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The Effect of Cover Crops on the Biodiversity and Abundance of Ground-Dwelling Arthropods in a Mediterranean Pear Orchard

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Abstract: The intensification of agriculture has led to the reduction of the diversity of arthropods in agroecosystems, including that of ground-dwelling species. The aim of our work was to assess the effect of a sown cover crop on the diversity of ground-dwelling arthropods, including key predators for pest control in pear orchards. The trial was carried out in a pear orchard divided in three blocks; two treatments (cover-cropping and control) were implemented in each block. A seed mixture of 10 plant species was used in the plots with the sown cover. The densities of ground-dwelling arthropods were sampled using pitfall traps. The ground cover had a significant impact on the diversity and abundance of arthropods. The Shannon–Wiener diversity index was significantly higher for the cover than for the control plots. Several families of spiders (Linyphiidae, Lycosidae), beetles (Carabidae, Staphylinidae) and hymenopterans (Scelionidae) were significantly more abundant in the cover-sown plots. Ants and collembola had a significantly higher abundance in the control plots. Some of these groups arthropods (ants and spiders), are represented by species that may commute between ground and pear trees, having an impact on pest control. The use of cover crops is encouraged to enhance biodiversity in farmlands.

Keywords: ground-dwelling arthropods; pitfall traps; cover crops; ecosystem services; natural enemies; pear pests; biological control

1. Introduction

Biodiversity is currently experiencing one of the greatest known regressions since the beginning of life on Earth [1–3]. Under the current scenario, it is predicted that about 20% of all species will be lost in the next three decades [1,4]. Changes in land use and cover are currently considered the single-most acute factor threatening biodiversity worldwide, since native diversity depends on the structural and compositional diversity of habitats [5]. Among these changes, the conversion of natural ecosystems such as forests or grasslands to agriculture is considered to make a particularly high contribution [6]. Croplands and pastures are today one of the largest terrestrial biomes, occupying approximately 40% of the land surface on the planet [3]. In addition, the intensification of modern agriculture has resulted in the simplification of agricultural landscapes [7–9]. Habitat loss and fragmentation, combined with high inputs of pesticides, are nowadays considered the main causes of the worldwide loss of biodiversity [10–12].

Soil is one of the most species-rich habitats of terrestrial ecosystems [13–15]. According to diverse estimates, the soil fauna represents approximately 23% of all described organisms, with arthropods

representing 85% of the species present in the soil fauna [16]. The arthropods that live on the soil surface ('ground-dwelling arthropods') also constitute an important part of the biodiversity of most terrestrial ecosystems [17,18]. The wide diversity of ground-dwelling arthropods includes several taxa that have a major presence in most of the surveys conducted in different ecosystems, such as Myriapoda, Collembola, Coleoptera (mainly carabids and staphylinids), Acari, Araneae and Formicidae [18–22]. Epigeic arthropods encompass a broad range of trophic guilds and ecological roles, thus influencing ecosystem function [17,18]. Many species of ground-dwelling arthropods do not spend their entire life on the soil surface, but commute between the ground and the aerial part of plants [13]. This is the case for many species of various groups of major predators, such as ants or spiders, which are ubiquitous in terrestrial ecosystems and essential to regulate the abundance of herbivores on plants [13,23]. Furthermore, many exclusively ground-dwelling arthropods may influence the population dynamics of aerial herbivores through cascading effects produced by "top-down" regulation processes, due to their interaction with commuting species [24–26]. For example, some carabids are known to feed on other predators of both the ground layer and the plant foliage, such as spiders, affecting their abundance via intraguild predation (IGP) and, consequently, the regulation of plant pest populations [27–29].

Common agricultural practices such as ploughing, the elimination of ruderal plants, and the use of fertilisers modify the conditions of soils and have a great impact on the diversity and abundance of epigeal arthropods, including many species that play a key role in the regulation of plant pests [30–33]. The relevance of biodiversity for the functioning of ecosystem processes together with the pivotal role that it plays in providing ecosystem services to humans makes it essential to plan conservation strategies to reverse the loss of species [5,34,35]. Biodiversity losses are associated with several key problems affecting the sustainability of farming systems, such as limited soil genesis and fertility, pollination, and pest control [36,37]. Because of the great extension of the Earth devoted to farming, conservation strategies aiming to increase the complexity of agricultural landscapes are expected to highly contribute to the maintenance of worldwide biodiversity and to the provision of ecosystem services [12]. Floral strips and cover crops are some of the agroecological practices used most frequently to enhance habitats of pollinating insects and natural enemies in environmentally degraded farmlands [3,34,38,39]. Green infrastructures are known to provide the missing habitat requirements for natural enemies (food resources, shelters, refuges, etc.), allowing them to overcome the disturbances derived from agricultural practices [40,41].

