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RESEARCH ARTICLE

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Effect of cover crops in olive groves on Cicadomorpha communities

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Abstract

Aim of study: To identify the environmental variables that affect the Cicadomorpha communities and the role played by cover crops in olive groves by comparing olive orchards with cover crop to those with bare ground.

Area of study: Córdoba, Spain.

Material and methods: Two study plots, one with cover crop and the other with bare ground, were delimited in three areas of olives orchards. Three passive samplings (May, June and July) were performed in each study plot to estimate the abundance and the species richness of potential Cicadomorphas vectors of Xylella fastidiosa. In each sampling, eight yellow sticky traps (22 × 35 cm) were randomly distributed in each study plot (n = 144 traps).

Main results: The Cicadomorpha communities were mainly affected by landscape variables (such as the total surface and the distance to remnants of natural vegetation) and environmental variables (such as the temperature, moisture or ETo), whereas cover crops played a secondary role in the abundance of the Cicadomorpha.

Research highlights: The results of the study suggest that Cicadomorpha richness and abundance depend on the structural complexity provided by cover crops (positive effect) and live hedges (negative effect), which may be owing to the higher food abundance and shelter when cover crops are present, whereas higher insect predation may occur close to hedges, probably owing to insectivorous song birds.

Additional key words: Auchenorrhyncha; bare ground; ground cover; xylem-fluid feeder insects; sharpshooters.

Abbreviations used: AESs (Agri-Environmental Schemes), AICc (corrected Akaike information criterion), dbRDA (distance-based redundancy analysis), DistLM (distance-based linear model), ETo (potential evapotranspiration expressed in mm per day-1), GPS (global positioning system), PERMANOVA (permutational multivariate analysis of variance), PW (previous week), SIMPER (similarity percentages); SW (sampling week).

Authors' contributions: AJC, JC and FST conceived and designed the experiment. AJC and MS performed the experiment. JC identified the specimens. AJC, MS and JC analysed the data. AJC, FST and JC wrote the paper. All authors read and approved the final manuscript.

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Introduction

The policies of the European Union (EU) have, over the last thirty years, progressively evolved in an attempt to halt the dramatic loss of biodiversity associated with agricultural expansion and intensification (Pe'er *et al.,* 2014). In this respect, the Common Agricultural Policy (CAP) has encouraged the development and promotion of Agri-Environmental Schemes, AESs, (Kleijn & Sutherland, 2003). These AESs include soil conservation practices in olive groves (*Olea europaea* L.), such as using herbaceous ground cover under mower control, in order to promote biodiversity and prevent erosion during the rainy season (Rodríguez-Entrena & Arriaza, 2013; Gómez *et al.,* 2014). One example of AES is cover crop, which consists of an inter-tree herbaceous vegetation strip, although it can also be extended as a continuous covering throughout the crop, which may be natural and spontaneous or cultivated vegetation (Simoes *et al.,* 2014; Guerrero-Casado *et al.,* 2015). Previous studies have shown the positive effect of the diversity of vegetation and landscape complexity on the abundance and diversity of arthropods in olive orchards, where cover crops strongly enhance their communities (Schaffers *et al.,* 2008; Castro *et al.,* 2017) and which also include pest control insect species (Kruess, 2003; Paredes *et al.,* 2013).

Despite its economic importance for agriculture (Dellapé *et al.,* 2013) there is little information about the relations between ecological and environment factors affecting Cicadomorpha communities in crops (Cotes *et al.,* 2011; Dellapé *et al.,* 2013; Markó *et al.,* 2013). Among the available bibliography some studies can be found in woody crops (Mazzoni, 2005; Bleicher *et al.,* 2006; Cotes *et al.,* 2011) and others carried out in grasslands (Morris, 1981; Gibson *et al.,* 1992). However, Hemiptera (group that Cicadomorpha belong), together with Coleoptera, have been described as potential bio-indicators of disturbances in olive crops during post-blooming period (Cotes *et al.,* 2011). Nickel & Hildebrandt (2003) employed Auchenorrhyncha communities as disturbances indicators in grasslands according to the following reasons: i) its high species and individual abundances in grasslands, ii) they form an important component of grassland fauna, iii) Auchenorrhyncha have specific life strategies and occupy specific spatial and temporal niches, iv) its communities have immediate responses changes to management, and v) sampling can be done quickly.

