant} + \text{treatment} + \text{sampling date} \tag{13}$$

In the global models, the year was included as a fixed effect. Within each year, the sampling date was also treated as a fixed effect since the models did not converge otherwise.

Since the vegetation data was recorded only once each year, such information could not be included in the arthropod models.

The effect of the explanatory variables was assessed using a Wald test. Then, Tukey´s pairwise comparison tests were used to assess which pair of groups (i.e. factor levels) differed significantly.

Non-metric multidimensional scaling (NMDS) was performed using the "*vegan*" package from R software (Oksanen et al., 2016) so as to examine the interrelations of soil-surface arthropod communities among treatments. For this analysis, all the data of each treatment were pooled into a single sample. Individuals in each functional group were also classified by taxa. Only groups with more than 25 individuals (in total) were included in the analyses. The convergent solution with the lowest stress value was chosen from all the 2-dimensional approach solutions obtained with the available dissimilarity indices in the "vegdist" function. In order to evaluate which axis allowed the discrimination of significant differences between years and/or treatments, the normality and homogeneity of variance of MDS scores were firstly checked, and then parametric or nonparametric tests (t-test or Mann Whitney for years; ANOVA or Kruskal-Wallis for treatments) were performed using the "*MASS*" package from R software. In order to associate the community composition with vegetation parameters, the *envfit* function was used to evaluate the associations between NMDS site scores as multivariate response variables and site environmental values related to vegetation parameters (% total cover vegetation and richness). The R^2 values are presented as the measure of these associations. The NMDS plots were produced using the R package *ggplot2* (Wickham, 2009).

In SPSS, Spearman's correlation (*r*) was performed to examine the association between the stability and biodiversity indices.

3. Results

3.1. Effect of management practices on cover vegetation

Fifty-nine species of plants were observed throughout both years, among which: 72 % in the SOWN treatment, 66 % in SPONT, and 61 % in TILL. Following to Raunkiaer's typification (Braun-Blanquet, 1979), these plants were distributed as follows: 59 % terophytes, 29 % hemicriptophytes, 3 % chamaephytes, 1 % nanophanerophytes, and 1 % microphanerophytes.. In general, the most common families were Asteraceae, Poaceae and Fabaceae, which occurred in all treatments.

The IndVal analysis detected three indicator species: *O. sativus* (IV = 1.00, $p < 0.01$ in 2014, and IV = 0.68 and p = 0.01 in 2015) and *Lolium rigidum* Gaudin (IV = 0.66, p = 0.02 in 2014) were significantly associated with SOWN, while *Polygonum aviculare* L. was significantly associated with TILL (IV = 0.69, $p < 0.01$, in 2015).

In 2014, plant richness was significantly higher in SOWN than in the TILL treatment but did not differ between SPONT and the two other treatments, while in 2015, it did not differ among treatments. In both years, the percentage of total cover was significantly higher in both SPONT and SOWN than in the TILL treatment (Table 1).

With three retained components, the PCA score 3D-plots allowed explaining 80.94 % of the total variance in 2014 (PC1 = 44.28 %, PC2 = 22.21 % and PC3 = 14.15 %) and 76.40 % in 2015 (PC1 = 38.54 %, PC2 = 21.12 % and PC3 = 16.73 %), respectively. A structural similarity between the SPONT and SOWN sample areas can be observed in PCA, which was more evident in 2015 (Fig. 1).

3.2. Effect of management practices on the activity density and diversity of soil arthropods

3.2.1. Soil-surface arthropods

A total of 18,020 soil-surface arthropods belonging to 219 morphospecies were collected during the study (Fig. 2). Arthropods were grouped into detritivores (70.20 %) [which included Oribatida, Isopoda, Collembola, Coleoptera (Scarabaeidae, Latridiidae, Aderidae, Tenebrionidae), Hymenoptera (the Formicidae *Cataglyphis* sp. Foster), and Diplopoda], herbivores (8.80 %) [which included Coleoptera (Chrysomelidae, Buprestidae, Carabidae (*Harpalus* sp. Latreille, *Ophonus rupicola* (Sturn), *Amara aenea* (De Geer)), Curculionidae, Elateridae, Oedemeridae), Hymenoptera (Formicidae *Messor barbarus* L.), Hemiptera (Aphididae, Cicadellidae, Lygaeidae, Cydnidae, Scutelleridae, Pentatomidae), Lepidoptera, and Orthoptera], potential natural enemies (4.50 %) [which included Opiliones, Scorpiones, Araneae, Coleoptera (Anthicidae, Carabidae, Staphylinidae, Coccinellidae, Scydmaenidae, Meloidae, Melyridae, Cantharidae), Hemiptera (Nabidae, Anthocoridae), Hymenoptera (Vespidae, Mutillidae, Scollidae, Dryinidae, Braconidae, Chalcidoidea), and Chilopoda], omnivores