Fruit tree orchards may benefit from the adoption of agroecological practices, especially in simple landscapes. Orchards represent around 2% of the agricultural land utilised in the European Union (EU), with more than 3.4 million ha dedicated to fruit growing. Pears are one of the most important fruit crops in the EU. In 2018, more than 116,000 ha were devoted to pear production [42]. Therefore, increasing plant diversity in fruit tree orchards is expected to enhance biodiversity at a global scale, with a likely positive impact on ecosystem services such as pest control. A significantly higher abundance of natural enemies and improved pest control have been registered in fruit tree orchards with cover crops [39,43–45]. Pest control in pear orchards has traditionally relied on chemicals, but due to the restriction in the application of insecticides and the development of resistances, integrated pest management (IPM) has become the most-sustainable alternative [46–48]. Pear orchards with limited use of pesticides can be inhabited by a rich community of arthropods, which includes many natural enemies such as anthocorids, mirids, ants, and spiders that contribute to the regulation of the populations of herbivorous species [49–53]. In some parts of the Mediterranean area, ants (namely, *Lasius grandis* Forel, Hymenoptera: Formicidae) have been reported to be the key predator for the control of the pear psyllid [52,53]. This ant species spends the main part of its life cycle in the soil or on the soil surface; thus, its abundance and foraging activity may be greatly influenced by agricultural practices that modify soil conditions. Little information is available on the effect of cover crops on ground-dwelling invertebrates, especially the main groups of generalist predators [45].

Pear orchards are currently managed in a very intensive way, with the alleys between the lines of trees and the area surrounding the crop kept free from ruderal plants by ploughing or the regular use of

herbicides. This way of farming is expected to have a high impact on the local diversity of arthropods, including some of the species that play a key role in the regulation of pests. Therefore, the aim of our study was to investigate how cover crops influence the diversity and abundance of ground-dwelling arthropods in a pear orchard. Predators that commute between the soil surface and the canopy of pear trees (e.g., ants and spiders) were of particular interest because of their likely impact on pest control.

2. Materials and Methods

2.1. Experimental Design

The present study was carried out in an organic pear orchard of approximately 5 ha (450 m-long, 110 m-wide) located near the locality of Jumilla (Murcia Province, 38°23′56″ N, 001°23′19″ W) in Southeastern Spain, during the spring of 2019. The effect of cover crops on the diversity and abundance of ground-dwelling arthropods was tested in a randomised block design experiment with three replicates of two treatments (i.e., cover crops and bare soil, Figure 1). The pear orchard had 26 lines of 540 trees each, with trees trained in trellises, the separation being 4 m between lines and 0.8 m between trees within lines. The orchard was divided in three blocks of approximately 1.6 hectares each. In each block, two plots, each 80 m-long and 20 m-wide (five lines of pear trees), separated by at least 4 lines of pear trees, were established. The two treatments were assigned randomly, one of the two plots of each of the three blocks being sown with a mixture of herbaceous plants, while the other maintained free from ruderal plants by periodical cuttings (every 2–3 weeks) and tillage. The mixture of seeds included the following herbaceous plants: *Borago officinalis* L., *Coriandrum sativum* L., *Calendula arvensis* L., *Calendula officinalis* L., *Diplotaxis erucoides* (L) DC., *Echium vulgare* L., *Hordeum vulgare* L., *Medicago sativa* L., *Phacelia tanacetifolia* Benth and *Vicia faba* L. These plant species were chosen with the aim of providing plentiful floral resources for beneficial arthropods and alternative prey/hosts for natural enemies and for improving soil fertility [54,55]. The pear trees were watered by above-ground drip irrigation twice a week; in addition, the sown plots were irrigated once a week by sprinklers to enhance the growth of the cover in the central part of the alleys between the lines of trees.
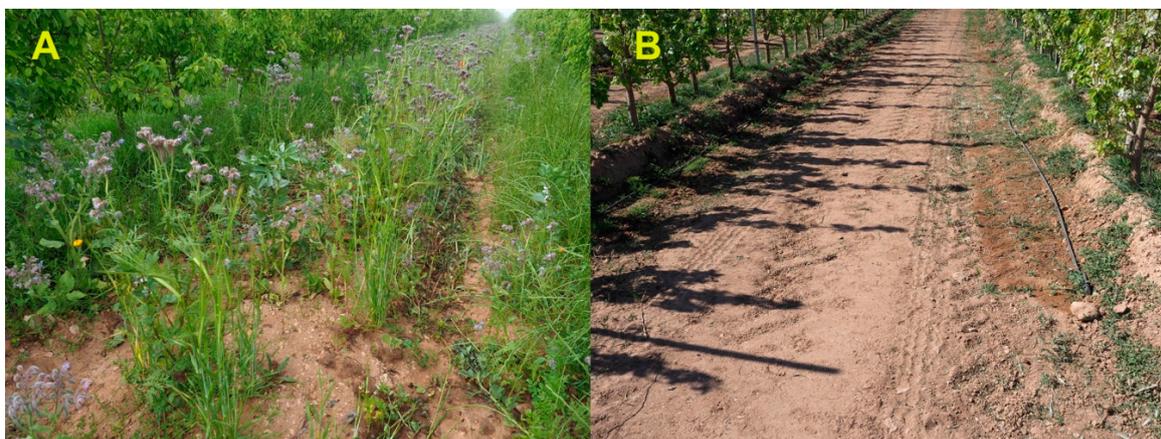

Figure 1. Example of the ground cover in the two treatments: the sown cover (**A**) and the control (**B**).

2.2. Sampling

The plots were monitored periodically in order to determine the effect of the sown cover on the structure of the community of ground-dwelling arthropods. The diversity and abundance of ground-dwelling arthropods were estimated using pitfall traps. Each trap consisted of a 500 mL plastic container (8 cm in diameter) partially filled with a mixture of water (94%), propylene glycol (5%) and soap (1%) and placed in the soil with its opening level with the soil surface. Three traps were set up in each of the two plots (i.e., cover and control) of each block; the traps were placed diagonally across the middle of the three central alleys of each plot. The traps were kept in the field for seven days, and then

the specimens were collected and preserved in 70% alcohol for their identification. The samples were collected on 24 April, 13 May, 28 May and 11 June 2019. This period was chosen both because it is favourable for the development of the cover and because it is characterised by a high activity of insects and spiders [51,52]. The summer months in southern Spain are very arid, and plant covers dry out. The plots were sampled every two weeks because it was known from previous studies that the density of insects changes very little between two consecutive weeks [51,52].

