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Below-ground arthropod diversity in conventional and organic vineyards: A review

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A B S T R A C T

Viticulture is one of the most important agricultural sectors in the Mediterranean area but also one with substantial impact on the soil ecosystem. Some of the most common practices in viticulture, such as tillage, inter-row management, fertilization and use of pesticides, can have important effects on soil communities. The latter significantly contribute to several fundamental soil processes such as decomposition, nutrient and carbon cycling, and microbiota regulation. In perspective, it is therefore necessary to assess the effects of agronomical practices on soil biological communities. The increasing shift towards organic viticulture is seen as a promising management model to maintain soil functionality and preserve soil biodiversity. Below, we present an appraisal of the main practices in conventional and organic viticulture and their possible effects on soil mesofauna. Understanding the extent to which organic practices contribute to maintaining/altering soil functionality and biodiversity is a fundamental step towards the development of an environmentally sustainable viticulture.

1. Introduction

Sustainable soil management became part of the United Nations Global Agenda for the mitigation of climate change effects and for the fight against desertification and soil depletion (Amelung et al., 2020; Baronti et al., 2021; FAO. Food and Agriculture Organization of the United Nations, 2022). Overconsumption of land, intensive agriculture and soil erosion are the main threats, and are currently worsened by the increase in the frequency of extreme weather events (Montanarella, 2007). To date, it is considered of utmost importance to safeguard the soil and its functions with a view to sustaining productivity, achieving an efficient agriculture, and ensuring water availability (Aspetti et al., 2010; Simoni et al., 2018). In this context, awareness has increased that soil biota significantly contributes to aboveground functioning of terrestrial ecosystems and their capacity to resist and react to environmental changes (Bardgett and van der Putten, 2014). Soil microarthropods play a pivotal role in many fundamental soil processes such as decomposition, nutrient and carbon cycling, microflora regulation and bioturbation (Nielsen et al., 2011; Lakshmi et al., 2020; Menta and Remelli, 2020). Microarthropod biomass reflects the amount of organic matter in the soil, and species community composition indicates the rates of nutrient turnover (Maienza et al., 2023). In turn, soil communities can be influenced and shaped by several above- and belowground factors, such as soil porosity and compaction (Cambi et al., 2017), moisture (Tsiafouli et al., 2005; Platen and Glemnitz, 2016; Ghiglieno et al., 2020), carbon and nutrient availability (McCormack et al., 2013; Ghiglieno et al., 2020), soil Ph (Ghiglieno et al., 2020; Viketoft et al., 2021), presence of toxic substances (Migliorini et al., 2004; Singh and Tripathi, 2009). Moreover, given their limited dispersal capabilities, the community structure of soil microarthropods can be strongly influenced by habitat fragmentation (Åström and Bengtsson, 2011). A highly diversified soil fauna is generally related to low biocide applications, high amounts of organic matter, and low mechanical perturbance (Miyazawa et al., 2002; Menta and Remelli, 2020).

Viticulture is one of the most important agricultural sector, with about 7.5 million ha of global production and more than 3 million ha in Europe (Karimi et al., 2020; Ghiglieno et al., 2021; Giffard et al., 2022). Amongst agricultural activities, viticulture is not immune to soil biodiversity decline, since widespread viticultural practices, such as pesticides and tillage, profoundly affect soil biodiversity and may have a detrimental effect on microarthropods populations, in terms of abundance, diversity and community structure (Paiola et al., 2020). Many of the most common viticultural practices can lead to soil degradation and loss of soil functions, with consequent impact on production itself. For

