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# Soil Arthropod Responses in Agroecosystem: Implications of Different Management and Cropping Systems

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**Abstract:** The EU's Common Agricultural Policy (CAP 2014–2020) on soil management points to the combination of sustainable food production with environmental protection, reduction of CO<sub>2</sub> emissions, and safeguarding of soil biodiversity. In this study, three farms (in the Emilia-Romagna region), managed with both conventional and conservation practices (the last ones with and without sub-irrigation systems), were monitored from 2014 to 2017 to highlight the impact of different crops and soil managements on soil arthropods, in terms of abundance, composition, and soil biological quality (applying QBS-ar index). To do this, linear mixed models were performed, whereas arthropods assemblages were studied through PERMANOVA and SIMPER analysis. Soil communities varied among farms, although most differences were found among crops depending on management practices. Nonetheless, conservation systems and a wider reduction in anthropogenic practices provided better conditions for soil fauna, enhancing QBS-ar. Moreover, arthropod groups responded to soil practices differently, highlighting their sensitivity to agricultural management. Community assemblages in corn and wheat differed between managements, mainly due to Acari and Collembola, respectively. In conservation management, wheat showed the overall greatest abundance of arthropods, owing to the great number of Acari, Collembola, and Hymenoptera, while the number of arthropod groups were generally higher in crop residues of forage.

**Keywords:** soil biodiversity; bioindicators; soil quality; mesofauna; soil degradation; land management

## 1. Introduction

Soil provides the basics for human livelihood and well-being, including food supply, freshwater and many others ecosystem services, in addition to biodiversity [1]. This is especially the case with the soils of agricultural areas, which account for 13% of the total ice-free land cover at the global scale, and are amongst the most important resources for ecosystem functioning, often compromised by mismanagement. Biodiversity plays a crucial role in ecosystem functioning and services [2]; nevertheless, many authors have highlighted the negative effects of conventional management on soil biodiversity multifunctionality [3]. Practices such as tillage, overfertilization, monoculture, and pesticide application often give rise to increased soil erosion, decay of organic matter content, salinization, and compaction, which may lead to a reduction in crop productivity and soil biodiversity, and subsequent socioeconomic losses [3,4]. In the past decade, research on conservation practices such

as long-term tillage, diversification of crop production systems, rotation, and crop perennialization has proven to enhance the stabilization of soil organic matter aggregates [5], enhancement of crop yields, improvement of carbon sequestration, nutrient retention, and water infiltration [4].

Soil fauna plays an important role in maintaining soil quality and health, as well as providing ecosystem services [6] through processes such as organic matter translocation, fragmentation and decomposition, nutrient cycling, soil structure formation and, consequently, water regulation [7–9]. Some groups are highly sensitive to changes in soil quality because they are adapted to specific soil conditions [10,11]. Among soil fauna, mesofauna (200  $\mu\text{m}$ –2 mm) are affected by both above- and belowground environmental factors since their activity occurs mostly in the top 20 cm of the soil profile. Within aboveground factors, mesofauna presence is affected by plant cover, which sensibly impacts soil properties by shading and regulating soil temperature, allowing steady environmental conditions. Moreover, plants generate litter inputs, thereby enhancing soil hydrophobicity and protecting it from erosion. Within belowground factors, instead, rhizosphere organic compounds that involve the root exudates represent food resources for soil mesofauna. However, due to their small dimensions, these organisms use existing pores or channels for locomotion, which makes many of them sensitive to any interference with the soil environment. Within the habitable pore space, their activity is influenced by water-air proportion, such that both saturation and desiccation processes, resulting in anaerobiosis and dehydration respectively, are detrimental to soil fauna populations [12]. Cole et al. [13] concluded that communities inhabiting agroecosystems are primarily structured by agricultural practices, since anthropogenic activities of agricultural systems alter natural soil dynamics and promote the decay of soil mesofauna populations.

Soil management practices lead to alteration of plant litter inputs and soil microhabitat, in terms of both soil physical and chemical qualities, thus impacting soil fauna assemblages [14]. It has been widely observed that tillage impacts negatively on soil-dwelling arthropod communities: enhancing the exposure of soil organisms to desiccation, through the destruction of upper horizons; and negatively affecting access to food sources, through the decrease in the soil moisture available and the disruption of existing plant systems [15–17]. Conversely, no-tillage practices leave the soil surface covered with residues of previous crops, thereby protecting the soil from water and wind erosion and enhancing decomposer fauna abundance [18]. These effects increase in continuous no-tillage systems, due to the higher soil stratification and concentration of organic matter, nutrients, and microbial activity near the surface [19]. Several studies found that even mite, generally widespread in soils under no-till practices or uncultivated soils, are negatively affected by conventional tillage, especially those belonging to Oribatida [20–22]. Cortet et al. [15] observed a reduction by more than 50% in the number of Acari in tilled soil. On the other hand, even if it has been widely accepted that Collembola are highly discriminant among agricultural management systems, the response is inconsistent between studies. For example, Filser et al. [23] found a higher abundance of Collembola associated with intensive and moderate systems compared to sustainable systems, suggesting that springtails can create large populations under high management intensity; while Maraun et al. [24] suggested that Collembola are sensitive to mechanical disturbances, even more than oribatid mites. Not only Collembola, but also Isopoda and Pauropoda meet a significant reduction caused by mechanical and chemical perturbations produced in conventional agricultural management practices [25,26]; for instance, Palacios-Vargas [27] noted that Pauropoda are very sensitive to agricultural practices, the impact of which is demonstrated to have reduced their populations by about 70%. Moreover, since Symphyla are negatively affected by high bulk density, soil compaction through tillage practices is suggested to influence their occurrence as well [26].

Another decisive factor, when assessing the effect of management practices on soil arthropods, is crop rotation [18]. Meyer et al. [28] discovered an ecological ‘memory effect’ in the soil community, i.e., an influence from the preceding crops on soil fauna composition, suggesting that crop rotation can be a useful tool to increase arthropod biodiversity and biomass, particularly in areas managed with

monocultures. Actually, Jones et al. [29] observed that monoculture cropping system is considered a cause of decrease in the diversity of microhabitats, thus of Isoptera.

On the other hand, organic fertilizers, like manure, are generally beneficial to almost all soil organisms, even though these beneficial effects may be partly due to the high number of soil arthropods found in the manure itself [30]. Nevertheless, the dosage could affect the outcome of the fertilizer and occasionally produce negative effects [31]. On the other hand, Kautz et al. [32] suggested that the abundance of soil arthropods increases differently depending on regimes of organic manuring; for example, they found that the application of straw and green manure increased the abundance of soil arthropods, contrary to mineral nitrogen. They also highlighted that fertilizer application could not take enough time for a significant induced modification of the fauna composition, so only effects on abundance may be observed. Nevertheless, Cluzeau et al. [33] noted that Collembola abundance increased with both mineral and organic fertilization, while mites tend to take more advantages by fertilisation with manure than using mineral fertilisers alone [34].

