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Sown ground cover in pear orchards influences the abundance of key predators with variable results on pest control depending on the species

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Abstract Enhancing ground cover vegetation may favour biological pest control. This research aimed to test the effect of cover management on the abundance of natural enemies and pest control in pear orchards. Two types of cover management (i.e., sown/mown cover) were tested in an organic pear orchard during three years in southern Spain. The cover and pear trees were sampled periodically between April and June to estimate the abundance of arthropods. The abundance of all the groups of natural enemies, including ants, spiders, predatory thrips, hemipterans and four families of parasitoids, as well as phytophagous insects such as aphids and psyllids, was significantly higher in the vegetation of the sown than in the mown cover. The sown cover was found to significantly reduce the abundance of aphids on pear trees, while it had a neutral effect on *Cacopsylla pyri*. This reduction in aphid numbers could be mainly attributed to the increase in the abundance of spiders and predatory mirids on the trees with the sown cover. In contrast, the sown cover was found to significantly reduce the abundance of the ant *Lasius grandis* on pear trees in relation to the mown cover. Overall, the management of the cover had a stronger effect on the assemblage of arthropods on the understory vegetation than on pear trees. The increase of the abundance of natural enemies on pear trees with the sown cover could have been due to their movement from the cover and/or the reduction of harassment due to the lower ant activity.

Keywords Biological pest control · Cover management · Ants · Spiders · Generalist predators · Parasitoids · Aphids · Psyllids

Introduction

Intensive agriculture has greatly simplified the rural landscape, while preserving and restoring semi-natural habitats has been advised to enhance biodiversity and ecosystem services such as pest control (Rusch et al. 2016). Intensively managed crops are inhospitable to most natural enemies and planting cover crops is a practice frequently adopted to restore habitat quality at a local scale (Gurr et al. 2017; Daane et al. 2018). Enhancing the ground cover in fruit tree orchards has often resulted in increased abundances of natural enemies and reduced pest populations (Rieux et al. 1999; Gómez-Marco et al. 2016; Daane

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et al. 2018). However, even if plant diversity generally increases the population of natural enemies, it does not always guarantee an improvement of pest control in crops and there are many cases where negative or neutral results have been reported (Letourneau et al. 2011; Tscharntke et al. 2016; Sanchez et al. 2022).

Several arguments have been put forward to explain the lack of correlation between plant diversity and pest control in crops (Tscharntke et al. 2016). In the first place, phytophagous insects, including pests, may benefit from increased plant resources, and natural enemies can switch to alternative prey, reducing their impact on target pest species (Daane et al. 2018; Shapira et al. 2018). Secondly, higher richness means high probability of interspecific interactions, including intraguild predation and hyperparasitism, which may have a negative impact on key enemy species reducing pest control (Macfadyen et al. 2009; Daane et al. 2018). Finally, crops and non-crop habitats may differ in the assemblage of arthropods they harbour and higher preferences for non-crop habitats can limit the movement of natural enemies to crops, reducing the probability of encounter with pest species (Macfadyen and Muller 2013; Feng et al. 2017; Sanchez et al. 2022).

Pear orchards are permanent habitats providing residence to specific assemblages of natural enemies that live on phytophages commonly present on these crops (Solomon et al. 2000). Some of these species establish permanent populations while others move periodically between external habitats and orchards (Scutareanu et al. 1999; Solomon et al. 2000; Ramírez-Soria et al. 2018). For instance, in southern Mediterranean pear orchards, some key species such as ants (e.g., *Lasius grandis* Forel; Hymenoptera: Formicidae), predatory mirids (e.g., *Pilophorus gallicus* Remane; Hemiptera: Miridae) and some spider species are continuously present when friendly pest control strategies are adopted (Sanchez and Ortin-Angulo 2012; de Pedro et al. 2020; Sanchez et al. 2020b). In contrast, other predators frequently found in pear orchards, such as anthocorids (*Anthocoris* spp. and *Orius* sp.), coccinellids, etc., build up their population in nearby habitats and then move to pear orchards (Scutareanu et al. 1999). Therefore, their abundance will depend to a great extent on the quality of neighbouring habitats and local practices such as the management of the understory vegetation in orchards. Restored habitats are expected to boost the populations of natural enemies and to increase their spill over to crops enhancing pest control (Blitzer et al. 2012). However, the fact is that little is known on the interaction of the assemblage of arthropods between crops and non-crop habitats and its outcome in terms of pest control (Wilson et al. 2017; Shapira et al. 2018). Neighbouring habitats offering higher resources than crops may have undesirable effects, such as attracting and acting as a sink for natural enemies, reducing the predation pressure and increasing pest numbers in crops (Sanchez et al. 2022). For instance, in the case of pear orchards, the presence of aphids on the cover could lure in ants, thus reducing their activity on the canopy of pear trees, which will in turn have important cascading effects on the structure of the assemblage of arthropods because of the high number of interactions that ants establish with honeydew-producing hemipterans and predators (Sanchez et al. 2020b). Pear psyllids and aphids are important pests of pear trees and changes on the populations of natural enemies due to the management of the understory vegetation may have a great impact on pest control (Sanchez et al. 2020b; Gajski and Pekár 2021; Reeves et al. 2024).

In this research, the effect of the management of the understory vegetation by periodically mowing the spontaneous plants or by sowing a cover crop on the populations of natural enemies and pest control was investigated in pear orchards. The working hypotheses were that: (1) the sown cover would increase the abundance of natural enemies on pear trees and enhance the control of aphids and psyllids (the key pests in pear orchards), and (2) the management cover was expected to affect the assemblage of arthropods in the canopy of pear trees, producing changes on the abundance of key species (e.g., ants) and cascading effects at lower trophic levels.