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these reasons, a major shift is necessary leading towards an agroecological approach for a sustainable viticulture, boosting those techniques that can ensure quality production and a low impact on biodiversity (Karimi et al., 2020). From this perspective, organic viticulture is seen as a promising option in the development of an environmental-friendly agriculture (Ostandie et al., 2021). In general, organic managed fields host a greater diversity and density of soil arthropods than conventionally-managed ones (Bengtsson et al., 2005; Hole et al., 2005; Bavec and Bavec, 2015). However, although organic farming is generically seen as beneficial, the comparative analysis organic *vs.* conventional does not always clarify which aspects have a stronger influence in shaping the biodiversity of soil arthropods (Hole et al., 2005; Tuck et al., 2014). Conversion to organic farming may positively affect soil biota, but it is often complex to determine which is the main driver of the observable changes in soil microarthropod communities (Werner and Dindal, 1990). Observed changes in abundance or composition in soil arthropod communities are the result of the concerted action of multiple factors, combined with management practices (Viketoft et al., 2021). Furthermore, it cannot be ruled out that some organic practices may have a negative effect on some components of soil biodiversity (Tuck et al., 2014; Buchholz et al., 2017). As far as it is known, soil quality is generally higher in organic vineyards than in Integrated Pest Management (IPM) and conventionally-managed ones (Peverieri et al., 2009; Gagnarli et al., 2015; Menta et al., 2015; Simoni et al., 2019; Ghiglieno et al., 2020, 2021). However, as already mentioned, results are not always straightforward and, in some cases, organic practices, such as tillage, can impact much more than others on the community structure of soil arthropods (Seniczak et al., 2018).

In the following, we will evaluate the studies carried out on the soil mesofauna - with particular reference to the most abundant groups such as springtails (Collembola) and mites (Acari) - in organic and conventional vineyards, attempting to appraise how individual management practices impact on the diversity and composition of the soil biota. Althought not all of the variables – and their interactions – impacting soil arthropod diversity in the viticultural agroecosystem can be exhaustively examined, significant features from the literature are reported and the major points highlighted.

2. Microarthropods as bioindicators of soil quality

The development of standardized methods for soil quality evaluation is crucial to assess and monitor soil changes in composition and functionality over time in response to natural and anthropogenic factors. Soil quality depends on multiple and interactive physical, chemical, and biological properties as well as historical land use (Knoepp et al., 2000; Gagnarli et al., 2015). The multitude of factors involved makes an exhaustive analysis of the soil complex, just as it makes it reductive to use a single parameter to assess its health. Over the course of time, various indices - chemical, physical, and biological - have been developed for the assessment of soil quality, depending on the scopes and scale of application (Aspetti et al., 2010). In this context, biological indices provide a good representation of the state of the soil, as the biological elements reflect the simultaneous action of its chemical and physical characteristics. The functionality of the soil and, consequently, the ecosystem services it provides, largely depends on the biological activity within it, therefore measuring this biodiversity can reflect the capacity of the soil to deliver ecosystem services (Menta et al., 2018b). Classical ecological indices – i.e., Shannon-Wiener, evenness, Margalef, equitability, Berger-Parker – can be an effective tool in mirroring changes in soil communities due to heavy disturbance related to agricultural practices (Caruso et al., 2007; Gagnarli et al., 2015), but they sometimes fail to highlight differences in community structure and ecological differentiation of species (Menta and Remelli, 2020). Alternatively, in the past two decades, several authors proposed methods to define soil quality based on a single taxon (see Menta and Remelli, 2020).