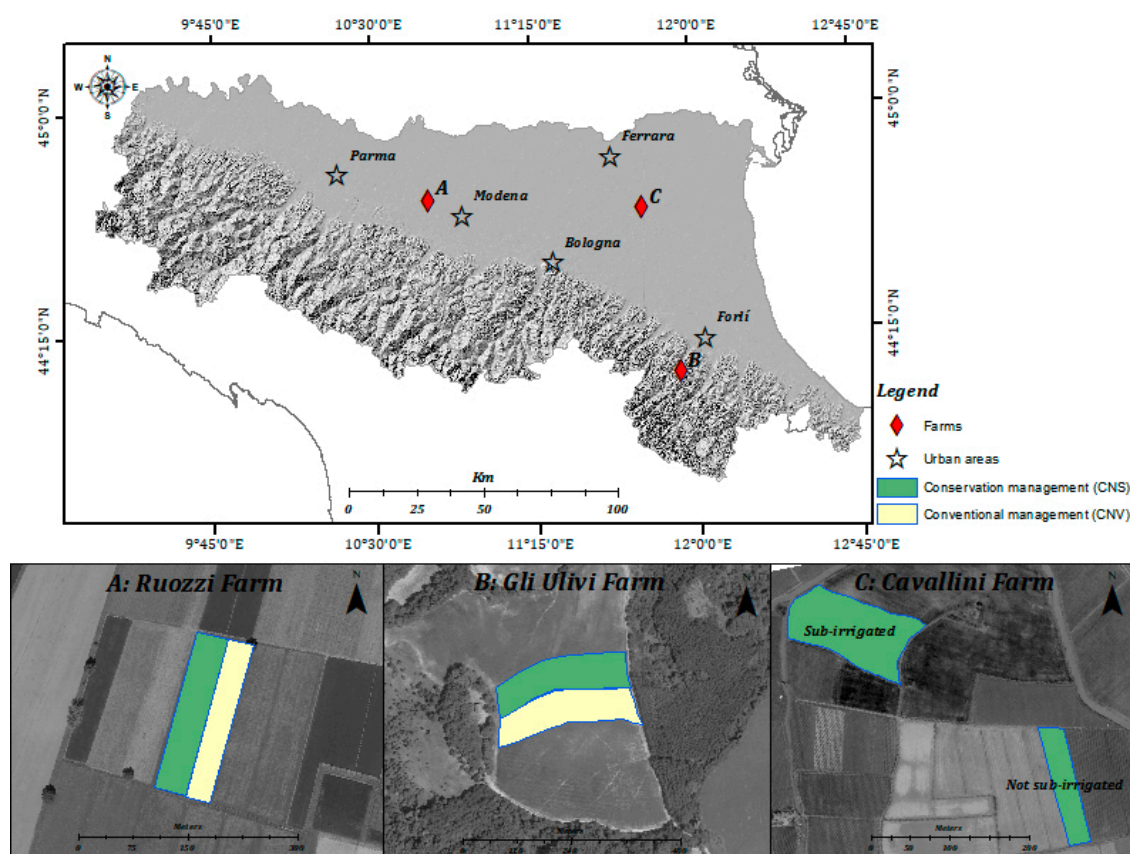
Changes in species diversity can be observed between crops, depending on plant physiology and consequently on biochemical processes and metabolism. These properties acquire much more importance since the carbon intake of below-ground soil fauna could derive from roots, other than from litter [35]. For example, compared to sugar beets, wheat plants generally possess a more complex system of roots and associated microorganisms, along with greater quantities of exudates [36]. Thereby, wheat rhizosphere could provide a more diversified food base for soil organisms. Sticht [37] suggested that these different nutritional conditions affect the community composition and dominance distribution of collembolans, leading to greater diversity under winter wheat. This result is supported by other organisms such as carabid fauna: Holland and Luff [38] found that although no species has been linked with a particular crop plant, the greatest difference occurs between winter sown crops (namely, cereals and oilseed rape) and spring sown root crops (namely, potatoes, sugar beet, maize, carrots), with the latter ones usually having lower abundance and diversity. Moreover, this study also suggests that differences at the species level could be a consequence of the microclimate established in root and cereal crop systems, it being much drier and warmer in cereals.

In order to protect natural resources and environment, the Emilia-Romagna Region (located in north-central Italy, between the Po River and the Apennine Mountains) has adopted soil conservation management practices. The aim is to achieve production with less pesticides, chemicals, and water inputs and reductions in CO<sub>2</sub> emissions, as required by the EU's Common Agricultural Policy (CAP 2014–2020). To support this policy, in 2013, Emilia-Romagna and four other northern Italian regions (Friuli Venezia Giulia, Veneto, Lombardy, and Piedmont), set up a Life project called HelpSoil, which ended in June 2017. This project was financed by the European Commission and aimed to compare soil management practices of conservation agriculture (no/minimum tillage, permanent soil cover) with conventional plowing-based techniques on twenty demonstration farms located in the five regions. In addition to the Life HelpSoil project goals, additional soil samples were collected on three chosen farms of the Emilia-Romagna, in order to improve understanding of soil arthropod communities in different agricultural systems. This paper reports the results of this study, which aimed to evaluate how different crops and soil management practices affect soil arthropod communities, in terms of both abundance and composition, as well as soil biological quality using QBS-ar, index applied on soil arthropod community [39]. In detail, our hypotheses are: (i) comparing the effects of conventional (higher disturbance) and conservation (lower disturbance) farming practices on soil arthropod communities, we assume that minimum disturbance increases soil arthropods abundance and diversity; (ii) highlighting the effects of cover crops on soil arthropod communities between and within agronomic and sub-irrigation systems, we assume that permanent soil cover can promote soil arthropods. At the end, individualization of the most sensitive arthropod taxa (at orders or class level) to agricultural practices, may target potential indicators of soil health in agricultural ecosystems.

## 2. Materials and Methods

### 2.1. Farm Characteristics and Soil Management

In the present study, the fields belonging to three farms (Ruouzzi, Gli Ulivi, and Cavallini) located in the Emilia-Romagna region (Northern Italy) were monitored from 2014 to 2017 through four sampling periods (autumn 2014, spring and autumn 2015, spring 2017). The three farms are inserted in an intensive agriculture scenario characterized by cereal, cereal-forage crop and fruit production, where soil threats and environmental issues are different due to different pedo-climate conditions (Figure 1).



**Figure 1.** Geographical position of the three farms in the Emilia-Romagna region, using ArcGIS (version 10.4.1) and Google Earth Pro (v. 7.3.2.5776): (A): Ruouzzi farm; (B): Gli Ulivi farm; (C): Cavallini farm [40–43].

Two management types, i.e., conventional (CNV) and conservation (CNS), were compared on both Ruouzzi and Gli Ulivi farms. Conservation practices only were adopted on Cavallini farm. In this farm, the presence/absence of sub-irrigation was compared. Soil data were determined according to the official methods of soil analysis in Italian legislation (DM 13/09/1999 SO n.185; Table S1) [44]. Crop types for each sampling period in the three farms—Ruouzzi, Gli Ulivi, and Cavallini—are shown in Table 1.

The Ruouzzi agro-zootechnical farm is located in the Po alluvial plain, Reggio Emilia province (Figure 1A). The soil is classified as fine, mixed, active, mesic Vertic Calcicustept (USDA 2010), and is characterized by a high percentage of clay up to 100 cm deep; consequently, it is subject to cracking in the dry period and is very adhesive and plastic when wet (Table S1). One of the main problems of this farm is to ensure good soil drainage and the use of innovative techniques for manure fertilization, aimed at reducing ammonia emissions. The land was used for forage crops (feed wheat from October 2013 to May 2014), followed by a short annual forage crop sown after wheat and harvested in August

2014, and cereal (corn from April to September 2015 and wheat from October 2015 and June 2016); no-tillage practice was adopted under the conservation management, and the permanent cover of soil was ensured through cover-crops (from September 2014 to April 2015) and crop residues during winter 2016/2017. At the sampling periods, the fields (both conventionally and conservatively managed) were covered with crop residues after the annual forage crop in September 2014; corn in June 2015; wheat in November 2015; bare soil after tillage in the conventional system, and crop residues of wheat in the conservation system in March 2017 (Scheme S1A).

**Table 1.** Crop types for each sampling period in the three farms: Ruoizzi, Gli Ulivi, and Cavallini.

Sampling Period	Management	Irrigation System	Ruoizzi	Gli Ulivi	Cavallini
2014-Autumn	CNV	NS	After annual forage crop, soil covered by crop residues	Alfalfa	-
	CNS	NS	After annual forage crop, soil covered by crop residues	Alfalfa	Cover crop
		S	-	-	-
2015-Spring	CNV	NS	Corn	Wheat	-
	CNS	NS	Corn	Wheat	Soybean
		S	-	-	-
2015-Autumn	CNV	NS	Wheat	Bare soil	-
	CNS	NS	Wheat	Cover crop	Cover crop seeding
		S	-	-	-
2017-Spring	CNV	NS	Bare soil	Wheat	-
	CNS	NS	After wheat, soil covered by crop residues	Wheat	After soybean, soil covered by crop residues
		S	-	-	-

CNV: Conventional management, CNS: Conservation management, NS: No Sub-irrigation system, S: Sub-irrigation system.