Materials and methods

Location, orchard management and ground cover

The research was carried out during three years, from 2019 to 2021, in an organic pear orchard of approximately 6 ha, located in the municipality of Jumilla (Murcia province) in the south-east of Spain (38º23′56″ N, 001°23′19″ W, 408 m asl). The orchard was planted in 2014 with the pear (*Pyrus communis*

L.; Rosaceae) variety "Ercolini", with "Abate Fétel" used for cross-pollination (one line every five), and it was managed under the organic regulations using low-toxic insecticides (e.g., paraffinic oil) only when honeydew started to accumulate on leaves (Supplementary Table S1). The insecticides used, such as paraffinic oil and the fungus *Beauveria bassiana* (Bals.-Criv.) Vuill., are known to have a low impact on natural enemies (Sanchez and Ortin-Angulo 2012; Morda et al. 2024).

The pear orchard had 26 lines of 540 trees each, with trees 4 m apart between rows and 0.8 m within rows, and was transversally divided into three blocks of approx. 2 ha each. Two plots of five lines of 100 trees each (80 m long × 20 m wide), separated by at least eight lines of pear trees, were established on every block. Two different types of cover management, assigned at random, were adopted in each of the two plots of each block. In one of the plots, the herbaceous vegetation was mown manually every two weeks. In the other plot, a mix of seeds were sown manually on December 2018 and 2019. The soil was superficially ploughed before the sowing and then slightly compressed to bury the seeds. In the third year, enough plants emerged spontaneously and it was not necessary to sow again (Supplementary Figure S1). The mixture of seeds included herbaceous plants from the families Apiaceae (*Coriandrum sativum* L.), Asteraceae (*Calendula arvensis* L. and *Calendula officinalis* L.), Brassicaceae [*Diplotaxis erucoides* (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 because previous research showed that they host a wide range of predators, but they were not intended as a cash crop (Sanchez et al. 2024). The sown cover was irrigated once a week using sprinklers, while the mown cover was not irrigated.

The ground cover was estimated by taking three high resolution photograph of the vegetation within three 1 × 1 m plastic frame squares placed at random on the interrows of each experimental plot on every sampling date (See Fig. 4 for specific dates). The GIMP v2.8.14 software (Free Software Foundation, Boston, MA, USA) was used to process the images. The estimation of the general cover and that of each plant species separately was calculated by dividing each image into 100 quadrants of 10 × 10 cm each and recording the presence/absence of vegetation in general or of plant species in particular.

Sampling of arthropods

The cover and pear trees in all the plots were sampled to estimate the abundance of arthropods on the same dates every one or two weeks between April and June over the three years of the research (sampling dates are given in Fig. 4). In each plot and sampling date, the numbers of psyllids (nymphs and adults) and aphids were counted visually in situ, with the help of a hands-free magnifying glass (1.8–4.8×), on the first five apical leaves of sixty shoots from different trees randomly selected. The parasitised aphids and other arthropods of interest were also counted. Natural enemies were sampled by beating pear trees, using 28-cm-diameter funnels with a 100 ml plastic bottle at the bottom to collect the samples. On every sampling date, two samples of 30 branches each were taken from every plot by beating the branches three times at the base with a wooden stick over an entomological funnel. The branches were taken from individual trees randomly selected. The arthropods of the cover were sampled using 35-cm-diameter sweeping nets. On each sampling date (see Fig. 4), two samples of sixty sweeps each were taken from each plot and then transferred to individual plastic bottles. All the samples were placed in refrigerated containers and taken to the laboratory. Most of the predators such as spiders, anthocorids, chrysopids, staphylinids, and coccinellids were identified to the family level. Ants, predatory mirids, predatory thrips, psyllids and aphids collected on pear trees were identified to the genus or species level. On the cover, psyllids and aphids were identified to the family level. All the parasitoids were identified to the family level, but only Aphelinidae, Braconidae, Encyrtidae and Ichneumonidae were included in this work because of their higher relevance for the biological control of aphids, psyllids and moths on pears (Cross et al. 1999). The following references were used for the identification of arthropods: Blackman and Eastop (2000) for aphids, Péricart (1972) and Wagner and Weber (1964) for heteropterans, Martínez et al. (1985) for ants, and Nentwig et al. (2022) for spiders.

Data analysis

The effect of cover management and year, as fixed factors, on the presence or absence of vegetation in the 100 cells in which the 1 × 1 m sampling squares were divided was tested with Generalised linear mixed models (GLMM) using the "glmer" function ("lme4" package) with the binomial family and a logit link function (Bates et al. 2015). Block, date of sampling and square were entered in the models as nested random factors. The χ^2 and p-values were obtained with the Wald test using the "Anova" function in the R car package (R Core Team 2024).

GLMM were also used to test the effect of cover management and year, plus their interactions, as fixed factors, on the abundance of the main natural enemies such as the ant *L. grandis*, the predatory mirid *P. gallicus*, spiders and other important groups (e.g., anthocorids, predatory thrips, parasitoid families, staphyliniids, coccinellids, etc.), and phytophagous species (i.e., aphids and psyllids) on the canopy of pear trees and the cover crop (see all taxa in Tables 1 and 2). The number of captures of the different groups of arthropods in samples collected by beating pear tree branches over entomological funnels and using sweeping nets in the cover were entered in the models as dependent variables. In the case of the beating sampling, except for *L. grandis* that had high abundance, the captures of the two repeats were summed for the analyses. In the case of aphids and psyllids, as well as aphid mummies, on pear trees the counts on leaves were used. The years with no captures were excluded from the analyses. For the natural enemies on pear trees, block and week of sampling were treated as nested random factors. Additionally, repeat was entered as a random factor for the models of the cover, and for *L. grandis* on pear trees. As for aphids, aphid mummies and psyllids on leaves, block, week of sampling, shoot and leaf position were entered as nested random factors.

