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Sown Covers Enhance the Diversity and Abundance of Ground-Dwelling Predators in Mediterranean Pear Orchards

Luis Gabriel Perera-Fernández , Luis de Pedro  and Juan Antonio Sanchez

Biological Pest Control & Ecosystem Services Laboratory, Instituto Murciano de Investigación y Desarrollo Agrario y Medioambiental (IMIDA), 30150 La Alberca, Spain; luis_depdro@yahoo.es (L.d.P.); juana.sanchez23@carm.es (J.A.S.)

* Correspondence: luisg.perera@carm.es

Abstract: Intensive agriculture has a strong impact on the structure of arthropod communities in soil. Sown covers can contribute to their conservation, especially for generalist predators such as spiders and predatory beetles. The aim of this research was to assess the effect of cover crop management on the abundance and diversity of ground-dwelling arthropods. For this purpose, a three-year experiment was conducted in a pear orchard that was divided into three blocks with two plots each: one with a sown cover of mixed plants from different families, including Boraginaceae, Asteraceae, Apiaceae, Brassicaceae, and Fabaceae, and the other with no cover, in which any spontaneous plants were periodically removed without using herbicides. The abundance of ground-dwelling arthropods was sampled using pitfall traps. The sown cover increased the overall richness of arthropods. Additionally, spiders from the families Lycosidae and Linyphiidae, as well as beetles from the families Carabidae and Staphylinidae, were more abundant in the sown cover. Conversely, detritivores such as collembolans and beetles from the family Tenebrionidae were less abundant in the cover. The abundance of ants was not affected by the type of cover. The sown cover increased the diversity of arthropods in the crop, as well as the abundance of generalist predators.

Keywords: sown covers; ground-dwelling arthropods; predators; ecosystem services; pear orchards



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1. Introduction

In recent decades, practices related to intensive agriculture, such as pesticide use, soil erosion, and the loss and simplification of habitats, have resulted in a decline in arthropod diversity [1,2]. Arthropods play a vital role in ecosystems as herbivores, predators, decomposers, and pollinators, so their disappearance may have significant ecological and economic consequences [3,4]. This situation, along with the emergence of pesticide-resistant species [5] and a greater awareness among consumers, who increasingly demand organically grown products [6], has led to the promotion of more sustainable agriculture with the aim of minimizing the impact of pests and the use of pesticides while maintaining production [7,8]. In 2020, of the 162.2 million ha dedicated to agriculture in the EU, only 7.5% were allocated to organic farming [9], but this percentage is expected to increase to 25% by 2030 [10].

Previous studies have demonstrated that increasing biodiversity in ecosystems can enhance the abundance of natural enemies, reduce the abundance of phytophagous pests, and reduce pesticide use [11,12]. Some effective measures for increasing biodiversity include crop diversification, the sowing of floral strips to provide food and shelter for pollinators, and the use of cover crops [12–15]. In addition to enhancing biodiversity, a green cover can improve soil quality, reduce erosion, enhance nutrient cycling, control weeds and pathogens, and increase habitat heterogeneity, thereby promoting stability and creating niches for new species [16–18]. Despite these advantages, the implementation of vegetative covers entails disadvantages that must be taken into account, such as the economic and

time costs for farmers, the increase in water consumption in arid areas, the failure of the cover to adapt, and the risk that it may harbor pest species or pathogens [17,19–21]. As a result, studying the type of cover that is best suited to the terrain, the crop, and the intended purposes is essential. For example, the inclusion of species from the Boraginaceae (e.g., *Borago officinalis* L.) or Brassicaceae (e.g., *Diplotaxis catholica* (L.) DC.) families would attract pollinators to crops, while species such as *Vicia villosa* Roth and *V. dasycarpa* Ten. are the most suitable for nitrogen production [19,22]. Additionally, it is important to consider factors such as the germination rates, coverage, and blossoming of the different species that will be used in the cover to ensure its successful establishment [23].

Ground-dwelling arthropods are one of the groups that are most affected by cover crops because they are particularly sensitive to practices such as mulching, tillage, and the use of herbicides [24–26]. This group includes organisms with key functions in this ecosystem—for instance, springtails, which feed on decomposing organic matter and play an important role in nutrient cycling and soil microorganism composition [26,27]. Other members of the soil arthropod community are generalist predators, and they include spiders and coleoptera, such as carabids and staphylinids [15,28]. Spiders in particular have proven to be effective biological control agents in crops [29–31]. The increase in the complexity of the habitat generated by a cover crop benefits predators, as it generates better microclimatic conditions and more niches and offers greater availability of prey, less intraguild predation, and access to other resources, such as nectar or pollen [32–35].

Pear (*Pyrus communis* L. (Rosaceae)), with over 107,000 hectares dedicated to its cultivation and a production of 1.07 million tons in 2019, is one of the most important crops in the EU [9]. Most of the production of this crop is under chemical control; however, this management has proved ineffective against the current main pest of pear orchards, the pear psylla (*Cacopsylla pyri* L. (Hemiptera: Psyllidae)) [5,36,37]. This is due to its quick adaptation to pesticides and the negative effect that chemicals have on the main natural enemies of this pest. Integrated pest management (IPM) has become the most effective approach to controlling this psyllid [5]. Previous works showed that ground-dwelling arthropods, such as the ant *Lasius grandis* Forel (Hymenoptera: Formicidae), are key predators for the control of *C. pyri* in southern Spain [37,38]. Therefore, understanding the effect of ground vegetation on this ant and other predators would be of great help to improve the biological control of pear psyllids and reduce the use of pesticides.

The aim of this study was to assess the effect of a sown cover on the diversity, abundance, and community structure of ground-dwelling arthropods in a pear orchard. Our working hypothesis was that the sown cover would increase the richness of ground-dwelling arthropods, as well as the abundance and number of species of generalist predators.