In addition, Cicadomorpha can also have negative effects on crops, acting as pests or vectors of diseases to be xylem-feeder (Frazier, 1965; Novotny & Wilson, 1977; Weintraub & Beanland, 2006; Weintraub, 2007). For example, the leafhopper *Scaphoideus titanus* Ball (Hemiptera: Cicadellidae) act as vector of flavescence dorée, a serious disease for European vine plants (Chuche & Thiéry, 2014). Other plant disease transmitted by the leafhoppers *Recilia dorsalis* Motschulsky (Hemiptera: Cicadellidae) is the rice stripe mosaic virus (RSMV). The rice is the most cultivated cereal around the world, in consequence, the RSMV have important economic repercussions (Yang *et al.,* 2017). Cicadomorpha can act as potential vectors of *Xylella fastidiosa* (Wells *et al.,* 1987), a bacterium that cause the death of many woody crops, such as olive trees, almonds (*Prunus dulcis* Mill) or vineyards (*Vitis vinifera* L), in Central and Southern Europe (EFSA Panel on Plant Health *et al.,* 2019) and in America since the 18th century (Purcell & Finlay, 1979; Purcell, 1997; Hopkins & Purcell, 2002; Almeida & Nunney 2015). This bacterium is xylem-inhabiting and is transmitted by the Hemiptera species, the xylem-fluid feeder species (Janse & Obradovic, 2010). Vectors of the bacterium are present throughout the Mediterranean basin and the threat as a result of its introduction into Europe is consequently significant (EFSA, 2015).

Cover crops may favour the presence of Cicadomorpha (containing Cicadellidae, Cercopidae, Cicadidae and Aphrophoridae families), as occurs with other taxonomic groups (Evans, 1947). Unfortunately, there is neither data on the biology of many Cicadomorpha species nor knowledge regarding the different species' habitat preferences. In the particular case of leafhoppers (Cicadellidae family) its populations are mainly influenced by composition and physical structure of vegetation (Waloff, 1980; Biedermann *et al.,* 2005). Some researchers have showed that the Cicadellidae species richness and abundance are sometimes correlated with plant diversity, height and spatial complexity (Denno, 1994; Achtziger, 1997). However, the vegetation structure is closely related with soil moisture, nutrient status and soil pH (Biedermann *et al.,* 2005). Abiotic factors as temperature have also influence on Cicadomorpha populations, being its abundances increased with summer temperatures in argentine orange orchards (Dellapé *et al.,* 2013). Furthermore, as other arthropod taxa, anthropogenic activities especially in agrosystems can affect to Cicadomorpha populations. An example is the application of biocides treatments to prevent *X. fastidiosa* vectors. Its effectiveness is remain unknown and it is, therefore, relevant to attain a broader knowledge of the role played by cover crops or by patches of remnant natural vegetation (for example, in borders, hedges or streams) (Redak *et al.,* 2004) in the abundance and richness of the Cicadomorpha species. In summary, leafhopper communities are affected (directly or indirectly) by soil and vegetation parameters affected, in turn, by management (Biedermann *et al.,* 2005).

The aim of this study was to identify the environmental variables that affect the Cicadomorpha communities and the role played by cover crops in olive groves by comparing olive orchards with cover crop to those with bare ground.

Material and methods

Study area

The study area comprised three areas of olives orchards located in Cordoba province, Southern Spain. Two study plots, one with ground cover and the other with bare ground (mean ± SD plot size 5.9 ± 1.6 ha), were delimited in each of the three areas (Fig. 1). All the olive orchards selected for this study had undergone the same type of insecticide treatments (comprising patching treatments using 40% dimethoate ($C_5H_{12}NO_3PS_2$) plus hydrolyzed protein), none of which were organic. The elimination of the vegetation cover in plots with bare ground was performed by conventional tillage (consisting of three to four passes, 0.15 m deep, with a rotary tiller (5.5 h.p.) per year, starting after the first rain in late September or early October to control weeds in the streets of the olive groves (Gómez *et al.,* 2009). In addition, for removal of vegetation under the canopy, glyphosate was applied (Piton, 0.36 kg a.e. (acid equivalent) L^{-1}, Dow AgroSciences, Indianapolis, Indiana) at 2.1 kg a.e. ha^{-1} (in both study areas).