Among soil microarthropods, Acari and Collembola have been largely employed as bioindicators since they are by far the most abundant groups of soil biota (van Straalen, 1998; Coleman and Wall, 2015; Vaj et al., 2014; Gruss et al., 2019). As biological regulators in several soil functionalities, they have been regarded as the most sensitive components to soil degradation and land use (Chauvat et al., 2007; Buchholz et al., 2017; Costantini et al., 2018). The ratio between the abundances of these two major groups has been used as soil indicator in several studies, based on the assumption that, under good soil quality conditions, the abundance of mites is greater than that of springtails (Menta et al., 2008; Vaj et al., 2014; Menta and Remelli, 2020). However, since the identification at the genus or species level of soil invertebrates often requires expertise, several authors have proposed indices based on higher taxonomic levels and a multitaxon approach (e.g., Cortet et al., 2002; Parisi et al., 2005; Ruiz et al., 2011). Indeed, information obtained at the macro-taxonomic level is usually sufficient to detect the effects of anthropogenic disturbances on the soil ecosystem, without resulting in a significative loss of information (Caruso and Migliorini, 2006). In Italy, QBS-ar (Soil Biological Quality-arthropod) has been widely adopted for assessing soil quality in different environmental contexts, as it is relatively easy to apply and does not require taxonomic identification to the species-level (Aspetti et al., 2010; Menta et al., 2018a, 2018b). Since its introduction, this method has caught on and found application in various environmental contexts (Menta et al., 2018a, 2018b). In this integrated approach, all collected microarthropods are determined at a macro-taxonomic level (Class or Order) and an ecomorphological index based on their degree of adaptation to the edaphic environment (EMI, ranging from 1 to 20 depending on the degree of adaptation) is attributed to each taxon (here defined as a biological form); the resulting QBS-ar value will be given by the sum of the EMI values attributed to the biological forms collected in each soil sample (Parisi, 2001; Parisi et al., 2005). The principle underlying this index is that the greater the presence of taxa strongly adapted to the soil microenvironment (hemi- or euedaphic forms), the higher the quality of the soil itself (higher EMI values) (Parisi, 2001; Parisi et al., 2005). Euedaphic forms are the most sensitive to changes caused by human activities and can be relevant for monitoring purposes (Parisi et al., 2005; Menta et al., 2018b). These forms often require a long time to recover after an external disturbance (Costantini et al., 2015). Few versions of this index have been proposed: some extended to taxa other than arthropods (i.e., Menta et al., 2015; Bigiotti et al., 2023), others restricted to considering a subset of taxa (Parisi and Menta, 2008). Overall, QBS-ar has proven to be a valid method to assess the quality of soil, reproducible at different scales and applicable over both short and long periods of time (Menta et al., 2018a, 2018b).

3. Use of agrochemicals and impact on soil microarthropods

Synthetic pesticides and fertilizers are among the biggest threats to soil invertebrates, such as mites and springtails (Gunstone et al., 2021). Albeit designed for protecting plants from specific pests, their impact on harmless soil fauna can be serious, and their action can drift to non-target areas (Vaj et al., 2014). In addition, most data available on the effects of these chemicals on soil organisms come from laboratory tests on model species, and only a limited data are available on non-model taxa in field experiments (Gunstone et al., 2021). In conventional agriculture, the use of synthetic agrochemicals to protect plants against pests (insecticides or acaricides) or to control diseases (fungicides) and weeds (herbicides) may exert a clear impact on soil biodiversity, at least during the period of greatest chemical load (Vaj et al., 2014). Additive effects may also arise as a consequence of the accumulation of agrochemical residue mixtures in treated fields (Panico et al., 2022). Conversely, the absence or reduction of pesticide application in organic farming translates in a drop of their negative effects on soil organisms (Karimi et al., 2020; Bosco et al., 2022). However, the response to biocides may vary amongst different taxa according to organism absorption, biotransformation, and detoxification routes as well as to pesticide avoidance behavior (Vaj et al., 2014; Joimel et al., 2022). In general, most of the effects of pesticides on soil fauna are negative, with insecticides and broad-spectrum chemicals having by far the greatest negative impact on soil biodiversity compared to herbicides and fungicides (Gunstone et al., 2021; Beaumelle et al., 2023). In addition, the accumulation of high residue concentrations in the soil can persist over time, slowing down the recovery of microarthropod communities after the physiological seasonal decline (Vaj et al., 2014; Beaumelle et al., 2023). Pesticides can affect soil arthropod populations directly or indirectly (Lins et al., 2007; Zaller et al., 2016). Indirect effects are mainly caused by pesticide-induced changes in ground cover vegetation (Edwards and Thompson, 1973) or by a cascading effect related to changes in fungal communities that represent the main trophic resource for several species (Mandl et al., 2018). Furthermore, surface species are more likely to be affected by pesticides than soil-dwelling ones (Fiera et al., 2020). At the same time, pesticides may have a bigger impact on species with low dispersal ability, since they cannot avoid sprayed areas by moving to undisturbed nearby zones (Zaller et al., 2016; Buchholz et al., 2017; Maderthaner et al., 2020).