2. Materials and Methods

2.1. Experimental Location

This study was performed in a 5 ha organic pear orchard located near Jumilla (province of Murcia) in southeastern Spain (38°23'56" N, 001°23'19" W, 408 m asl). The climate is classified as dry Mediterranean Continental, with an annual average temperature of 14.9 °C and annual mean precipitation of 313 mm [39]. The pear orchard had 26 lines of 540 trees each (*P. communis* Ercolini variety). The trees were 4 m apart between rows and 0.8 m apart within rows. The experiment had a complete randomized block design with three replicates. The orchard was divided into three blocks of the same size. In each block, two plots were established, with each one holding one of the two management strategies under study (i.e., sown cover and control), and these were assigned at random. Each plot consisted of five lines of pear trees (80 m long and 20 m wide) and was separated from the adjoining plot by at least 8 lines of pear trees. In the sown cover, a mixture of seeds was used, and this included herbaceous plants from the families Apiaceae (*Coriandrum sativum* L.), Asteraceae (*Calendula arvensis* L. and *Calendula officinalis* L.), Brassicaceae (*Diplotaxis eruroides* (L.) DC.), Boraginaceae (*Echium vulgare* L., *Borago officinalis* L. and *Phacelia tanacetifolia* Benth.), Poaceae (*Hordeum vulgare* L.), and Fabaceae (*Medicago sativa* L. and *Vicia faba* L.). These plant

species were selected for their suitability for the terrain (e.g., germination rates, coverage, and blossoming) and for their provision of resources for different groups of beneficial arthropods [23]. In the control plots, the herbaceous vegetation was mowed by hand every two weeks. The sown cover crop was irrigated once per week using sprinklers.

2.2. Arthropod Sampling

Arthropods were sampled from 17 April to 11 June 2019, from 3 April to 29 May 2020, and from 5 April to 21 June 2021. Sampling was conducted using pitfall traps consisting of a 500 mL plastic container with an 8 cm diameter, and they were partially filled with a dilution of water (94%), propylene glycol (5%), and soap (1%). Three traps were placed diagonally at ground level on each plot. The traps remained active for 1 week and inactive for the following week, except in 2020, when sampling was carried out weekly. The samples were processed in the laboratory using stereoscopic microscopes (Leica MZ16). The specimens were identified at the species or morphospecies level, except for collembolans and mites, which were identified at the order level. For this purpose, the keys of Martínez et al. [40] for ants, Nentwig et al. [41] for spiders, and Albouy et al. [42] for beetles were used.

In each of the three interrows in which pitfall traps were placed, the vegetation within a 1 m × 1 m plastic square was photographed to estimate the ground cover (i.e., 18 photographs were taken on each sampling date). The GIMP v2.8.14 software (Free Software Foundation in Boston, MA, USA) was used to process the images. For the estimation of the cover, each image was divided into 100 quadrants of 10 cm × 10 cm, and for each one, the presence/absence of vegetation was recorded.

2.3. Data Analyses

The percentages of green cover between different types of cover management and between years were tested using a linear mixed-effects model (LMM) with the “lmer” function in the “lme4” package, and the χ^2 and p -values for the fixed factors were obtained by using the Wald test using with the “Anova” function in the R “car” package [43]. The percentage of cover was transformed by the square root of the arcsine to correct the deviation of the data from normality. The “qqp” function in the “car” package was used to compare the empirical quantiles of the dependent variable to the theoretical quantiles of the normal distribution [43]. Cover management and years were introduced as fixed factors, while the block and date of sampling were treated as nested random factors. A post hoc analysis was performed to determine which treatments or sampling year significantly differed from each other using the “emmeans” R package (adjustment: Tukey) [44].

The richness of species/morphospecies of soil arthropods was calculated over the three years of the experiment to assess whether the use of different types of sown cover had an effect on their diversity. In addition, the richness was independently tested for Araneae, Coleoptera, and Hymenoptera; it was calculated for each sampling date using the abundance of the species/morphospecies with the “diversity” function in the “vegan” package [45]. General linear mixed models (GLMMs) were used to test for the effect of the sown cover on the annual richness of ground-dwelling arthropods. The GLMMs were run using the “glmmPQL” function (“MASS” package) [44] with the gaussian family (link = “identity”) to explain the distribution of error. The cover management and year were entered as fixed factors, while the block and date of sampling were entered as nested random factors in the models. The χ^2 and p -values for the fixed factors were obtained by using the Wald test with the “Anova” function in the “car” package [44]. A post hoc analysis was performed to determine which treatments or sampling years significantly differed from each other using the “emmeans” R package (adjustment: Tukey) [44].

GLMMs were also used to test the effects of the cover management and year on the abundance of ground-dwelling arthropods from different orders and families throughout the sampling period. Only orders, families, and species/morphospecies of ground-dwelling arthropods with more than 1% occurrence were included in the analyses. For that purpose, the “glmmPQL” function (“MASS” package) with the gaussian family (link = “log”) was

used. The same fixed and random factors as those described in the previous paragraph were used. The χ^2 and p -values for the fixed factors were obtained by using the Wald test with the “Anova” function in the “car” package [44]. A post-hoc analysis was performed as explained in the previous paragraph.

To assess the effect of cover management on the structure of the communities of ground-dwelling arthropods, PERMANOVA was run using the Bray–Curtis dissimilarity index with the “Adonis” function (“vegan” package) [45]. These distributions of the samples were illustrated using non-metric dimensional scaling (NMDS) with the “metaMDS” function (“vegan” package) and “ggplot2” [45,46]. The relative contributions of species to the dissimilarities between types of management were determined using the similarity percentage (SIMPER) with the “simper” function (“vegan” package) [45].

All of the statistical analyses were performed in R v.4.2.1 (R Development Core Team, Vienna, Austria) [44], and p -values of <0.05 were considered statistically significant.