The Gli Ulivi agro-zootechnical farm is located on the hills of the Romagna Apennines (in the south-east of the E-R region) (Figure 1B). The soil is classified as fine loamy, mixed, superactive, mesic Typic Haplustept (USDA 2010), and is characterized by medium-texture calcium carbonate aggregations, low content of organic carbon, and a 10 to 40% slope (Table S1). Due to the slope, the soil is difficult to work and is vulnerable to water erosion; consequently, fertility loss is one of the main problems of this place. The land was used for forage crops (alfalfa at its 4th year of vegetation until October 2014) and cereal (wheat in 2014/2015 and 2016/2017, sorghum from May to October 2016); no-tillage practice was adopted under the conservation management, and the permanent cover of soil was ensured through cover-crop (from August 2015 to March 2016). At the sampling periods, the fields (both conventionally and conservatively managed) were covered with alfalfa in September 2014; wheat in May 2015; bare soil after tillage in the conventional system and cover crop in the conservation system in November 2015; wheat in March 2017 (Scheme S1B).

The Cavallini farm is a fruit and cereal farm located in the plain of the Po's ancient delta (Figure 1C). The soil is classified as fine silty, mixed, superactive, mesic Typic Calciustept (USDA 2010), and is characterized by medium to moderately coarse texture, low content of organic carbon and rich in carbonate (Table S1). The soil is susceptible to crusting due to the high percentage of silt in the topsoil, while the presence of sand in depth increases the risk of water deficit. On this farm, both test fields considered in this study were subject to conservation management, but only one had a sub-irrigation plant to limit water consumption. The land in the sub-irrigated field (S) was used for wheat (in both 2013/2014 and 2015/2016) and soybean (from May to October 2015); the other field (NS) was for wheat (in 2013/2014) and soybean (from June to October in both 2015 and 2016). No-tillage practice was adopted in either systems, and the permanent cover of soil was ensured through the use of cover-crop (before soybean in both fields) and crop residues (from autumn 2016 to spring 2017). At the sampling periods, the fields were covered with dried weed in the sub-irrigation system, and cover crop in the no sub-irrigation system in October 2014; soybean in both systems in June 2015; wheat seeding and cover

crop seeding, in the sub-irrigation system and no sub-irrigation system, respectively, in November 2015; crop residues of wheat and soybean, in the sub-irrigation system and no sub-irrigation system, respectively, in March 2017 (Scheme S1C).

## 2.2. Soil Sampling and Arthropod Extraction

Each field was sampled four times during the monitoring period (autumn 2014, spring and autumn 2015, spring 2017). Each time, three replicates of soil cores (10 × 10 × 10 cm) were collected from each field, starting of the field center, following a triangle path, and sampling 60 m away from the other two points. Arthropod extraction was performed by Berlese-Tüllgren funnel for 10 days. The extracted specimens were collected and preserved in 75% ethyl alcohol and 25% glycerol by volume. For defining soil biological quality, the QBS-ar index was applied. This index is based on the biological form approach: (1) the arthropod groups classified at class level for Myriapoda, order level for Hexapoda, Chelicerata, and Crustacea; (2) the different adaptation level of specimens belonging to the same taxon; (3) the adults and larvae of Holometabolous insects (Diptera, Coleoptera, Lepidoptera, Hymenoptera) are considered separately, taking into account the different role and soil adaptation of these two stages. Following the QBS-ar protocol, an ecomorphological score (EMI) was assigned to each taxon found, ranging between 1 and 20 depending on their adaptation to soil (1: low adaptation; 20: maximum adaptation) [39,45]. For each replicate, the QBS-ar value was calculated as the result of the sum of the highest EMI values for each taxon [39].

## 2.3. Statistical Analysis

Given the particular situation of each location (resulting from specific soil properties; Table S1), consequently to the differences in agricultural management, the statistical analysis was carried out separately per farm.

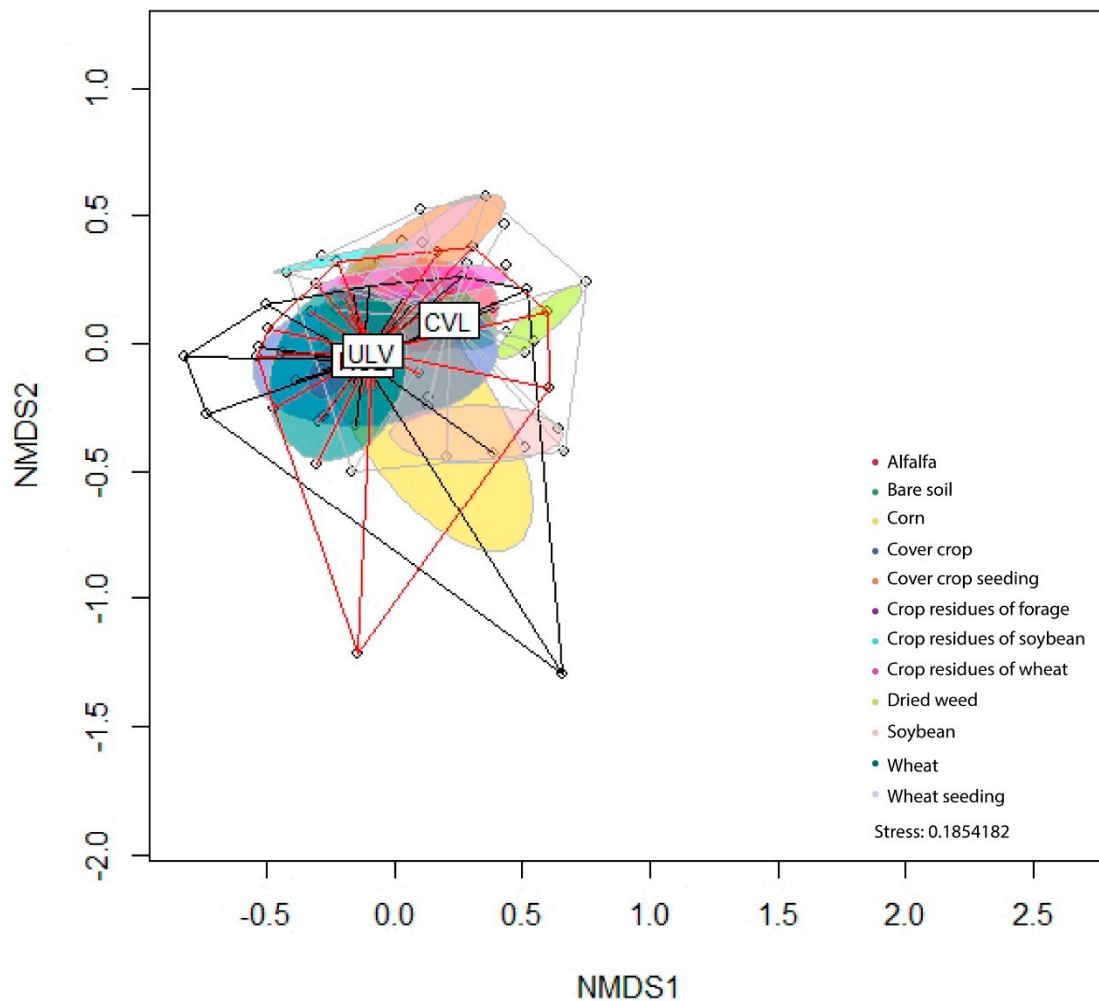
Linear mixed modelling, using lme4 package, was conducted to evaluate the effect of independent factors on the dependent variable [46]. Managements (conservation vs. conventional) and crop types were considered as independent factors for Ruozzi and Gli Ulivi, whilst for Cavallini sub-irrigation (sub-irrigated vs. not sub-irrigated) replaced management in the model. The dependent variables, analysed one at a time, were: total arthropod abundance, number of ecomorphological groups (EMI), QBS-ar value, proportion of the groups with EMI 20, and the abundance of the biological forms highly representing the soil fauna total abundance, so  $\geq 3\%$ , detected on each farm (i.e., Acari and Collembola on the three farms, Hymenoptera on Ruozzi and Gli Ulivi, Symphyla and Diptera larvae on Cavallini). All factors and interactions were modelled as fixed effect, using a within-subject design to account for repeated measures in the fields. The significance of the model compared with others (with different implementation) was evaluated using log-likelihood ratio. Pair-wise comparisons using the least square means were performed with multcompView and lsmeans packages [47] by applying Holm-Sidak correction for multiple interaction comparisons.

