Response of the Arthropod Community to Soil Characteristics and Management in the Franciacorta Viticultural Area (Lombardy, Italy)

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Abstract: Soil represents an important pool of biodiversity, hosting about a quarter of the living species on our planet. This soil richness has led to increasing interest in the structural and functional characteristics of its biodiversity. Studies of arthropod responses, in terms of abundance and taxon richness, have increased in relation to their ecological value as bioindicators of environmental change. This research was carried out over the 2014–2018 period with the aim to better understand arthropod taxa responses in vineyard soils in Franciacorta (Lombardy, Italy). To determine the biological composition in terms of arthropod taxa presence, one hundred soil samples were analysed. Environmental characteristics, such as chemical composition, soil moisture and temperature, and soil management were characterized for each soil sample. A total of 19 taxa were identified; the NMDS model analysis and the cluster analysis divided them into five groups according to their co-occurrence patterns. Each group was related to certain abiotic conditions; of these, soil moisture, temperature and organic matter were shown to be significant. A decision tree analysis showed that a longer period since conversion from conventional to organic farming lead to a higher arthropod biodiversity defined as a higher number of taxa.

1. Introduction

Soil has recently been described as the most complex and diverse ecosystem in the world [1], and it represents an important pool of biodiversity. It is indeed one of the richest habitats of terrestrial ecosystems in terms of species diversity [2,3]. The European Commission [4] estimates that about a quarter of living species on our planet are found in the soil, and the importance of this biodiversity has already been described in relation to the functional roles that the soil biota plays in regulating ecosystem processes [5]. However, despite the increasing number of studies on soil biodiversity, many structural and functional aspects of this biodiversity remain largely unexplored [5,6]. In this context, the investigation of the relationship between soil arthropod communities, in terms of abundance and taxa richness, and environmental conditions played an important role. The sensitivity of soil arthropods to environmental conditions [7,8], soil properties [9] and soil management practices [10] allows them to be considered as bioindicators of environmental change [11,12].

The relative importance of the factors influencing soil arthropod diversity and abundance in agroecosystems is still far from being understood. Indeed, the influence of abiotic and biotic variables and their interactions [13,14] varies according to the climate, type of soil and agricultural practices. The influence of meteorological variables (i.e., precipitation and air temperature), soil moisture and temperatures on soil arthropods has already been evaluated in different habitats [15–23]. Soil moisture and soil temperature have emerged as important factors that determine arthropod distribution [16,19,21,24,25], but the response of soil arthropods to soil water availability and temperature has been shown to vary between taxa [26–29]. In general, the positive effect of soil moisture on the abundance of soil arthropod communities has been emphasised [16,30] and an optimum temperature range of between 5 °C and 10 °C was identified for species active in winter, and between 10 °C and 18 °C for those active in summer [31] (p. 6). Soil chemical and physical characteristics have been identified as important drivers in soil arthropod distribution and abundance [9,11,13,20,32–38]. Soil texture [39], soil organic matter content [40,41], pH [11,37,38] and heavy metal concentration [13,20] have been shown to have a major influence on soil biota. Of these, soil pH and soil organic matter represent the most significant drivers in relation to the influence of soil pH variation on soil arthropods presence [11,37] and to arthropods role in soil organic matter degradation [34,35]. Soil arthropods contribute, in fact, to nutrient cycling as secondary decomposers, conditioning litter through comminution and passage through the gut, for further breakdown by the microflora [34] and stimulating microbial mineralisation of nutrients through grazing activity [35].

The influence of management on soil arthropods has been investigated in different agricultural contexts [10,42–46]. In particular, different studies have focused on the effect of organic viticulture on soil arthropod communities; different authors [15,47,48] show the general positive effect of organic management on soil arthropod abundance and distribution. However, the results have varied for each taxon investigated [49,50]. Furthermore, only few studies have been carried out evaluating the role of time of organic practice application on soil arthropod biodiversity [51]. Further research is therefore needed to assess the medium and long-term effects of organic agriculture on soil biodiversity [52].

In this paper, we report on the results of a 5-year investigation into the responses of the arthropod community to soil characteristics and vineyard management in the Franciacorta viticultural area (Lombardy, Italy). The diversity and co-occurrence patterns of different taxa were analysed in relation to abiotic factors, such as soil temperature, soil moisture and soil chemical properties. Moreover, the influence of vineyard management (conventional vs. organic) and the time of conversion from conventional to organic on arthropod biodiversity was investigated.