3. Results

3.1. Proportion of Ground Covered

The proportion of ground covered was significantly higher in the plots with the sown cover than in the control plots ($\chi^2 = 773$; $df = 1$; $p < 0.001$). In the plots with the sown cover, the proportion of cover was very similar during the three years (0.92 ± 0.02 (mean $\pm$ SE), 0.98 ± 0.00 , and 0.98 ± 0.00 , respectively), and no significant differences were found ($\chi^2 = 1.82$; $df = 2$; $p = 0.4$). In the control plots, the values for 2019 and 2020 were similar (0.52 ± 0.05 and 0.54 ± 0.04 , respectively; $p = 0.96$), while in 2021, the proportion of cover was lower but not significantly different from that in the two previous years (0.39 ± 0.26 ; $p = 0.83$ and $p = 0.62$, respectively) (Figure 1).

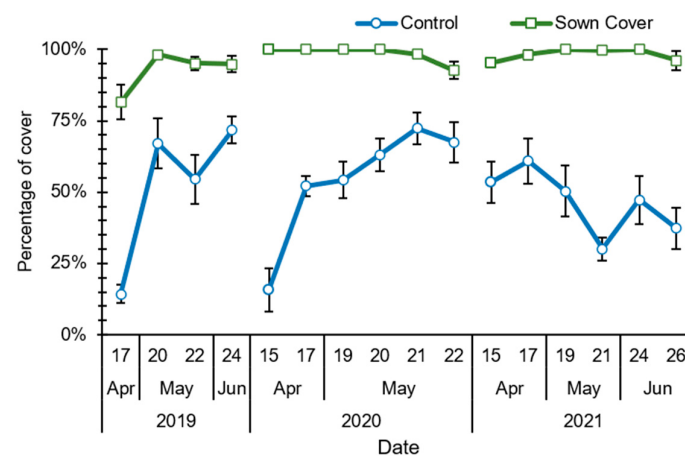


Figure 1. Dynamic of the percentage of ground covered (mean $\pm$ SE) in the cover plots and in the control plots for each sampling date (week number, month, and year).

3.2. Effects of Cover Crops on the Biodiversity of Ground-Dwelling Arthropods

The richness of ground-dwelling arthropods was significantly higher in the plots with a sown cover ($\chi^2 = 29.6$; $df = 1$; $p < 0.001$). Significant differences in species richness were also observed between years ($\chi^2 = 50.9$; $df = 2$; $p < 0.001$). The richness in the sown cover significantly increased from an annual average of 15.4 ± 1.8 (mean $\pm$ SE) species/morphospecies in the first year to 26.4 ± 1.3 ($p < 0.001$) in the second year and 24.8 ± 0.9 ($p < 0.001$) in the third year (Figure 2). In the control plots, the trend was similar to that in the covered plots, increasing from 14.0 ± 1.2 in 2019 to 23.6 ± 0.8 ($p < 0.001$) in 2020 and slightly decreasing in 2021 (19.0 ± 1.0 ; $p = 0.041$). Coleoptera with 49 species, Araneae with 30 species, and Hymenoptera with 10 species were the orders with the highest numbers of species (Supplementary Material, Table S1). The richness of spiders was significantly higher in the plots with a sown cover than in the control plots ($\chi^2 = 8.1$; $df = 1$; $p = 0.0045$) and varied between years ($\chi^2 = 39.4$; $df = 2$; $p < 0.001$), but the interaction

was not found to be significant ($\chi^2 = 1.33$; $df = 2$; $p = 0.5$) (Figure 3). In the sown cover, the number of spider species increased over the years from 5.2 ± 0.6 in 2019 to 9.3 ± 0.5 in 2021. In the control plots, the peak was reached in 2020 with 8.0 ± 0.5 species. Linyphiidae with 11 species/morphospecies (11 in the sown cover and 8 in the control) and Gnaphosidae with 9 species/morphospecies (9 in the sown cover and 9 in the control) were the families with the greatest richness.

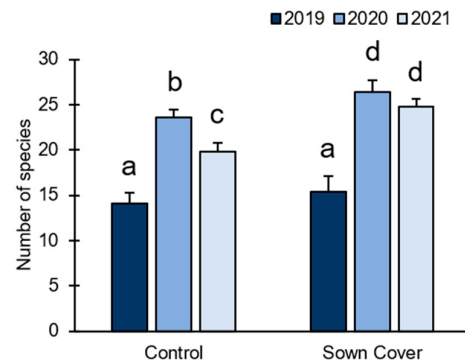


Figure 2. Richness (mean + SE) of ground-dwelling arthropods in the plots with a sown cover and control plots for each sampling year. Different letters indicate significant differences between treatments in the same year and among years within the same treatment ($p < 0.05$).

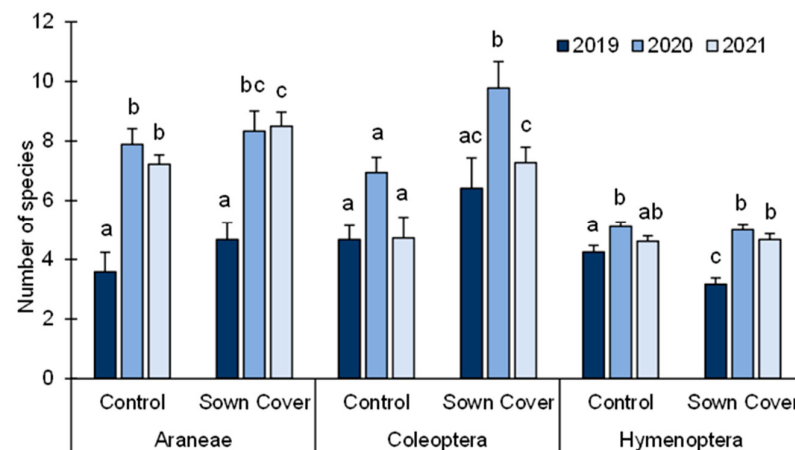


Figure 3. Richness (mean + SE) of Araneae, Coleoptera, and Hymenoptera in the sown cover and control plots for each sampling year. Different letters indicate significant differences between treatments in the same year and among years within the same treatment for the arthropod orders with the highest number of species ($p < 0.05$).