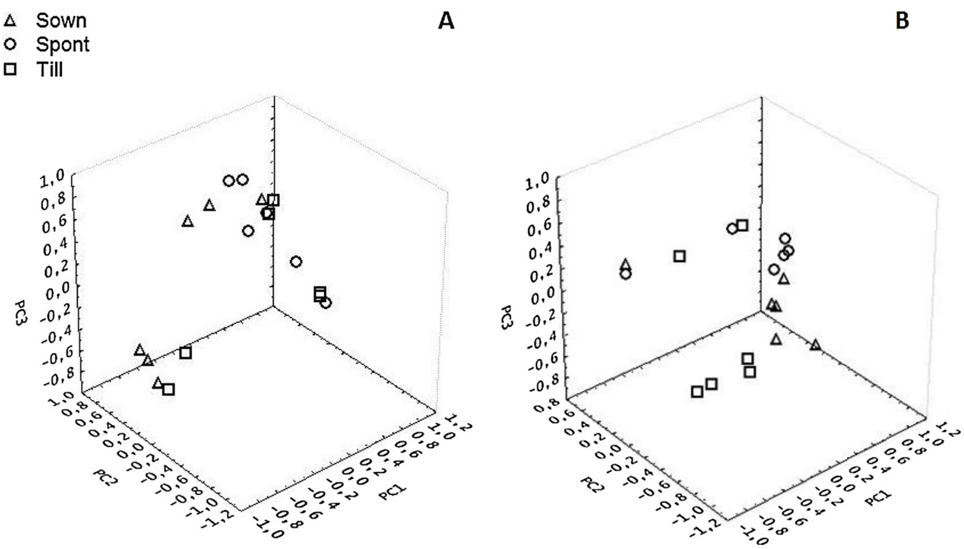

Fig. 1. Principal component analysis based on the plant richness and cover of each species in three different soil management practices used in vineyards (SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage), in 2014 (A) and 2015 (B).

(15.50 %) [which included the remaining Hymenoptera], and indeterminate (1.00 %) [which included other Acari, Diptera and other unknown Coleoptera families].

The activity density, richness, and SDI of total soil-surface arthropods differed significantly between years (Table 2); the NMDS analysis also revealed a clear separation between years, particularly in activity density (Fig. 3). The ultimate 2-dimensional NMDS solution for activity density was found with the Euclidean dissimilarity measure (stress of 0.149: moderate quality). The first axis allowed the separation of years ($t = -10.38$; $P < 0.01$) while the second axis allowed the separation of treatments ($\chi^2_{kw} = 15.73$; $P < 0.01$) (Fig. 3A). For richness, the ultimate 2-dimensional NMDS solution was found with Mountford dissimilarity (stress of 0.11: moderate quality). The first axis allowed the separation of years ($W = 269.00$; $P < 0.01$) and treatments ($\chi^2_{kw} = 8.52$; $df = 2$; $P = 0.01$) (Fig. 3B). The percentage of ground cover explained 22.10 % ($P = 0.02$) of the differences observed in the richness of total soil-surface arthropods.

In both years, the activity density of total arthropods was significantly higher in the ground cover treatments than in the TILL treatment (increasing by 23.7–45.9% in the SPONT treatment, and by 28.6–80.7% in the SOWN treatment, comparatively to the TILL treatment) (Tables 3 and 4). Moreover, while in 2014 the activity density did not differ significantly among ground cover treatments (Table 3), in 2015 it was significantly higher in SOWN than in the SPONT treatment (Table 4). In 2014, the NMDS analysis, whose ultimate 2-dimensional solution was found with Canberra dissimilarity (stress of 0.15: moderate quality), showed a high degree of overlap between treatments, not allowing an association with the activity densities of the groups observed (Fig. 4A). Even so, it is possible to note the association of potential natural enemies (mainly Coleoptera and Opiliones) with the SOWN treatment. In 2015, the ultimate 2-dimensional NMDS solution was found with Euclidean dissimilarity (stress of 0.17: moderate quality); in that year, the NMDS analysis revealed a clear separation of the different treatments in the first axis ($F_{(2, 15)} = 12.36$; $P < 0.01$); thus allowing the establishment of two distinct groups, the first one composed of the TILL treatment and the second one encompassing SPONT and SOWN treatments (Fig. 4B). The percentage of cover vegetation allowed explaining 47.50 % ($P = 0.02$) of the differences observed in the activity density for the year 2015.

The negative impact of tillage on total richness was only observed in 2015, and no significant differences were found between the SOWN and SPONT treatments (richness increased by 54.7 % in the SPONT treatment and by 37.1 % in the SOWN treatment, comparatively to the TILL treatment) (Table 4). The NMDS analysis enabled the distinction of two groups in both years: in 2014, the ultimate 2-dimensional NMDS solution was found with Manhattan dissimilarity (stress of 0.10: moderate quality); the first axis allowed separating the soil management practices ($F_{(2, 15)} = 6.20$; $P = 0.01$) and SOWN was significantly separated from TILL and SPONT (Fig. 4C); the percentage of cover vegetation explained 51.10 % ($P < 0.01$) of the differences found. In 2015, the ultimate 2-dimensional NMDS solution was found with Gower dissimilarity (stress of 0.19: moderate quality); the first axis allowed the separation of treatments ($F_{(2, 15)} = 4.05$; $P = 0.04$), and TILL was significantly separated from SPONT and SOWN (Fig. 4D).

The assemblage of detritivores was mainly composed of Collembola (Supplementary information, Table S1). Their activity density was higher in 2014 than in 2015 (Table 2). The NMDS analysis also revealed that the Collembola activity density was more associated with the year 2014 (Fig. 3A). In that year, the activity density of detritivores was significantly lower in TILL than in the other two treatments, which did not differ between them (Table 3).

In both years, the activity density of herbivores was significantly higher in the ground cover treatments than in TILL (increasing by 50.5–85.8% in SPONT and by 49.0–52.8% in SOWN, comparatively to the TILL treatment); richness did not differ significantly among treatments in any of the years; and SDI only differed in 2014, being lower in the TILL treatment, but only significantly different from the SPONT treatment (Tables 3 and 4).