The distribution of the experimental data was tested using the "fitdist" ("fitdistrplus" package) and the choice of the distribution function was based on the score of the Akaike's Information Criterion (AIC). In the case of the ant *L. grandis* and the mirid *P. gallicus* on pear trees, GLMM were run with the "glmmPQL" function ("MASS" package) using Log-normal distributions to explain the distribution of errors with a log link function, while for the rest of natural enemies on pear trees negative binomial distribution with a log link function were used instead. As for natural enemies on the cover and phytophagous hemipterans, both on pear trees and the cover, the "glmer" function ("lme4 package") with negative

Table 1 Summary of the statistics for GLMM testing the effect of cover management (i.e., mown and sown), year and their interaction on the abundance of different groups of natural enemies sampled using sweeping nets on the ground cover of a pear orchard in southern Spain during three consecutive years (2019–2021)

Order	Taxa	Cover		Year		Interaction	
		$\chi^2(1)$	P-val	χ^2 (2)	P-val	$\chi^2(2)$	P-val
Araneae	Araneae	227.1	< 0.001	32.7	< 0.001	0.937	0.625
Coleoptera	Coccinellidae	146.5	< 0.001	2.69	0.261	–	–
	Staphylinidae	118.4	< 0.001	6.69	0.035	1.54	0.463
Hemiptera	Anthocoridae	45.5	< 0.001	11.4	0.003	10.8	0.005
	Pilophorus gallicus	436.7	< 0.001	2.90	< 0.001	19.4	< 0.001
	Others	31.6	< 0.001	6.31	0.043	19.4	< 0.001
Hymenoptera (Formicidae)	*Lasius grandis*	118.9	< 0.001	6.03	0.049	0.727	0.695
	Other ants	14.2	< 0.001	26.4	< 0.001	17.7	< 0.001
Hymenoptera (Parasitoids)	Aphelinidae	147.1	< 0.001	38.1	< 0.001	18.6	< 0.001
	Braconidae	182.0	< 0.001	22.4	< 0.001	47.2	< 0.001
	Encyrtidae	18.2	< 0.001	21.7	< 0.001	10.2	0.001
	Ichneumonidae	34.4	< 0.001	3.61	0.165	8.50	0.014
Thysanoptera	Aeolothripidae	149.5	< 0.001	22.7	< 0.001	12.6	0.002

df are indicated within brackets after χ^2-values

Table 2 Summary of the statistics for GLMM testing the effect of cover management (i.e., mown and sown), year and their interaction on the abundance of different groups of natural enemies sampled beating branches on funnels on the pear tree canopy in a pear orchard in southern Spain during three consecutive years (2019–2021)

Order	Taxa	Cover		Year		Interaction	
		$\chi^2(1)$	P-val	χ^2 (2)	P-val	$\chi^2(2)$	P-val
Araneae	Araneae	20.1	< 0.001	23.2	< 0.001	2.25	0.324
Coleoptera	Coccinellidae	2.17	0.141	7.78	0.020	0.782	0.676
	Staphylinidae	0.039	0.845	0.671	0.413	3.344	0.068
Hemiptera	Anthocoridae	0.342	0.559	3.61	0.164	1.24	0.537
	Pilophorus gallicus	18.3	< 0.001	7.51	0.023	35.6	< 0.001
	Others	0.007	0.936	0.510	0.475	0.792	0.373
Hymenoptera (Formicidae)	*Lasius grandis*	80.2	< 0.001	8.65	0.013	11.6	0.003
	Other ants	29.4	< 0.001	5.92	0.052	1.31	0.519
Hymenoptera (Parasitoids)	Aphelinidae	0.129	0.719	0.181	0.914	1.55	0.461
	Braconidae	3.88	0.089	2.09	0.149	0.709	0.400
	Encyrtidae	0.005	0.946	4.36	0.113	17.8	< 0.001
	Ichneumonidae	0.783	0.376	3.76	0.153	6.86	0.032
Thysanoptera	Aeolothripidae	19.7	< 0.001	–	–	–	–

df are indicated within brackets after χ^2-values

binomial distribution with a log link function was used (R Core Team 2024). In all GLMM, the χ^2 and p-values for the fixed factors were obtained by the Wald test using the "Anova" function in the R "car" package (R Core Team 2024). The post-hoc pairwise multiple comparisons was run using the estimated marginal means (EMMs) with the function "glht" in the "multcomp" package in R (Hothorn et al. 2008).

Results

Ground cover on the sown and mown cover plots

The management of the cover had a significant effect on the proportion of ground cover ($\chi^2 = 3889.1$; df = 1; P < 0.001). The annual average proportion of cover was close to one in the sown cover plots and about 0.5 in the mown ones along the three years of the research (Fig. 1). However, significant differences were found among years ($\chi^2 = 201.1$; df = 2; P < 0.001). All the sown plants were represented on the cover with the exception of *D. erucoides*. In the first year, in the sown cover plots, *P. tanacetifolia* (24.4%), *H. vulgare* (10.8%), *B. officionalis* (10.0%) and *M. sativa* (8.1%) were the plants with the higher cover (Supplementary Figure S1). In the second and third year *P. tanacetifolia* and *H. vulgare* had a low cover, while *M. sativa* acquired a higher relevance (approx. 40%). *C. sativum*, *E. vulgare*, *Calendula* spp. and *Vicia sativa* were present in the three years but with a lower cover than the previously mentioned species. Wild Poaceae grew spontaneously and were well represented during the three years (21–31%) (Supplementary Figure S1). In the mown plots, in the first year, *Polygonum* sp. (Caryophyllaceae) had the highest cover (22.2%), while in the second and third year wild Poaceae were more abundant (20.1–28.1%) (Supplementary Figure S1). Other plant species such as *Sonchus* spp. (Asteraceae), *Chenopodium* spp. (Chenopodiaceae), *Bassia scoparia* (L.) Voss (Chenopodiaceae) and *Anacyclus clavatus* (Desf.) Pers. (Asteraceae) were also present with low cover in all the plots during the three years of the research (Supplementary Figure S1).