In the sown cover, 42 species of Coleoptera were found, while in the control plots (32 species), the richness was significantly lower ($\chi^2 = 22.6$; $df = 1$; $p < 0.001$) (Figure 3; Supplementary Material, Table S1). The richness of beetles varied significantly among years ($\chi^2 = 15.6$; $df = 2$; $p < 0.001$). In the plots with a sown cover, the beetle richness underwent an increase in 2020 compared to 2019 ($p = 0.005$), but it significantly declined in 2021 ($p = 0.02$). The year 2020 also saw the highest number of beetle species in the control; however, these differences were not significant ($p > 0.05$). (Figure 3). Staphylinidae with 15 species/morphospecies (14 in the sown cover and 8 in the control) and Curculionidae with 9 (8 in the sown cover and 6 in the control) were the Coleoptera families with the greatest richness (Supplementary Material, Table S1).

The richness of Hymenoptera was significantly lower in the plots with the sown cover ($\chi^2 = 4.02$; $df = 1$; $p = 0.044$). Significant differences in Hymenoptera richness were observed among years ($\chi^2 = 43.9$; $df = 2$; $p < 0.001$), with a significant interaction between cover management and years ($\chi^2 = 10.13$; $df = 2$; $p = 0.006$). In the plots with the sown cover, there

was a significant increase in hymenopteran richness between 2019 and 2020 ($p < 0.001$) and between 2019 and 2021 ($p < 0.001$). In the control plots, however, there were only significant differences between the first and second years of sampling ($p = 0.007$) (Figure 3).

3.3. Effects of Cover Crops on the Abundance of Ground-Dwelling Arthropods

3.3.1. Abundance and Trend of Microarthropods

A total of 105,180 soil arthropods were captured during the three years of sampling, 67.3% of which corresponded to microarthropods (Collembola and Acari), and the rest corresponded to macroarthropods. Collembola (57.0%) and Acari (10.4%) were the first and third most abundant taxa in this research. The number of collembolans captured in pitfalls was significantly lower in the plots with a sown cover than in the control plots ($\chi^2 = 103.6$; $df = 1$; $p < 0.001$) and significantly differed among years ($\chi^2 = 8.23$; $df = 2$; $p = 0.016$), with a significant interaction between the type of cover management and year ($\chi^2 = 11.55$ $df = 2$, $p = 0.003$). The abundance of Collembola in the control plots progressively increased in 2019 from zero to 781.1 ± 126.2 individuals per trap (mean $\pm$ SE), reaching the highest peak in the assay on the first sample date of 2020 (1132.2 ± 254.0) and decreasing thereafter until the end (57.0 ± 6.0), except for two lower peaks in 2021 (Figure 4A).

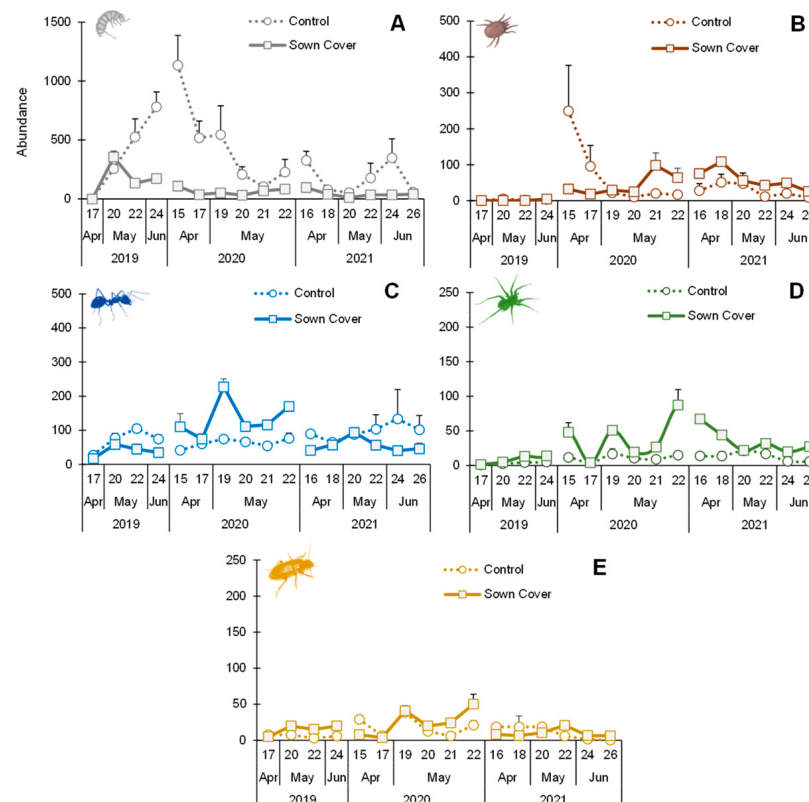


Figure 4. Abundance (mean $\pm$ SE) of the different orders of arthropods in the control plots and in the sown cover plots on each sampling date (week number, month, and year). (A) Collembola; (B) Acari; (C) Hymenoptera; (D) Araneae; (E) Coleoptera.

The abundance of mites was not significantly influenced by the sown cover ($\chi^2 = 2.24$, $df = 1$, $p = 0.13$) or the year ($\chi^2 = 0.86$, $df = 2$, $p = 0.65$), but a significant interaction between the cover and year was observed ($\chi^2 = 34.83$; $df = 2$; $p < 0.001$). The abundance of mites in the sown cover increased each year, reaching a peak at the beginning of 2021 (108.0 ± 12.9 individuals per trap) (Figure 4B). In the control plots, the abundance peak was observed in the first week of 2020 (249.7 ± 126.9) and decreased thereafter until the end of 2021 (8.8 ± 7.2 ; $p < 0.001$) (Figure 4B).