2. Materials and Methods

2.1. Study Sites

This study was carried out in a major Italian winemaking area. Franciacorta is the most famous Italian wine region for the production of sparkling wine using the champenoise method and is located in the Lombardy Region (Figure 1). The zone covers a total area of 2615 ha (as of 2018) and hosts 117 wineries (as of 2019). This research collected a total of 100 soil samples from 100 different vineyards over the period 2014–2018. Eighty-five per cent of samples were collected in spring (May or June) and 15% of samples in autumn (September, October or November). All the samples were characterised by presence of arthropods and the chemical characteristics of soil.

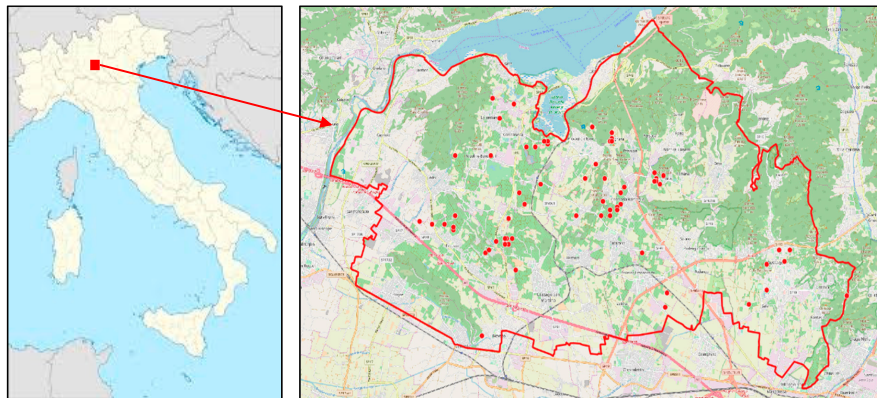In Figure 1, the location of each sampling site is shown.

Figure 1. Map of the Franciacorta DOCG (Designation of Controlled and Guarantee Origin) winegrowing area. The locations of vineyards where samples were collected are indicated with red dots.

Vineyard management systems were classified in two main groups: conventionally managed vineyards without any specific environmental certification (conventional) and organic vineyards managed in compliance with the European Regulation on organic farming (reg EC n. 2018/848 and subsequent amendments and additions) (organic). For organic vineyards, we refer to the presence of this certification that implies compliance with the provisions of the law. In addition to this, we have verified a minimal set of conditions occurred in each farm monitored in organic farming. These actions refer to: no use of synthetic chemicals for plant protection and for fertilizing the vineyard; the integration of organic matter into the soil through the supply of organic matrices; the total absence of use of herbicides and the management of the sub-row through mechanical intervention; the preservation of the herbaceous covering on the ground; the minimum tillage adoption. Organic vineyards were then further divided into three subgroups, on the basis of how long ago they had been converted from conventional to organic farming: 3 years or less (organic ≤ 3), between 4 and 9 years (4 ≤ organic ≤ 9), and 10 years or more (organic ≥ 10).

2.2. Environmental Variables

Soil moisture (SM) and soil temperature (ST) data for the Franciacorta area from 2014 to 2018 were obtained from the National Centers for Environmental Predictions [53]. These data were then re-analysed using the Weather Research and Forecasting (WRF) simulations [54]. The WRF model (version 4.02) was applied to a high spatial resolution grid (each cell of the grid representing a 2 × 2 km area) to generate hourly data. In particular, the Noah scheme [55] has been used as land surface model (LSM) scheme (i.e., Noah, Noah-MP, and CLM4) to assess detailed multi-layer soil moisture and soil temperature. We focused on a depth of 0–15 cm below land surface. Each vineyard was associated with the nearest grid node to allow extraction of the specific soil temperature and moisture values.

To assess the influence of environmental variables on the presence of soil arthropods, SM and ST were evaluated for each vineyard in a 30-days reference period prior to the sampling date (Table A1). Two thermal thresholds (ST_{low} and ST_{up}) were considered to define two intervals of temperature. These intervals characterise organisms that prefer lower temperature features (taxa occurring more frequently in the interval $[ST_{low}, ST_{up}]$) or higher temperature features (taxa occurring more frequently when soil temperature is higher than ST_{up}). The lower threshold (ST_{low}) was set at 10 °C and the upper threshold (ST_{up}) was set at 20 °C [31] (p. 6). Soil temperatures lower than 10 °C were not included since they can be considered to be below the lower development threshold for most taxa. Considering ST_{low} and ST_{up}, two variables related to soil temperature were calculated for the reference period (720 h):

$$TL = \frac{1}{24} \sum_{i=1}^{720} (ST_i - ST_{low}), \ ST_{low} \leq ST_i < ST_{up} \qquad (1)$$

$$\text{TH} = \frac{1}{24} \sum_{i=1}^{720} \left(\text{ST}_i - \text{ST}_{up} \right), \ \text{ST}_i \geq \text{ST}_{up} \tag{2}$$

where ST_i is hourly soil temperature. TL is the daily cumulative soil temperature degrees exceeding 10 °C when ST_i is between 10 °C and 20 °C; TH is the daily cumulative soil temperature degrees exceeding 20 °C when ST_i is greater than 20 °C.

