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Responses of epigeal beetles to the removal of weed cover crops in organic olive orchards

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Abstract

The study was conducted in an experimental organically managed olive orchard to test the short-term effects exerted on epigeal coleopteran populations by the removal of the plant cover (RPC) when compared to non-managed natural plant cover (NPC). The changes in abundance and diversity of beetles were analysed in three experimental blocks in which the cover crop was removed during the first week of June in 2005. Pitfall traps and coleopteran family level were a reliable approach to achieve the aim of this study. Related to soil conservation, maintenance of covers can potentially decrease soil erosion risk, and traditional soil practices tend to diminish diversity and activity of the soil fauna. This survey showed that abundance as well as family richness and dominance were greater in uncovered soils RPC compared to control covered soils NPC. Therefore, after a rainfall period, some coleopteran families can be used as a quick assessment tool to evaluate effects of short-term disturbance (abiotic factor) on soil arthropod population. Beetle assemblage under vegetable cover seems to be more favourable. As a matter of fact weeds offer advantage (hospitable temperature and moisture) to beetles with respect to bare soils. Finally silvanids could be used as an indicator group of impact of agronomic practices applied to this soil in olive organic farming, since the removal of any kind of cover in olive orchards is an undesirable practice in terms of erosion protection and in terms of diversity conservation.

Key words: Coleopteran families, disturbance, biodiversity measure, pitfall trap, soil management.

Introduction

Soil management in olive farming can be employed in different ways, ranging from intensively managed arable land to sown or naturally covered soils. However, Spanish olive farmers routinely eliminate vegetation from soils as a fire prevention measure or out of tidiness (Pastor, 2004). These practices not only contradict the current recommendations of the regional government of Andalusia (Junta de Andalucía, 2002) to reduce erosion by keeping some kind of cover on soils but they also go against good agricultural practices of Cross Compliance of the European Union (Council Regulation No 1782/2003), arguing that covers in olive orchards can efficiently reduce run-off, making more water available to the crop (Rozmarynowska *et al*., 2003). Soil studies in Andalusia have shown that most land has to cope with severe problems of erosion (Sala *et al*., 1991; Milgroom *et al*., 2007) and the practice of maintaining bare soil year-round, underneath and between olive trees is one of the main factors in the reduction of the organic-matter content and the water-infiltration capacity of the soil (de Graaff and Eppink, 1999; Milgroom *et al*., 2007). Intermittent severe thunderstorms during September and October cause an autumn peak in precipitation (Sumner *et al*., 2001), making the issue of covered soils important. In this sense, several studies have been carried out in Andalusia to ascertain the current situation of the olive soils under different farming methods, showing that low impact techniques seem to be more common in the case of organic management (Parra López and Calatrava Requena, 2006). It is demonstrated that the shift to organic farming in olive orchards in some provinces can be accompanied by increased protection of the soil and lower erosion risk (Milgroom *et al*., 2007), although the weed removal continues to be a widespread practice even in organic farming.