3.3.2. Abundance and Trend of Spiders

A total of 5721 spiders were captured. The effect of the cover management was significant for this group, with 76% of the specimens being captured in the pitfalls from plots with a sown cover ($\chi^2 = 173.5$; $df = 1$; $p < 0.001$). Significant differences in spider abundance were found among years ($\chi^2 = 23.5$; $df = 2$; $p < 0.001$). An increase in abundance in 2020 and 2021 compared to 2019 was observed ($p < 0.001$). In the sown cover, spiders peaked in the last week of 2020 (87.3 ± 22.4 individuals per trap), while in the control plots, the abundance peak was in early May 2021 (21.1 ± 2.3) (Figure 4C). The most abundant spider family was Lycosidae (68%), followed by Zodariidae (13%) and Gnaphosidae (11.5%). The spider community was dominated by one species: *Pardosa proxima* (C.L. Koch, 1847) (Lycosidae), which amounted to 65% of the specimens, 90% of which were captured on the cover. *Zodarion styliferum* (Simon, 1870) (Zodariidae) was the second most abundant species, with 13% of the total number of spiders, and 62% of them were captured in the control plots (Supplementary Material, Table S1). Lycosidae and Linyphiidae were significantly more abundant on the ground of the cover plots than on that of the control plots (Table 1). In contrast, Zodariidae was significantly more abundant in the control plots. Conversely, no significant differences were found between the cover and the control plots for Gnaphosidae (Table 1). Significant differences were observed in the abundance of Lycosidae, Linyphiidae, and Zodariidae among the years (Figure 5A; Table 1).

Table 1. Results of the generalized linear mixed models (GLMMs) for the effects of treatment, year, and their interaction on the abundance of the main orders and families in pear crops.

Order	Family	Treat		Year		Interaction	
		$\chi^2(1)$	p	$\chi^2(2)$	p	$\chi^2(2)$	p
Araneae	Gnaphosidae	0.18	0.66	3.5	0.17	13.29	0.0013
	Lycosidae	167.76	<0.001	21.52	<0.001	5.3	0.07
	Zodariidae	4.96	0.026	9.2	0.01	34.58	<0.001
	Linyphiidae	14.31	<0.001	8.7	0.013	4.5	0.1
Coleoptera	Anthicidae	2.03	0.15	5.38	0.067	37.3	<0.001
	Carabidae	22.22	<0.001	30.28	<0.001	4.12	0.127
	Histeridae	43.51	<0.001	3.54	0.17	2.5	0.286
	Staphylinidae	145.7	<0.001	12.4	0.002	1.15	0.56
	Tenebrionidae	23.05	<0.001	1.8	0.4	12.1	0.002
Hymenoptera	Scelionidae	57.11	<0.001	17.06	<0.001	0.22	0.89
	Formicidae	0.62	0.43	4.59	0.1	129.75	<0.001

3.3.3. Abundance and Trend of Beetles

A total of 4170 coleoptera were captured, 57% of which were found in the sown cover. The abundance of coleoptera was significantly higher in the plots with the sown cover than in those where herbaceous vegetation was periodically removed ($\chi^2 = 5.52$; $df = 1$; $p = 0.019$). The abundance of this group also significantly differed among the years ($\chi^2 = 9.82$; $df = 2$; $p = 0.007$). In the sown cover, the greatest abundance of beetles was reached at the end of 2020 (50.1 ± 13.6 individuals per trap), while in the control plots, the greatest abundance was in the mid-season of 2020 (38.6 ± 9.5) (Figure 4E). Tenebrionidae (43%), Staphylinidae (22.5%), Carabidae (11%), Histeridae (8.4%), and Anthicidae (4.4%) were the most abundant families. While Tenebrionidae were significantly more abundant in the control plots, Staphylinidae, Carabidae, and Histeridae were more abundant in the sown cover (Table 1). Carabidae and Staphylinidae were the only Coleoptera families that showed significant differences among the years (Table 1). The greatest abundance of Staphylinidae was in 2020 both in the sown cover (26.0 ± 6.5 individuals per trap) and in the control plots (5.0 ± 1.3). The maximum number of Carabidae captured in pitfalls was in 2019 in the sown cover (16.6 ± 3.7) and in 2021 in the control plots (2.7 ± 0.9) (Figure 5C). The abundance of Tenebrionidae peaked in 2020 both in the control plots (34.3 ± 8.7)

and in the sown cover (20.9 ± 3.7). *Gonocephalum granulatum pusillum* (Fabricius, 1791) (Tenebrionidae) was the most abundant coleopteran, representing 43% of the arthropods captured, with 66% of the captures being in the control plots. *Oxyptoda* sp. Mannerheim, 1830 (Staphylinidae) (representing 22.9%) and *Harpalus distinguendus* (Duftschmid, 1812) (Carabidae) (representing 10.9%) were the second and the third most abundant species in this research. *Oxyptoda* sp. and *H. distinguendus* were captured mainly in the sown cover (88% and 82%, respectively) (Supplementary Material, Table S1).

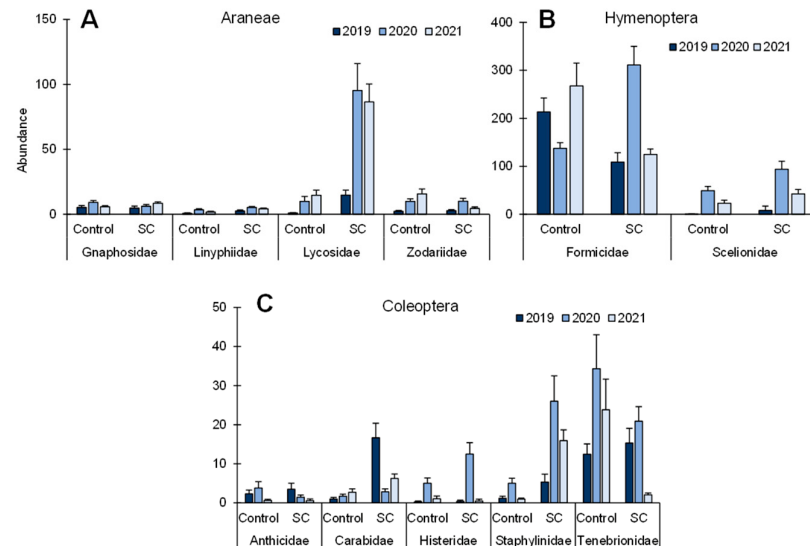


Figure 5. Abundance (mean $\pm$ SE) of the main families in each sampling year: (A) Araneae, (B) Hymenoptera, and (C) Coleoptera.