Non-metric multidimensional scaling (NMDS), based on Bray-Curtis dissimilarity index, was performed to visualize how patterns (farms and crop type first, and subsequently management and crop type) influenced the grouping of arthropods communities. The results were plotted in an NMDS ordination diagram, fitting them onto the first two axes. Permutational multivariate analysis of variance (PERMANOVA) was used to test for differences in assemblages among the different patterns visualized with NMDS. In each farm, after a significant PERMANOVA test, an analysis of similarity percentages (SIMPER) was used to test which arthropod groups were driving the differences in assemblages within and between managements. Ordination, PERMANOVA, and SIMPER were performed with the vegan package [48].

Square-root and arcsine transformations were applied on count data and proportions, respectively, in order to meet homoscedasticity and normality of the residuals [49]. A  $p$ -value  $\leq 0.05$  was considered significant. All analyses were performed using R (version 3.6.3) [50].

### 3. Results

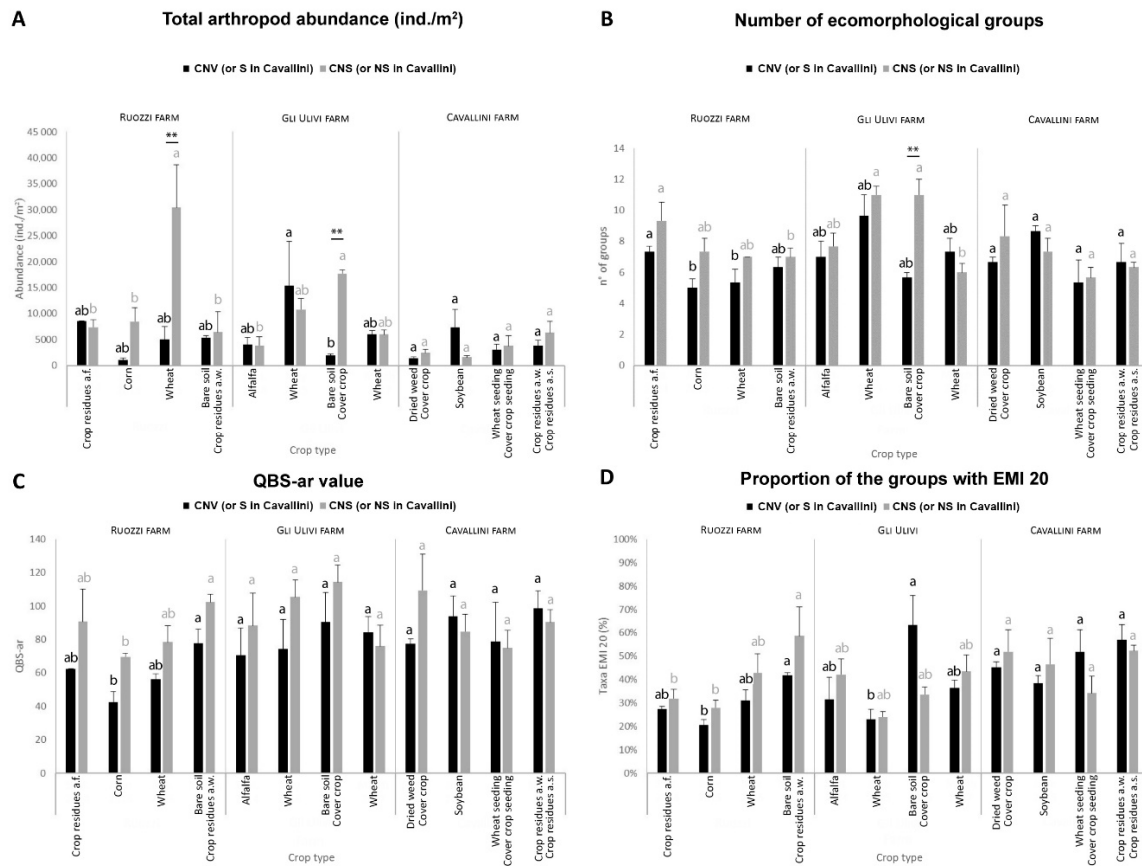
Overall soil arthropod abundance ranged between 382 and 44,222 ind./m<sup>2</sup> of soil. The highest density was observed on RuoZZi farm, in the field conservatively managed under wheat (November 2015), whereas the lowest value was observed on the same farm, but in the field conventionally managed with corn (June 2015; Table S2A). Twenty biological forms were extracted in total, with a minimum of three on the Cavallini farm in the sub-irrigated field after wheat seeding (November 2015; Table S2C), and a maximum of thirteen on Gli Ulivi farm in cover crops (November 2015) in the conservatively managed field (Table S2B). The most abundant groups were Acari (44%), Collembola (37%), Hymenoptera (12%), Coleoptera larvae (1%), Diptera larvae (1%), and Symphyla (1%), accounting for approximately 97% of the organisms collected. Other groups such as Hemiptera, Coleoptera adults, Psocoptera, Araneae, Chilopoda, Pauropoda, and Protura comprised >2%; the remaining taxa were Diplopoda, Thysanoptera, Diplura, Isopoda, Diptera, and Lepidoptera larvae, and reached totally <1%. Among the groups, Acari and Collembola were ubiquitous, but their abundances varied greatly depending on soil management and crops. Both crop typology and farm, as well as their interaction, were correlated with community assemblages, as confirmed by PERMANOVA ( $p \leq 0.001$ , for both factors and their interaction; Figure 2), so the following analyses were performed separately for each farm.



**Figure 2.** Bray-Curtis based NMDS plot of the arthropod community composition. Points represent samples. “Spider” diagrams connect each point to the belonging farm: ROZ: RuoZZi farm, in black, ULV: Gli Ulivi farm, in red, and CVL: Cavallini farm, in grey. Ellipses represent crop variables.

### 3.1. RuoZZi Farm

Differences were observed between crop typology as regards the total abundance of soil arthropods ( $p < 0.01$ ; Figure 3A). Contrary, no differences were highlighted between CNV and CNS.