Both springtails and mites are vulnerable to the use of insecticides (Gunstone et al., 2021). For instance, Ostandie et al. (2021) showed that the intensity of insecticide use, either organic or synthetic, has negative effects on the abundance of springtails regardless of the adopted farming system. In some cases, insecticide-induced changes in soil community structure may favor certain species, as a consequence of the disappearance of direct competitors or predators (Vaj et al., 2014; Gunstone et al., 2021). The response of soil invertebrates to fungicides and herbicides is more variable than that to insecticides, (Gunstone et al., 2021), as both fungicides and herbicides have being conceived to target non-animal groups (Beaumelle et al., 2023). On the other hand, too few studies have been carried out to draw generalized conclusions on the direct effects of fungicides and herbicides on soil communities (Beaumelle et al., 2023). Both synthetic and non-synthetic fungicides are reported to directly affect non-target soil arthropods in vineyards (Pozzebon et al., 2010; Reiff et al., 2021). Allarmingly, in their review on the contamination of vineyard soils, Komárek et al. (2010) observed that Cu-based fungicides exceed EU legislative limits in most of European vineyards, posing a significant environmental and toxicological hazard. Even in organic vineyards, where the use of synthetic products is banned (Regulation (EU) 2018/848), high concentrations of copper as a fungicide have been shown to have a negative effect on springtail abundance, suggesting that the fungicidal activity can exert a cascading negative effect on soil communities regardless of the type of cropping system (Mandl et al., 2018; Ostandie et al., 2021). In the case of herbicides, negative effects on soil fauna may be a consequence of weed reduction (Miyazawa et al., 2002). Indeed, the preservation of weed cover due to the suppression of the herbicide application benefits organisms in the more superficial layers of the soil (Renaud et al., 2004) since vegetation can provide shelter from high temperatures and constitutes a source of nourishment for various phytophagous (Gonçalves et al., 2020). Albeit the use of herbicides may lead to lower values in the abundance and diversity of microarthropods, the timing of herbicide administration may also have different effects on soil fauna (Renaud et al., 2004). The search for sustainable practices that can maintain soil fertility has led to an increasingly restricted use of herbicides, with their application limited to the post-emergence period (Renaud et al., 2004). In vineyards where post-emergence application of herbicides has been carried out, a relatively high presence of soil microarthropods was found with respect to vineyards where herbicide have been applied also in the pre-emergence phase (Reinecke et al., 2002; Renaud et al., 2004). In these cases, the supply of dead organic matter provided by the regrown plants seems to partly compensate the potential negative effects of herbicide application on soil fauna (Reinecke et al., 2002). In a study conducted in vineyards in the Valencian Community, Seniczak et al. (2018) showed that there was no difference in density or species diversity between oribatid mites from conventional and organic vineyards. The reasons for these apparently counterintuitive results probably lie in the mites' greater tolerance to the use of herbicides used in conventional agriculture paired with their sensitivity to mechanical tillage that was more intense in organic vineyards (Seniczak et al., 2018).