A soil moisture threshold (SM) was defined to discriminate between organisms that prefer drier conditions, i.e., taxa occurring more frequently when soil moisture ranges in the interval [0, SM], or wetter conditions, i.e., taxa that more frequently occur when soil moisture is in the range [SM,1]. SM was set equal 0.35 (corresponding to 35%), which represents a reference value that can be associated, in different ecological contexts, to a status that satisfies the requirements in terms of humidity of soil arthropods [21,22]. Two variables associated with soil moisture were calculated for the reference period (720 h):

$$\text{MD} = \frac{1}{24} \sum_{i=1}^{720} |\text{SM}_i - \text{SM}|, 0 \leq \text{SM}_i \leq \text{SM} \tag{3}$$

$$\text{MH} = \frac{1}{24} \sum_{i=1}^{720} (\text{SM}_i - \text{SM}), \ \text{SM}_i > \text{SM} \tag{4}$$

where SM_i is the hourly soil moisture. MD is the daily sum of absolute deviations in soil moisture values from the threshold value when SM_i is lower than 0.35; MH is the daily cumulative soil moisture exceeding 0.35, when SM_i is higher than 0.35.

2.3. Chemical Characterisation of Soils

Chemical analysis of soils was performed according to the Italian regulation (DM 13 September 1999). Soil samples were taken at a depth of 0–15 cm and mixed homogeneously. Leaf litter was excluded, as it is not part of the soil itself. The collected soil samples were air-dried, homogenized and passed through a 2 mm sieve for chemical analysis.

Characterisation of the soil chemistry involved measuring soil texture (TXT), pH, active limestone (expressed in g $CaCO_3$/kg of soil) (AL), organic matter content (expressed in g/kg of soil) (SOM), available phosphorus (mg P_2O_5/kg of soil) (P), available potassium (mg K_2O/kg of soil) (K), available magnesium (mg MgO/kg of soil) (Mg) and copper content (mg/kg) (Cu). Soil texture was classified following the USDA soil texture triangle classification [56] (p. 125).

2.4. Soil Arthropods Identification

A cubic sample of soil (with a dimension of about 30 cm^3) was collected at the same depth described for chemical soil analysis, at each vineyard. Arthropods were extracted by placing the soil sample in a Berlese–Tüllgren funnel under a 60 W incandescence bulb, leading soil arthropods to migrate towards the damp part of the soil sample (away from the light). The soil arthropods fell through the cavity, into a preserving solution (2/3 alcohol and 1/3 glycerol). Determination of biological forms was carried out according to the QBS-ar (Soil Biological Quality-arthropod) method as proposed by [57], and the definition of the taxonomic entities and the biological stages is in agreement with the one reported in the same paper.

2.5. Data Analysis

2.5.1. Taxa Co-Occurrence Patterns

To measure soil arthropods biodiversity a taxa co-occurrence approach was used. For each vineyard, a taxa presence profile was defined, i.e., a vector indicating the presence or absence of the taxa in each vineyard. The presence profile did not consider population abundance. Based on the presence profiles, vineyards and taxa were described in a J dimensional space (J is the number of taxa

considered), allowing taxa to be ordered by their vineyard presence profiles. Two taxa are close to each other if they share a similar pattern of co-occurrence in the vineyards, they are far from each other if one is present in the vineyards where the other is absent and vice versa.

To allow easy visualisation and interpretation of dissimilarity in soil biodiversity and taxa co-occurrence, it is useful to represent these profiles in a two-dimensional space, called an ordination plane. Non-metric multidimensional scaling (NMDS) can be used to summarise information and reduce the dimensionality of profiles [58]. By applying NMDS, vineyards and taxa can be ordered by the dissimilarity of the presence profiles. Bray–Curtis dissimilarity [59], used extensively in the ecological field, was adopted. NMDS analysis was performed using the metaMDS function of the vegan package in R [60]. Loss of information due to a reduction in dimensionality is assessed by the stress value, which refers to the disagreement between 2-D representation and original positions of taxa in multidimensional space.