Abundance of natural enemies and phytophagous insects on the ground cover

On the vegetation of the cover, including both the sown and the mown cover, the ant *L. grandis*, with 2857 individuals captured, was the most abundant predator (32.8% of the predators included in this research). Other less represented ants were *Cardiocondila* spp. (7.3% of the ants), *Tetramorium* spp. (2.5%) and *Formica* spp. (1.4%). Parasitoids of the families Aphelinidae, Braconidae, Encyrtidae and Ichneumonidae were as abundant as ants (N = 2312), representing 21% of all the natural enemies captured. Spiders (N = 1710, 19.6%), *Aeolothrips* spp. (N = 1322, 15%) were also highly represented on the samples. Among the predatory

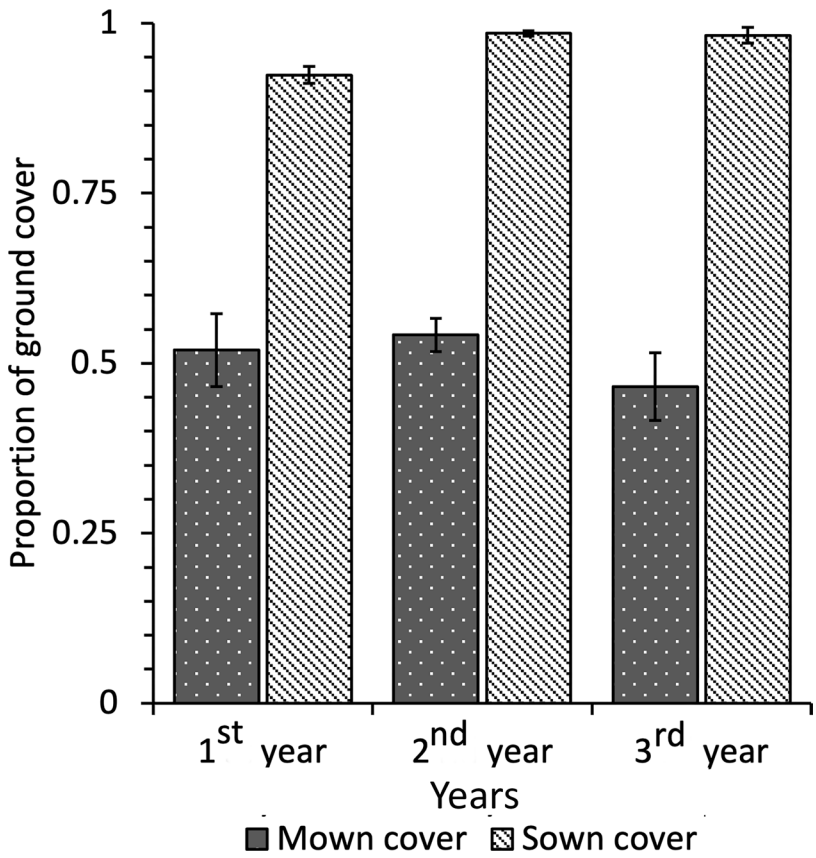


Fig. 1 Annual average proportion ± SE of ground cover in plots with two types of cover management (i.e., mown and sown) during three consecutive years (2019–2021), in a pear orchard in southern Spain

hemipterans, *Orius* spp. (Anthocoridae) (N = 651, 7.5% of the predators) were more represented than the mirid *P. gallicus* (N = 78, 0.9%) and the rest of predatory hemipterans (N = 197, 2.3%). Staphylinidae (N = 241, 2.8%), Coccinellidae (N = 108, 1.2%) were also minor groups. Chrysopidae (N = 10, 0.1%) and Forficulidae (N = 1, 0.01%) were rarely captured.

The abundance of almost all the groups of predators, with the exception of ants other than *L. grandis*, and that of the four families of parasitoids was significantly higher in the sown than in the mown cover (Table 1, Fig. 2). Significant differences in the abundance of many groups of natural enemies were found among years, and the interaction between cover management and year was found to be significant on many occasions (Table 1). The abundance of the ant *L. grandis* during the three years of the research was between 4.2 ± 1.4 (± SE) and 5.8 ± 0.9 times higher in the sown than in the mown cover (Fig. 2, Table 1). Spiders experienced a similar 4.2 ± 0.4-to 6.4-fold increase. Remarkable increases were also observed in the abundance of some other predators (e.g., *Aeolothrips* spp.) and parasitoids (Fig. 2).

Aphids were the main phytophagous insects captured on the ground cover (N = 16,816 individuals), their abundance being significantly higher in the sown than in the mown cover ($\chi^2 = 154.8$; df = 1; $P < 0.001$). Significant differences were also found among years ($\chi^2 = 20.7$; df = 2; $P < 0.001$). On the sown cover, the average annual abundance was 15.0 ± 1.5, 130.1 ± 17.8 and 245.8 ± 36.9 individuals per 60 sweeps for the first, second and third year, respectively. In contrast, the abundance of aphids on the mown cover was lower, being 3.8 ± 1.6, 14.8 ± 2.0 and 62.3 ± 7.2 individuals per 60 sweeps for the first, second and third year, respectively. The abundance of psyllids (N = 116 individuals) was also significantly higher on the sown than on the mown cover ($\chi^2 = 43.8$; df = 1; $P < 0.001$). However, their abundance was much lower than that of aphids both on the sown (1st year: 0.17 ± 0.09, 2nd year: 0.94 ± 0.24, 3rd year: 1.22 ± 0.22 individuals per 60 sweeps) and the mown cover (1st year: 0.27 ± 0.03, 2nd year:

0.22 ± 0.07, 3rd year: 0.47 ± 0.22 individuals per 60 sweeps).

Abundance of natural enemies and pests on pear trees

On pear trees, the ant *L. grandis* was the most abundant predator (number of captures, N = 22,352), which represented 87.9% of the predators included in the present work. *Formica* spp. were the other ants present (N = 96). Other less abundant predators were the predatory mirid *P. gallicus* (N = 2374, 9.3%) and spiders (N = 460, 1.8%). Other predators, such as Anthocoridae (N = 48, 0.2%), Coccinellidae (N = 46, 0.2%), Chrysopidae (N = 38, 0.1%), Forficulidae (N = 32, 0.1%), Staphylinidae (N = 23, 0.1%), *Aeolothrips* spp. (N = 16, 0.1%), and other predatory hemipterans (N = 6, 0.02%) were captured occasionally. Parasitoids, including Aphelinidae, Braconidae, Encyrtidae and Ichneumonidae, on pear trees, were less abundant (N = 453) than predators (Fig. 3).