Low-intensity cropping systems have been related to a most favourable abundance and activity of beneficial ground-dwelling arthropod communities (Lundgren *et al*., 2006). According to Guzmán and Alonso (2004), conventional soil practices tend to diminish diversity and activity of the soil fauna. Inventories at species level require an enormous amount of time and financial resources (Cardoso *et al*., 2004; Wilkie *et al*., 2003), mainly due to the necessity of taxonomist employment at previous stages of studies (Biaggini *et al*., 2007). The use of higher taxa level is particularly useful when rapid biodiversity surveys are required (Andersen, 1995; Oliver and Beattie, 1996). Coleopterans are one of the best represented arthropod orders, due to their contribution to pest control (Iperti, 1999; Kromp, 1999) or their role as a food source for farmland birds (Holland and Luff, 2000). As a result of their sensitivity, their reaction can be used to detect and identify the nature of disturbances or changes in environmental quality (Çilgi, 1994), as well as to predict the impact of disturbances (Bohac, 1999), therefore the beetle response can be considered as indicator (McGeoch, 1998). It is safe to say that epigeal coleopteran families (e.g. carabids and staphylinids) have often been used as indicator groups in agro-ecosystems biodiversity assessment (Woodcock *et al*., 2006; Biaggini *et al*., 2007; Bohac, 1999; Cotes *et al*., 2009), and previous studies have already shown that soil beetles of olive orchards can be affected by the soil management (Castro *et al*., 1996; González *et al*., 2004; Morris and Campos, 1999). The effects of elimination of covers on the whole epigeal beetle community (carnivorous, detritivorous, herbivorous living directly on the ground) can be assessed by pitfall traps, although they are not selective (Adis, 1979; Spence and Niemelä, 1994), they passively collect organisms moving across the ground, and thus provide measures of activity rather than absolute density (Southwood, 1994). Pitfall traps are the best known and most often used inventory method in agroecosystems (Duelli *et al*., 1999), even though they have already been used within the same issue of this study, arriving at an indication of habitat quality (Perner and Malt, 2003; Mossakowski and Paje, 1985; Cole *et al*., 2005; Krooss and Schaefer, 1998).

This survey seeks to determine: (1) how weed cover and weed-management practices (mowing and removal) could influence on abundance and composition of epigeal beetle families in olive orchards; (2) how coleopterans can be used as a quick assessment tool to evaluate effects of short-term disturbance on soil arthropod population; and (3) which beetle family or families could be used as indicator groups of impact regarding the agronomic practices applied to this soil in olive organic farming.

Materials and methods

Design of the soil-cover management

Two soil treatments were compared, including a covered soil management (non-managed natural plant cover - NPC) and an uncovered soil management (removal of plant cover - RPC). In the NPC soil-treatment management, no crop was sown and the field was covered with the natural seed bank and roots of annual Gramineae (e.g. *Bromus* sp, *Hordeum* sp, and *Diplotaxis* sp) and finally, no herbicides were applied. In the RPC soil treatment, cover crop was managed by some agronomic practices during the first week of June 2005 as follows: (1) pre-sampling intervention consisted of passing a tine harrow over the dry remains of the cover trimmed by the mower; (2) remains were shredded and tilled into the soil to a depth of a few centimetres; (3) the litter and seed remained in the soil, though partially buried; and (4) the mower was applied four times until the remains were not visible on the soil's surface. Plant litter, including fallen leaves and fruits, were later gathered by hand under the canopy of olive trees. Four sampling times were carried out: 14, 30, 75 and 90 days after the removal of natural vegetation.

Field-experiment description

The study was conducted in a large olive-growing orchard in southern Spain, located at the coordinates of 37°51'38"N - 3°38'36"W. The organically managed orchard consisted of single-trunk olive trees (cv. Picual), with a crown diameter of 1.5-3 m, planted on 8 x 8 m. A randomized complete block design was performed with two treatments, covered (NPC) and uncovered soils (RPC) grouped into three blocks. Within each isolated block, the conditions were as uniform as possible, but between blocks, marked differences existed. In the in-line array of blocks the distance of separation between them was 0.5 km.

Each block, with 429 trees (88 x 312 m), consisted of two plots representing the two treatments. In each single plot, with 121 trees (88 x 88 m), a total number of 20 pitfall traps were set just below the canopy of 20 selected trees. The sampling unit consisted of a row of five trees separated by unsampled one, and each sampling unit was separated from the other by two unsampled rows of trees.

Furthermore, rainfall data were collected from the three weather stations closest to the experimental orchard (maximum distance of 20 km) and the average precipitation was calculated for the whole sampling period (figure 1).

Coleoptera collection

The epigeal beetles were collected in pitfall traps which were set on a north- facing site, consisting of glass cups 11 cm in diameter and set in the soil for 48 h. The pitfall traps were filled with Scheerpeltz liquid (60% ethanol 97º, 38% distilled water, 1% pure acetic acid, 1% glycerine).

