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Natural enemies associated with cereal cover crops in olive groves

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Abstract

The use of cover crops is the most effective method to combat soil degradation due to erosion in olive cropping in Spain. Within the framework of Integrated Pest Management (IPM), a compelling question is how cover crops would affect elements of the olive-agroecosystem such as natural enemies. Accordingly, the objective of this study was to examine the effects of cereal cover cropping on natural enemy communities in olive groves. Samples of the arthropod communities were collected in olive groves under tillage and cover cropping systems at five different locations in the same province. Cereal cover crops significantly increased the abundance of parasitoids in the olive canopy, especially *Ageniaspis fuscicollis* Dalman (Hymenoptera Encyrtidae) a parasitoid of the olive moth *Prays oleae* Bernard (Lepidoptera Yponomeutidae), the most common insect pest of olive trees. However, parasitoid abundance and structure depended on olive grove location suggesting the importance of crop surroundings in parasitoid community dynamics. Predators numbers were slightly higher in tilled olive groves but no significant differences were found between the two soil management systems.

Key words: agroecology, biological control, insects, *Olea europaea*, spiders.

Introduction

Ground erosion is probably the most serious environmental problem associated with olive cultivation (Gómez *et al*., 2009; Graaff *et al*., 2010). In recent years, cover crops have been promoted as an alternative to bare soil in olive groves in Southern Spain due to their ability for reducing soil erosion from water, especially in sloping olive groves. Other potential benefits include improved ground quality (increasing surface soil organic matter, enhancing nutrient cycling, improving water infiltration and soil tilt) and effective control of weeds and soil-borne diseases.

In southern Spain, several species including barley (*Hordeum vulgare* L.), vetch (*Vicia sativa* L.) and natural grasses have been recommended as winter cover crops for olive groves. Several cruciferous species are also being introduced mainly because they have a high potential for controlling important olive soil-borne diseases like *Verticillium dahliae* Klebahn. Regarding the cover crop management, the rows between the trees are planted in autumn while the area under the canopy is kept free of vegetation. Cover crops are killed by mowing or herbicides in early spring before weeds start to compete with the crop for moisture (Francia *et al*., 2006).

In grove systems, cover crops between tree rows are not only efficient for controlling erosion, they also contribute to biodiversity. Biological control can be enhanced by providing plant resources for natural enemies. Cover crops increase biodiversity by favouring direct and indirect trophic interactions among community components, weeds, arthropod pests, and their natural enemies (Norris and Kogan, 2005). They modify the unfavourable summer microclimate and might protect such natural enemies from exoskeleton abrasion by reducing dust levels (Pettigrew, 1998). They could be important as overwintering sites for natural enemies and may provide increased resources such as alternative hosts/prey, pollen or nectar for parasitoids and predators (Landis *et al*., 2000; Phatak, 2000; Nicholls, 2006).

Compared with other agricultural systems, cultivated olive groves continue to be considered quite a stable crop due to the stability of the environment itself, the trend of production, the small number of really pernicious pests, the tolerance of pest damage, and the abundant beneficial arthropod fauna (Cirio, 1997). Olive trees are associated with a wealth of beneficial arthropods while phytophagous families, that include the most damaging pests, comprise less than 44% of the total families (Belcari and Dagnino, 1995). However, there is no information about effects associated with the presence of ground cover management on natural enemy populations in olive groves. Therefore, the question arises of how cover crops as an alternative practice to bare soil, affect other elements of the olive agroecosystem such as natural enemies of common olive.

Considering this, and the growing interest in planting cover crops for their potential to reduce soil degradation, this study was conducted to determine the effect of cereal cover crops on natural enemies of olive pests in olive groves in southern Spain, the area with the highest production of olive oil in the world.

Materials and methods

Survey of beneficial arthropods

The study was conducted in olive groves in the province of Jaén, in Andalusia (southern Spain) (figure 1). Andalusia, which accounts for 75% of Spanish production, has the biggest olive crop under cultivation in the world. Jaén province is the largest producer in the Andalusia region with 589,532 ha of olive crop (figure 1).