To test which environmental drivers (Cu, pH, AL, SOM, P, K, Mg, TL, TH, MD and MH) are significantly correlated to the first two axes of the NMDS ordination plane, we applied the envfit function of the vegan R package [60]. Each variable was correlated independently and plotted on the plane as a vector. The direction of the vector represents the gradient direction of the environmental driver, while the length of the vector is proportional to the correlation of the ordination system and the environmental driver.

Taxa were grouped into clusters as homogeneous as possible in terms of co-occurrence patterns, based on taxa ordination results [59]. To perform hierarchical cluster analysis, the hclust function of R software [61] was applied.

2.5.2. Vineyard Management Impact

To assess the impact of vineyard management on the biodiversity of soil biota, decision tree analysis was performed. The number of taxa present in each soil sample was considered as a measurement of edaphic biodiversity, and three categories of soil biodiversity were defined: 'low' when the number of taxa was lower or equal to 4, 'medium' when the number of taxa in the soil sample was between 5 and 8, and 'high' when the number of taxa was greater than 8. A classification decision tree allowed to split the soil samples into homogeneous groups according to edaphic biodiversity based on the different vineyard management classes. Recursive partitioning and regression tree (RPART) analysis were performed by applying the rpart package of R software [62]. The fitting of the model was investigated using the accuracy index that corresponds to the percentage of cases correctly classified.

3. Results

3.1. Descriptive Analysis

3.1.1. Environmental and Vineyard Management Variables

The descriptive statistics for environmental variables included in the full model are shown in Table 1.

Seven types of soil texture were considered: clay, clay loam, silty clay loam, sandy clay loam, loam, silt loam and sandy loam.

Vineyard management was categorised into four classes: conventional management (7% of the sample), vineyards converted to organic farming in the last three years (45% of the sample), vineyards converted between 4 and 9 years ago (31% of the sample), and vineyards converted at least 10 years ago (17% of the sample).

Table 1. Descriptive statistics of continuous variables (soil characteristics and environmental drivers) included in the analysis.

	Unit of Measure	Mean ± Standard Deviation	Median (Q25–Q75)	Min	Max
Cu	(mg/kg)	58.68 ± 32.81	55.40 (36.9–72.2)	4.20	170.00
pH		7.10 ± 0.87	7.30 (6.35–7.9)	5.30	8.20
AL	(g CaCO$_3$/kg)	10.16 ± 22.62	0.00 (0.00–13.50)	0.00	130.00
SOM [1]	(g/kg)	21.94 ± 9.08	23.00 (15.00–25.00)	5.00	42.00
P	(mg P$_2$O$_5$/kg)	54.47 ± 40.20	51.00 (26.00–64.00)	9.00	222.00
K	(mg K$_2$O/kg)	148.52 ± 67.53	145.00 (94.00–178.00)	60.00	354.00
Mg	(mg MgO/kg)	165.75 ± 75.37	138.00 (117.00–210.00)	66.00	383.00
TL [2]	°C	68.76 ± 44.90	69.75 (33.67–104.39)	0.00	161.46
TH [3]	°C	106.05 ± 59.06	121.76 (55.73–153.38)	14.20	241.77
MD [4]	Pure number	10.39 ± 26.03	5.16 (1.51–7.88)	0.00	135.53
MH [5]	Pure number	0.11 ± 0.20	0.00 (0.00–0.156)	0.00	0.63

[1] SOM: soil organic matter. [2] TL: daily cumulative soil temperature exceeding 10 °C when soil temperature is between 10 and 20 °C. [3] TH: daily cumulative soil temperature exceeding 20 °C when soil temperature is higher than 20 °C. [4] MD: daily sum of absolute deviations in soil moisture when soil moisture is lower than 0.35. [5] MH: daily cumulative soil moisture exceeding 0.35 when soil moisture is higher than 0.35.

3.1.2. Taxa Identification

A total of 19 taxa were identified in the soil samples. In case of Diptera and Coleoptera, the biological stage of larvae were also detected (Table 2).

Collembola, Acari and Hymenoptera recorded the highest frequency of presence in the soil samples analysed. Collembola and Acari were reported in 89 of the 100 vineyards, Hymenoptera in 80 vineyards. The lowest frequency of occurrence was recorded for Psocoptera, Thysanoptera and Isopoda (8/100, 7/100, 6/100 respectively).

Table 2. Distribution of taxa according to stages considered in the analysis and presence (i.e., number of soil samples in which the taxon has been identified).