3.3.4. Abundance and Trend of Hymenoptera

A total of 22,868 hymenopterans were captured in this study, with no significant differences in their abundance between the sown cover and the control plots ($\chi^2 = 0.82$; $df = 1$; $p = 0.36$). In contrast, their abundance significantly differed among the years ($\chi^2 = 10.95$; $df = 2$; $p = 0.004$), with a significant interaction between the cover and year ($\chi^2 = 29.13$; $df = 2$; $p < 0.001$). Specifically, significant differences were observed within the sown cover between 2019 and 2020 ($p = 0.0014$) and again between 2020 and 2021 ($p = 0.0002$). In the control plots, the abundance of hymenopterans showed an ascending trend during the sampling period, the minimum value having been registered on the first sampling date (82.3 ± 9.8) and the maximum at the end of 2021 (400.3 ± 13.8). In the plots with the sown cover, the trend was upward, reaching its peak in early May 2020 (683.3 ± 129.3) and subsequently declining. (Figure 4C). Only two families of Hymenoptera were found in the assay: Formicidae (83%) and Scelionidae (17%). Scelionidae was only represented by the genus *Baeus* Haliday, 1833. The abundance of this apterous wasp was significantly greater on the sown cover (66%; Table 1), and 2020 was the year that registered the greatest abundance both in the sown cover (94.0 ± 16.7 ; $p < 0.001$) and the control plots (49.3 ± 8.8 ; $p < 0.001$) (Figure 5B). Formicidae was the most abundant macroarthropod family in this study, accounting for 55.5% of the macroarthropods captured in the pitfalls. Although no significant differences were found in ant abundance between treatments and years, the interaction between these factors was significant (Table 1). In 2020, there was a significant decrease in ant abundance in the control plots compared to 2019 (from 213.4 ± 28.8 to 137.6 ± 11.7 individuals per trap; $p = 0.0016$), which contrasted with the increase in the cover plots from 2019 to 2020 (from 108.8 ± 19.4 to 310.9 ± 39.2 ; $p < 0.001$) (Figure 5B). The most abundant ant species were *L. grandis* (56%) and *Tetramorium caespitum* (L.) (38%) (Supplementary Material, Table S1).

3.4. Structure of the Assemblage of Ground-Dwelling Arthropods in Soil with and without Cover

NMDS showed a segregation of the samples in relation to the type of management of the cover (Figure 6). PERMANOVA showed a significant effect of the cover on the abundance of the species (stress value: 0.12; $R^2 = 0.12$; $F = 13.31$; $p < 0.001$). *P. proxima* and *Oxypoda* sp. were the species that were most associated with the sown cover, while *G. granulatum pusillum*, *Cardiocondyla* sp. Emery 1869, and *Collembola* spp. were more associated with the control (Figure 6)

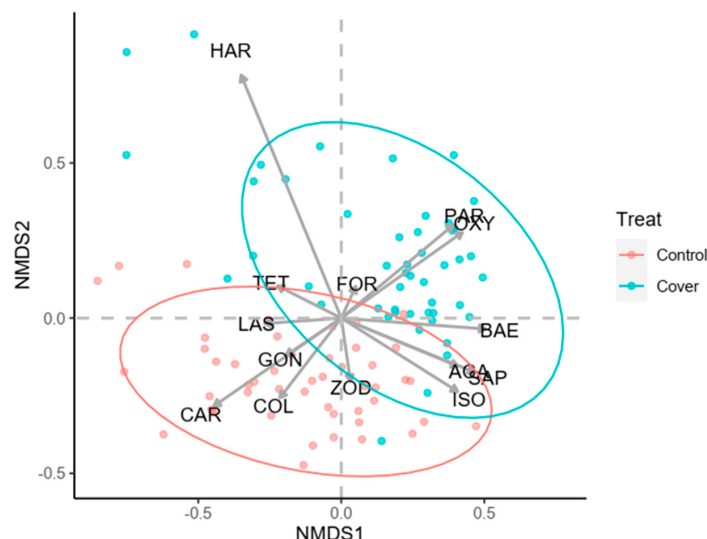


Figure 6. Non-metric multidimensional scaling (NMDS). Plot of the main species composition in the treatments. ACA: Acari spp.; PAR: *Pardosa proxima*; ZOD: *Zodarium styliferum*; HAR: *Harpalus distinguendus*; SAP: *Saprinus* sp. OXY: *Oxypoda* sp. GON: *Gonocephalum granulatum pusillum*; COL: *Collembola* spp.; CAR: *Cardiocondyla* sp.; FOR: *Formica* sp.; LAS: *Lasius grandis*; TET: *Tetramorium caespitum*; BAE: *Baeus* sp.; ISO: *Isopoda* sp.

According to SIMPER, *Collembola*, *L. grandis*, and *Acari* were responsible for 74.4% of the dissimilarity between the two types of cover, but only *Collembola* ($p < 0.001$) and *L. grandis* ($p < 0.04$) were significant in the pairwise comparisons (Table 2). Other species, such as *P. proxima*, *Oxypoda* sp., *Zodarium styliferum*, *G. granulatum pusillum*, *Cardiocondyla* sp., and *H. distinguendus*, significantly ($p < 0.05$) contributed to the differences between the sown cover and the control (Table 2).

Table 2. Percentages of contribution of the most abundant species to differences between treatments according to the SIMPER test.