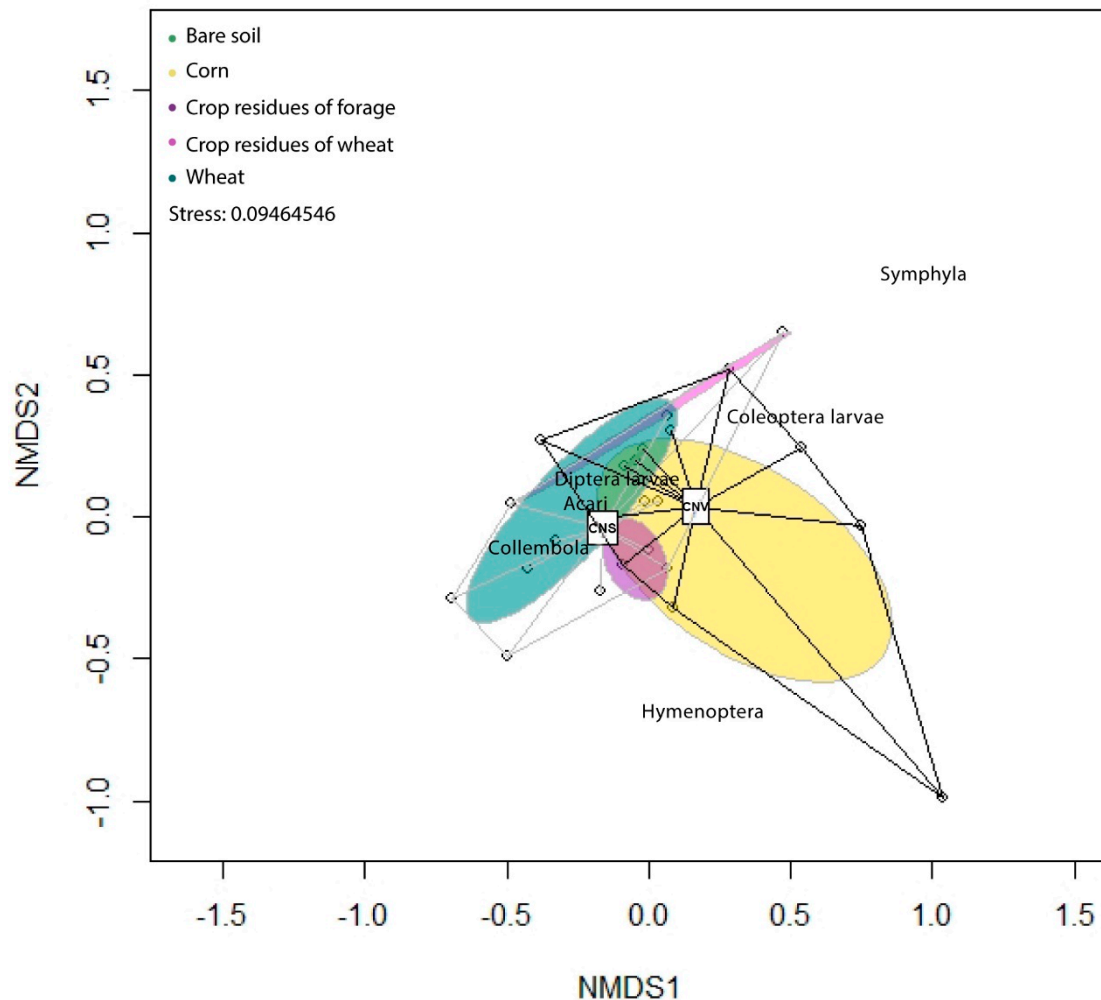


**Figure 3.** Barplots and standard error of (A): total arthropod abundance (ind./m<sup>2</sup>); (B): number of ecomorphological groups; (C): QBS-ar value; (D): the proportion of groups with EMI 20. Results for crop types in the three farms are shown; after annual forage crop (a.f.), after wheat (a.w.) and after soybean (a.s.). In the legend, CNS: conservation (or NS: no sub-irrigation system) and CNV: conventional management (or S: sub-irrigation system). Within management, significance ( $p \leq 0.05$ ) is indicated by different letters. Between management, significance is indicated with asterisks: \*\*  $p \leq 0.01$ .

However, this variable appeared to be affected by the interaction between management and crops ( $p < 0.01$ ); a difference was indeed highlighted between CNV and CNS in wheat (November 2015) In CNS, soil arthropod abundance in wheat was higher than in the three other crops. In CNV, the different crops showed no significant differences. The number of groups was significantly influenced by the type of crops ( $p < 0.01$ ; Figure 3B): in CNS, it was significantly higher in crop residues after annual forage crop (September 2014) than in crop residues of wheat (March 2017); even in CNV, crop residues after forage crop (September 2014) were higher than corn (June 2015) and wheat (November 2015). The number of groups did not differ between management types. In terms of QBS-ar index, crop type was the only factor affecting the dependent variable significantly ( $p < 0.001$ ; Figure 3C). Within soil management, CNS showed a significant difference between corn (June 2015) and crop residues of wheat (March 2017), higher in the latter, and the same result was highlighted in CNV. The same differences were highlighted for the proportion of EMI-max values (crop type factor only was found significant,  $p < 0.001$ ), where the differences between corn (June 2015) and crop residues of wheat (March 2017) were significant in both managements (Figure 3D). Moreover, the proportion of groups with EMI max found in crop residues of wheat within CNS (March 2017) was significantly higher



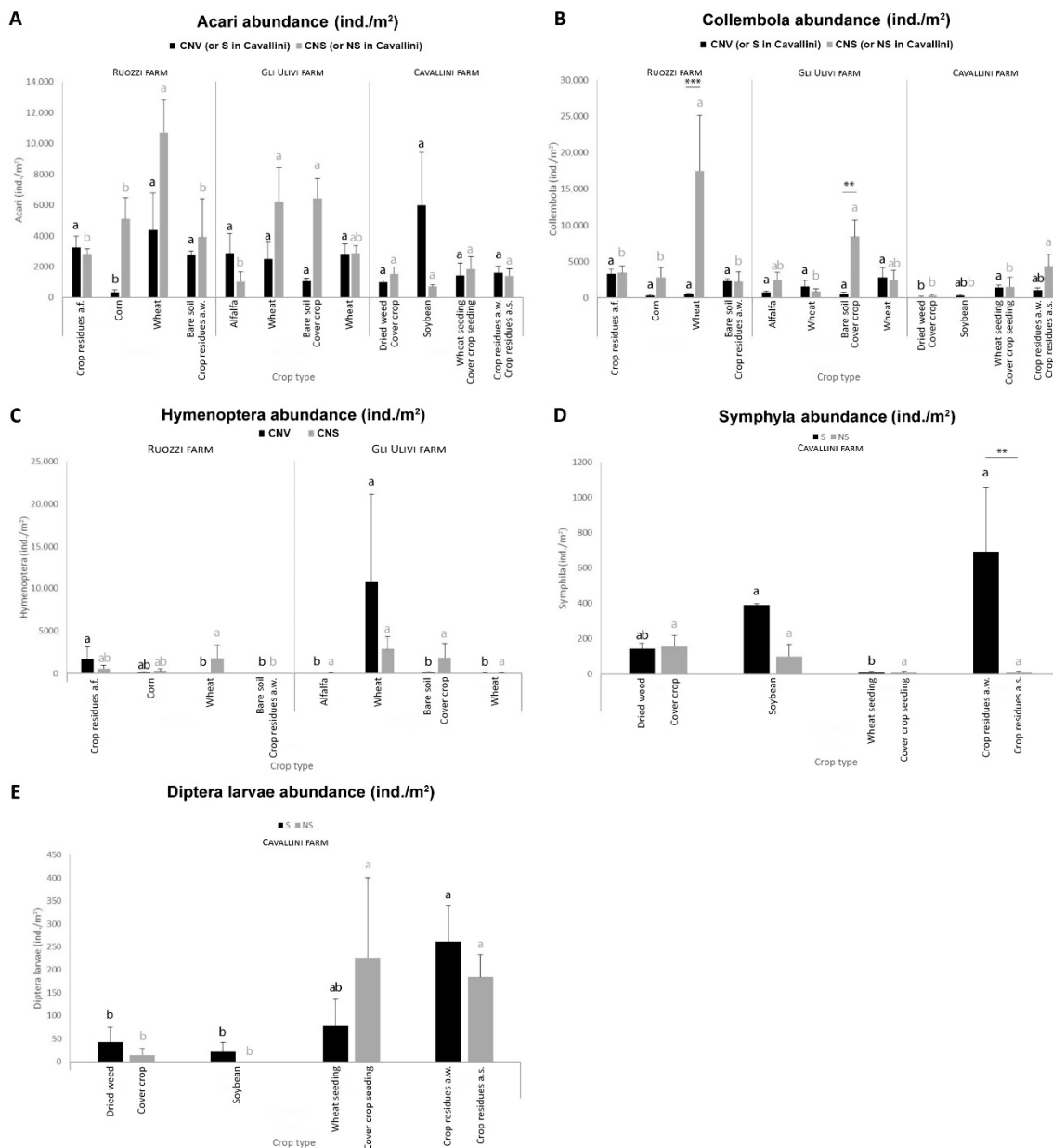
than crop residues after annual forage crop (September 2014). The community dissimilarity between samples in Ruoizzi farm was explained by both management and crop typology, as well as by the interaction between them ( $p < 0.001$ , for both factors and their interaction; Figure 4).



**Figure 4.** Bray-Curtis based NMDS plot of the arthropod community composition in Ruoizzi farm. Points represent samples. “Spider” diagrams connect each point to the belonging management type: CNS: conservation, in grey, and CNV: conventional, in black. Ellipses represent crop variables. To avoid overlapping, only the six more abundant groups were labelled.

Results of SIMPER analysis are shown in Table S3A. Overall dissimilarity within CNV was higher than 50% in all contrasts that involve corn, and was due mainly to Collembola, Acari, Hymenoptera, and Diptera larvae (Table S3(A1)). While, within CNS, an overall dissimilarity higher than 50% was observed only between wheat and crop residues of wheat, with Collembola, Acari, and Hymenoptera accounting for more than 70% of the dissimilarity. Corn and wheat dissimilarities between management were higher than 50% and influenced by Acari, Collembola and, for wheat, Hymenoptera (Table S3(A2)).

On Ruoizzi, Acari, Collembola, and Hymenoptera represented the most abundant groups (46%, 45%, and 6%, respectively). Considering the differences within the single group abundance, Acari were observed to be influenced by management, crop type, and the interaction between these two factors ( $p < 0.01$ ,  $p < 0.01$  and  $p < 0.05$ , respectively; Figure 5A).