Concerning the potential natural enemies, their activity density, richness, and SDI were significantly higher in 2015 than in 2014 (Table 2). In both years, the activity density of potential natural enemies was significantly higher in the ground cover treatments than in the TILL treatment (increasing by 63.0–176% in SPONT and by 54.2–218% in SOWN comparatively to TILL), and no differences were found between ground cover treatments (Tables 3 and 4); however, the negative impact of tillage on richness and SDI was only found in 2015 (Tables 3 and 4); richness of potential natural enemies increased 93.0 % in both ground cover treatments comparatively to the TILL treatment.

Regarding omnivores (exclusively composed of Formicidae), their activity density differed significantly among treatments in both years (Table 2), although these differences were not consistent between years. While in 2014 the activity density was significantly higher in the TILL treatment (Table 3), in 2015 it was higher in SOWN than in the other treatments (Table 4). Significant differences in SDI only occurred in 2015 and only between two of the treatments, being significantly higher in SPONT than in the TILL treatment (Table 4).

Fig. 2. Soil arthropods frequently found in vineyards from the Douro Demarcated Region: Soil-surface arthropods [Collembola (a); Opiliones (b); Araneae (*Zodarion* sp) (c); Isopoda (d); Formicinae (*Messor barbarus*) (e); Carabidae (f); Diplopoda (g); and Chilopoda (h)] and soil-living arthropods [Collembola (i); Acari;(*j*, k, and l); Diplura (m); Palpigradi (n); Protura (o); Symphyla (p); Chilopoda (q); Pseudoscorpionida (r); Formicidae (s); Coleoptera (t)].

3.2.2. Soil-living arthropods

A total of 11,221 soil-living arthropods were collected (Fig. 2). The most abundant were Acari and Collembola, representing more than 95 % of the total soil-living arthropods collected in each treatment. Symphyla, Lepidoptera (larvae), Hemiptera, Formicidae, Chilopoda, Coleoptera, and Diptera, which occurred in all treatments, represented between 3.20 % and 4.24 % of the soil-living arthropods (Supplementary information, Table S2 and Figure S1). The remaining taxa accounted for 0.22 % to 0.53 % of the total organisms: Araneae, Pseudoscorpionida and Palpigradi only occurred in the SPONT treatment; Protura and Psocoptera only occurred in the SOWN treatment; Diplura, Diplopoda, and Hymenoptera (other than Formicidae) occurred in both SPONT and SOWN treatments (Supplementary information, Table S2 and Figure S1). Ground cover treatments positively affected both the activity density and richness of soil-living arthropods, being these diversity components significantly higher in those treatments than in the TILL treatment (comparatively to the TILL treatment, the activity density and richness of soil-living arthropods increased by 100 % and 77.3 % respectively in SPONT, and by 88.9 % and 86.6 % respectively in the SOWN treatment) (Table 5). SDI did not differ significantly among treatments (Table 5).

3.3. Effect of management practices on the stability of soil-surface arthropods

In 2014, stability indices did not differ significantly among treatments (Table 6). However, in 2015, the SOWN treatment always recorded a significant positive effect on stability indices. Thus N_{ne}/N_h and S_{ne}/S_h were significantly higher in SOWN than in the TILL treatment; on the other hand, $(N_{ne} + N_n)/N_h$ and $(S_{ne} + S_n)/S_h$ were significantly higher in SOWN than in the SPONT treatment (Table 6).

In 2014, positive correlations were found between total activity

Table 2
Generalized linear model analysis (global model) for soil-surface arthropods (total, detritivores, omnivores, herbivores, and potential natural enemies) comparing the effect of year and soil management practices (treatments) on their activity density, richness, and Simpson's diversity index (SDI).

Functional group	Wald χ^2 global	*p*-value	Individual effect	
			Year	Treatment
Activity density				
Detritivores	5839.80	< 0.01	*	*
Herbivores	66.00	< 0.01	n.s	*
Natural enemies	291.10	< 0.01	*	*
Omnivores	146.70	< 0.01	n.s	*
Total	5076.00	< 0.01	*	*
Richness				
Detritivores	45.50	< 0.01	*	n.s
Herbivores	3.50	> 0.05	n.s	n.s
Natural enemies	62.00	< 0.01	*	*
Omnivores	9.20	< 0.05	n.s	*
Total	33.60	< 0.01	*	*
Simpson's diversity index				
Detritivores	10.30	< 0.05	*	n.s
Herbivores	3.10	> 0.05	n.s	n.s
Natural enemies	22.30	< 0.01	*	*
Omnivores	5.90	> 0.05	n.s	n.s
Total	27.90	< 0.01	*	n.s

SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage. n.s. – no significant effect; * - significant effect ($p < 0.05$).

density and the $(N_{ne} + N_n)/N_h$ index in both TILL (r = 0.47, p = 0.02) and SOWN (r = 0.59, p < 0.01) treatments. In the TILL treatment, richness was positively correlated with N_{ne}/N_h (r = 0.57, p < 0.01), S_{ne}/S_h (r = 0.59, p < 0.01) and $(S_{ne} + S_n)/S_h$ (r = 0.52, p = 0.01). SDI was negatively correlated with the $(N_{ne} + N_n)/N_h$ index in SPONT (r = -0.49, p = 0.02) and SOWN (r = -0.61, p < 0.01) treatments, and positively correlated with the S_{ne}/S_h index in TILL (r = 0.45, p = 0.03) and SOWN (r = 0.45, p = 0.03) treatments. In 2015, the SPONT treatment activity density was negatively correlated with the N_{ne}/N_h index (r = -0.48, p = 0.03), while SDI was positively correlated with the same index (r = 0.53, p = 0.02).