The specimens collected were observed under a stereomicroscope and identified to the species level, whenever possible. When the identification to the species level was not possible, the specimens were assigned to morphospecies based on easily observable morphological characters [56]. The specimens were identified following the keys of Martínez et al. [57] for ants, Goulet and Huber [58] for other Hymenopterans, Nentwig et al. [59] for spiders and Salgado et al. [60] for beetles. The reference collection of voucher specimens is held by the IMIDA (Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario).

The proportion of ground covered by vegetation for each plot was estimated by taking one high-resolution photograph, framing a 1 × 1 m plastic stick square, in each of the three alleys where pitfall traps were placed (i.e., 18 pictures per sampling date). The pictures were subdivided in 100 quadrants (10 cm × 10 cm), and the presence/absence of vegetation in each quadrant was scored. The GIMP v2.8.14 software (Free Software Foundation, Boston, MA, USA) was used for image processing.

2.3. Data Analysis

Generalised linear mixed-effects models (GLMM), run with the "lmer" function ("lme4" package) for normally distributed data, were used to compare the proportion of ground cover between the plots with and without the sown cover [61]; block and date of sampling were introduced in the models as random factors.

To test for the effect of ground cover, only the species that live on the ground or that spend part of their lives on the ground were considered in this study. The following taxa were included: Collembola, four families of Coleoptera (Anthicidae, Tenebrionidae, Carabidae and Staphylinidae), four families of Araneae (Gnaphosidae, Zodariidae, Lycosidae and Linyphiidae) and two families of Hymenoptera (Formicidae and Scelionidae).

The richness of species/morphospecies and the Shannon–Wiener diversity index were used to test for the effect of ground cover on the diversity of ground-dwelling arthropods. The effect of sown cover on the number of species/morphospecies of ants, spiders and beetles was estimated using GLMM run with the function "glmmPQL" (library "MASS") set for normal distributed data, i.e., family = gaussian (link = "identity"), in R [62]. Block and date of sampling were introduced in the models as random factors. The same procedure was used to estimate the effect of the sown cover on the Shannon–Wiener diversity index. The diversity index was calculated for each sampling date using the total number of captures of each of the species/morphospecies of the above-mentioned families, with the "diversity" function in the "vegan" package in R [62]. The χ^2- and *p*-values were obtained using the "Anova" function in the R "car" package [62].

The assemblages of ground-dwelling arthropods were compared between the plots with cover and the controls by PERMANOVA, using the function "adonis", the Euclidean distances being calculated with the "vegdist" function; these two functions are available in the "vegan" package in R [62]. The number of specimens (i.e., the sum of the three pitfall traps in each plot) of the abovementioned families of ground-dwelling arthropods collected on each sampling date were introduced in the models as dependent variables. Redundancy analyses (RDA) were applied to find out how samples clustered in relation to the presence/absence of the sown cover. The function "rda" in the "vegan" package was used to perform RDA on the number of ground-dwelling arthropods of the different families collected in the plots with the sown cover and the control plots on each sampling date; the captures of the three pitfall traps for each plot and sampling date were summed for every family of arthropods.

To determine the contribution of the abundance of every family of ground-dwelling arthropods —as a dependent variable—to the differences between the plots with cover and the controls—type of cover as fixed factor–GLMM were used. The "lmer" function ("lme4" package) was used to perform these analyses [61]; block and date of sampling were introduced in the models as random factors. For all the families, the numbers of captures were transformed by the natural logarithm of (x + 1) to correct the deviation of the data from normality. The χ^2- and *p*-values were obtained as explained above.

3. Results

3.1. Ground Cover and Diversity of Ground-Dwelling Arthropods

The proportion of ground covered with vegetation was significantly higher in the plots sown with the mixture of seeds than in the control plots (χ^2 = 61.38, df = 1, *p* < 0.001). The ground of the sown cover plots was almost entirely covered with vegetation during the whole sampling period, while in the control plots, the proportion of cover was very low on the first sampling date (0.143 ± 0.029), increasing to 0.718 ± 0.067 at the end of the experiment.

Along this study, a total of 25,139 arthropods were captured in the pitfall traps, with Collembola representing most of the captures (79.7%) (Supplementary Material, Table S1). Excluding Collembola, the most abundant arthropods collected in the pitfall traps were ants (76.0%), followed by Coleoptera (13.8%), spiders (8.1%) and scelionids (2.1%).