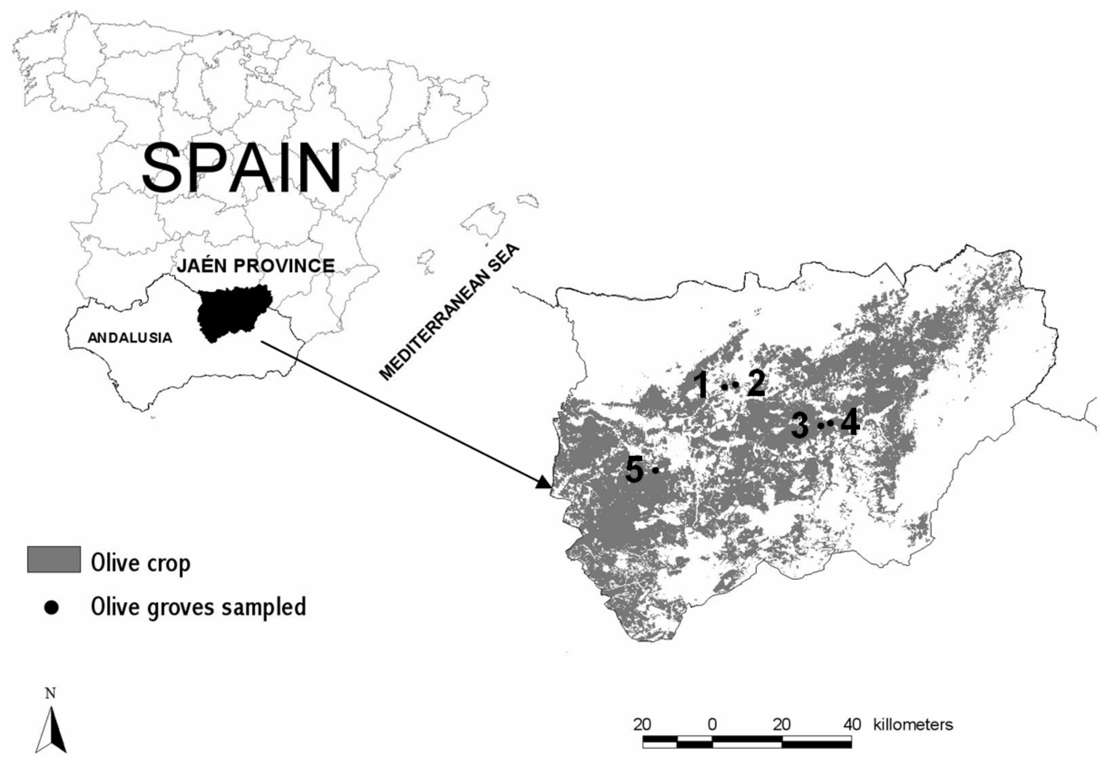

Figure 1. Location of olive groves sampled and geographic distribution of olive cultivation in Jaén province, Andalusia (southern Spain).

Five areas of olive groves with different sizes between 2 and 20 ha were selected from different geographical locations in the province (grove 1, 2, 3, 4 and 5) (figure 1). Two olive groves, each one with two different ground management systems, tillage (T) and cover cropping (C), were chosen in each olive area. A cereal cover crop, between the olive tree rows, had been used for the previous ten years and is one of the most common cover types used by olive growers in Spain. The cereal was barley (*H. vulgare*) since seeds are inexpensive and it is easy to establish and manage. Furthermore, previous results have tended to show that barley cereal cover crops had no impact on various different olive pests, including all those that spend part of their development cycle in the soil, such as *Bactrocera oleae* (Rossi) (Díptera Tephritidae), *Prays oleae* (Bernard), and *Otiorhynchus cribricollis* Gyllenhal (Coleoptera Curculionidae) (Rodríguez *et al*., 2009). Barley covers have also advantages for *V. dahliae* control as it is not a plant host.