3.4. Effect of management practices on the biological soil quality index

The number of eco-morphological groups was significantly lower in TILL (3.94 ± 0.46) than in the other two treatments (6.06 ± 0.38 in SPONT and 6.22 ± 0.45 in SOWN) (Wald $\chi 2$ = 17.00, p < 0.01). Also, the QBS-ar index was significantly lower in TILL (47.94 ± 4.56) than in the other two treatments (77.89 ± 5.61 in SPONT and 81.61 ± 5.70 in SOWN) (Wald χ^2 = 23.80, P < 0.01).

4. Discussion

4.1. Effect of management practices on cover vegetation

The data from 2015 shows that the structural composition of vegetation in SOWN treatments tended to get closer to that of SPONT treatment, and 54.7 % of the richness taxonomy observed was shared by the two treatments. Thus, as pointed by the literature, these results suggest that spontaneous vegetation is the most efficient practice to guarantee more resilient vegetation responses (Gunderson, 1999; Margules and Pressey, 2000).

The vegetation resilience observed in the present study shows the natural ability of this spontaneous vegetation to reestablish ecological functionality. This resilience was also demonstrated by the only indicator species (also referred to as diagnostic species) associated with the SOWN treatment in the two years. the mentioned species was the sowing species *O. sativus*. *P. aviculare*, that was associated with the TILL treatment, possibly due to its need for light in order to germinate, which is facilitated by tillage (Batlla et al., 2007).

4.2. Effect of management practices on the activity density and diversity of soil arthropods

Results shows that vineyard soil cover, with either spontaneous or sown vegetation, incremented significantly the activity density and diversity of both soil-surface and soil-living arthropods.

The benefit of non-tillage systems to soil arthropods diversity has been demonstrated in several studies (Brévault et al., 2007; Roger-Estrade et al., 2010). This is because the mechanical impact and the lower food sources in tillage systems cause habitat disturbance and remove the essential reproduction sites or resources (Brévault et al., 2007), which results in negative impacts on soil arthropods. Moreover, tillage is also known to affect soil organisms directly, by killing, injuring or exposing them to predators (Roger-Estrade et al., 2010). On the other hand, the organic residues present in ground cover treatments not only represent a feeding source for soil arthropods, involved in their decomposition and transformation (Conti, 2015), but also benefit other arthropods by providing them shelter and favorable microclimate, protecting them against drastic variations in humidity and temperature, and also increasing alternative food for natural enemies (Brévault et al., 2007; Roger-Estrade et al., 2010).

The high activity density of detritivores (mainly composed of Collembola) observed in 2014 may be associated with the rainfall

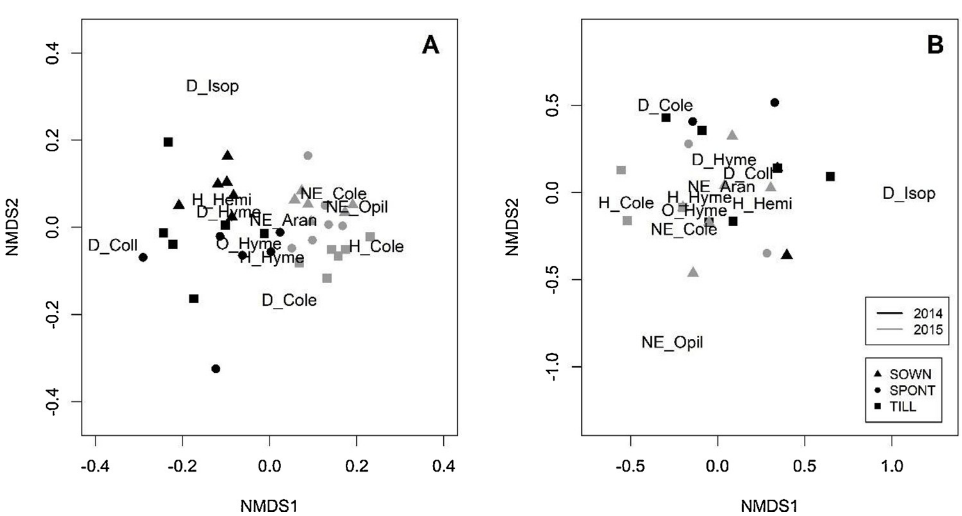

Fig. 3. NMDS ordination plots of the activity density (A) and richness (B) of functional groups of soil-surface arthropods, in three different soil management practices used in vineyards (SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage) in the two years under study (2014 and 2015) (D – detritivore; H – herbivore; NE – potential natural enemy; O – omnivore; Aran – Araneae; Coll – Collembola; Col – Coleoptera; Hemi – Hemiptera; Hym – Hymenoptera; Isop – Isopoda; Opil – Opiliones).

Table 3
Generalized linear model analysis (annual model - 2014) for soil-surface arthropods (total, detritivores, omnivores, herbivores, and potential natural enemies) comparing the effect of the sampling date and soil management practices (treatments) on their activity density, richness, and Simpson's diversity index. Data are presented as mean (S.E.).