Taxa	Larvae	N° of Presences	Other Stages [1]	N° of Presences
Acari			x	89
Myriapoda—Diplopoda			x	12
Myriapoda—Chilopoda			x	17
Myriapoda—Symphyla			x	56
Myriapoda—Pauropoda			x	32
Hymenoptera			x	80
Thysanoptera			x	7
Pseudoscorpionida			x	11
Psocoptera			x	8
Coleoptera			x	31
Coleoptera larvae	x	39		
Collembola			x	89
Diptera			x	31
Diptera larvae	x	32		
Protura			x	25
Diplura			x	27
Hemiptera			x	12
Isopoda			x	6
Other_holometabolous [2]			x	20

[1] Other stages include all forms that produce active participation in soil cycles (e.g., pupae are excluded). In the case of the 'Other_holometabolous' taxon, the pupal stage is also included. [2] Other_holometabolous taxa include Mecoptera, Neuroptera and Raphidioptera orders in agreement with QBS-ar (Soil Biological Quality-arthropod) method [57].

3.2. Co-Occurrence Pattern Identification

Taxa dispersion in the non-metric multidimensional scaling plane is shown in Figure 2. Taxa were ordered according to their co-occurrence profiles. Neighbouring taxa in the plane were characterised by the presence in the same vineyards (e.g., Collembola and Coleoptera larvae, Psocoptera and Pseudoscorpionida); the more distant are two taxa, greater is the difference in terms of their presence in the vineyards (e.g., Diptera and Psocoptera, Acari and Pauropoda). The stress value estimated for the model was equal to 0.2, indicating the model has good ability to predict data in the reduced space.

The results of analysis of the correlation between environmental drivers and the NMDS plane are shown in Figure 2.
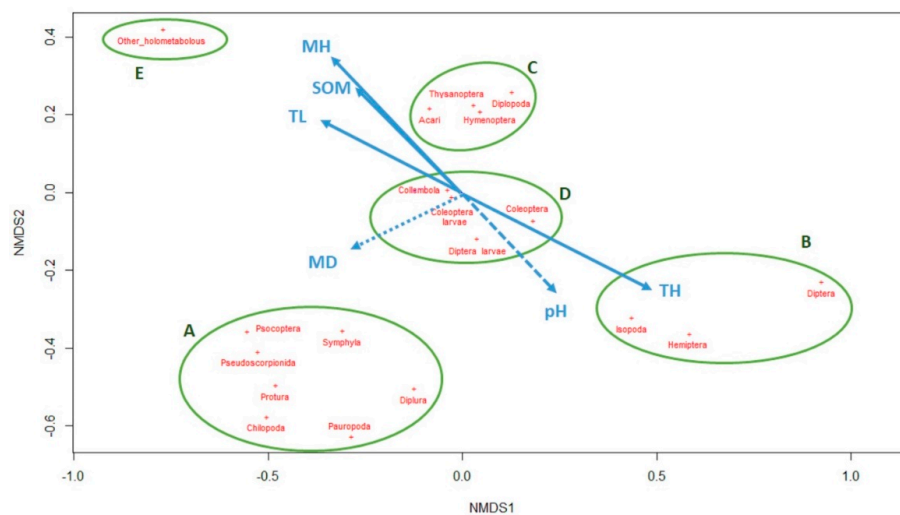

Figure 2. Results of non-metric multidimensional (NMDS) analysis: dispersion of taxa (red points) according to their co-occurrence profiles (NMDS1 and NMDS2 are the two axes of the ordination plane). Blue arrows refer to the correlation of environmental drivers and soil characteristics with NMDS ordination pattern (solid line ——— *p*-value < 0.5, dashed line – – – *p*-value < 0.1, dotted line ········ *p*-value < 0.15). The five clusters of taxa according their presence pattern are highlighted with the green circles.

p-Values of the correlation coefficients were used to discriminate the intensity of the relationship between environmental drivers and the taxa ordering system (Table 3): strong correlation for SOM, TL, TH and MH (*p*-value < 0.05); medium intensity correlation for pH (*p*-value < 0.1); low intensity correlation for MD (*p*-value < 0.15). The other environmental drivers were not significantly correlated with the first two axes of the NMDS system.

The results obtained from NMDS and cluster analysis (Figure 3) allowed the taxa to be divided into five groups according to their co-occurrence pattern. The five clusters shown in the cluster dendrogram correspond to the clusters identified by the green circles in the NMDS plane (Figure 2).