Herbicides were used in March (glyphosate 1.5 L/ha) and in October (simazine 2 kg/ha and glyphosate 1.5 L/ha) to limit weeds and cover crop growth within tree-rows. In olive groves under conventional tillage, bare ground is maintained by repeated tillage throughout the year.

The predominant olive variety was Picual. The trees were more than 70 years old, spaced 10 × 10 m and pruned every two years. The average yield is 50 kg of olives per tree. The typical continental Mediterranean climate means that the temperature reaches over 40 ºC in summer and falls below 0 ºC in winter. Chemical treatments applied included Bordeaux mixture (8.3 g/L) to control fungal attack of *Cycloconium oleaginum* Castagne in spring and autumn and dimethoate (40% 1.25 cc/L) to prevent *P. oleae* attacks on flower generation (May).

The samples were taken monthly from June to September, when arthropod populations are the highest around the olives (Ruano *et al*., 2004). The sampling unit was a block consisting of a row of five randomly sampled trees, each tree separated from the others by a non-sampled tree, such that the distance between sampled trees was 20 m, with each block being separated from other blocks by two rows of non-sampled trees. Five blocks were selected per olive grove. Therefore, 25 olive trees were randomly sampled per olive grove in each sampling date. In the canopy the trees were sampled by beating, five times, four branches per tree (one for each orientation), also chosen at random, over an insect net 50 cm in diameter.

Sampling of epigeal arthropods was carried out using pitfall traps. Each trap consisted of a 200 ml plastic container (7 cm in circumference) filled with water and detergent. Traps were placed in holes dug carefully with the minimum possible soil and vegetation disturbance such that the lip of the trap was even with the surface of the ground. The traps were collected after 24 h.

The samples, both from the canopy and the ground, were frozen and afterwards arthropods were separated from vegetable and inorganic remains and then, classified at family level. Arthropods from predaceous or parasitoid families, or genera or species within a family that are known to be predaceous or parasitoid, were included as natural enemies. From the diverse range of invertebrates collected, we focused taxonomic efforts on predators and parasitoids likely to contribute to pest control in the olive crop. Parasitoids were identified based on taxonomic keys of Goulet and Huber (1993) and using the olive particular arthropods collection of the research group.

Statistical analysis

The data corresponding to the numbers of both parasitoids and predators captured were tested for normality using the Kolmogorov-Smirnov test. While predator numbers were found to follow a normal distribution in the canopy as well as on the ground, parasitoid numbers were not. Therefore, we used the non-parametric Mann-Whitney test and a one-way ANOVA to compare the number of parasitoids and of predators respectively between locations (with crop cover and under conventional tillage). To evaluate the effects of the two types of treatment and location and their interaction a two-way ANOVA test was used after log transformation of the data. P < 0.05 was considered significant. All the statistical analysis was performed using the SPSS statistical package version 15.0 for Windows.

Results

Parasitoids in olive groves canopy

More hymenopterous parasitoids were collected in olive groves with the cover crop than in tilled olive groves (Mann Whitney U: Z = −2.020, $P < 0.05$). However, there was a significant interaction between cover crop and location ($F = 4.37$; df = 4; $P < 0.05$) so, the mean number of parasitoid individuals changed significantly at different locations and significant differences were only found at locations 2 ($F = 6.877$; df = 1; $P = 0.039$) and 3 ($F = 4.634$; df = 1; $P = 0.001$), where the highest number of parasitoids were collected (table 1). Therefore, parasitoids reacted differently to cover crops and their response depended on the locations.

Parasitoids were well represented throughout the sampling period (figure 2). The greatest number of parasitoids was collected from June to August in both types of olive groves (figure 2). Although the number of parasitoids did not differ greatly across sampling periods, there were significantly more at locations 2 and 3, those with cover crops during June ($P = 0.023$; $P = 0.001$), July ($P = 0.004$; $P = 0.001$), and August ($P = 0.017$; $P = 0.038$) (figure 2).

Table 1. Mean and ± SD of parasitoids per olive tree captured in the canopy of olive trees at five different locations.