Functional group	Wald χ^2 global	*p*-value	Individual effect		Treatment		
			Treatment	Date	SPONT	SOWN	TILL
Activity density							
Detritivores	6528.10	< 0.01	*	*	175.46 (61.96) b	182.83 (48.91) b	123.04 (43.49) a
Herbivores	138.60	< 0.01	*	*	12.42 (4.39) b	12.29 (2.09) b	8.25 (1.49) a
Natural enemies	15.60	< 0.01	*	n.s.	3.13 (0.46) b	2.96 (0.45) b	1.92 (0.37) a
Omnivores	717.10	< 0.01	*	*	12.92 (2.14) a	13.83 (2.54) a	31.54 (17.72) b
Total	6868.8	< 0.01	*	*	203.92(61.83) b	211.92 (47.93) b	164.79 (47.26) a
Richness							
Detritivores	2.50	> 0.05	n.s.	n.s.	3.67 (0.21) a	4.42 (0.23) a	3.71 (0.21) a
Herbivores	12.30	< 0.05	n.s.	*	1.88 (0.24) a	2.04 (0.19) a	1.50 (0.13) a
Natural enemies	9.10	> 0.05	n.s.	n.s.	2.38 (0.29) a	2.33 (0.30) a	1.58 (0.28) a
Omnivores	2.70	> 0.05	n.s.	n.s.	1.83 (0.12) a	2.08 (0.17) a	1.83 (0.16) a
Total	13.90	< 0.05	n.s.	*	9.75 (0.46) a	10.88 (0.55) a	8.67 (0.41) a
Simpson's diversity index							
Detritivores	68.70	< 0.01	n.s.	*	0.40 (0.06) a	0.40 (0.05) a	0.42 (0.05) a
Herbivores	47.10	< 0.01	*	*	0.24 (0.05) ab	0.32 (0.05) b	0.16 (0.04) a
Natural enemies	6.90	> 0.05	n.s.	n.s.	0.44 (0.06) a	0.38 (0.07) a	0.30 (0.06) a
Omnivores	13.30	< 0.05	n.s.	*	0.28 (0.04) a	0.37 (0.04) a	0.29 (0.05) a
Total	53.70	< 0.01	n.s.	*	0.59 (0.06) a	0.57 (0.06) a	0.61 (0.05) a

SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage; values with different letters are significantly different from each other ($p < 0.05$); n.s. – no significant effect; * - significant effect.

occurred during the sampling periods, since 2015 was hotter and drier than 2014 (IPMA, 2014, 2015), and Collembola are dependent on weather conditions, remaining in deeper soil layers during dry seasons (Detsis, 2000). Moreover, the activity density of detritivores in 2014 was higher in the ground cover vegetation treatments, which might be related to the possibility of these specimens feeding on organic residues supplied by covers. Also, Renaud et al. (2004) in France, and Sturm et al. (2002) in Germany, found positive effects of vineyard ground covers on Collembola when compared to tilled soils.

Contrariwise, Pfingstmann et al. (2019) found that in Vienna (Austria), the activity of Collembola in vineyards was higher in mechanically disturbed soils than in soils under permanent green cover. According to these authors, tilled soils have a rougher surface and provide better shelter for Collembola, while soils with permanent green cover tend to have a more compacted topsoil, providing them less favorable habitats.

Regarding herbivores, our results showed that ground cover treatments had a significant positive effect on their activity density However, from a conservation biological control perspective, the increase in soil herbivores activity density found in ground cover treatments should not be a concern to winegrowers, as most of them do not feed on vines. Additionally, herbivores can control the population of weeds through herbivory and help control certain pests through competitive exclusion or by helping maintain their populations of natural enemies by acting as alternative prey or host. Most herbivores found in our study, such as *Harpalus* sp., *O. rupicola* and *A. aenea* (Carabidae) (Aguiar and Serrano, 2013), and *M. barbarus* (Formicidae) (Baraibar et al., 2019) (Supplementary information, Table S1), are weed seed

Table 4
Generalized linear model analysis (annual model - 2015) for soil-surface arthropods (total, detritivores, omnivores, herbivores, and potential natural enemies) comparing the effect of the sampling date and soil management practices (treatments) on their activity density, richness, and Simpson's diversity index (SDI). Data are presented as mean (S.E.).

Functional group	Wald χ^2 global	*p*-value	Individual effect		Treatment		
			Treatment	Date	SPONT	SOWN	TILL
Activity density							
Detritivores	821.00	< 0.01	n.s.	*	16.00 (4.25) a	14.46 (4.15) a	14.92 (3.21) a
Herbivores	700.20	< 0.01	*	*	14.08 (4.02) c	11.58 (3.80) b	7.58 (2.07) a
Natural enemies	100.70	< 0.01	*	*	10.13 (1.90) b	11.67 (1.66) b	3.67 (0.61) a
Omnivores	542.80	< 0.01	*	*	13.33 (2.26) a	32.79 (13.18) b	12.25 (3.26) a
Total	1288.7	< 0.01	*	*	58.21 (8.84) b	72.08 (14.97) c	39.92 (5.95) a
Richness							
Detritivores	7.50	> 0.05	n.s.	n.s.	2.17 (0.22) a	2.04 (0.27) a	1.79 (0.18) a
Herbivores	11.10	< 0.05	n.s.	*	2.33 (0.30) a	1.88 (0.28) a	1.79 (0.23) a
Natural enemies	21.40	< 0.01	*	n.s.	4.67 (0.33) b	4.67 (0.50) b	2.42 (0.29) a
Omnivores	21.90	< 0.01	n.s.	*	3.00 (0.29) a	2.50 (0.28) a	1.88 (0.26) a
Total	36.00	< 0.01	*	*	13.54 (0.54) b	12.00 (0.60) b	8.75 (0.68) a
Simpson's diversity index							
Detritivores	8.90	> 0.05	n.s.	n.s.	0.33 (0.05) a	0.25 (0.05) a	0.26 (0.04) a
Herbivores	15.80	< 0.01	n.s.	*	0.36 (0.05) a	0.19 (0.05) a	0.23 (0.05) a
Natural enemies	8.50	> 0.05	*	n.s.	0.64 (0.04) b	0.56 (0.05) ab	0.45 (0.06) a
Omnivores	38.40	< 0.01	*	*	0.49 (0.05) b	0.36 (0.05) ab	0.30 (0.06) a
Total	22.70	< 0.01	*	n.s.	0.83 (0.01) b	0.75 (0.03) ab	0.73 (0.03) a

SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage; values with different letters are significantly different from each other ($p < 0.05$); n.s. – not significant effect; * - significant effect.