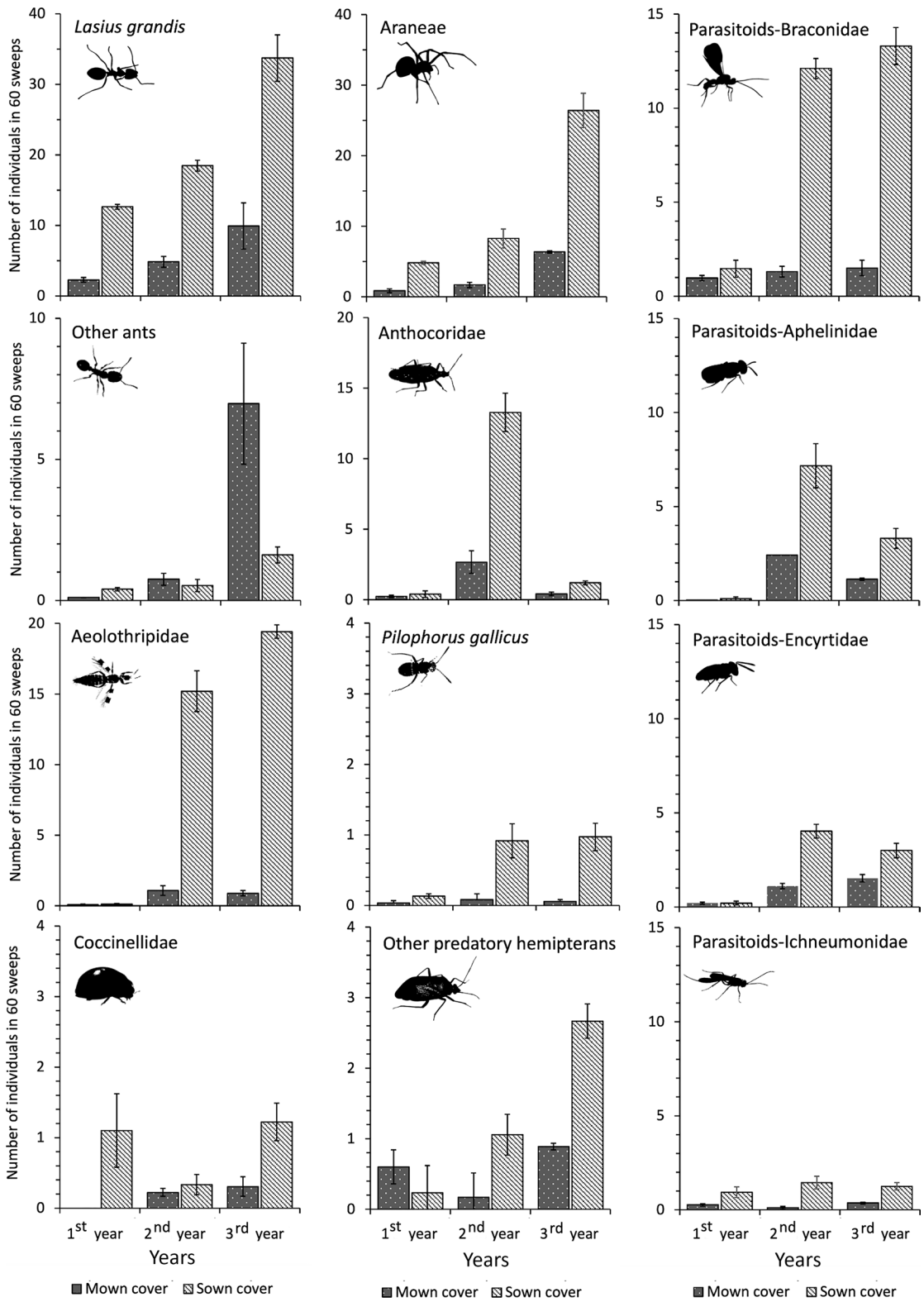
The abundance of several groups of predators was significantly influenced by the management of the cover (Table 2, Fig. 3). The abundance of *L. grandis* was significantly lower on the pear trees with the sown cover (Table 2, Fig. 3). During the three years of the research, the abundance of *L. grandis* on pear trees with a sown cover was from 0.66 ± 0.05 to 0.84 ± 0.05 times lower than in the mown cover (Fig. 3). In contrast, other ants (*Formica* spp.), although much less numerous than *L. grandis*, showed significantly higher abundances on the trees with the sown cover (Table 2, Fig. 3). The abundance of spiders was also significantly higher on the trees with the sown cover, the annual abundance of spiders being from 1.40 ± 0.02 to 1.9 ± 0.6 times higher on the trees with a sown cover than in those with a mown cover (Fig. 3). Overall, the factors management of the cover and year had a significant effect on the abundance of the predatory mirid *P. gallicus* (Table 2). However, cover management was found to have a significant effect only in the third year (Table 2, $P < 0.001$), being its abundance double on the pear trees with the sown cover (Fig. 3). *Aeolothrips* spp. were only observed in the third year, with significant differences between treatments (Table 2, Fig. 3). No significant differences among treatments were found for anthocorids, other predatory hemipterans, coccinellids and staphylinids (Table 2, Fig. 3). As for the parasitoids, only braconids were significantly more abundant on trees with the sown cover (Table 2, Fig. 3).

On pear trees, *Aphis* spp. (*A. gossypii* Glover, *A. pomi* De Geer, *A. spiraecola* Patch; Hemiptera: Aphididae) and psyllids (*Cacopsylla pyri* L.; Hemiptera: Psyllidae) were the most abundant phytophagous species. The abundance of aphids on pear shoots was significantly lower in the plots with the sown than in those with the mown cover ($\chi^2 = 28.2$; df = 1; $P < 0.001$) (Fig. 4). The management of the cover did not have a significant effect on the number of aphid mummies on pear trees ($\chi^2 = 0.130$; df = 1; $P = 0.718$). The maximum average number of mummies observed in a date over the three years of the research was 0.34 ± 0.01 and 0.48 ± 0.32 mummies per leaf on pear trees with the sown and the mown cover, respectively.