Group A included the largest number of taxa and specifically the Pseudoscorpionida, Psocoptera, Protura, Diplura Chilopoda, Symphyla and Pauropoda. Group B was made up of Diptera, Hemiptera and Isopoda taxa, while the larval form of Diptera was located in group D, together with Coleoptera, both as larvae and other biologic forms, and Collembola. The Acari, Hymenoptera, Thysanoptera and Diplopoda taxa made up group C. Group E is only represented by the taxa defined as 'Other_holometabolous'.

Table 3. Correlation analysis of environmental drivers and soil characteristics with NMDS ordination pattern.

Variable	Squared Correlation Coefficient	p-Value [6] of Correlation Coefficient	
Cu	0.05	0.17	
pH	0.06	0.09	**
AL	0.02	0.48	
SOM [1]	0.08	0.05	***
P	0.02	0.43	
K	0.01	0.66	
Mg	0.01	0.64	
TL [2]	0.08	0.04	***
TH [3]	0.15	0.01	***
MD [4]	0.05	0.15	*
MH [5]	0.12	0.01	***
TXT	0.04	0.83	

[1] SOM: soil organic matter. [2] TL: daily cumulative soil temperature exceeding 10 °C when soil temperature is between 10 and 20 °C. [3] TH: daily cumulative soil temperature exceeding 20 °C when soil temperature is higher than 20 °C. [4] MD: daily sum of absolute deviations in soil moisture when soil moisture is lower than 0.35. [5] MH: daily cumulative soil moisture exceeding 0.35, when soil moisture is higher than 0.35. [6] * p-value < 0.15, ** p-value < 0.1, *** p-value < 0.05.
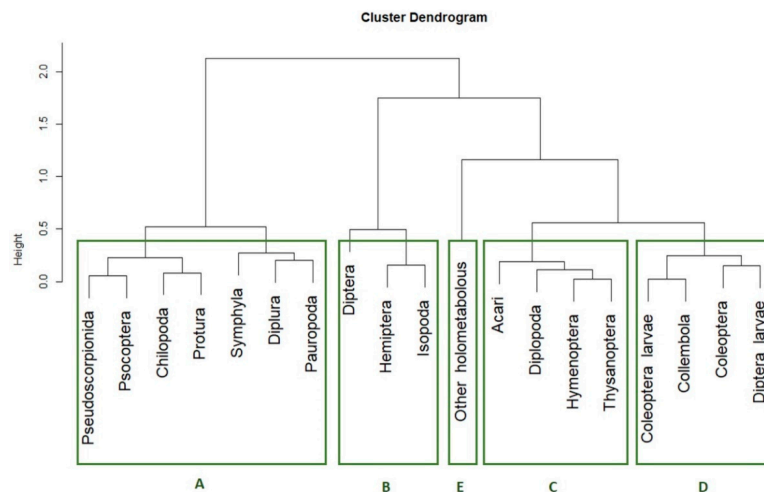
Figure 3. Dendrogram of hierarchical cluster analysis of taxa based on NMDS results. The five clusters are highlighted in green.

3.3. Vineyard Management

The results of the classification tree showed that variable vineyard management could be useful for discriminating different categories of soil biodiversity. In particular, the analysis of the tree shown in Figure 4 showed that conventionally managed vineyards were associated with a low level of biodiversity, vineyards that had adopted organic management for a maximum of three years were associated with a medium level of biodiversity, and vineyards that had adopted organic management for at least four years were associated with a high level of biodiversity.

The accuracy index showed a good fit of the model as 57% of cases was correctly classified.
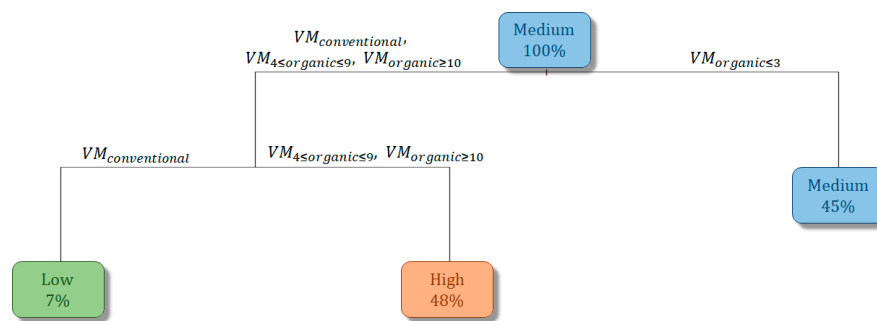
Figure 4. Classification decision tree of soil samples to predict soil biodiversity according to vineyard management. The predicted level of soil biodiversity (low, medium, high) is reported in the squared box, together with the percentage of soil samples included in that node. The paths from the initial box (with 100% of cases) to the final boxes represent the classification rules.