Location	With cereal cover crop	Tillage soil
1	0.33 ± 0.33 a	0.25 ± 0.13 a
2	0.93 ± 0.53 a	0.23 ± 0.05 b
3	8.18 ± 6.86 a	0.70 ± 1.07 b
4	0.28 ± 0.05 a	0.30 ± 0.16 a
5	0.40 ± 0.08 a	0.30 ± 0.14 a
Total	2.02 ± 4.19 a	0.36 ± 0.47 b

Different letters indicate significant differences at $P < 0.05$.

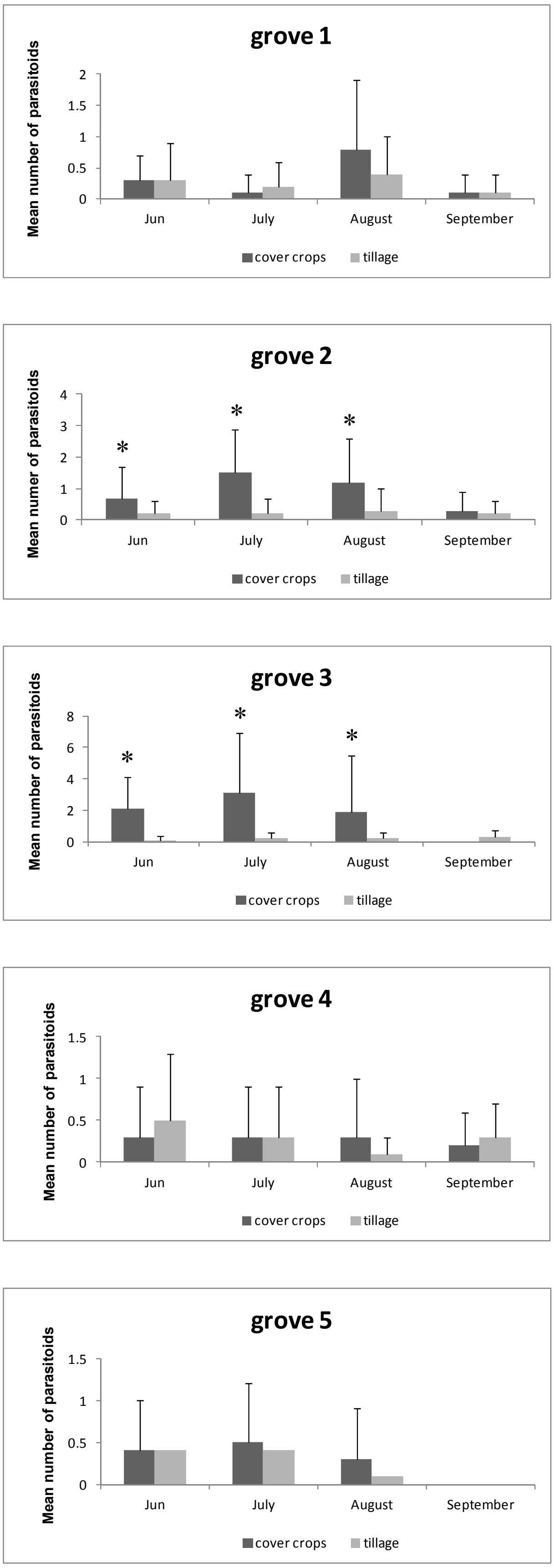

Figure 2. Mean and ±SD of parasitoids per olive tree collected during the sampling period at five different olive groves, each one with cover and tillage soil in the olive canopy. (*) indicates significant differences at $P < 0.05$ level.

A total of 441 adults from 17 families were found in the canopy in both types olive groves (table 2). Encyrtidae was the most abundant family, representing 45.4% of the total, followed by Scelionidae (16.3%) and Chalcididae (14.3%). Most of these families were also collected from the cover crops (table 2). Among encyrtids, the most abundant parasitoid species collected was *Ageniaspis fuscicollis* var. *praysincola* (Dalman).