In contrast to aphids, no significant differences in the abundance of psyllids were found in relation to cover management ($\chi^2 = 0.111$; df = 1; $P = 0.739$) (Fig. 4), but the interaction between cover management and year was found to be significant ($\chi^2 = 28.9$; df = 2; $P < 0.001$). For instance, in the first year, the number of psyllids per pear leaf was found to be significantly higher in the plots with a sown cover than in those without cover ($P < 0.001$), while in the second year the opposite trend was observed ($P < 0.001$). In contrast, in the third year no significant differences were observed between the two treatments ($P = 0.448$) (Fig. 4).

Discussion

In the present research, enhancing plant abundance and diversity by sowing a cover crop in pear orchards was found to have both positive and neutral effects on pest control, depending on the pest species. In agreement with our working hypothesis, aphids were significantly less abundant on pear trees with a sown cover than on those where the vegetation of the cover was periodically mown. In contrast, the abundance of psyllids on pear trees was not significantly influenced by the management of the ground cover. In agreement with these results, increasing plant diversity by providing floral strips or plant covers has also been reported to reduce the abundance of aphids in fruit tree orchards (Wyss et al. 1995; Wan et al. 2014; Gómez-Marco et al. 2016). FitzGerald and Solomon


Lasius grandis
Araneae
Parasitoids-Braconidae
Other ants
Anthocoridae
Parasitoids-Aphelinidae
Aeolothripidae
Pilophorus gallicus
Parasitoids-Encyrtidae
Coccinellidae
Other predatory hemipterans
Parasitoids-Ichneumonidae
Number of individuals in 60 sweeps
1st year
2nd year
3rd year
Years
Mown cover
Sown cover

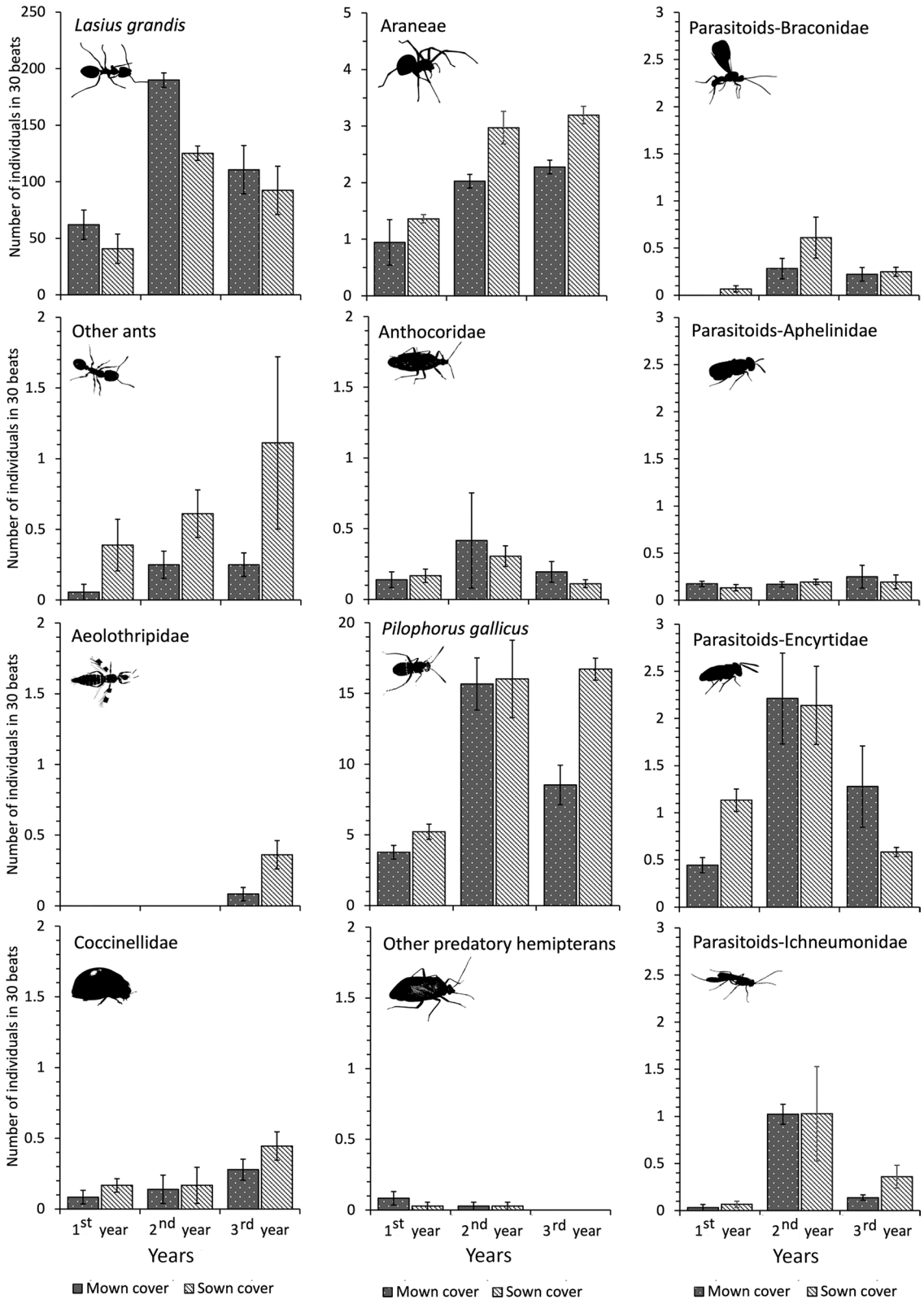
◂**Fig. 2** Annual average ± SE of the abundance of natural enemies sampled using sweeping nets on the vegetation of the ground cover with two types of management (i.e., mown and sown) during three consecutive years (2019–2021), in a pear orchard in southern Spain

(2004) also found that cover crops did not have a significant effect on the numbers of another psyllid species, *Cacopsylla pyricola* (Förster) (Hemiptera: Psyllidae), in pear orchards.