4. Discussion and Conclusions

The results obtained in this study allowed to identify the co-occurrence pattern for 19 taxa of soil arthropods on the basis of a 5-year investigation carried out in the Franciacorta viticultural area (Lombardy, Italy). The NMDS showed significant relationships between investigated soil arthropod taxa and soil moisture (MD and MH), soil temperature (TL, TH), soil organic matter (SOM) and pH. The decision tree showed an increased taxa diversity in relation to organic vineyard management and to the increase of time period of conversion from conventional to organic management.

In line with the expectations, Collembola and Acari were the most frequent of the 19 taxa identified, confirming that they are the most present groups of arthropods in soil [36,47,51]. The high level of presence of Hymenoptera recorded in our analysis is in agreement with other studies carried out in different agricultural contexts and reporting a significant presence of this taxon, mostly represented by Formicidae, in vineyard soils [63].

Based on taxa co-occurrence patterns, identified through NMDS analysis, five groups were found. Moreover, NMDS analysis made it possible to explore the relationship between soil abiotic variables and the aggregation of arthropod taxa in groups. In particular, the results obtained from our study pointed out that presence patterns characterising group A showed only one significant correlation (*p*-value < 0.15) with low soil moisture (MD). This result is compatible with the hypothesis that the taxa included in group A were relatively less dependent on high humidity values. The taxa in group B and the Coleoptera and Diptera larvae taxa (group D) were associated with higher pH (*p*-value < 0.1) and higher soil temperatures (TH) (*p*-value < 0.05), in line with the possible thermophilic habit of some representatives of these taxa [22,31,64]. The relationship with a higher pH level is more evident for the Isopoda and this is in agreement with van Straalen [11], who underlined weakly alkaliphilous or sub-neutral behaviour for some species of Isopoda. The detected ubiquitous presence of Collembola (group D) could be partially explained by the significant variability of responses to soil temperature, moisture and chemical properties of the different species of this taxon. In particular, the effect of soil moisture on Collembola has been documented by different authors [25,65], while species-specific responses have been reported [21]. Furthermore, Heiniger et al. [66] highlight that the role of microclimate for Collembola could be less important for their distribution than the role of trophic resources and competition. The presence of taxa in groups C and E is mostly determined by soil organic matter (SOM), soil moisture value higher than threshold level of 0.35 (MH) and lower temperature (TL) (*p*-values < 0.05). The relationship with SOM can be related to the involvement of these taxa in the soil food webs that starts from decomposition of dead organic matter generated by the activity of bacteria and fungi [32]. Diplopoda (Millipedes) are involved in SOM degradation, as their feeding activity is focused on dead organic matter [35,67]. A significant influence of soil nitrogen on species richness and biodiversity has been observed for this taxon [68], while Hymenoptera are involved in the decomposition of organic substances [35]. In relation to the positive response of group C to soil

moisture increase, some authors have underlined that soil water availability is an important factor controlling presence of mites (Acari) [69]. Other authors have showed that Oribatid mites (Acari: Oribatida) are positively influenced by soil temperature [27] and that their distribution is dependent on soil moisture [35]. The relationship observed between group E and soil moisture can be related for Mecoptera (included in Other holometabolous taxon) with data reported for pre-imaginal stages of this order which develop in the soil and showed preference for high soil moisture [70].

The co-occurrence pattern of the taxa identified in our study is in line with similar pattern reported in the literature. Taxa co-occurrence in group B agrees with the results in [71] that confirmed Diptera and Isopoda co-existence in some specific habitats. Acari and Hymenoptera (group C) have also been grouped together by other authors [41]. The composition of groups A and C suggests that the co-occurrence pattern can also be influenced by biotic relationships among taxa. According to Eisenbeis and Wichard [31] (p. 192), the trophic niche of Diplura includes Symphyla, while Weygoldt [72] noted that Pseudoscorpionida feed on different orders of small soil arthropods, including Psocoptera. All these associations support the taxa co-occurrence in group A. Similarly, Coleoptera contain taxa (e.g., Carabid beetle) that have been described as predators of Collembola [73]. This association is in line with the co-occurrence of these two taxa in group D.