**Figure 5.** Barplots with standard errors of the abundance (ind./m<sup>2</sup>) of the taxa that represent  $\geq 3\%$  of the total abundance of the soil fauna found in each farm. In the three farms, (A): Acari; (B): Collembola. In RuoZZi and Gli Ulivi farms, (C): Hymenoptera. In Cavallini farm, (D): Symphyla; (E): Diptera larvae. Results for crop types are shown; after annual forage crop (a.f.), after wheat (a.w.), and after soybean (a.s.). In the legend, CNS: conservation (or NS: no sub-irrigation system) and CNV: conventional management (or S: sub-irrigation system). Within management, significance ( $p \leq 0.05$ ) is indicated by different letters. Between management, significance is indicated with asterisks: \*\*  $p \leq 0.01$ .

Although conservation management results in higher Acari abundance than the conventional one, post-hoc comparisons highlighted no difference between a specific combination of management and crop type. However, within the same management, the abundance of Acari was higher in wheat in CNS (November 2015) compared to the other crops. In addition, the Acari abundance was lower in corn in CNV (June 2015) compared to the other crops. Collembolan abundance was affected by both management and crop type, as well as by their interaction ( $p < 0.001$ ,  $p < 0.01$  and  $p < 0.001$ , respectively; Figure 5B). This group highlighted a difference between the two managements in wheat (November 2015). Differences are observed within CNS management, where wheat showed the highest

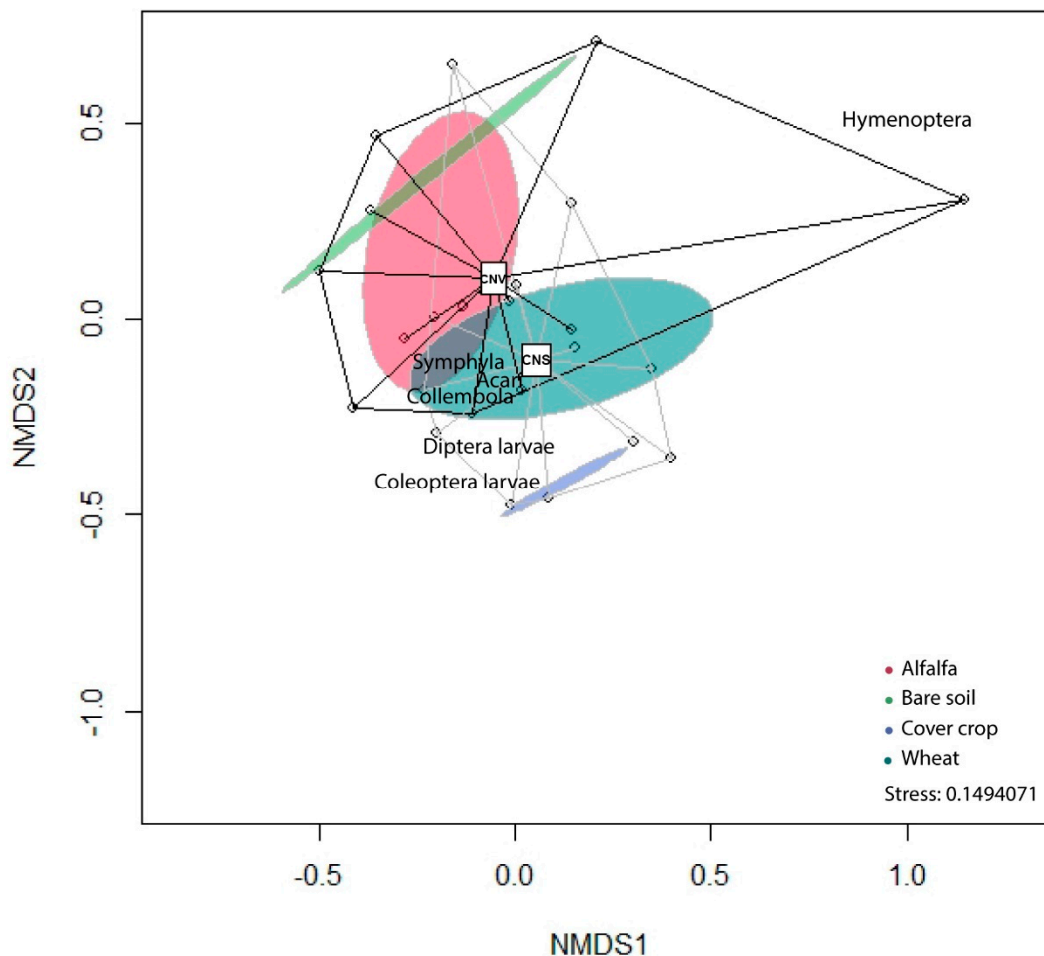
abundance of this group when compared to crop residues after annual forage crop (September 2014,  $p \leq 0.01$ ), corn (June 2015), and crop residues of wheat (March 2017). The Hymenoptera group, on the other hand, was affected by crop type factor only ( $p < 0.05$ ), showing the same trend of Collembola in CNS when comparing wheat with crop residues of wheat (March 2017; Figure 5C). Within CNV management, Hymenoptera displayed the highest abundance in crop residues after annual forage crop (September 2014) when compared to wheat (November 2015) and bare soil (March 2017).

### 3.2. Gli Ulivi Farm

The total abundance of arthropods in the soils of Gli Ulivi farm highlighted no differences depending on conservation or conventional management only (Figure 3A). On the other hand, there emerged differences depending on crops and their interaction with management type ( $p < 0.01$ ;  $p < 0.001$  respectively): a higher abundance in CNS was detected with cover crop (November 2015) when compared to CNV with bare soil (November 2015). Within management type, in CNS under cover crop (November 2015) abundance was higher than under alfalfa (September 2014); while in CNV, higher abundance was observed in wheat (May 2015) when compared to bare soil (November 2015). The number of groups resulted affected both by management and crop type, and by the interaction between the two factors ( $p \leq 0.1$ ;  $p < 0.001$ ;  $p \leq 0.001$ ; Figure 3B). As for the abundance, a higher number of groups was found in CNS cover crop when compared to CNV bare soil (both in November 2015); within CNS, instead, differences were highlighted in the March 2017 wheat, which was lower than the May 2015 wheat, and the November 2015 cover crop. No differences were observed for the QBS-ar comparison, neither between managements systems or different crops within the same management, nor for the interaction of the two factors (Figure 3C). Differently, the proportion of groups with EMI 20 showed differences associated with crops and their interaction with management type ( $p < 0.01$  and  $p \leq 0.01$ , respectively; Figure 3D). Post-hoc analysis highlighted only one difference within conventional management, between wheat (May 2015) and bare soil (November 2015), in which the EMI max was higher in the latter. The significance of management, crop variable, and their interaction were assessed with PERMANOVA after fitting management and crop variables onto community ordination ( $p < 0.01$ , for management and crop type, and  $p < 0.05$ , for their interaction; Figure 6).

From SIMPER analysis was observed an assemblage dissimilarity higher than 50% only within CNV, between wheat and bare soil, where Hymenoptera, Acari, Collembola, Psocoptera, and Hemiptera accounted for a cumulative dissimilarity of more than 70% (Table S3(B1)). Between managements, bare soil and cover crop account for an overall dissimilarity of 60%, mostly determined by Collembola, Acari, Hymenoptera, and Diptera larvae (Table S3(B2)).

On Gli Ulivi, Acari, Collembola, and Hymenoptera represented the most abundant groups (39%, 32%, and 23%, respectively). Acari abundance showed differences only in the interaction between management and crop type ( $p < 0.01$ ; Figure 5A). No differences emerged from the post-hoc analysis for the four conditions between the two managements. Within the same management, some differences were detected only in CNS: alfalfa (July 2014) showed lower Acari abundance than wheat (May 2015) and cover crop (November 2015). Like Acari, differences were observed in the interaction between management and crop type for Collembola ( $p \leq 0.001$ ): a higher abundance of collembolans was found in CNS with cover crop compared to bare soil in CNV collected in the same sampling period (November 2015; Figure 5B). Within the same management, only CNS showed a difference—higher in cover crop (November 2015) than in wheat (May 2015). The Hymenoptera abundance appeared to be affected by crop type only ( $p < 0.05$ ; Figure 5C). The abundance of this group was generally low or absent in both managements and in all crops, except for the CNV wheat in May 2015, which was higher than all other crops.