The reduction in aphid numbers on the pear trees with a sown cover was probably due to the effect of spiders and, in the last year, to the predatory mirid *P. gallicus*. The ant *L. grandis* had significantly lower numbers in the pear trees with the sown cover and previous research showed that it does not prey on aphids (Sanchez et al. 2020a). In contrast, investigations carried out in apple and pear orchards in other regions of Europe have shown that aphids are an important component of the diet in spiders (Pkekár et al. 2015; Mezőfi et al. 2020; Gajski and Pekár 2021; Hambäck et al. 2021). However, positive effect of enhancing ground cover on spiders populations in association with aphid control in fruit orchards has rarely been proved. To our knowledge, only Wyss et al. (1995) found that weed strips favoured aphidophagous insects and spiders and reduced aphid populations in apple orchards (Wyss et al. 1995). In contrast, other researchers have found both positive and neutral effects of cover crops on spiders in orchards, but without a significant effect on pest density (Wyss 1996; Costello and Daane 2003; Daane et al. 2018). Predatory mirids are also renowned aphid predators and enhancing the ground cover has been reported to increase the abundance of some predatory hemipteran favouring pest control (Rieux et al. 1999; Solomon et al. 2000). In the present research, anthocorids and coccinellids, although observed in low numbers, could have contributed to the regulation of the aphids and psyllid populations, but it is unlikely that they were cause for the lower aphid abundances on the pear trees with the sown cover because no differences on predator abundance were found between treatments. Syrphids were not included in this research because of the inadequacy of beating and sweeping net sampling, but they were rarely observed on aphid colonies on the sampling of leaves. As for parasitism, although the abundance of braconids in some years was significantly higher on pear trees with the sown cover, the number of aphid mummies was very low and no differences were found between treatments.

The lack of effect of the sown cover on pear psyllids was surprising because the management of the cover had a significant effect on the populations of key predators such as *L. grandis,* spiders and *P. gallicus*. On one hand, the reduction of ant activity on pear trees with the sown cover was expected to increase psyllid numbers because ants were known to prey on psyllids (Sanchez et al. 2020a, 2021). On the other hand, the higher abundance of spiders and *P. gallicus* were expected to reduce pear psyllid populations (Sanchez et al. 2020b). The lack of effect of generalist predators on psyllid abundance could have been due, among other reasons, to prey preference (Hambäck et al. 2021). Mezőfi et al. (2020) found psyllids among the more frequent prey items consumed by spiders in Central Europe, but they represented a much lower percentage (4%) than aphids (71.5%). Philodromids have been as well found to prey and track the abundances of psyllids on pear and other pome fruit trees in Central Europe, but their contribution to the control of psyllids was argued to depend on the abundance of other more preferred prey such as Acari and Collembola, among others (Pkekár et al. 2015; Gajski and Pekár 2021). In the same way, Hambäck et al. (2021) found that *Philodromus* spiders seem to mainly consume aphids (30%) and thrips (60%) in Swedish apple orchards. Intraguild interactions could also have been responsible for the lack of effect on psyllid populations observed in the present research. They also reported that a high proportion of the spider's prey were other natural enemies, being predatory hemipterans such as mirids and anthocorids highly represented in the spiders gut content from Spanish apple orchards (Hambäck et al. 2021).

The significant increase in the abundance of spiders on pear trees with the sown cover could have been due to the movement of individuals from the cover to pear trees. However, this is less likely for *P. gallicus* because its abundance on the cover was very low. The increase in the number of *Aeolothrips* spp. and braconids could also have been favoured by the movements of individuals from the cover. Horton et al. (2009) found that 15.9–17.4% of the spiders collected on the canopy of pear trees had visited the cover crop. A significant increase in the number of spiders was also reported on vines with a grass cover in comparison to those with bare soil (Daane et al.


Lasius grandis
Araneae
Parasitoids-Braconidae
Other ants
Anthocoridae
Parasitoids-Aphelinidae
Aeolothripidae
Pilophorus gallicus
Parasitoids-Encyrtidae
Coccinellidae
Other predatory hemipterans
Parasitoids-Ichneumonidae
Number of individuals in 30 beats
1st year
2nd year
3rd year
Years
Mown cover
Sown cover

◂**Fig. 3** Annual average ± SE of the abundance of natural enemies sampled beating branches on funnels, on pear trees with two types of cover management (i.e., mown and sown) during three consecutive years (2019–2021), in a pear orchard in southern Spain

2018). In contrast with our suggestion, high rates of movement between pear trees and the cover has been reported for predatory mirids (Horton et al. 2009). The increase in the abundance of some taxa of generalist predators on the canopy of pear trees with the sown cover could also have been resulted from the reduction of *L. grandis* harassment. Ants are keystone species in terrestrial agroecosystems and changes in their abundances in habitats may have strong cascading effects on many species of arthropods (Stadler and Dixon 2008; Offenberg 2015; Mestre et al. 2016). Several authors have reported negative effects of ants on natural enemies in Mediterranean fruit-tree orchards, including spiders and predatory hemipterans (Miñarro et al. 2010; Calabuig et al. 2015; Mestre et al. 2016; Sanchez et al. 2020a). The effect of the sown cover on the reduction of the activity of *L. grandis* on the canopy of pear trees was probably due to the presence of myrmecophilous aphids on some of the plant species of the sown cover. The activity of ants on plants is known to be modulated by the presence of sugar sources, such as honeydew produced by phloem-feeding hemipterans (Rico-Gray and Oliveira 2007; Sanchez et al. 2020a).

The changes produced by the sown cover on the assemblage of arthropods in the canopy of pear trees were of a much lower magnitude than those observed on the understory vegetation. The abundance of all the groups of natural enemies greatly increased in the sown cover in comparison to the mown cover. In contrast, for most of the groups of natural enemies (e.g., coccinellids, anthocorids, etc.) little change in their abundance was found on pear trees with different cover management. This is in agreement with the observations of other authors who found increased populations of natural enemies on the flowering cover crop, but a much weaker response in the crop. For instance, Wilson et al. (2017) found that in vineyards cover crops attracted natural enemies but their populations in the vine canopy experienced no variation. In the same way, Saenz-Romo et al. (2019) found that the abundance of predators and pests on the vine canopy was not affected by the management of the cover. Derocles et al. (2014) found that parasitoids sharing crop and non-crop habitats were rare, which suggested that the contribution of field margins as a source of biocontrol agents was much lower than expected. A significant increase in the abundance of most of the natural enemies between the first and the second-third year was observed on the vegetation of the cover and, to a lower extent, on pear trees. The increase in the abundance of some groups of predators could have been due to the building up of their populations over time. Several authors have also observed higher populations of natural enemies, such as spiders, coccinellids and parasitoids, on the canopy of fruit trees over the years following the enhancing of the ground cover vegetation (Silva et al. 2010).