The richness of ground-dwelling species in cover and control plots varied in the different orders of arthropods (Figure 2A). Hymenopterans were mainly represented by ant species (Supplementary Material, Table S1), and their richness was significantly lower in the plots with cover than in the controls (χ^2 = 3.91, df = 1, *p* = 0.048). The number of species of hymenopterans collected in the pitfall traps experienced little variation, the highest values being registered at the end of the experiment, in both the cover (3.7 ± 0.3, mean ± SE) and the control plots (5.0 ± 0.0). In contrast, the richness of spiders was significantly higher with a sown cover than in the control plots (χ^2 = 17.79, df = 1, *p* < 0.001). In the cover plots, the number of species of spiders was the lowest (2.7 ± 0.7) in the first week of sampling and reached its maximum (7.3 ± 0.9) at the beginning of May. In the control plots, the lowest (1.3 ± 0.9) and highest (5.0 ± 0.6) numbers of spiders were registered at the end of April and May, respectively. In the same way, the richness of beetles was also significantly higher in the grounds with a sown cover than in the control plots (χ^2 = 16.65, df = 1, *p* < 0.001). The trend in the number of species of beetles was very similar to that of spiders (Figure 2A). In the cover plots, the lowest (3.3 ± 0.7) and highest (7.0 ± 1.2) values were registered at the end of April and May, respectively. In the control plots, the numbers of species of beetles increased progressively from the beginning until the end of the study, ranging between 3.3 ± 0.7 and 4.3 ± 0.3. No distinction among species/morphospecies was made in springtails.

The Shannon–Wiener diversity index of ground-dwelling arthropods was significantly higher in the plots with a sown cover than in the control plots (χ^2 = 25.52, df = 1, *p* < 0.001) (Figure 2B). The plots with cover showed a progressive increase in the Shannon–Wiener diversity index throughout the period of study, reaching the highest value at the end of the study in June (2.04 ± 0.13). In the control plots, the diversity index varied little among the sampling dates, reaching its lowest value at the end of May (0.77 ± 0.16); thereafter, it increased until June (1.20 ± 0.16).

3.2. Structure of the Assemblages of Ground-Dwelling Arthropods in Pear Orchards

The plots with and without the sown cover differed in their assemblages of ground-dwelling arthropods (PERMANOVA, F = 2.44, df = 1, 22, *p* = 0.030). In the RDA analysis, practically all the samples from the plots with the sown cover clustered on the positive side of the first component of RDA, while the samples from the control plots grouped on the negative side (Figure 3). The first constrained axis (RDA1) explained 16.5% of the variance in relation to cover (F = 4.35, df. 1, 22, *p* < 0.001). Carabidae, Linyphiidae, Staphylinidae and Lycosidae were the families of arthropods

with the highest correlation in relation to cover. In contrast, Collembola and Formicidae were highly correlated with plots without sown cover (Figure 3).
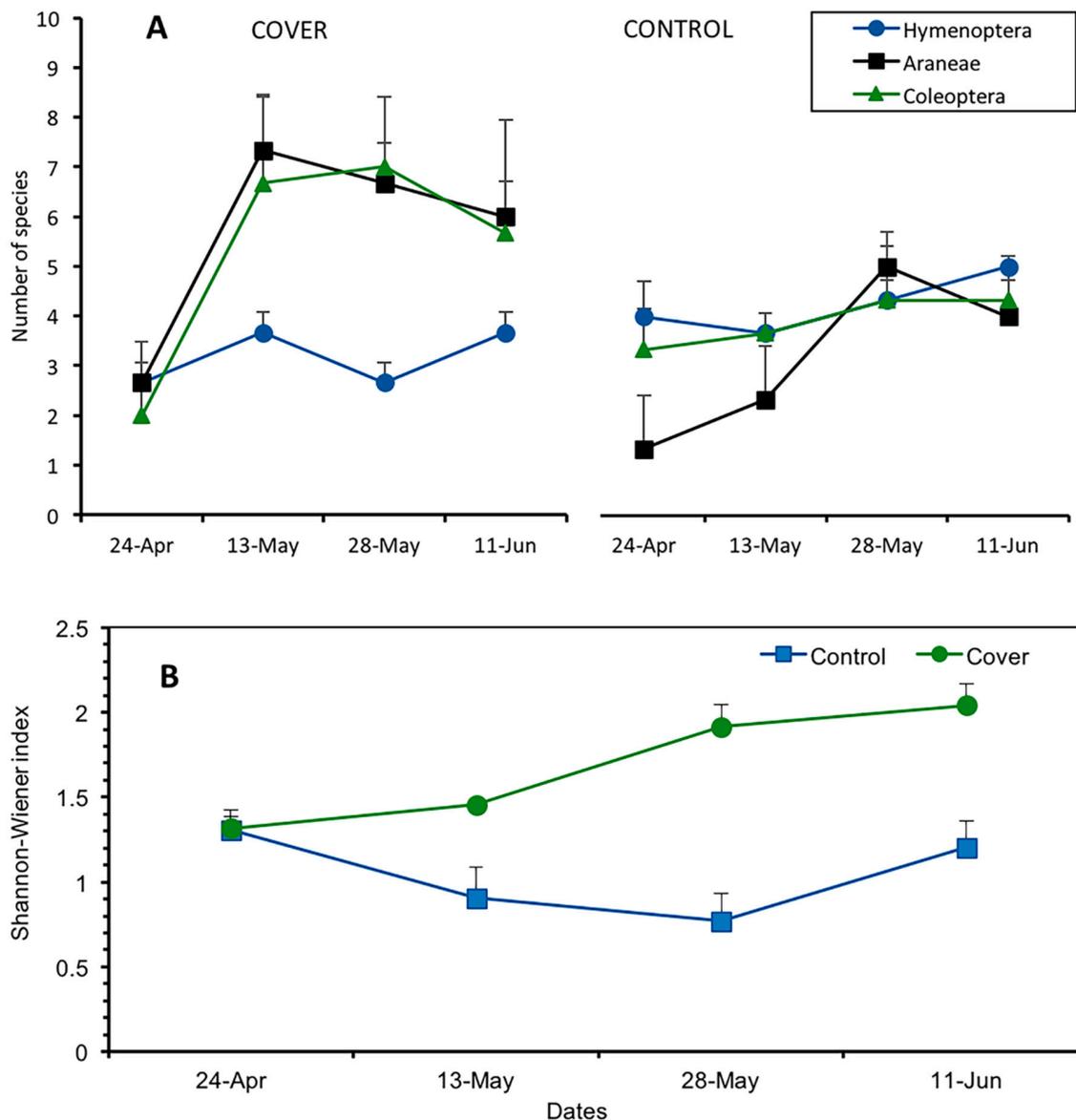