Captured arthropods were separated from the vegetal and inorganic remains, and beetles were identified under a stereomicroscope (Stemi SV8, Zeiss) as to the taxonomic level of order and family.

For the assessment of Coleoptera diversity, the following measures were calculated: family richness, dominance and Hurlbert's PIE (probability of interspecific encounters) index. Family richness and dominance are the most commonly used facet of biodiversity (Purvis and Hector, 2000). The Hurlbert's PIE index indicates the probability of two individuals randomly sampled from the same population belonging to two different families. The indices were calculated by the program Ecosim 7.0 (Gotelli and Entsminger, 2001).

Statistical analysis

With five tree rows as the unit sampling size, a comparison was made between NPC and RPC in terms of total abundance, abundance of different families, as well as the diversity measures in each sampled period. After

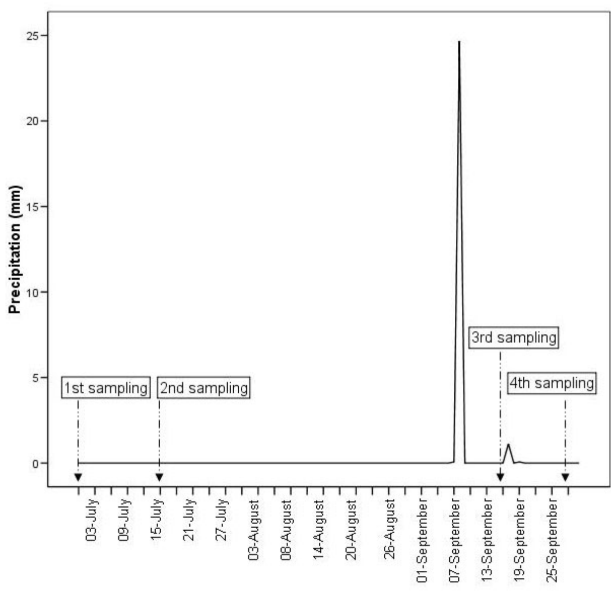

Figure 1. Precipitation (mm) values of the three nearest weather stations from the first to the last sampling.

testing to confirm that the data did not have a normal distribution, a log transformation [Ln (x + 1)] was performed to normalize the data. The parametric Student's t-test for two independent groups was used to test for statistical differences among soil treatments and dates. In addition repeated measures MANOVA within-subject factors (sampling period and soil treatment) was performed in order to analyze the most coleopteran families, using SPSS 15.0 for Windows.

Finally to visualize the results, a Principal Component Analysis (PCA) was performed to relate soil treatments and the abundance of the most abundant families. Calculations and resulting biplots were performed using XLStat (Addinsoft, 2004).

Results

The total number of specimens collected at the end of the sample periods was 348 in the NPC and 617 in RPC (966 beetles altogether). The abundance of collected beetles varied on a monthly basis, the highest numbers being captured in the last sampling, 90 days after the removal of the natural cover (table 1).

The beetles were classified into 19 families, 18 of which being found in RPC and only 16 in NPC (table 1). The most abundant family was Tenebrionidae, accounting for over 50% of the total of captured beetles. Aphodiidae was the second most numerous family (18% of the beetles collected), followed by Silvanidae (10%), Anthicidae (5%), Carabidae (4%), Curculionidae (3%), Cucujidae and Staphylinidae (1%). The 11 remaining families accounted for over 4% of the total of captured beetles (table 1).