The present research shows that enhancing the abundance and diversity of plants in the understory of pear orchards had a positive effect on the control of aphids on pear trees, while it had a neutral effect on psyllids. The effect of the sown cover on the abundance of aphids could be mainly attributed to the increase in the abundance of spiders and the predatory mirid *P. gallicus*. We predict that the increase in the abundance of these and other natural enemies on the canopy of pear trees may have been due to the movement of individuals from the understory vegetation to pear trees, and/or to the reduction of ant activity on the canopy of pear trees and, thus, less harassment of natural enemies. The sowing of the cover crop increased the abundance of most of the groups of natural enemies on the understory vegetation. However, this had little impact on the abundance of most of the groups of natural enemies in the canopy of pear trees, which suggests some degree of habitat compartmentalization. We hypothesise that the main effect of the cover crop was due to changes on the structure of the assemblage of arthropods through interactions mediated by the ant *L. grandis*. More research is needed to understand the lack of correspondence between the increase in the abundance of natural enemies in the understory vegetation and pear trees as well as to know why the abundance of the pear psyllid was not affected by the changes on the abundance of some generalist predators.

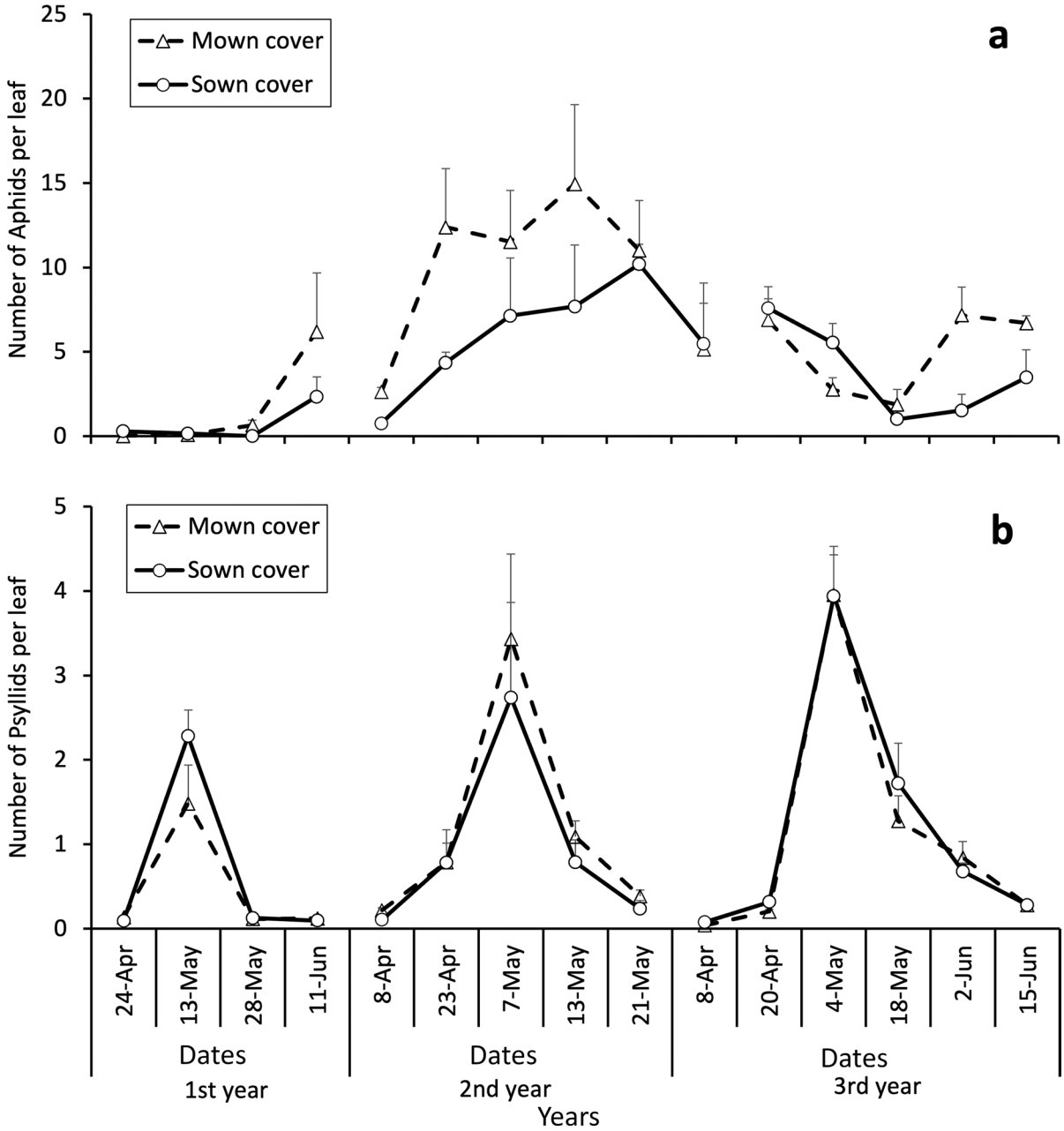


Fig. 4 Average number (+ SE) of aphids (**a**) and psyllids (**b**) per pear leaf counted visually on apical leaves in plots with two types of cover management (i.e., mown and sown) during three years of study (2019–2021) in a pear orchard in southern Spain

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Declarations

Conflict of interest The authors declare no conflicts of interest.

Research involving human and animal participants The present research does not involve any experimentation with human participants and/or other animals.

Informed consent The research was always carried out following informed consent procedures.

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