The results obtained analysing the role of vineyard management on soil arthropods diversity allows to identify an increase of taxa diversity in relation to organic vineyard management. This is consistent with previous studies, which reported a general increase of arthropod biodiversity [48] and arthropod abundance [47] associated to organic vineyard management. This effect was evident even before a 3-year period after conversion. The effect on arthropod biodiversity markedly increases with the length of the period since organic farming adoption.

The results obtained in this study provide additional knowledge supporting the interpretation of diversity and co-occurrence patterns in soil Arthropoda in vineyard. The importance of abiotic variables together with the interpretation of the possible role of biotic relationship among taxa have been explored in the specific geographic context of the Franciacorta viticultural area. Furthermore, our study confirmed the effect of organic vineyard management in increasing arthropod taxa diversity and, most importantly, it showed the critical role of the time of conversion from conventional to organic farming in increasing arthropod biodiversity. Further experiments are needed to extend these results to other viticultural contexts.

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Appendix A

Table A1. Average values of soil temperature (ST °C) and soil moisture (SM measured in the interval 0–1) of the 30-days reference period prior to the sampling date for each site.

ID Field	Date	ST	SM	ID Field	Date	ST	SM
1	14 May	20.20	0.087	51	15 June	24.90	0.299
2	14 May	20.21	0.090	52	15 June	24.61	0.221
3	14 May	19.65	0.085	53	15 June	24.85	0.227
4	14 May	19.72	0.091	54	15 June	24.54	0.244
5	14 May	20.27	0.106	55	15 June	26.14	0.225
6	14 May	20.31	0.082	56	15 June	25.21	0.226
7	14 May	20.28	0.082	57	15 June	25.21	0.225
8	14 May	20.19	0.088	58	15 June	25.97	0.223
9	14 May	20.18	0.086	59	15 June	25.97	0.222
10	14 May	20.28	0.087	60	16 June	21.71	0.340
11	14 May	20.29	0.084	61	16 June	21.71	0.341
12	14 May	20.70	0.100	62	16 June	21.71	0.340
13	14 May	20.71	0.103	63	16 June	21.71	0.339
14	14 May	20.52	0.101	64	16 June	25.75	0.370
15	14 May	20.52	0.102	65	16 June	25.76	0.370
16	14 May	19.26	0.128	66	16 June	20.29	0.344
17	14 May	19.26	0.127	67	16 June	26.05	0.369
18	14 May	19.22	0.145	68	16 June	25.75	0.370
19	14 May	19.53	0.121	69	16 June	26.05	0.369
20	14 May	19.44	0.120	70	16 June	26.05	0.369
21	14 May	19.58	0.122	71	16 June	25.75	0.370
22	14 May	20.52	0.100	72	16 June	26.02	0.369
23	14 May	20.52	0.100	73	16 June	20.29	0.344
24	14 May	20.52	0.099	74	16 June	26.05	0.369
25	14 May	19.63	0.087	75	16 June	26.56	0.370
26	14 May	20.17	0.087	76	16 June	20.29	0.344
27	14 May	20.17	0.088	77	16 June	26.04	0.369
28	14 September	23.47	0.190	78	16 June	21.54	0.337
29	14 September	23.58	0.325	79	16 June	25.14	0.371
30	14 September	24.56	0.188	80	16 June	21.38	0.326
31	14 September	24.56	0.185	81	16 June	18.98	0.352
32	15 May	18.70	0.353	82	16 June	18.98	0.350
33	15 May	19.97	0.336	83	16 June	18.98	0.352
34	15 June	22.98	0.361	84	16 June	18.98	0.354
35	15 June	22.98	0.345	85	16 June	18.98	0.352
36	15 June	22.92	0.361	86	16 June	18.98	0.351
37	15 June	24.74	0.230	87	17 September	27.97	0.349
38	15 June	24.74	0.228	88	17 September	27.84	0.349
39	15 June	25.02	0.300	89	17 September	22.95	0.353
40	15 June	23.89	0.275	90	17 September	21.67	0.164
41	15 June	24.74	0.176	91	17 September	21.67	0.162
42	15 June	24.70	0.178	92	17 September	21.67	0.159
43	15 June	24.70	0.177	93	17 September	25.84	0.339
44	15 June	24.75	0.165	94	17 September	25.84	0.340
45	15 June	25.08	0.299	95	17 September	21.67	0.162
46	15 June	24.90	0.302	96	17 September	25.84	0.340
47	15 June	24.14	0.336	97	17 September	25.84	0.340
48	15 June	24.13	0.338	98	18 June	24.37	0.323
49	15 June	24.14	0.344	99	18 June	24.37	0.322
50	15 June	24.11	0.334	100	18 June	24.37	0.323

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