**Figure 6.** Bray–Curtis based NMDS plot of the arthropod community composition in Gli Ulivi farm. Points represent samples. “Spider” diagrams connect each point to the belonging management type: CNS: conservation, in grey, and CNV: conventional, in black. Ellipses represent crop variables. To avoid overlapping, only the six more abundant groups were labelled.

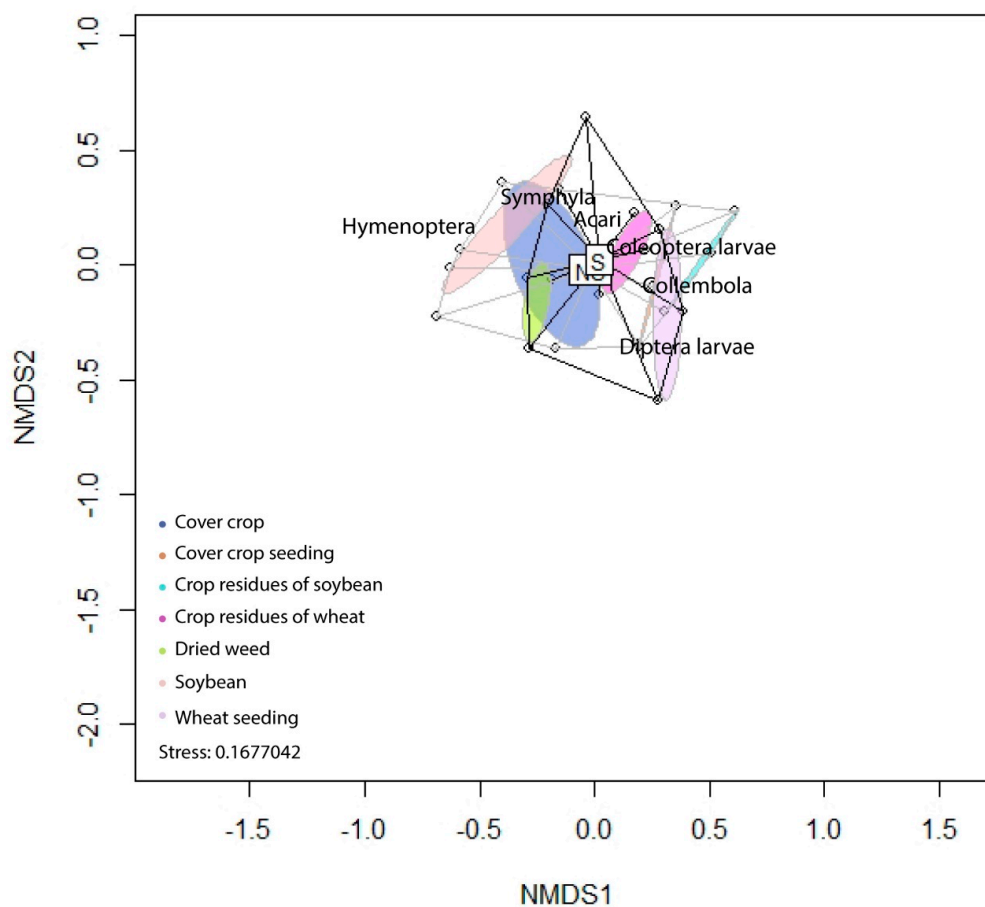
### 3.3. Cavallini Farm

On the Cavallini farm, neither total abundance, number of groups and QBS-ar, nor the proportion of groups with EMI 20 appeared to be affected by the presence (S) or absence (NS) of sub-irrigation system and crop type. PERMANOVA revealed an influence of the irrigation system and crop type, and the interaction between them, on arthropods assemblages ( $p < 0.001$ , for irrigation system and crop type,  $p \leq 0.01$ , for their interaction; Figure 7).

In Cavallini, within management dissimilarities in arthropods assemblages higher than 50% were observed in S between soybean and wheat seeding, with Acari, Collembola, Symphyta, Hemiptera, and Coleoptera accounting for a cumulative dissimilarity of 71% (Table S3(C1)). Within NS, all contrasts that involve soybean had an overall dissimilarity higher than 50%, as well as the contrast between cover crop and crop residues of soybean, and in both cases, these dissimilarities were due to at least five arthropods groups. Between S and NS, overall differences in arthropods assemblages were less than 50% for all crop types (Table S3(C2)).

Moreover, the community composition on Cavallini farm differed from the ones of Ruoizzi and Gli Ulivi (Figure 2). The most abundant groups on Cavallini farm were Acari, Collembola, Symphyta, and Diptera larvae (52%, 31%, 5%, and 3%, respectively). Acari abundance appeared to be affected by the interaction between sub-irrigation system and crop type ( $p < 0.05$ ; Figure 5A). Post-hoc analysis, however, highlighted no specific combination of the two factors. Collembolans showed an influence of crop type ( $p < 0.001$ ; Figure 5B). Within NS, soil with crop residues (March 2017) resulted in higher

Collembola abundance than the other crop types, i.e., cover crops (October 2014), soybean (June 2015), and cover crop seeding (November 2015). Within S, instead, differences were highlighted between wheat seeding (November 2015) and dried weed (October 2014, with higher abundance of collembolans in the former). Symphyla abundance appeared to be affected both by crop type and its interaction with the sub-irrigation system ( $p < 0.001$  both; Figure 5D). In March 2017, crops residues in S showed a higher abundance of Symphyla than the NS ones, whilst within S, the abundance in the wheat seeding (November 2015) resulted lower than in soybean (June 2015) and in crop residues (March 2017). Diptera larvae were affected by crop type only ( $p < 0.001$ ; Figure 5E). Where sub-irrigation was absent (NS), cover crop (October 2014) and soybean (June 2015) showed lower results than cover crop seeding (November 2015) and crop residues (March 2017). In the presence of sub-irrigation (S), the number of Diptera larvae was higher in crop residues (March 2017) compared to cover crop (October 2014) and soybean (June 2015).



**Figure 7.** Bray–Curtis based NMDS plot of the arthropod community composition in the Cavallini farm. Points represent samples. “Spider” diagrams connect each point to the belonging irrigation system: NS: no sub-irrigation, in grey, and S: sub-irrigation, in black. Ellipses represent crop variables. To avoid overlapping, only the six more abundant groups were labelled.

### 3.4. Comparison between the RuoZZi and Gli Ulivi Farms

On the basis of the community data visualized through NMDS, RuoZZi and Gli Ulivi farms appeared to be more similar to each other than Cavallini (Figure 2), thereby allowing a comparison between their results. On both farms, total arthropod abundance appeared to be affected by crops and their interaction with management type, but not by management itself only. Moreover, a similar trend was observed in the differences found between 2014 and autumn 2015 in conservation management, and in autumn 2015 between conservation and conventional management, despite the different crops

on the two farms (Figure 3A). On the other hand, the number of groups appeared to be a more sensitive variable on the Gli Ulivi farm, where it was affected by both management and crops and by their interaction, while only crop type showed an impact on this variable on Ruozzi farm (Figure 3B). On Ruozzi, crop type was the only factor affecting QBS-ar and the proportion of groups with maximum EMI, showing the same response for both variables (Figure 3C). On the other hand, on Gli Ulivi, QBS-ar did not appear to be significantly affected by the factors considered, while the proportion of groups with EMI 20 was influenced both by crops and their interaction with management type (Figure 3D). Changes in Acari and Collembola abundances followed roughly the same pattern on both farms, and generally resulted higher in wheat, mainly in conservation on Ruozzi, while the other most abundant groups did not appear to be linked to each other with a specific crop either (Figures 4 and 6). The abundances of Acari and Collembola were affected by the interaction between crops and by management type on Ruozzi and on Gli Ulivi, and on Ruozzi by crops and management type taken individually too (Figure 5A,B). High values were generally found in conservation management, in wheat on Ruozzi and in cover crop on Gli Ulivi. Hymenoptera were affected by crop types on both farms, but in no case by management (Figure 5C). Traditional and conservation management yielded similar results for the three groups in 2017 on both farms.