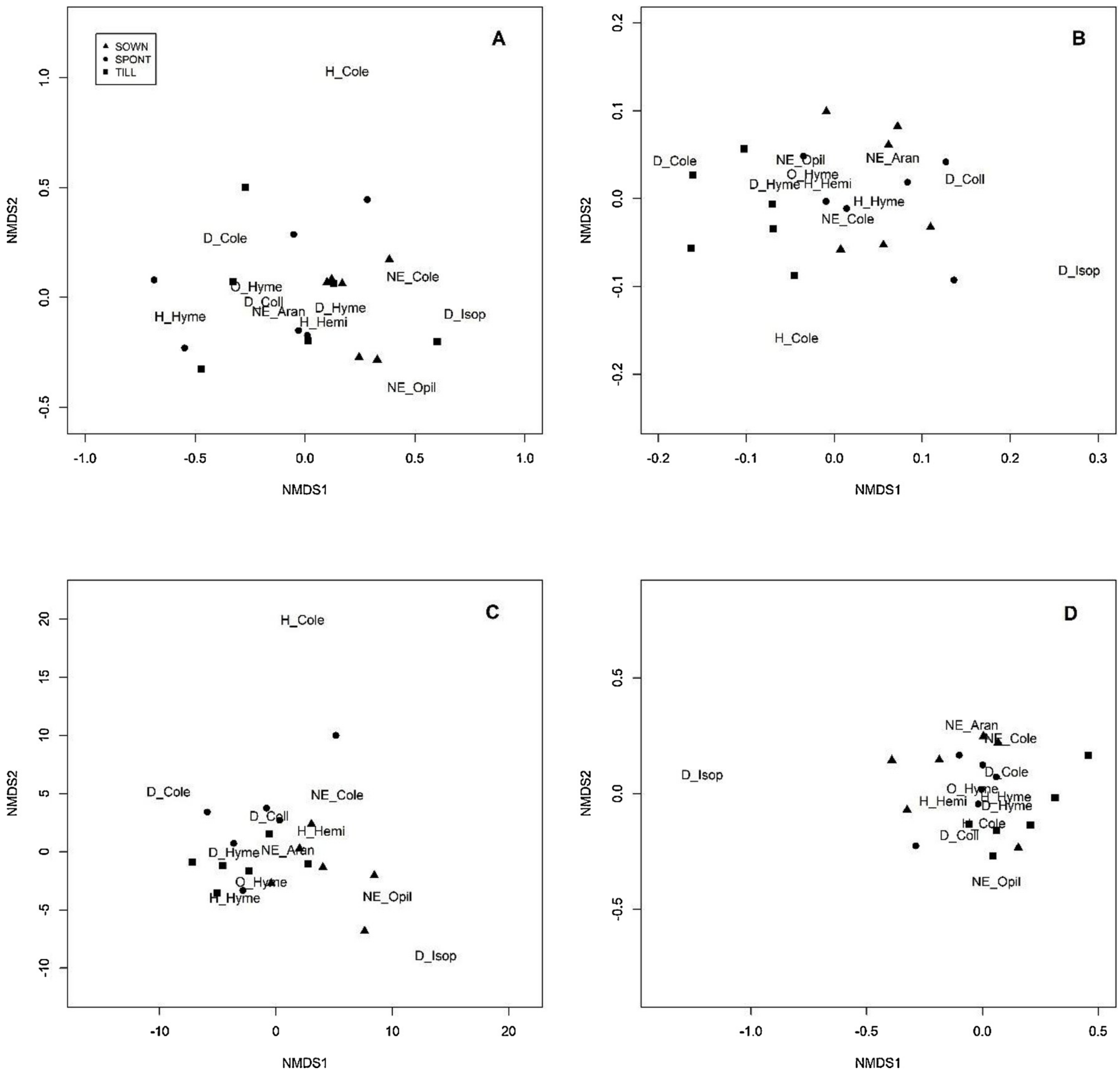

Fig. 4. NMDS ordination plots of the activity density and richness of functional groups of soil-surface arthropods in 2014 (A and C, respectively) and 2015 (B and D, respectively), in three different soil management practices used in vineyards (SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage) (D – detritivore; H – herbivore; NE – natural enemy; O – omnivore; Aran – Araneae; Coll – Collembola; Col – Coleoptera; Hemi – Hemiptera; Hym – Hymenoptera; Isop – Isopoda; Opil – Opiliones).

Table 5
Generalized linear model analysis for soil-living arthropods comparing the effect of soil management practices in vineyards on their activity density, richness, and Simpson's diversity index (SDI). Data are presented as mean (S.E.).