Regarding sampling dates, 15 and 30 days after the removal of natural cover, the number of individuals increased significantly in RPC (first sampling: $t = -5.47$, gl = 22, $P < 0.0001$; second sampling: $t = -2.82$, gl = 22, $P < 0.05$). This increase was due mainly to silvanid beetles, which were positively influenced by the elimination of covers. Silvanidae specimens were mainly captured during the two first samplings and presented significant differences with regard to sampling at 14 days ($t = -4.85$, gl = 22, $P < 0.001$) and sampling at 30 days ($t = -2.82$, gl = 13.4, $P < 0.05$). In the third trapping, the number of beetles decreased suddenly in RPC but increased in NPC. In this period aphodiid beetles, which started to become active in September in the olive orchard, were significantly more abundant in NPC ($t = 2.96$, gl = 22, $P < 0.05$), indicating that they preferred covered soils. Finally, in the last trapping, RPC values peaked due to an increase in tenebrionid beetles; this family showed significant differences 90 days after the removal of natural cover ($t = -2.29$, gl = 22; $P < 0.05$), the number of specimens being favoured by this fact. After running the repeated measures MANOVA procedure, the six most abundant families (Tenebrionidae, Aphodiidae, Silvanidae, Anthicidae, Carabidae and Curculionidae) were analyzed, obtaining different significances for the 2 within-subject factors (sampling period and soil treatment). On the one hand, the sampling period significantly contributed to the model in the case of Tenebrionidae ($F = 9.66$, $P < 0.0001$), Aphodiidae ($F = 15.54$, $P < 0.0001$), Silvanidae ($F = 11.214$, $P < 0.0001$) and Anthicidae ($F = 10.62$, $P < 0.0001$), while the same kind of treatment contributed only in Aphodiidae ($F = 6.15$, $P < 0.05$), Silvanidae ($F = 44.41$, $P < 0.0001$) and Curculionidae ($F = 15.63$, $P < 0.05$). On the other hand, the interaction between sampling period and soil treatment showed to contribute to the model only in silvanids ($F = 6.28$, $P < 0.05$).

In order to find a better representation of the six most abundant families and soil treatment, a PCA was performed to establish the relationship between these data, with a total explained variance of 70.6% (figure 2). Axis 1 (39.3% of the variance) represents the family data, covered sampling units in the left corners, and uncovered sampling units in the right corners. As the PCA shows, the removal of the plant cover is related to the presence of silvanids, tenebrionids, and to a lesser extent of curculionids, anthicids and carabids, while the presence of non-managed vegetation in soils seems to favor the presence of aphodiids.

With regard to the diversity measures (table 1), during the first two samplings, 14 days after the removal of vegetation, higher family richness and dominance were found in RPC than in NPC, although in the second sampling, the values tended to become similar. As with the abundance, a different trend was found in the third sampling, since higher family richness and dominance were found in NPC and, only 15 days later (fourth sampling), both richness and dominance again became higher in the RPC. However, no diversity measures showed significant differences among treatments over time.

With regard to precipitation, a few days before the third sampling (8 September), heavy rainfalls were registered (figure 1). Flash storms, even for a few days, can be considered as an erosive factor in bare-soil areas.

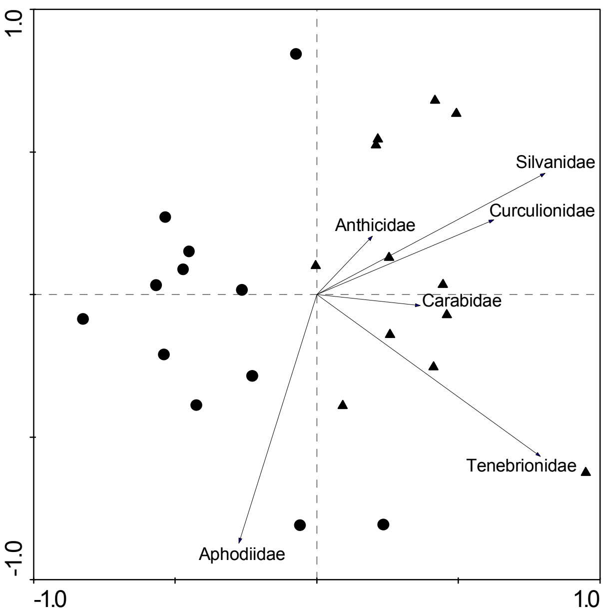

Figure 2. Principal Components Analysis (PCA) of covered (circle) and uncovered sampling units (triangle) and the most abundant families of all sampling periods.