4. Response of soil microarthropods to fertilization practices

Fertilizers are substances that provide crops with necessary nutrients in forms that are easy to use and handle. They can be in the form of solids, liquids, or gases. Applying fertilizers can be done either to the soil or directly to the foliage (Angus, 2012). Soil fertilization in conventional farming can be accomplished using synthetic minerals or a combination of synthetic and organic fertilizers (Christel et al., 2021), whereas in organic farming, fertilization is entirely based on organic matter, livestock or green manure, or multiannual crop rotation that includes leguminous crops (Regulation (EU) 2018/848). The addition of mineral or organic amendments can have a positive impact on the abundance of soil biota. However, the specific response may vary depending on the type of fertilizer, the regime of manuring and the functional group being considered (Kautz et al., 2006; Axelsen and Kristensen, 2000; Viketoft et al., 2021; Betancur-Corredor et al., 2023). In addition, the impact of fertilization is influenced by climate and soil characteristics (Betancur-Corredor et al., 2023). In springtails, changes in chemical properties of the soil due to fertilizer addition may play a role in shaping their communities, as springtails are usually sensitive to pH variations (Viketoft et al., 2021); moreover, an increase in organic matter in organic fertilized fields leads to an augmentation of the bacteria and fungi on the surface, fostering the abundance of epiedaphic and hemiedaphic springtail species (Betancur-Corredor et al., 2023). A few studies demonstrated that abundance of mites is usually enhanced by organic fertilizers more than mineral ones (Platen and Glemnitz, 2016; Viketoft et al., 2021), but response to fertilizers may strongly vary across different groups, depending on their feeding habits (Cao et al., 2011; Gruss et al., 2018; Viketoft et al., 2021). For example, high additions of phosphorus may have a detrimental effect on fungi, thus exerting a top-down control on micophagous mites (Cao et al., 2011; Sun et al., 2017); at the same time, an increase in predatory mites, such as Mesostigmata, can be a consequence of higher prey density in organic fertilized fields (Cao et al., 2011; Betancur-Corredor et al., 2023). More recently, a technique that is successfully spreading in viticulture concerns the conversion of chopped and dried vine prunings into biochar, a high-carbon by-product resulting from the pyrolysis of feedstock in the absence of - or with very limited - oxygen (Wang and Wang, 2019; Cataldo et al., 2021). Its application in organic farming has been suggested to counteract soil carbon depletion and reduce the adaptive stress of crops in arid or semi-arid areas (Chagas et al., 2022; Maienza et al., 2023). In the Mediterranean vineyards, which can be frequently affected by summer droughts, biochar application does not alter the community structure of soil microarthropods (Andrés et al., 2019), and a single application increases the soil biological quality (Maienza et al., 2023). In addition, due to its ability to augment water retention, biochar may have a positive effect on water-dependent species of soil biota, such as springtails (Andrés et al., 2019), even if the repeated application may result in the reduction of species turnover (β-diversity), promoting the establishment of those species better suited to wet environments (Maienza et al., 2023). In general, to promote a long-term increase in soil fauna, the addition of organic or mineral amendments should be combined with agricultural practices affecting soil quality, such as reduced tillage or crop rotations (Kautz et al., 2006; Viketoft et al., 2021).