	SPONT	SOWN	TILL	Wald $\chi 2$	*p*-value
Activity density	25505.56 (6478.24)b	24083.33 (5346.85)ab	12750.00 (5231.24)a	6.60	< 0.05
Richness	23.44 (2.61)b	24.67 (3.19)b	13.22 (2.42)a	10.40	< 0.01
SDI	0.46 (0.04)a	0.52 (0.02)a	0.39 (0.05)a	1.90	> 0.05

SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage; values with different letters are significantly different from each other ($p < 0.05$).

predators. Blubaugh et al. (2016) showed that populations of weed seed predators significantly increased in ground covered soils, highlighting their importance in weed control and subsequent reduction of the need for traditional weed control practices, such as the use of herbicides. On the other hand, Baraibar et al. (2019) showed that tillage can disturb or even kill *M. barbarus* colonies while no-tillage systems promote a more even distribution of their nests, which should result in higher and more regular levels of weed seed predation across the field. Furthermore, herbivores also influence nutrient cycles and can contribute to soil fertility by enhancing primary production (Noriega et al., 2018).

The obtained positive impact of ground cover treatments on potential natural enemies (i.e., higher activity and richness) was expected. In a similar study, held in La Rioja (Northern of Spain), Sáenz-Romo et al. (2019) also found that the abundance of insect predators was significantly higher in vineyards with ground cover management (spontaneous and flower-driven cover) than those with tillage management. Plants provide arthropods with supplementary food resources, suitable shelter, and mating sites (Heimpel and Jervis, 2005). The probability of soil arthropod predators benefiting directly from nectar and pollen provided by the plants is reduced, however, it may be

Table 6
Generalized linear model analysis (annual models – 2014 and 2015) comparing the effect of the sampling date and the soil management practices (treatment) in vineyards on the different stability indices of the soil-surface arthropods community. Data are presented as mean (S.E.).

Year	Index	Wald χ^2 global	*p*-value	Individual effect		Treatment		
				Treatment	Date	SPONT	SOWN	TILL
2014	N_{ne}/N_h	16.70	< 0.01	n.s.	*	1.22 (0.36)	0.44 (0.08)	0.51 (0.16)
	S_{ne}/S_h	6.50	> 0.05	n.s.	n.s.	1.66 (0.31)	1.39 (0.25)	1.15 (0.27)
	$N_{(ne+n)}/N_h$	27.30	< 0.01	n.s.	*	42.92 (17.74)	59.68 (31.64)	46.44 (23.52)
	$S_{(ne+n)}/S_h$	5.50	> 0.05	n.s.	n.s.	5.11 (0.65)	5.25 (0.53)	5.07 (0.58)
2015	N_{ne}/N_h	24.70	< 0.01	*	*	1.78 (0.67) ab	4.81 (1.36) b	1.07 (0.22) a
	S_{ne}/S_h	9.90	> 0.05	*	n.s.	1.59 (0.24) ab	3.09 (0.54) b	1.46 (0.22) a
	$N_{(ne+n)}/N_h$	10.00	> 0.05	*	n.s.	6.05 (1.65) a	21.41 (8.12) b	8.40 (2.06) ab
	$S_{(ne+n)}/S_h$	9.50	> 0.05	*	n.s.	3.87 (0.53) a	6.64 (0.78) b	4.42 (0.40) ab

SPONT: ground cover with spontaneous vegetation; SOWN: ground cover with sown vegetation; TILL: tillage; values with different letters are significantly different from each other ($p < 0.05$).

a subjacent cascade effect determined by the high number of herbivores which develop on those plants and can serve as alternative host and prey for natural enemies. Moreover, the vegetation debris which remain under the soil after mowing could work as mulch, providing shelter for predators and food for detritivores, thus also enhancing their abundance (Roger-Estrade et al., 2010). Mashavakure et al. (2019) found that the abundance of ground and plant wandering spiders increased in plots with no-tillage and with retention of plant residue on the soil surface. Even inhabiting the ground, these predators may be potentially important in the natural control of vineyard pests, since many of them search their preys both on the soil surface and in the crop canopy (Kendall, 2003). Thus, it was suggested that in Californian vineyards (Roltsch et al., 1998), some spider species can move between the ground cover and the canopy. In this assumption, they may link the food webs of the ground cover and the vineyard canopy (Hoffmann et al., 2017). Anyway, it is admissible that the most important role of soil arthropod natural enemies is the control of arthropods vine pests which spend part of their lifespan on the ground, namely *Otiorhynchus sulcatus* Fabr. (Easterbrook et al., 1997), or of other vine pests or vine disease vectors that could use plants from the ground cover as hosts, such as *Scaphoideus titanus* Ball. (Trivellone et al., 2013), *Tetranychus urticae* Koch (Villiers and Pringle, 2011), and *Philaenus spumarius* L. (Morente et al., 2018).

The results obtained regarding the effect of ground covers on omnivores, namely on ants, need to be clarified in future studies, due to the discrepancy between years and in comparison to thoese reported in the literature. Thus, while according to Fernandes et al. (2018) and White et al. (2011), ground cover (vegetation and mowing) has a positive impact on ant populations, in the present study, the activity density of omnivores (a group composed mostly by ants) in 2014 was significantly higher in the TILL treatment compared to both SPONT and SOWN treatments. On the other hand, the relatively high activity density of omnivores observed in 2015 in the SOWN treatment might have been due to the attraction exerted on ants by the populations of aphids, which developed abundantly in the plants of this treatment (personal observation), not being directly due to the impact of the ground cover.