Predators in olive groves

Cover crops were not associated with a higher mean number of predators in the olive canopy (Mann Whitney U: Z = -0.596, $P > 0.05$) (table 3). In fact, a significantly greater proportion of predators were captured in the tilled plots than the groves with cover crops at location 1 ($F = 6.298$; df = 1; $P = 0.046$) (table 3). There was no interaction between cover crop and location ($F = 0.727$; df = 4; $P > 0.05$).

Table 2. Total number and percentage of the parasitoids per olive tree collected from the canopy trees in covered (C) and tillaged (T) groves.

Parasitoids families	Total C	Total T	Total%
Aphelinidae	1	3	0.9
Braconidae	3	14	3.9
Ceraphronidae	5	2	1.6
Chalcididae	43	20	14.3
Chrysididae	0	1	0.2
Cynipoidea	1	1	0.5
Elasmidae	1	0	0.2
Encyrtidae	179	21	45.4
Eulophidae	0	1	0.2
Eupelmidae	2	1	0.7
Eurytomidae	1	0	0.2
Ichneumonidae	10	4	3.2
Mymaridae	1	2	0.7
Platygastridae	0	3	0.7
Pteromalidae	14	10	5.4
Scelionidae	54	18	16.3
Trichogrammatidae	10	0	2.3
Others	8	7	3.4
Total	333	108	

Table 3. Mean and ± SD of predators per olive tree captured in the canopy of olive trees at five different locations.

Location	With cereal cover crop	Tillage soil
1	2.15 ± 0.59 a	3.45 ± 0.85 b
2	2.28 ± 0.95 a	3.33 ± 2.62 a
3	1.68 ± 1.01 a	1.30 ± 0.93 a
4	2.60 ± 1.75 a	2.00 ± 1.79 a
5	2.65 ± 1.31 a	3.78 ± 2.02 a
Total	2.27 ± 1.12 a	2.77 ± 1.85 a

Different letters indicate significant differences at $P < 0.05$.

Heteroptera were the most abundant group of predators in the olive canopy (32.7%), followed by Coleoptera (26.2%), Neuroptera (22.6%) and Araneae (12.9%). The majority of Heteroptera (25.6%) belonged to the Miridae family. This family was more abundant in areas under tillage than where there was soil cover and it was mostly represented by a single species, namely *Brachynotocoris ferreri* n. sp. Baena (in litteris); (Heteroptera Miridae) (table 4). By the contrast, Anthocoridae was more numerous within the canopy of olives with ground cover (table 4).

Coccinellidae, in particular *Scymnus suturalis* Thunberg (Coleoptera Coccinellidae), formed the most abundant family in the canopies of groves under tillage (table 4).

On the ground, though more predators were collected in the olive groves under tillage, the difference with respect to plots with cover crops was not significant (Mann Whitney U: Z = −0.014, $P > 0.05$). However, at location 5 there were significantly more predators in the plots with cereal cover crops ($F = 12.757$; df = 1; $P = 0.012$) (table 5). In this case, there was a significant interaction between cover crops and location ($F = 2.501$; df = 4; $P < 0.05$).

The majority of predators from the ground belonged to the Formicidae family (89.55%), followed by Araneae (5.11%) (table 6). Consequently, it is quite probable that Formicidae were the group responsible for differences found at location 5 (table 5). Spiders were more abundant in plots with cover crops (table 6).

Table 4. Total number and percentage of the arthopods predators per olive tree captures in the canopy from covered (C) and tillage (T) olive groves.

Predators groups	Total C	Total T	Total %
HETEROPTERA			
Miridae	126	343	25.6
Anthocoridae	82	39	6.6
others	6	4	0.5
COLEOPTERA			
Coccinellidae	143	230	20.3
Carabidae	2	0	0.1
Staphylinidae	3	0	0.2
Cantharidae	44	2	2.5
others	15	9	1.3
HYMENOPTERA			
Formicidae	49	52	5.5
wasps	1	0	0.1
ARANEAE	133	104	12.9
NEUROPTERA			
Chrysopidae	85	67	8.3
others	119	143	14.3
DYCTIOPTERA			
Mantidae	19	11	1.6
DERMAPTERA	2	2	0.2
Total	829	1006	

Table 5. Mean and ± SD of predators per olive tree on the ground at five different locations.