Figure 2. (**A**) Richness of hymenopterans, spiders and beetles; (**B**) Shannon–Wiener index in the plots with a sown cover and in the control plots (mean ± SE).

The abundance of most of the families of arthropods collected in the pitfall traps, with the exception of some Araneae (i.e., Gnaphosidae and Zodariidae) and Coleoptera (i.e., Anthicidae and Tenebrionidae), differed significantly between the plots with cover and the controls (Table 1). Ants were represented by polyphagous species that may potentially commute between the ground and the aerial part of pear trees. *L. grandis* was the most abundant ant species (61.7%), followed by *Tetramorium* spp. (28.9%) and other minor species (<5%) such as *Formica* spp., *Cataglyphis* spp., *Cardiocondyla* spp. and *Solenopsis* spp. (Supplementary Material, Table S1). Ant numbers peaked in the plots with a cover in mid-May (176.3 ± 26.7, mean of the total number of individuals collected per plot ± SE) and in the control plots at the end of May (316.0 ± 36.1) (Figure 4).
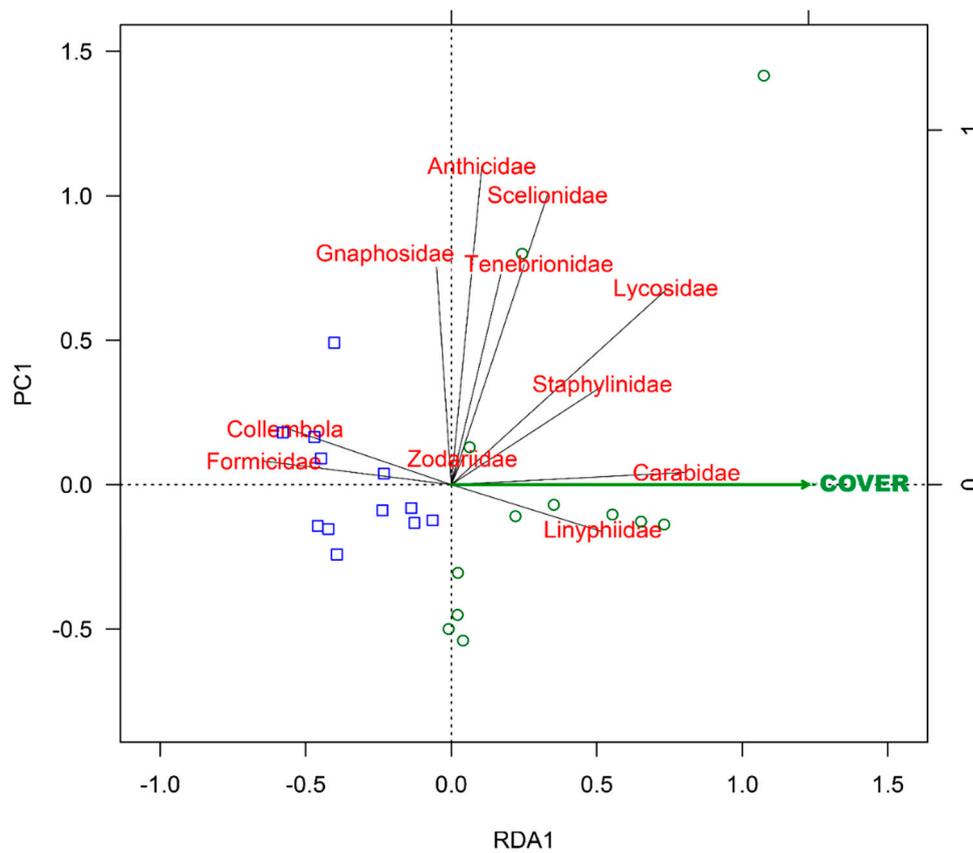
Figure 3. Plot of the first constrained ordination axis (RDA1) versus the first unconstrained axis (PC1) on the redundancy analyses (RDA) of samples of ground-dwelling arthropods collected in plots with (green circles) and without (blue squares) a sown cover.

Table 1. Coefficients and statistics of the generalised linear mixed effects models (GLMM) to test for the effect of the cover crop on the abundance of the main groups of ground-dwelling arthropods. χ^2 = Chi square; df = degrees of freedom.