Species	Cumulative	<i>p</i>
<i>Collembola</i> spp.	53.9	0.001
<i>Acari</i> spp.	65.7	0.147
<i>Lasius grandis</i>	74.4	0.04
<i>Tetramorium caespitum</i>	80.9	1.000
<i>Pardosa proxima</i>	86.8	0.001
<i>Baeus</i> sp.	91.5	0.993
<i>Gonocephalum granulatum pusillum</i>	93.7	0.001
<i>Isopoda</i> sp.	95.4	0.888
<i>Oxypoda</i> sp.	96.4	0.002
<i>Zodarium styliferum</i>	97.5	0.006
<i>Cardiocondyla</i> sp.	98.2	0.001
<i>Harpalus distinguendus</i>	98.8	0.013
<i>Formica</i> sp.	99.5	0.807
<i>Saprinus</i> sp.	100	1.000

4. Discussion

Cover crops have been argued to be some of the most effective measures for increasing the diversity and abundance of natural enemies that control pests in agroecosystems [11,12,47]. The positive effect of cover crops on arthropod diversity has been observed in different crops, such as vineyards [48–51], apple orchards [52,53], cereals [34,54], soybeans [55], and horticultural crops [56]. Arthropods contribute to several essential ecosystem services that provide economic and environmental benefits, such as pest control, plant pollination, soil formation, nitrogen fixation, and organic waste disposal [4,57,58]. In the present research, in agreement with our working hypothesis, sown covers in pear orchards increased the overall richness of ground-dwelling arthropods—particularly predators, such as spiders and rove beetles. These results are in agreement with previous studies that found that herbaceous cover had a positive effect on the richness of ground-dwelling arthropods [47,49–51]. However, other authors observed no such effects [48,59]. Factors such as plant selection, the surrounding landscape, or the time at which the cover crop was sown may account for the different responses to sown covers in terms of soil arthropod richness [59]. The targeted selection of plants for the green cover is a key factor, as observed in cereal crops, where the presence of cover crops with *Vicia* sp. resulted in a greater diversity of ground-dwelling predators, which was not achieved with covers of other plant species [34]. In vineyards, flowering showed a greater abundance of natural enemies than without flowers [60]. The time of sowing of the cover crop also appears to be decisive, as its presence during the winter promotes arthropod diversity [59]. Green covers sown in autumn had a greater effect on arthropod richness than those sown in spring [47,50,59].

In this research, predators—particularly generalist species such as spiders, carabids, and rove beetles—were the group of soil arthropods that benefited most from the sown cover. These generalist predators are the most common and important predators in the ground and play a significant role in pest suppression in several fruit crops [61–65]. In the case of spiders, the presence of a sown cover favored the abundance of Lycosidae and Linyphiidae, which is consistent with the results of other authors who obtained similar results and reported that the influence of covers on gnaphosids and zodariids was marginal [28,29,66]. Lycosidae—specifically, *P. proxima*—was the dominant spider in this research, as in other crops [62,67]. *Pardosa* is an important genus in agricultural ecosystems due to its efficacy as a predator of numerous pests [62,63,68,69]. The second most common predator group in our work was that of staphylinids, which were more abundant in the plots with sown cover, in agreement with previous works on other crops [25,70]. Although staphylinids have a wide variety of diets, most of the specimens captured in this work were predators from the superfamily Aleocharinae, which includes several species that can be used in the biological control of various pests [64,65]. Another important group of polyphagous ground beetles is carabids. In our work, the sown cover increased the abundance of carabid beetles compared to that in the control plots, though the results in the literature are not consistent. In apple orchards, carabid activity was reported to be higher in tilled plots than in mulched plots [25], while in vineyards, this family was more abundant in the cover crop management, although not for all species [28]. Discrepancies in the effect of sown covers on carabid abundance may be explained by the different feeding habits of this family.

The increase in the complexity of the habitat generated by a cover crop benefits predators by providing better microclimatic conditions, more niches, greater availability of prey, less intraguild predation, and access to other resources, such as nectar or pollen [32–35]. In general, cover crops afford lower temperatures and higher humidity than bare soil does, i.e., better conditions in arid environments [71,72], as well as protection against unfavorable weather conditions, e.g., heavy rains [73]. The resulting microclimate has different effects on the various species that make up the ground-dwelling arthropod community: Predatory species, such as spiders and carabids, benefit from the microclimatic conditions created by the sown cover, while other groups, such as detritivores, appear to prefer dry environments [35,71]. For instance, *G. granulatum pusillum*, the most abundant ground beetle in

this orchard, prefers low-humidity soils, as do springtails [74,75], so both detritivores were significantly more abundant in the plots without cover.

The lower preference of detritivores, such as springtails, for the conditions of sown covers is a relevant factor for understanding the effect of vegetation covers on the arthropod community, as the greater abundance of prey was one of the factors that may have accounted for the greater number of predators in the sown cover [76]. Along with the results observed in vineyards, few strictly phytophagous insects were captured in the traps, and none of them were potential pest species of the pear tree [28,50]. Given the low abundance of pest species, alternative prey, such as springtails, could serve as an important food source for ground-dwelling predators [77–79]. In addition, springtails are one of the most important groups in the soil fauna due both to their function as detritivores and to their involvement in a number of physicochemical processes in the soil, such as nutrient cycling and microbial activity [26]. The number of springtails captured in pitfall traps was significantly higher in the control than in the sown cover. These results are consistent with those obtained by other authors, who found a lower abundance of springtails in agroecosystems that were permanently covered [26,80,81]. However, these results are not unanimous in the literature, as in other studies, the abundance of springtails was found to be lower in soils without cover [50,82]. Discrepancies in the effects of cover crops on the collembola population may be due to the fact that complex habitats may interfere with the capture of this group in pitfall traps [83,84]. Aside from collembolans, mites are another very abundant group of soil fauna that may become an alternative prey [85]. In the present work, the abundance of mites did not differ between the sown cover and plots from which the cover was periodically mowed. Similar results were obtained in other studies on clementine crops [86]. The presence of springtails and other detritivores like mites, particularly favours Lycosidae immature and Linyphiidae, since small size spiders prefer this type of prey [85]. However, in our work, most of the lycosids were adults, and springtails were less abundant in the sown cover, suggesting that the availability of detritivore prey may not have been the primary factor explaining their presence in the sown cover. Schmidt et al. [35] found that habitat structure and complexity were more important for habitat selection by *Pardosa milvina* (Hentz, 1844) than the available prey and microclimatic conditions. The distribution of specialist predators closely follows the distribution of specific prey. *Z. styliferum*, for instance, which is a specialist predator of ants, seems to prefer habitats related to this group [87]. *Z. styliferum* and ants were more abundant in the control than in the sown cover, except in 2020, when both groups were more abundant in the sown cover. Even though Ortiz et al. [88] found that *Z. styliferum* feeds mainly on *Messor* spp. ants, the absence of this ant in this study suggests that the diet of this spider may be based on *T. caespitum* or *L. grandis*; nevertheless, *Lasius* does not seem to be a preferred prey for *Z. styliferum* [88]. Another specialist is the wasp *Baeus* sp., an egg parasitoid of spiders that can parasitize several species of the genus *Pardosa* Koch, 1847 [89].