4.3. Effect of management practices on the stability of soil-surface arthropods

Results of the present study show a relatively high number of neutral arthropods (such as Collembola) in the complex of arthropods found on the vineyard soils. Collembola are known to be an important source of prey for generalist predators such as spiders (Agustí et al., 2003; Kuusk and Ekbom, 2010; Oelbermann et al., 2008), thus contributing to the stability of the arthropod community. In general, the results of the present study show indices with values higher than one, which, as reported by Wan et al. (2014), suggests a direct antagonistic effect of the beneficial arthropods over the harmful ones, as well as a combined regulatory effect of the beneficial and neutral arthropods. However, significant differences between treatments were only found in 2015, with the higher values in the SOWN treatment.

In general, the correlations found between both the activity density and richness of total soil-surface arthropods and the stability indices were positive, suggesting a positive impact of activity density and richness on stability. However, in 2014, a negative correlation was found in SPONT and SOWN treatments, between Simpson´s diversity index (SDI) and the antagonistic and regulatory effect of the activity density of natural enemies and neutral arthropods on the activity density of hebivores $((N_{ne} + N_n)/N_{h)}$,.. Moreover, a negative correlation was also found in the SPONT treatment in 2015, between the activity density of total soil arthropods and the inhibitory effects of the activity density of natural enemies on the activity density of herbivores (Nne/Nh). These results may be an indication that coverage treatments can enhance the activity density, diversity and stability of arthropod communities, but such increase in activity density and diversity will not always positively affect arthropod stability. According to Wan et al. (2014), a positive relationship between arthropod stability and arthropod diversity has been shown in several studies, but such does not always happen and sometimes such relationship is not linear. Dovčiak and Halpern (2010) stated that positive relationships can arise if diversity has facilitative effects or if stability is a precursor to diversity rather than a response. On the other hand, Walker (1992) put forward the redundancy hypothesis, which is based on the idea that species may be divided into functional groups where after the removal of one species, there is density compensation among the remaining ones. This means that ecosystems can remain stable even in case of disturbance (Santoro et al., 2015).

4.4. Effect of management practices on the biological soil quality index

The QBS-ar index was significantly negatively affected by tillage. In this treatment, the activity density of microarthropods groups well-adapted to the soil, such as Symphyla, Protura, Diplura, Palpigradi, and Pseudoscorpionida was low or absent (Supplementary information, Table S2 and Figure S1). These microarthropods have morphological adaptations (small dimensions, colorless, anophthalmia, winglessness, thin cuticles) to soil characteristics (e.g. small spaces, darkness) (Parisi et al., 2005), but they are more sensitive and vulnerable to environmental changes, namely tillage. On the other hand, a higher number of such microarthropods was found in the soils with ground cover, probably due to a higher amount of vegetation and organic residues present in the soil after mowing or/and to the absence of practices highly impacting on them such as tillage. The effect of soil tillage and practices like cover crops and fertilization (organic vs mineral) on QBS-ar values has been reported in several studies (see the review of Menta et al., 2018). A low impact management and a grassy cover have been found to positively affect soil microarthropod communities (Menta et al., 2017b).

Anyway, the value of QBS-ar obtained in the investigated treatments was never above 93.70, the value suggested by Menta et al. (2018) as a tentative threshold that separates high-quality soils from poor soils. Even so, the QBS-ar index could be a suitable tool to evaluate the impact of soil management practices in vineyard soils, since a higher value was obtained in both ground cover treatments than in tillage. The advantage of the use of this index is that it adds an important value to the diversity concept, namely the introduction of the adaptation level of arthropods to the soil (Menta et al., 2018). However, this result must be confronted with other metrics of soil quality such as soil physicochemical parameters and soil microbial communities before drawing general conclusions on soil status (Nsengimana et al., 2018).

5. Conclusions

The results showed that soil cover with vegetation significantly incremented the activity density and diversity of both soil-surface and soil-living arthropods. As previously referred, such arthropods may potentially provide support and regulatory ecosystem services in vineyards such as pest and weed control, organic matter decomposition, and soil structure modification (Stockdale et al., 2006). Thus, by implementing management practices that maximize ground cover vegetation in vineyards, farmers may potentially favor the provision of those ecosystem services. According to the obtained results, this can be achieved by maintaining and promoting the growth of spontaneous ground cover or by sowing mixtures of selected plant species.

Sowing mixtures of selected plant species may eventually have the advantage of accelerating the floristic-structural recovery, under stressed environmental situations. On the other hand, soil cover with spontaneous vegetation should be preferred, since it appears to be the most efficient practice to guarantee more resilience. Native plants are adapted to local conditions and possibly require little or no maintenance. Moreover, increasing native plant diversity can simultaneously enhance potential natural enemy biodiversity and pest suppression (Daane et al., 2018).

Finally, it should be noted that the present study was conducted in an area of only about 2 ha, which may somewhat hinder more robust conclusions from the obtained results. Even so, such results will certainly be important as a basis for future research aiming to deepen the knowledge on the subject under analysis. In this sense, we suggest the conduction of studies aimed at evaluating the impact of the investigated management practices on canopy-inhabiting arthropods, including vineyard pests, along with their impact on grapevine vigor, yield and fruit quality, and the possible competition for soil resources such as water and nutrients. Additionally, other sowing mixtures r should be studied, namely using plant species of different families, different flowering periods and different root systems, so that full advantage can be taken of this management practice.

As pointed out by Garcia et al. (2018), the suggested approach should be to find appropriate species and management practice options according to the ecosystem service required, in order to achieve trade-offs between ecosystem services without impairing farmers' economic return.

Declarations of interest

None.

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