#### 4. Discussion

Perturbations on agroecosystem are typically much greater than the ones occurring on other terrestrial ecosystems, particularly in the case of systems that are continuously cropped and subject to disturbance caused by cultivation and other agricultural practices [51]. Some studies have indicated land use, farming system (conventional or conservation), crop type and rotation in croplands, and other aspects related to management (e.g., use of pesticides, herbicides, fertilizers) as factors affecting soil fauna, both acting individually or interacting in agricultural landscapes [15,19,25,52,53]. By studying the effects of different soil managements and crops on soil fauna on three farms, our research partially confirms these observations: farm, intended as agricultural landscape, management, and crop type are patterns that drive differences in soil fauna assemblages; however, other factors like total abundance, diversity, or presence of adapted groups resulted more affected by crops than by management type.

Our results suggest that soil fauna variability, in terms of community composition, are largely related to not only crop type, but also farm characteristics. Indeed, the three farms differed in soil and climate conditions, and variations in soil type and properties could be important factors to determine soil-inhabiting communities according to other studies [30,54]. Moreover, we found that arthropod assemblages differ greatly depending on management and crop type. However, even if conservation management generally shows higher abundance and biodiversity when compared with conventional ones [55], in our study, we have found that they were not significantly affected by management type, unless the interaction with crop type is considered. This result agrees with the findings by Bedano [56], who observed no conclusive trends regarding no-till benefits when compared to reduced tillage or conventional tillage. Moreover, Tuck et al. [54] highlighted that differences could be hidden by the local management, in the sense that soil animals and chemicals can move through the landscape. Our results could therefore be affected by the proximity of the conventionally managed fields to the conservation ones, on both Ruozzi and Gli Ulivi farms. Furthermore, at the time of this study the conservation practices had only been introduced three years earlier, and their positive effects could be evident only after a longer time of application, especially on the arthropods which are more adapted to soil, and consequently more sensitive, as estimated by the QBS-ar index. Indeed, Fiorini et al. [55] highlighted the positive effects on QBS-ar index in a seven-year experimentation of no-till compared with conventional agriculture practices, possibly related to the enhancement of SOC sequestration potential, as well as a higher chance for edaphic fauna of developing morphological adaptation in soils subject to less disturbance.

Tuck et al. [54] highlighted significant differences in the effect of organic farming among crop types, mainly between cereals. We observed a similar trend on Ruozzi farm, where the soil arthropod

abundance and diversity in corn differed from the one observed in wheat and wheat crop residues. We found generally lower values in corn for both abundance and taxa, as well as for soil quality, in terms of QBS-ar, and presence of groups more adapted to soil, notwithstanding a condition more favourable to soil fauna in conservation management, a result supported by Winter et al. [57]. Moreover, community assemblages in corn and wheat differed between managements, with a dissimilarity mainly due to Acari and Collembola, respectively. In conservation management, wheat showed the overall greatest abundance of soil arthropods, owing to the great number of Acari and, especially, Collembola and Hymenoptera, while the total number of arthropod groups were generally higher in crop residues of forage. The previous crop types in the field should be considered too, as noted by Cortet [15]. In this case, the influence of the previous crop is shown by the QBS-ar index, as well as by the proportion of taxa with EMI 20, which suggest that the field that supported the most adapted fauna was conservatively managed and had wheat residues. Conventional management showed a similar trend in bare soil. This condition can be explained by the lower anthropogenic activity related to the absence of a specific crop, followed by tillage as the only agricultural practice. Moreover, bare soil community assemblages were similar for more than 60% to those found in conservation management with crop residues of wheat. The effect of the previous crop appears to be emphasised on Gli Ulivi farm, too, where wheat after alfalfa crop supported a higher number of groups, along with Hymenoptera abundance, than wheat in 2017, perhaps a consequence of growing sorghum in the gap between cover crop and wheat. Indeed, in both managements, community assemblage too differed more than 40% between wheat after alfalfa and wheat in 2017, with Hymenoptera accounting for the greater difference. Generally, as on the Ruozzi farm, results on Gli Ulivi agree with findings by Rizk [58], showing that soil management techniques and crops that enhance diversity, as well as biological quality of the soil, involved conservation management, cover crops, and crop residues. On Gli Ulivi, the difference between conventional and conservation farming was evident in bare soil compared to cover crop, for fauna composition, number of taxa, and abundance, mainly of Collembola. This difference is probably due to the harrowing on bare soil in early November, practice that can drastically reduce diversity and activity of soil fauna. This was supported by Maraun et al. [24], who suggested that Collembola are sensitive to mechanical disturbances, even more than mites.

As reported by Menta and Remelli [59], some arthropod groups are widely used to detect soil quality and the effects of soil managements; among these arthropods, Collembola and Acari are the two most important groups in terms of abundance and species diversity [60], and subsequently the most investigated taxa. In our study Acari and Collembola were the groups that accounted for the greater dissimilarities, both within and between managements, generally followed by Hymenoptera. Comparing the abundances of Acari and Collembola on the two farms, they are generally higher on Ruozzi conservation wheat than on Gli Ulivi, where wheat appears to be a less favourable crop. Van de Bund [61] suggested that, even if crops showed a considerable influence on the fauna of mites and springtails, the preference for living under a special crop was not similar under different types of soil. However, another explanation could be the use of slurry on Ruozzi farm, which could increase the abundance of some tolerant arthropods like Collembola, while more sensitive ones could disappear [62,63]. In this case, Symphyla, Chilopoda, and Coleoptera larvae were not present in Ruozzi conservation wheat. Nevertheless, confirming Bund [61]'s observation that the abundances of these groups were much greater within the root system of plants than in bare soil, the overall distribution of Collembola and Acari in our study was similar on both Ruozzi and Gli Ulivi farms. On Cavallini their relative abundance is lower and a higher proportion of other groups, such as Symphyla and Diptera larvae, is observed, especially under sub-irrigation systems. Since Cavallini fields are conservatively managed, Acari and Collembola would be expected to be more abundant, even if the use of herbicides and fungicides on the farm, throughout the years, might have affected these groups negatively, especially herbivore and fungivore collembolans. In those fields, where the difference in management system was based on the presence of sub-irrigation, crop type influenced fauna abundance and diversity, so that different groups were advantaged by different crops. Moreover,

both the irrigation system and crop type influenced soil fauna assemblages. Under this conservation, management differences were driven by much more groups than in Ruozzi and Gli Ulivi farms, with some generally minor groups sometimes contributing more to the overall dissimilarity than Acari and Collembola, such as Hemiptera, that appeared particularly linked to soybean. On the other hand, decomposers generally prefer crop residues [64]. This is the case of Diptera larvae, widespread in crop residues and cover crop seedings, in the latter case probably enhanced by the lack of predators such as Araneae. Other taxa, such as Symphyla, generally take advantage of the interaction between crop and sub-irrigation system, together with conservation management. Indeed, Peachey et al. [65] observed that the number of Symphyla, which generally consume germinating seeds, plant roots, and plant parts in contact with the soil, may increase as a consequence of reduced tillage, notwithstanding that cover cropping seems to be the most powerful factor.

## 5. Conclusions

The aim of this study was to evaluate the effects of management systems and crop types on soil fauna. Considering both factors, crop type seemed to have a greater effect on the arthropod community, although the conservation system generally provides better conditions for soil fauna, often interacting with crop. Indeed, biodiversity, in terms of soil arthropod abundance and number of groups, and soil quality index, in terms of number of arthropods well adapted to soil, were higher in both conventionally and conservatively managed fields when less impacted by anthropogenic practices, such as cover crops and crop residues. However, arthropod assemblages respond to soil practices differently, thereby highlighting different sensitivity to soil agricultural management and crops, with Acari, Collembola, and Hymenoptera accounting for the major dissimilarities, as well as abundance. Further studies are needed to clarify the effects of different agricultural management on soil faunal dynamics in the era of agricultural sustainable intensification.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2073-4395/10/7/982/s1>, Scheme S1: Farm management and crop type in the sampling period. Under each farm management, the land use in the study period was indicated. A: Ruozzi farm; B: Gli Ulivi farm; C: Cavallini farm. Table S1: Analytical data of the three farms soils. Table S2: Taxa abundance (ind./m<sup>2</sup>) ± standard error for every crop type within the agricultural system in the three farms. A: Ruozzi farm; B: Gli Ulivi farm; C: Cavallini farm. Table S3: Results of SIMPER analysis in: A: Ruozzi farm; B: Gli Ulivi farm; C: Cavallini farm. Most influential arthropod groups accounting for a cumulative dissimilarity within (×1) and between (×2) management of 70% are shown.

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