Location	With cereal cover crop	Tillage soil
1	7.60 ± 5.25 a	13.80 ± 6.69 a
2	5.98 ± 1.66 a	7.13 ± 7.24 a
3	11.25 ± 4.51 a	11.75 ± 2.82 a
4	5.08 ± 0.95 a	6.70 ± 1.90 a
5	9.58 ± 3.59 a	2.78 ± 1.27 b
Total	7.90 ± 3.95 a	8.43 ± 5.79 a

Different letters indicate significant differences at $P < 0.05$.

Table 6. Total number and percentage of predatory arthropods per olive tree collected at ground of covered (C) and tillage (T) olive groves.

Predators groups	Total C	Total T	Total %
HETEROPTERA			
Miridae	2	1	0.05
Anthocoridae	1	0	0.02
others	15	16	0.47
COLEOPTERA			
Carabidae	20	29	0.74
Staphylinidae	17	25	0.63
Scraptidae	4	2	0.09
Melyridae	6	29	0.53
Curculionidae	6	3	0.14
others	37	63	1.50
HYMENOPTERA			
Formicidae	2838	3115	89.55
wasps	35	22	0.86
ARANEAE	208	132	5.11
OTHERS	11	11	0.34
Total	3200	3448	

Discussion

Parasitoids in olive groves canopy

Results showed that cereal cover crops had a significant beneficial effect on parasitoid wasp abundance in the olive canopy. However, families responded differently to cover crops and their response depended on the locations. Encyrtidae, Scelionidae and Chalcididae were the three families most favoured by cover crops in the canopy of the olive groves. Changes in parasitoid abundance have been identified in other studies, which have suggested that plant species composition is important for these types of insects because parasitoid wasps rely on them for sources of food (honeydew, pollen and nectar), shelter, and breeding sites in the adult stages (Landis *et al.,* 2000; Norris and Kogan, 2005). Accordingly, abundance and diversity of entomophagous insects within a field are related closely to the nature of the surrounding vegetation so any complex vegetation added to olive-agroecosystem may tend to increase the abundance of certain hymenopterous parasitoids (Altieri and Letourneau, 1982).

Encyrtidae is one of the most useful families for biological control of pests (Goulet and Huber, 1993). Among encyrtids collected, *A. fuscicollis* was the main species responsible for the parasitoid abundance in these olive groves with barley cover crops. In particular, *A. fuscicollis* has been reported to be a biological control agent for *P. oleae* (Campos and Ramos, 1982) an economically important pest of olive trees. *P. oleae* has also been reported in our previous results to be more abundant in olive groves with cereal cover crops (Rodríguez *et al*., 2009). So, there is evidence that vegetation diversity can have direct effects on populations of herbivorous insects and associated natural enemies. Usually, host-specific parasitoids exhibit positive numerical responses to increasing pest densities (Hammond and Stinner, 1999).

Parasitoids were especially important in the olive canopy from June to August, when cover crops provided dead mulch through the warm season to avoid water loss and competition with olive trees. Parasitoids possibly move from the cereal vegetation into the olive. Indeed, several studies have indicated that high densities of natural enemies can occur in cover crops and then disperse to the main crop or surrounding areas in different seasons (Altieri and Letourneay, 1982; Sullivan, 2003).

Finally, tillage was the traditional soil-management practice for olive groves and remains the most common approach, that is, the use of cover crops has not yet been adopted as the preferred system on a large scale in olive cultivation. Furthermore, in the study area, olive monoculture itself dominates agriculture, and the result is a monotonous landscape with very limited diversity. Therefore, arthropod community structure has probably not been able to become well established in the olive-cereal cover crop polyculture system. This may explain why there have been few definitive results concerning the impact of cover cropping on beneficial insects. In particular, species at higher levels in a community such at parasitoids are normally more susceptible to changes than species at lower levels. This makes it very difficult to accurately determine the role of parasitoid wasps in this polyculture system.