5. Management practices in viticulture and soil communities

Viticulture has witnessed a recent shift to more soil conservative techniques such as minimum or no tillage, living mulches, and cover-crops, that can preserve soil functioning and ecological services (Conti, 2015; Sommaggio et al., 2018; Cataldo et al., 2021). In intensive viticulture, tillage, mulching, and the use of herbicides are applied to reduce competition between the inter-row vegetation and the vine. On the contrary, under extensive management, the inter-rows space can be maintained with permanent grass cover (Bordoni et al., 2019). Inter-row management practices have a profound effect on the community of soil organisms, and mites and springtails are sensitive to the modification in soil structure due to management practices (Tabaglio et al., 2009; Simoni et al., 2018; Möth et al., 2023). In vineyards, inter-row management can be carried out in different ways, with the aim of weed control, water retention and soil erosion prevention. Depending on the management policy adopted, vineyard soils can be kept bare as a result of periodic and intensive tillage, show alternating tillage (i.e. a field in which an inter-row with vegetation is alternated with an inter-row where tillage is applied), or have no tillage (i.e. inter-rows left permanently covered by vegetation) (Buchholz et al., 2017; Pfingstmann et al., 2019). Tillage is a common practice that involves mechanical manipulation of the soil to loosen compact soil, manage soil water retention, and incorporate organic matter (Dobrei et al., 2015). Soil changes due to tillage can make the habitat less favorable, affecting organisms according to their susceptibility to soil compaction and disturbance (Schrader and Lingnau, 1997; Buchholz et al., 2017; Gonçalves et al., 2020; Menta et al., 2020). In general, the response of soil micro- and mesofauna to tillage is negative, leading to a net decline in community complexity as result of organism exposure to desiccation, moisture decrease, reduction of plant cover, and change in food availability (Cortet et al., 2002; Menta et al., 2015, 2018b; Bordoni et al., 2019). Even deep tillage activities prior to vineyard plantation can have detrimental effects on soil biota (Costantini et al., 2015; Gagnarli et al., 2021). Hemiedaphic and eudaphic springtails appear to be particularly sensitive to tillage practices, with fewer species in response to tillage-induced changes in moisture and more numerous populations in undisturbed soils (Simoni et al., 2018). An apparently bucking result was obtained by Pfingstmann et al. (2019), that showed how the diversity of springtails remains unaffected in vineyards where tillage is applied. Similarly, Fiera et al. (2020), in a survey carried out in Romanian vineyards, found that tillage intensity may actually forster springtail assemblages. However, it should be pointed out that pitfall sampling in both Pfingstmann et al. (2019) and Fiera et al. (2020) may have captured predominantly topsoil species, which can be favored by a greater food availability, the creation of shelters due to tillage practices, and the disruption of predator control mechanisms (Fiera et al., 2020; Ostandie et al., 2021). Mites are generally sensitive to tillage (Tabaglio et al., 2009), although the response may vary depending on the biological characteristics of the species. For example, tillage has been shown to have a greater effect on low vagile groups, such as Oribatida, whereas it has little or no effect on predatory Mesostigmata that are able to move large distances to colonize new habitats (Seniczak et al., 2018). Although the negative effects of tillage on soil biota are well documented, Buchholz et al. (2017) suggested that, in vineyards, the adverse impact of tillage on mesofauna can be partly compensated by establishing plant covers during the rest of the year. In vineyards, grass cover, either with spontaneous or sown plants, promotes arthropod richness (Winter et al., 2018; Gonçalves et al., 2020; Paiola et al., 2020; Bosco et al., 2022; Möth et al., 2023), increasing the presence of beneficial species (Burgio et al., 2016; Sommaggio et al., 2018). In general, crops with permanent grass cover show a higher diversity of soil microarthropods (Nannelli and Simoni, 2002; Parisi et al., 2005; Gagnarli et al., 2015; Bordoni et al., 2019; Coller et al., 2023; Möth et al., 2023). Maintaining vegetation cover can help creating a favorable microhabitat, providing organic matter, mitigating the effects of drought and solarization, and providing shelters from predators (Renaud et al., 2004; Gonçalves et al., 2020; Coller et al., 2023). Even in the case of herbicide application, the presence of cover grass may exert a beneficial effect on soil fauna compared to bare soil (Reinecke et al., 2002; Renaud et al., 2004). Another commonly used technique in vineyards is mulching, a practice that involves soil covering with organic or inorganic materials for maintaining soil moisture, reduce soil compaction, and protect soil surface (Fraga and Santos, 2018; Cataldo et al., 2021). Mulching can create a humid microclimate favorable for soil mesofauna, and, when living plants are involved, may prevent weed development and enhance nutrient levels available for soil biota (Favretto et al., 1992; Fraga and Santos, 2018). Springtails and mites can be strongly influenced by mulching in vineyards (Nannelli and Simoni, 2002; Gagnarli et al., 2019), with the former being more sensitive to moisture, and usually favored by a more humid microclimate (Tsiafouli et al., 2005). However, the outcomes of mulching are not always straightforward and its impact on soil arthropods may vary depending on the type of mulch and the crop being grown (Noor-ul-Ain et al., 2022).