Order	Family	Coefficient	χ^2	df	*p*
Hymenoptera	Formicidae	−0.664	24.032	1	<0.001
	Scelionidae	0.710	5.161	1	0.023
Araneae	Gnaphosidae	−0.227	0.720	1	0.396
	Linyphiidae	0.674	9.705	1	0.002
	Lycosidae	1.799	67.751	1	<0.001
	Zodariidae	−0.010	0.002	1	0.970
Coleoptera	Anthicidae	0.144	0.336	1	0.562
	Carabidae	2.058	43.180	1	<0.001
	Staphylinidae	0.806	6.008	1	0.014
	Tenebrionidae	0.097	0.071	1	0.790
Collembola	-	−0.650	10.063	1	0.002

In the case of spiders, most of the families collected in the pitfall traps (i.e., Gnaphosidae, Lycosidae and Zodariidae) forage on the ground, while Linyphiidae are also found on the canopy. The most abundant family of spiders was Lycosidae (45.6%), followed by Gnaphosidae (27.0%), Zodariidae (15.5%) and Linyphiidae (11.8%). The highest number of spiders collected belonged to *Pardosa* spp. (39.4% of the captures), *Micaria* spp. (19.3%) and *Zodarion* spp. (15.5%) (Supplementary Material, Table S1). The abundance of Lycosidae and Linyphiidae was significantly higher in the cover plots than in the control plots (Table 1). In the plots with a sown cover, the abundances of these two families gradually increased until the end of May, when lycosids reached the highest values recorded among the spiders

(26.0 ± 4.0); the linyphiids reached a much lower peak (7.0 ± 2.7) (Figure 4). In the control plots, the abundances of lycosids and linyphiids were very low. In contrast, the abundances of Gnaphosidae and Zodariidae did not differ significantly between the two treatments (Table 1), with very similar numbers of specimens captured in both types of plot along the study (Supplementary Material, Table S1). These two families peaked at different times: the zodariids at the end of May (Control: 5.7 ± 0.7; Cover: 5.7 ± 1.3), and the gnaphosids at the beginning of June (Control: 12.0 ± 1.2; Cover: 11.3 ± 4.1) (Figure 4).
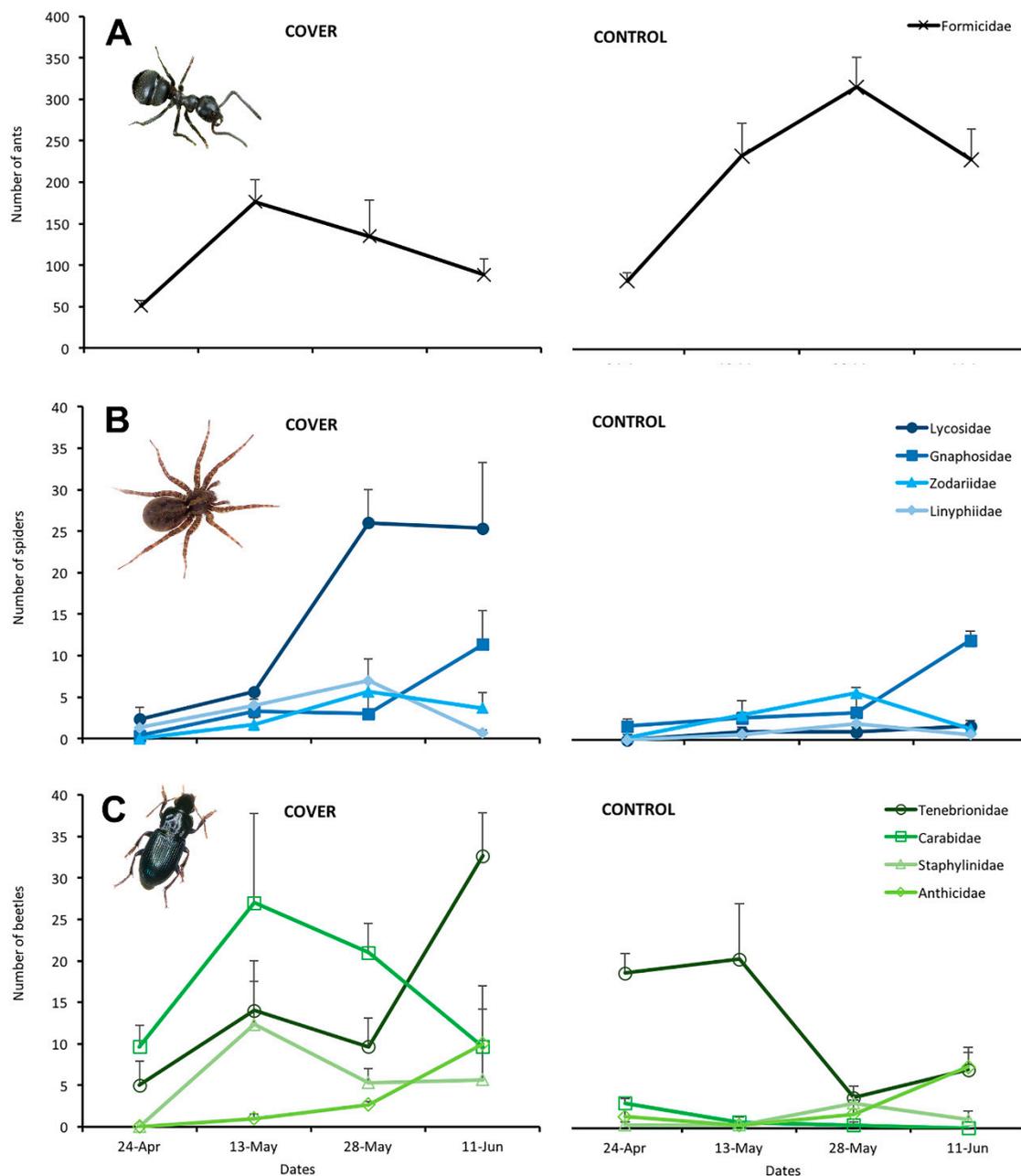

Figure 4. Number of the different families of ants (**A**), spiders (**B**) and beetles (**C**) (mean ± SE) collected in pitfall traps in the plots with a sown cover and in the control plots.