Table 1. Mean and standard deviation (SD) of total abundance, family abundance and diversity measures of beetles captured in natural plant covered (NPC) and in removal plant covered (RPC) over time.

Family	Treatment	14 days Mean ± SD	30 days Mean ± SD	75 days Mean ± SD	90 days Mean ± SD
Tenebrionidae	NPC	0.06 ± 0.20	0.17 ± 0.31	0.12 ± 0.27	1.87 ± 1.17
	RPC	0.35 ± 0.55	0.39 ± 0.50	0.26 ± 0.41	2.87 ± 0.95
Aphodiidae	NPC	0	0	1.62 ± 0.67	1.35 ± 0.96
	RPC	0	0	0.75 ± 0.77	1.18 ± 0.72
Silvanidae	NPC	0.31 ± 0.51	0.17 ± 0.31	0	0
	RPC	1.40 ± 0.58	0.98 ± 0.94	0.06 ± 0.20	0
Anthicidae	NPC	0.51 ± 0.56	0.57 ± 0.65	0	0
	RPC	0.24 ± 0.45	0.81 ± 0.68	0	0.12 ± 0.27
Carabidae	NPC	0.12 ± 0.27	0.17 ± 0.31	0.12 ± 0.27	0.12 ± 0.27
	RPC	0.48 ± 0.58	0.51 ± 0.60	0.12 ± 0.27	0.15 ± 0.36
Curculionidae	NPC	0.09 ± 0.32	0	0.12 ± 0.27	0.12 ± 0.27
	RPC	0.46 ± 0.66	0.26 ± 0.41	0.15 ± 0.36	0.23 ± 0.34
Cucujidae	NPC	0.12 ± 0.27	0	0	0
	RPC	0.29 ± 0.46	0.23 ± 0.34	0	0
Staphylinidae	NPC	0	0.12 ± 0.27	0.12 ± 0.27	0
	RPC	0.21 ± 0.39	0.06 ± 0.20	0	0.06 ± 0.20
Scraptiidae	NPC	0.12 ± 0.27	0.21 ± 0.39	0	0
	RPC	0.12 ± 0.27	0	0	0
Anobiidae	NPC	0.06 ± 0.20	0	0	0.06 ± 0.20
	RPC	0.06 ± 0.20	0.12 ± 0.27	0	0.12 ± 0.27
Cetoniidae	NPC	0	0.06 ± 0.20	0	0
	RPC	0.23 ± 0.45	0	0	0
Cryptophagidae	NPC	0	0	0	0
	RPC	0.06 ± 0.20	0	0.06 ± 0.20	0
Histeridae	NPC	0	0	0.06 ± 0.20	0
	RPC	0	0	0	0.09 ± 0.32
Byrrhidae	NPC	0	0	0	0
	RPC	0.06 ± 0.20	0	0.06 ± 0.20	0
Coccinellidae	NPC	0.06 ± 0.20	0	0	0
	RPC	0	0.06 ± 0.20	0	0
Dermestidae	NPC	0	0.12 ± 0.27	0	0
	RPC	0	0	0	0
Chrysomelidae	NPC	0	0	0	0
	RPC	0	0	0	0.06 ± 0.20
Nitidulidae	NPC	0	0	0.12 ± 0.27	0
	RPC	0	0.06 ± 0.20	0.06 ± 0.20	0.06 ± 0.20
Laemophloeidae	NPC	0	0.06 ± 0.20	0	0
	RPC	0	0	0	0.06 ± 0.20
Average of total abundance	NPC	1.13 ± 0.44	1.06 ± 0.79	1.82 ± 0.52	2.40 ± 1.02
	RPC	2.13 ± 0.45	1.93 ± 0.71	1.11 ± 0.81	3.05 ± 0.93
Family Richness	NPC	5.00 ± 1.00	6.50 ± 0.71	4.67 ± 0.58	3.67 ± 1.15
	RPC	8.67 ± 1.53	7.33 ± 1.53	4.33 ± 2.08	6.67 ± 2.08
Hurlbert's PIE index	NPC	0.83 ± 0.14	0.77 ± 0.16	0.30 ± 0.07	0.46 ± 0.18
	RPC	0.75 ± 0.13	0.79 ± 0.07	0.58 ± 0.38	0.28 ± 0.13
Dominance	NPC	0.36 ± 0.09	0.45 ± 0.20	0.84 ± 0.04	0.68 ± 0.18
	RPC	0.43 ± 0.19	0.40 ± 0.03	0.60 ± 0.30	0.83 ± 0.10