The cover crop composition in plot with cover crop in study area 1 was mainly integrated by: Asteraceae (species as *Conyza canadensis* (L.) Cronq. or *Leontodon longirostris* (Finch & P.D. Sell)), Poaceae (species as *Bromus rubens* L. or *Poa annua* L.), *Rubiaceae (Galium murale* (L.) All.), and Fabaceae (*Trifolium* sp.); instudy area 2 was composed by: Asteraceae (species as *Chrysanthemum coronarium* L), Brassicaceae (species as *Diplotaxis catholica* (L.) DC.), and Poaceae (species as *Bromus rubens* L.); while in study area 3 was mainly composed by: Malvaceae (species as *Lavatera cretica* L. or *Malva hispanica* L.), Poaceae (*Hordeum murinum* L. or *Poa annua* L.), and Urticaceae (*Urtica dioica* L.). The climate in the region is characterised by warm dry summers and mild winters, which are typical of the Mediterranean climate (annual average ± SD temperature 17.6ºC ± 7.2ºC between the years 2010 and 2017). Study area 1 corresponded with an average maximum temperature of 26.2ºC, an average minimum temperature of 10.3ºC (the maximum temperature being 42.8ºC and the minimum being 5.1ºC) and a precipitation of 376.6 L in the study

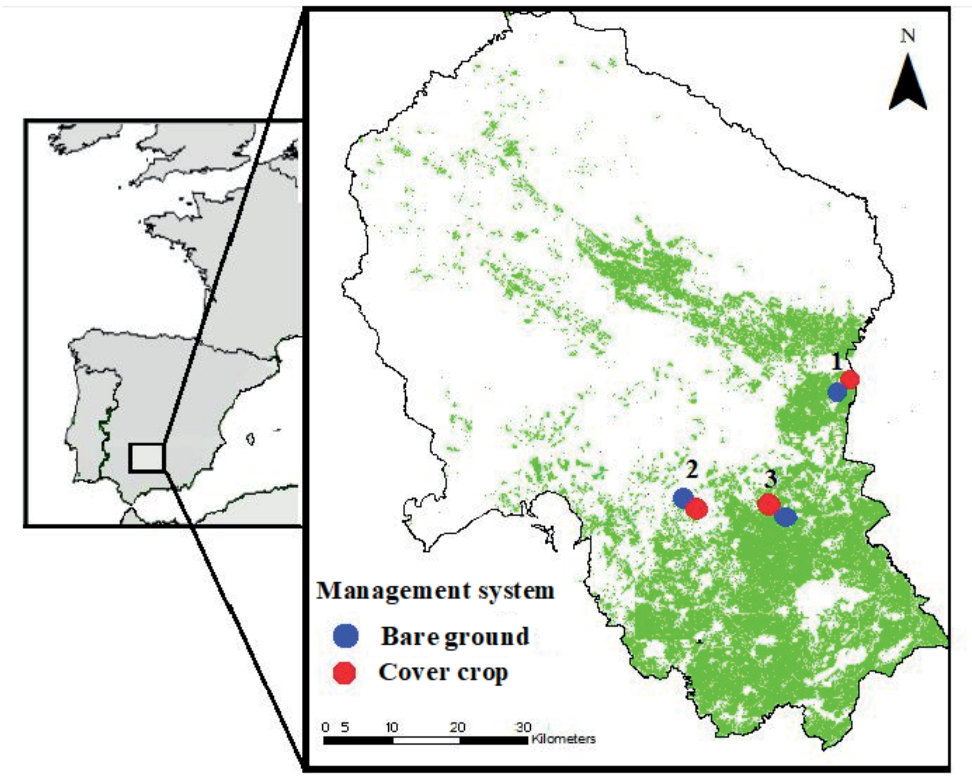

Figure 1. Study plots (coloured points) and distribution of olive groves (green areas) in Córdoba province (Andalusia, Spain).