Beetles were represented by families with different feeding habits. Phytophagous species of the families Tenebrionidae (47.4%) and Carabidae (namely, *Harpalus* spp., 30.4%) represented most of the Coleoptera collected in pitfall traps; polyphagous species, such as staphylinids (11.9%) and anthicids (10.2%), were less represented (Supplementary Material, Table S1). The four families of beetles showed

different trends in their abundances along the sampling period in relation to the type of cover (Figure 4). Tenebrionids and anthicids did not show significant differences between the plots with a cover and the controls (Table 1). In contrast, carabids, represented only by the species *Harpalus*, and staphylinids were much more numerous in the plots with a sown cover (Table 1). The abundance of tenebrionids increased in the cover plots to reach a peak in June (32.7 ± 5.2 individuals), while in the controls, the lowest abundances were registered on the last two sampling dates. Carabids and staphylinids peaked in mid-May in the plots with a sown cover (Carabidae: 27.0 ± 10.8; Staphylinidae: 12.3 ± 5.2), their abundances decreasing thereafter. In the controls, these families were scarcer, with carabids (3.0 ± 0.6) peaking at the end of April, and staphylinids (3.0 ± 1.0) at the end of May. The numbers of anthicids, despite being generally low, gradually increased along the sampling period, peaking on the last sampling date in the two treatments (Control: 7.3 ± 2.4; Cover: 10.0 ± 4.1).

Scelionids were collected only occasionally, but they are relevant for being egg parasitoids of arthropods. They were mainly represented by the genus *Baeus* Haliday (93.4% of the captures). These hymenopterans were significantly more numerous in the cover plots than in the control plots (Table 1). The abundance of scelionids was very low in the first three samplings and increased considerably at the beginning of June in the cover plots (32.0 ± 19.3), relative to the control plots (1.7 ± 1.2). Finally, springtails showed significantly higher abundances in the control plots than in those with a sown cover (Table 1). Springtails gradually increased in number in the control plots, peaking in June at 2343.3 ± 378.9 individuals; in contrast, in the cover plots they peaked in mid-May (1068.3 ± 149.5 individuals), with their abundances decreasing thereafter.

4. Discussion

Agroecological practices such as the implementation of cover crops are known to contribute to the maintenance of local biodiversity in farming systems [3,12,34]. The results of the present work indicate that a rich cover of vegetation increases the biodiversity of ground-dwelling arthropods in pear orchards. The Shannon–Wiener diversity index was significantly higher in the presence than in the absence of a sown cover. In addition, the richness of spiders and beetles was significantly higher in the plots with a cover. A mix of herbaceous plants similar to the one used in the present work was reported to produce an increase in the abundance and diversity of wild bees in areas of intensive agriculture [55]. Considering the growing interest in green infrastructures for the conservation of biodiversity in agricultural lands, relatively little information on the impact of cover crops on the diversity of ground-dwelling arthropods is available. Sommaggio et al. [45] found a significant higher activity and density of isopods, staphylinids, carabids and grillids in the soil surface of a vineyard with several types of cover crop, relative to the control, which was exposed to periodical tillage; however, only a faba bean cover had a significantly higher number of species than the control. Surprisingly, no significant differences were found between any of the treatments and the control for the Shannon–Wiener index, with the exception of a buckwheat cover that registered lower values that the control. In contrast, Cárdenas et al. [63] found no significant differences in spider diversity between ground with cover and that where the vegetation had been removed. Rieux et al. [64] reported a higher diversity index for arthropods on sown cover than on bare ground and natural vegetation cover in French pear orchards. However, it has to be taken into account that, because sampling was carried out using sweeping nets, these indexes represent the diversity of arthropods living on plants rather than of those living on the ground.

Most of the main groups of ground-dwelling arthropods collected were significantly affected by the presence of a sown cover. Among them, only springtails and ants showed lower abundances on the ground with a sown cover than on the ground without a cover; additionally, the ant richness was lower on the ground with a cover. This is in contrast with previous studies reporting higher ant abundances under cover-cropping management [65–68]; however, it should be noted that most of these studies compared soils with cover crops with recently tilled soils, and intense tillage is known to have a detrimental effect on ant abundances [69]. Regarding springtails, our results are in agreement with those

of Buchholz et al. [70], who stated that the abundance and diversity of surface-dwelling springtails were diminished by the greater plant biomass provided by covers. Beetles (i.e., carabids and staphylinids) and spiders (i.e., lycosids and linyphiids) were more numerous on the ground with a sown cover. The beneficial effects of covers on carabids and staphylinids have been extensively reported [45,71,72], while in the case of spiders the results are more variable. Several studies have reported an increase in the abundance of spiders on the ground in orchards with a vegetation cover [73–75], while in other studies, a non-significant effect in comparison to bare ground was registered [45,63]. The scelionids were another group of insects that benefited from the sown cover. Other authors have also reported increased abundances of scelionids on grounds with cover, in different types of orchards [76,77].