Besides providing an animal food source, the sown cover itself can supply soil arthropods with vegetable food resources [73] such as nectar and pollen that are produced by different cover plants—for instance, *Vicia faba*. Chen et al. detected nectar traces in 13.8% of *Pardosa* spp. captured on different crops [90]. The availability of a greater abundance and variety of seeds in the sown cover may also influence granivorous arthropods, such as carabids [73]. In corn, the abundance of granivorous carabids was greater in conventional crops without tillage than in organic crops, although the abundance of carabids in general (granivorous, predatory, and polyphagous carabids) was greater in fully conventional plots than in organic and conventional plots without tillage [91].

Intraguild competition and cannibalism are also factors that must be taken into consideration to understand the community of ground-dwelling arthropods. High predator diversity can lead to an increase in pest presence due to intraguild competition [69]. For instance, larger species of carabids can prey on other ground spiders, such as lycosids and linyphiids [92,93]. Cannibalism is a common practice among spiders, especially in

systems where resources are scarce [94]. According to Halaj et al. [85], larger lycosids can feed on smaller spiders that may benefit from alternative prey such as collembolans in a trophic cascade [92]. One of the most important benefits of sown covers for predators is the reduction of intraguild competition due to the increased habitat complexity and greater prey abundance. However, in tests under laboratory conditions, neither increased arena complexity nor a greater presence of prey such as collembolans reduced the rate of cannibalism among immature lycosids [94]. None of the captured arthropod species appears to be a potential predator of *P. proxima* adults; however, given the large number of specimens of this species, it cannot be disregarded that the immature stages of these lycosids serve as an important food source for other predators and even other individuals of *P. proxima*.

Canopy arthropods can influence the population dynamics of ground-dwelling arthropods as well. Previous studies have demonstrated that the phytophagous activity of aphids on plants leads to a greater accumulation of dead root material, consequently increasing the abundance of fungal decomposers and springtails, which can feed on both dead roots and fungi [75]. Ants such as *L. grandis* and *T. caespitum*, the most abundant species in this study, can establish mutualistic relationships with several aphid species [38,95]. Aphids such as *Aphis craccivora* Koch, 1854 live in the aerial parts of plants used in cover crops, such as *V. faba* and *M. sativa* [96,97]; their presence there could affect the behavior of ants. In works with *V. faba*, it was found that *Lasius niger* (L.) and *T. caespitum* established mutualistic relationships with *A. craccivora*. *Lasius* established in the upper parts of the plant and *T. caespitum* closer to the soil [95]. Although this mutualistic interaction could explain a preference of the ants for the sown cover, the distribution of ants did not follow a clear pattern during our experiment; in 2019 and 2021, they were more abundant in the plots where the herbaceous vegetation was removed, while in 2020, they were more abundant in the plots with the sown cover. This irregular pattern was also observed in other studies with cover crops [50,53]. Ants play different roles in the ecosystem as arthropod predators, seed predators, seed dispersers, and influencers of different soil properties [98–100]. Such different roles may explain the distribution of ants in the crop. For instance, the presence of a sown cover may have a minor influence on *L. grandis*, since this ant establishes a mutualistic interaction with tree aphids by suppressing other competitor pests such as *C. pyri*, thus becoming one of the key natural enemies for its control in southwestern Mediterranean pear orchards [38]. In addition, *L. grandis* builds its nests under pear trees, so this species may be less affected by variations in cover management practices [25,53]. *T. caespitum* is mostly a granivorous ant that needs dry chambers to prevent seed deterioration [101]. The torrential rains that occurred in the spring of 2020 caused waterlogging in the control plots, which may have resulted in poorer conditions for their nests than in the sown cover, where the conditions were more stable.

Although the percentage of cover remained consistent in both treatments over the assay period, the abundance and richness of ground-dwelling arthropods differed among the years. The richness and abundance of most arthropods significantly increased from the first to the second year and slightly decreased in the last year, independently of the type of cover management, which suggested the implications of other factors. Other authors have also reported inter-annual changes in the abundance of ground-dwelling arthropods, which are generally associated with climatic factors—in particular, a reduction in arthropod abundance with heavy rainfall [28,65]. However, in the present research, climatic factors were probably not responsible for the inter-annual differences because the temperatures were similar among the years, and torrential rains were recorded only in May 2020, which was precisely the year with the highest abundance and richness of arthropods. Other factors, such as changes in the vegetation surrounding orchards or interactions among the species, may have been responsible for the variations among the years.

In conclusion, this research shows that the presence of a sown cover has a significant effect on the diversity of ground-dwelling arthropods, and it is especially beneficial for generalist predators, such as spiders and ground beetles. Although the impact of the sown

cover on other groups that can be of benefit to crops, such as springtails or ants, was variable, the overall presence of the cover had a positive effect. Further investigation is needed to study the effects of the sown cover on the arthropod communities living on the canopy and on the trees of crops.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/agronomy13123049/s1>, Table S1. List of taxa collected in pitfall traps in the plots with a sown cover and in the control plots.

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Data Availability Statement: The analysed and generated datasets will be maintained at the IMIDA repository and will be available upon request.

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