year. The average maximum temperature in study area 2 was 25.3ºC, while the average minimum temperature was 11.2ºC (the maximum temperature being 38.8ºC and the minimum being 8.8ºC) and the precipitation was 581.2 L. In study area 3, the average maximum temperature was 25.8ºC, the average minimum temperature was 11.1ºC (reaching a maximum temperature of 41.1ºC and a minimum temperature of 6.4ºC) and the precipitation recorded during the climatic year was 334.6 L. The study was performed in a region in which the predominant orchard is populated by traditional olive trees that are between 20 and 100 years old, although there are also areas where the cultivation of other species, such as crop plants or vines, takes place. The cultivated olives were of medium size (3–4 m tall) and their density varied between 100 and 200 trees ha^{-1}.

Experimental design and arthropod sampling

Three passive samplings were performed in each study plot (n = 6) to estimate the abundance and the species richness of Cicadomorpha. The distance between the study plots in each study area was 2.2±1.3 km, and the average distance between the three study areas was 30.2±7.3 km. Sampling was performed in the year 2017, during spring, the period in which this insect group is most active (La Spina *et al.,* 2005). The three samplings were performed in the first weeks of May, June and July. In each sampling, eight yellow sticky traps (22 × 35 cm) (Pedigo & Buntin, 1993; Weintraub & Orenstein, 2004; Weintraub & Beanland, 2006) were randomly distributed in each study plot (n = 144 traps). The traps were placed in olive trees at a height of 1.5-2 m and in a vertical position (Prischmann *et al.,* 2007). The position of each trap was georeferenced by means of GPS in order to calculate the average distance between them and the vegetation. The traps were deployed for a one-week period, after which the captured insects were unglued from the traps by employing ethyl acetate 99.8% and were then transferred to plastic bottles containing 90% of ethanol until identification. Specimens belonging to Cicadomorpha suborder (leafhoppers, froghoppers, treehoppers and cicadas) were identified to species level following the methods described by Della Giustina (1989) and Le Quesne (1965, 1969).

Collection of environmental variables

Owing to the strong effect of environmental conditions on insect activity, the environmental conditions were recorded in each study area (1, 2 and 3) during the previous and the sampling week (PW and SW respectively) (Hay *et al.,* 1996). The environmental data were obtained from agroclimatic stations located close to the three study areas, which were the agroclimatic stations of El Carpio, Córdoba and Baena for study areas 1, 2 and 3, respectively (distance between agroclimatic stations and study areas: 27.4, 25.6 and 18.4 km, respectively). The environmental variables obtained were: maximum, minimum and average temperature, maximum, minimum and average air moisture, precipitation, solar radiation and potential evapotranspiration (ET_o, expressed in mm day^{-1}). Averages per week were calculated for each environmental variable.

Landscape variables

According to Körösi *et al.* (2012) and Fereres (2017), the surrounding vegetation may enhance the presence and abundance of Cicadomorpha (Cicadellidae and Cercopidae) and we, therefore, recorded the distance between each sticky trap and vegetation. The GPS position of the traps was used to calculate the distance to the closest natural vegetation element (including boundaries, hedges and streams). Linear meters of natural vegetation were calculated in a buffer of 500 meters around every plot.

Data analysis

The total and average abundance of each Cicadomorpha species collected were calculated for all the study plots. A Spearman matrix was performed in order to exclude environmental variables with collinearity among them (Acevedo *et al.,* 2005). Two variables were considered to be correlated when $r > 0.8$.