Cover crops may affect ground-dwelling arthropods in several ways. For instance, by creating physical barriers that hamper their movement on the ground surface and/or by increasing the availability of niches in habitats [70,78,79]. In the present work, these two factors could explain the decline of springtails observed in the plots with a sown cover. Buchholz et al. [70] argued that plant covers not only hinder the rapid movement of springtails, increasing the risk of them falling prey, but also benefit the establishment of predators. In our case, lycosids, that benefited from the sown covers, are known to prey on springtails [80,81]. In relation to ants, very few species of ant predators—restricted to a few families of spiders—have been reported in agroecosystems [82,83]. Therefore, in the present work, the lower abundance of ants (namely, *L. grandis*) registered on the ground with cover was more likely due to physical interference and/or to interactions with other species. For instance, several herbaceous plants included in the cover host ant-mutualistic aphids that may divert the attention of ants to these plants [44,84,85]. In the case of spiders, a significant increase in the number of lycosids and linyphiids was registered on the ground with more vegetation. These two families have been reported to benefit from the structural complexity and hideouts provided by herbaceous plants [78,79]. Moreover, these plants may increase the availability of phytophagous and saprophagous prey, which constitute a great part of the diet of these spiders [86,87]. The abundance of spiders could explain the higher number of scelionids in the plots with a sown cover crop. This hymenopteran family was mostly represented by the genus *Baeus*, an obligate parasitoid of spider eggs known to target egg sacs of *Pardosa* wolf spiders [88]. In the case of the two main families of ground-dwelling coleopterans found in the present work, carabids and staphylinids, the factors that may have contributed to their increase on the ground with a sown cover are not easy to determine. Most previous studies focused on predatory species and argued that an improved physical structure of microhabitats, higher alternative food availability, reduced competition and/or an increase in the prey population could be the main explanations for higher densities of these beetles in cover crops [45,71]. In this study, all the carabids collected belonged to the genus *Harpalus* Latreille, which includes mostly phytophagous species [45]. In this regard, Shearin et al. [33] observed a beneficial effect of cover crops on the abundance of the species *Harpalus rufipes* De Geer (Coleoptera: Carabidae), suggesting higher seed availability as the main factor behind this trend. Ground-dwelling arthropods are also influenced by the variation in microclimatic conditions due to cover crops [89,90]. Vegetation gives shelter to ground-dwelling arthropods against extreme temperatures and provides higher environmental humidity. The abundances of carabids and spiders have frequently been found to be positively correlated with soil moisture [91,92]. In particular, the higher recaptures of *H. rufipes* in a cover crop, in comparison to fallow treatments, were attributed to higher humidity and lower temperature [33]. In the present study, the increase in humidity produced by the greater vegetation cover and the extra watering of the cover crop may have also benefited some arthropods, such as carabids and spiders.

This and earlier studies have demonstrated that vegetation covers allow the existence of a more abundant and diverse arthropofauna in crops [67,93,94]. Cover crops may increase the availability of resources (e.g., pollen, nectar, alternative host and prey species, shelter) to support a rich community of natural enemies that may eventually move to adjacent crop plants and exert a beneficial effect [34,95,96]. Evidence of generalist predators, such as spiders, commuting between a legume cover crop and the canopy of pear trees has been found using immunomarkers [97]. Although the relationship between

biodiversity and ecosystem functioning is controversial [12], increasing the diversity of vegetation in crops has frequently been reported to enhance ecosystem services such as pest control [93,98]. Several studies have provided evidence of plant covers enhancing the abundance of natural enemies and pest control in fruit tree orchards [39,44,45,99,100]. In the case of pear trees, there is some evidence of a positive effect of ground covers on beneficial fauna [64,97,101]. In the present study, some of the ground-dwelling arthropods influenced by the plant cover, namely, ants and spiders, are key species for the assemblage of arthropods in pear orchards in the Mediterranean area [51–53]. Therefore, increasing the herbaceous vegetation in pear orchards is expected to have an impact on the population dynamics of the species in the canopy of the trees. However, the outcome of the interaction among species is difficult to predict. Ants are known to establish antagonistic–mutualistic interactions with psyllids, being the key species for the control of pear psyllids in some parts of the Mediterranean area [52,53]; thus, the foreseen change in the foraging pattern of ants due to increased vegetation may have either a positive or a negative effect on the control of pear psyllids. The effect of cover crops on spiders as biological control agents is expected to be lower than that on ants, especially because they are much less numerous than ants [51] and because, of the families found in the canopy of pear trees (J. A. Sanchez, non-published data), only the Linyphiidae were found to be influenced by the cover. Other spiders not affected by the cover, such as the genus *Zodarion* Walckenaer, have been described as specialist ant predators that prey on medium-sized ants, such as *Lasius* spp. [83,102]. However, the impact of *Zodarion* spp. on ants is expected to be low because of their low abundance.

In the present work, it was found that cover crops had a significant effect on the diversity of ground-dwelling arthropods, including some key predators for the control of pests in pear orchards, such as ants and spiders. This work outlines how agroecological practices may contribute to the maintenance of local biodiversity and the importance of including farmlands in the plans for the conservation of the species. The impact of cover crops in terms of pest control is uncertain; therefore, more work is needed to determine how cover crops affect the population dynamics of pests and predators in the aerial part of pear trees, as well as how the interactions among species on the ground influence population dynamics in the canopy. Although this work was carried out only during one year and over a short period of time, it provides evidence that plant covers influence the diversity of ground-dwelling arthropods. Samplings over a more extensive period will reveal the impact of cover crops under different environmental conditions and on other groups of arthropods that had little representation in this study.

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