Discussion

The removal of the natural cover (RPC) increased the abundance, family richness, and dominance of epigeal beetles with a significant tendency in the samplings, except for the third sampling period. Therefore, this managed cover instead of non-managed natural cover proved to have some effect on epigeal beetle populations in olive orchards. These effects are evident even over a short-term after the removal. From the results, three situations can clearly be identified. Firstly, 30 days after the removal of the cover (14 July), families such as Silvanidae, which primarily feed on seeds, were encouraged to further explore the open space and as a result found more food, or better climatic conditions and, although richness and abundance increased, the dominance was also higher in bare soils. However, 70 days after removal of covers (14 September), beetle diversity, richness, and abundance suddenly decreased in RPC, while the abundance remained high and even increased in NPC. Precipitation could have had a dramatic impact on beetle communities in RPC. In this sense, aphodiids beetles (strictly coprophagous) appeared to be the most sensitive group to rainfall and due to the lack of cover, they were much more abundant in NPC. The soil surface without vegetation did not offer any shelter and beetles had to take refuge in other places, resulting in more unstable beetle assemblages in uncovered soils. Nearly 20 days after the rainfall (last sampling), beetle abundance and dominance was higher in RPC. Tenebrionids, detritivorous beetles, were the group most significantly abundant in the last period, favoured by the elimination of weeds. The polyphagous families: anthicids and curculionids, as well as the predatory family carababid were favoured by the removal of vegetation, although less numerous than tenebrionids, silvanids and aphodiids, which predominantly seemed to be more related to uncovered soils. There is evidence that soil biodiversity confers stability to stress and disturbance (Brussaard *et al*., 2007), and resistance and resilience appeared to be greater in beetles assemblages in NPC, given that they continued to increase in abundance. Meanwhile, after a rainfall period, RPC values abruptly declined. As discussed above, harvesting and mowing of vegetation significantly alter the microclimate, particularly soil-surface temperatures, and this can affect beetle assemblages, which are sensitive to microclimatic and soil moisture (Perner and Malt, 2003). Consequently, beetles in RPC responded to these changing parameters, making the response of beetle assemblage or some beetle families a quick assessment tool for changes in the agroecosystems.

From the significance tests, silvanids were significantly different keeping into account the interaction between sampling period and soil treatments. The fact that the abundance of the captured silvanids was significantly different over the sampling periods, this family becomes a possible indicator group of impact on soils. Nowadays, carabids and staphylinids are being proposed as indicators groups to assess the soil health, because they are predators and abundant in soils. However**,** several studies show that their populations are favoured by non-managed soils (Castro *et al*., 1996; Fereres, 1997; Andersen, 1999; Marasas *et al*., 2001). In the case of olive orchards higher carabid population was related with higher intensity of soil agronomic practices (Castro *et al*., 1996), but in our study coinciding with others (González *et al*., 2004), they represent a small part of the total captured beetles.

Conclusion

This study shows that the removal of the natural cover (RPC) in organic olive orchards augmented the abundance, richness and dominance of epigeal beetle families captured by pitfall traps (tenebrionids and silvanids). Although an abrupt decrease in primarily tenebrionid abundance might be caused by abiotic factors such as a thunderstorm, a quick assessment tool could be used to evaluate effects of short-term disturbance on soil arthropod in RPC. Silvanid could be used as an indicator group of impact of this soil agronomic practice in olive organic farming, since the removal of any kind of cover in olive orchards is an undesirable practice in terms of erosion protection and in terms of diversity conservation.

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