Two generalised linear mixed models (GLMMs) were performed to determine the relationships between environmental variables (type of ground cover treatment, environmental and vegetation variables) with regard to two response variables: Cicadomorpha abundance (Model 1) and Cicadomorpha species richness (Model 2). In these analyses, the study area (3 levels) was considered as a random factor, while ground cover treatment (2 levels: cover crop/bare ground) and date (3 levels: May, June and July) were included as fixed factors. The distance from traps to natural vegetation, the linear meters of natural vegetation and the environmental variables (average temperature, average air moisture and precipitation from the PW and average temperature, average air moisture and ET_o of the SW) were included in the model as covariates. A Poisson function and log–link function were used in both models. The best model was selected by employing the forward-stepwise procedure of selecting the model with the lowest corrected Akaike information criterion (AICc) value. These analyses were carried out using the InfoStat software programme (Di Rienzo *et al.,* 2011).

Dissimilarity and differences in species composition among types of soil management (cover crops and bare ground) were tested using the permutational multivariate analysis of variance (PERMANOVA) (Anderson, 2001). PERMANOVA was employed in order to check significant differences between Cicadomorpha communities according to olive management. This analysis was performed by employing the farming system (2 levels: cover crop and bare ground) as a fixed factor and the environmental variables selected by the previous models (Model 1 and 2) as covariables. Type I Sum of Squares was used, and 9999 permutations were performed with the objective of increasing the power and precision of the analysis (Hope, 1968; Anderson *et al.,* 2008). We also conducted a similarity percentages analysis (SIMPER; Clarke, 1993) so as to determinate which Cicadomorpha species explain the differences in the community composition observed in olive plots with cover vs. bare ground.

The distance-based linear model (DistLM) is analogous to linear multiple regression and was employed to identify the relationship between environmental variables (climate and vegetation) and the biological Bray–Curtis dissimilarity matrix (Anderson *et al.,* 2008). Two DistLM were employed to identify the relationship between samples and environmental conditionals. The first DistLM was performed with a forward procedure, 9999 permutations and R^2 as criteria. The sequential test obtained in this analysis made it possible to select those environmental variables that had a significant effect on variability (p<0.05). These variables were included in the second DistLM and were also performed with 9999 permutations. AICc was employed as a selection criterion (owing to the low ratio of samples/environmental variables), while "best" was employed as the selection procedure (Anderson *et al.,* 2008). Finally, a distance-based redundancy analysis (dbRDA) was employed to visualise the DistLM results as principal components (McArdle & Anderson, 2001).

Results

Descriptive results

A total of 1409 specimens were collected, belonging to 2 families of Cicadomorpha (Cicadellidae and Cercopidae), 3 subfamilies, 10 genders and 11 species (Table 1). However, 30 of the Cicadomorpha could not be identified to the species level owing to damage to the specimens and were, therefore, excluded from the statistical analysis. A total of 979 specimens from 10 species were captured in olive groves with cover crops, while, 400 specimens belonging to 7 species were captured in olive groves with bare ground (Table 1). An average of 9.89 insects was collected per trap. With regard to the sampling period, the greatest number of specimens was collected in June (the second sampling; 1200 individuals); followed

Table 1. Total abundance of Cicadomorpha (Suborder) collected in olives groves with cover crops and bare ground.

Family	Subfamily	Tribe	Species	Cover crop	Bare ground
Cicadellidae	Deltocephalinae	Deltocephalini	*Paramesus* sp.	7	8
		Macrostelini	*Macrosteles variatus*	823	344
			Macrosteles horvathi	1	0
		Athysanini	*Allygus mixtus*	47	18
			Hardya sp.	2	1
			Euscelidius variegatus	28	10
		Opsiini	*Opsius stactogalus*	1	0
		Platymetopiini	*Platymetopius* sp.	66	18
	Typhlocybinae	Erythroneurini	*Hauptidia* sp.	1	0
	Agallinae	Agalliini	*Austroagallia sinuata*	0	1
Cercopidae	-	-	*Cercopis sanguinolenta*	1	0
			Species richness	10	7
			Total abundance	979	400

Table 2. *p*-values and coefficients of variables included in the mixed linear model to explain the abundance (Model 1) and species richness of Cicadomorpha (Model 2). The coefficients for the level of fixed factors were calculated according to the reference value of 'May' for the variable 'date' and 'bare ground' for the variable 'treatment'.