6. Future perspectives for soil biota in organic viticulture

Vineyards are among the most intensively managed agroecosystems and widespread practices such as tillage, mineral fertilization and the absence of inter-row plant cover can have a strong impact on the soil biotic component (Gonçalves et al., 2021; Andrés et al., 2022). At the same time, a decline in soil biodiversity and a change in the structure of biotic communities can have major consequences on the yield and quality of the wine produced (Priori et al., 2016). Therefore, a conversion of viticulture towards an eco-sustainable agroecological model, which recognizes the importance of biotic communities in maintaining soil health and functionality, appears necessary (Gonçalves et al., 2021). In this context, the shift towards organic viticulture, encouraging practices such as the reduction or elimination of tillage, permanent plant cover, and the reduction of herbicides and synthetic fertilizers, is seen as promising management model to maintain soil functionality and preserve soil biodiversity (Conti, 2015; Christel et al., 2021; Gagnarli et al., 2021; Andrés et al., 2022).

Historically, the benefits of organic farming for soil biodiversity have been attributed to the ban on synthetic pesticides and fertilizers, higher levels of organic matter in the soil and the maintenance of cover crops (Hole et al., 2005). However, some practices, such as the use of copper-based fungicides or tillage, which are more prevalent in organic than in conventional agriculture, may interact negatively with soil biodiversity (Ostandie et al., 2021). Indeed, although soils in organic vineyards exhibit an overall higher quality than those in conventional ones (Peverieri et al., 2009; Gagnarli et al., 2015; Menta et al., 2015; Simoni et al., 2019; Ghiglieno et al., 2020, 2021), in organic farming, where tillage is the only technique allowed for weed control in the absence of herbicide application, the effects of mechanical disturbance on mesofauna may overshadow the benefits of the pesticide ban (Linnyk et al., 2019). In addition, tillage, even when performed infrequently, can have negative effects on the organic matter pool, nullifying the mitigating effect of cover crops (Belmonte et al., 2018). Excessive earth works and accelerated erosion can lead to a reduction in soil fertility regardless of organic management, with cascading effects on soil arthropod communities (Costantini et al., 2018). Lastly, some studies have highlighted how the beneficial effects of conversion to organic farming may be scale- and crop-dependent, raising the need to evaluate the impact of agricultural management practices in different contexts (Gabriel et al., 2010; Pfingstmann et al., 2019; Menta et al., 2020; Ostandie et al., 2021). The effects of organic farming may be masked by the proximity of conventional crops, or by residual effects from previous land use (Menta et al., 2020). Further investigations are needed to unravel the drivers of change in community composition of soil mesofauna at different temporal and spatial scales, and how these communities respond to modifications induced by ongoing climate change.

The brief review provided here is little more than a glimpse at the complex interactions occurring in the soil ecosystem, where it is often complicated to clearly distinguish how individual factors contribute to modelling soil communities. Paradoxically, monocultures such as vineyard, as simplified systems, are ideal models for studying the processes involved in observed patterns of abundance and diversity of soil microarthropods (Gergócs et al., 2022). In general, the use of synthetic biological indices such as QBS-ar proves to be adequate for evaluating the short- and long-term effects of anthropogenic factors on soil biota (Menta et al., 2018b). However, a higher taxonomic resolution is sometimes necessary in order to find out how agronomic disturbances affect the relationship between soil chain components (Viketoft et al., 2021) and how they impact organisms characterized by different biological traits and belonging to different feeding guilds (Gagnarli et al., 2017; Simoni et al., 2019). Although organic farming is therefore an ever-expanding model, the management aspects of organic versus conventional farming are not entirely clear, and the emergence of conflicting responses underlines how crucial it is to assess the effects of management practices at the level of individual functional groups and not just as a whole.

CRediT authorship contribution statement

F. Di Giovanni: Writing – review & editing, Writing – original draft, Conceptualization. **F. Nardi:** Writing – review & editing, Supervision, Funding acquisition. **F. Frati:** Writing – review & editing, Supervision. **M. Migliorini:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

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

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