Predators in olive groves

Responses of predators to cover crops were very different depending on taxonomic group, location and stratum (canopy or ground). Just as expected, predator abundance was much higher on the ground than in the canopy of the olive grove (Campos *et al*., 2000), since the ground is the typical habitat of important soil-surface dwelling arthropod predators such us ground beetles (Coleoptera Carabidae), ants (Hymenoptera Formicidae) and spiders (Arachnida Araneae). Overall, no differences were found in predator populations between cleared and covered soil, although predator densities, were higher both in the canopy and on the ground under tillage than in groves with cover crops. However, cover crops significantly enhanced the abundance of ants on the ground, while coccinellids decreased in the canopy of certain olive groves in this study. Such differences between locations, where the soil management practice is similar, could be due to the structure of the olive grove itself. Agroecological infrastructure together with degree of heterogeneity of agroecosystems determine the biodiversity present in each agricultural area (Nicholls, 2006), and these characteristics have a great impact on the abundance and collection of predator species (Boccaccio and Petacchi, 2009).

Formicidae accounted for nearly all of the overall abundance of arthropods on the ground of olive groves. The presence of a relatively large proportion of ants was explained by Redolfi *et al*., (1999), who found that most of the ant species made their nests in the soil under the tree canopy. Tillage tended to increase the number of ants on the ground near the olive trees but, of the five locations under study, significant differences were only found in one of the olive groves with cover crops. This result is consistent with the conclusions from the aforementioned authors who indicated that differences in the myrmecofauna at different sites are attributable to little changes of agricultural practices at each site.

With regard to Coccinellidae, this family has been reported to be an important predatory family of aphids (Belcari and Dagnino, 1995). In particular, *S. suturalis* is mainly an aphidophagous coccinellid species and is among the dominant coccinellid predators of phytophagous insects in the olive canopy in Spain (Morris *et al*., 1999). These authors indicated that the response of coleopteran predator density in the olive canopy was determined by the type of soil management practices applied. In line with this similarly, a survey on epigeal beetle populations in olive groves showed that abundance as well as family richness and dominance were greater in bare soils compared to control covered soils (Cotes *et al*., 2009).

Among Neuroptera, *Chrysoperla carnea* (Stephens) (family Chrysopidae) was the most abundant species and is reported to be one of most important polyphagous predators in olive groves (Campos, 2001); other Neuroptera collected belonged to other species of chrysopids and to family Coniopterygidae, which are predators of mites and small arthropods (Canard, 2001).

Castro *et al*., (1996) reported that bare soil management reduced the abundance of spiders on the ground near olive trees and Cárdenas *et al*. (2005), found that two species, *Thyene imperialis* (Rossi) (Araneae Salticidae) and *Loxosceles rufescens* (Dufour) (Araneae Sicariidae) may be favoured by cereal cover crops. Tillage usually reduces the abundance of less mobile soil-surface spiders such as Lycosidae family and other hunting spiders in soil ecosystems, whereas highly mobile spiders such as Lyniphiidae family may resist and adapt to this type of soil management. In olive, Thaler and Zapparoli (1993) reported Linyphiidae, Erigonidae, Lycosidae, Dysderidae, Gnaphosidae and Theridiidae as the most abundant spider families on the ground around olives, while Morris *et al*., (1999) cited Salticidae and Philodromidae as the most abundant families in the olive canopy.

In conclusion, winter cereal cover crops increased the abundance of parasitoid populations in the olive canopy. The increase only significantly affected some parasitoid families, namely primarily from the Encyrtidae, Scelionidae and Chalcididae. Parasitoid abundance and structure depended on location suggesting the importance of crop surroundings in parasitoid community dynamics. The response of predators to cereal cover crops was uneven, varying as a function of variable by taxonomic group, location and stratum (canopy or ground). Notably, coccinellids were more abundant in the canopy of trees under tillage management. Although some olive areas are using winter cover crops effectively, more olive groves need to adopt the practice for the real impact of cereal cover crops on natural enemy populations to become clear. In addition, wide spread use and long-term studies of the practice would help to improve our understanding of the complex relationships between cover crops and with natural enemies and to assess their impact on olive pest populations.

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