Variable	df	*F*-value	*p*-value	Estimate ± SE
Model 1 (Abundance)				
Date	2	11.65	<0.0001	June 2.42 ± 0.51
				July 1.81 ± 0.52
Treatment	1	7.83	0.0059	Cover crop 0.22 ± 0.08
Distance to vegetation	1	20.26	<0.0001	5.0E-0.3 ± 1.1E-03
Linear meters of vegetation	1	227.13	<0.0001	1.1E-0.3 ± 7.4E-05
Average moisture SW	1	55.64	<0.0001	-0.20 ± 0.03
ET_o SW	1	4.88	0.0288	-0.43 ± 0.20
Average temperature SW	1	5.92	0.01163	-0.11 ± 0.05
Model 2 (Richness)				
Linear meters of vegetation	1	3.17	0.0772	3.6E-04 ± 2.0E-04
Average moisture SW	1	22.09	<0.0001	0.08 ± 0.02
ET_o SW	1	21.21	<0.0001	0.71 ± 0.15

ET_o: potential evapotranspiration expressed in mm per day^{-1}. SW: sampling week.

by the May and July samplings (102 and 89 specimens, respectively).

Environmental factors affecting the abundance and species richness of Cicadomorpha

Model 1 showed significant effects of the sampling date, ground cover treatment, distance to vegetation, linear metres of vegetation, ET_o, average temperature and moisture of the SW on the abundance of cicadellids and cercopids (Table 2). The distance to the vegetation and the linear meters of vegetation had positive correlation on the abundance (that is, a lower abundance of insects closer to natural vegetation remnants), whereas the moisture, the ET_o and the average temperature had negative effects on abundance (Table 2), while average temperature, average moisture and precipitation of the PW showed no effect. With regard to the ground cover treatment, plots with cover crops had a significantly higher abundance of Cicadomorpha than did the olive groves with bare ground. Furthermore, and with regard to the sampling date, the highest abundance of specimens was recorded during the month of June, followed by May and July. Model 2, related the Cicadomorpha richness to the environmental variables, found a significant effect of the average moisture and ET_o of the SW. As in the case of abundance, the PW variables did not show any relationship. The linear meters of vegetation did not have a significant relationship with the species richness, although it was retained by the best model (Table 2). In accordance with the results obtained in Models 1 and 2, the environmental variables distance to vegetation, linear meters of vegetation, average moisture (SW), ET_o and average temperature (SW) were employed as covariates in the PERMANOVA analysis.

Differences in Cicadomorpha communities

The PERMANOVA supports the presence of the effects of treatment and sampling date on Cicadomorpha communities obtained in the GLMM models. The interaction between both factors also had a significant effect on the communities' composition. All the environmental variables indicated by Models 1 and 2 were significant for Cicadomorpha, with the exception of the ET_o for the sampling week. The pair-wise results of the interaction between soil management systems and sampling date indicated significant differences in the Cicadomorpha communities recorded in May and June, but not for July (Table 3). The dissimilarity in Cicadomorpha species composition between cover crop and bare ground treatments were 37%, 51% and 33% for May, June and July, respectively, and only the differences observed in May and July were significant (Table 3), suggesting seasonal changes in Cicadomorpha communities.

According to the SIMPER results, the average dissimilarity in Cicadomorpha species between both olive managements was 88.1% and 4 species were responsible for 94% of this dissimilarity. The species that contribute most

Table 3. PERMANOVA analysis of Cicadomorpha communities based on olive management systems and sampling date, including covariables selected by generalized linear mixed models (GzLMMs) and result of pair-wise test.

Variable		df	MS	Pseudo-F
Date	Treatment	1	4031	4.51**
Factors	Date	2	3167	35.46***
	Treatment × Date	2	2697	3.02**
	Distance to vegetation	1	2931	3.28*
Covariables	Linear meters of vegetation	1	3846	4.30**
	Average moisture SW	1	8658	9.69***
	ET_o SW	1	2234	2.50
Residuals		133	893	
Total		143		
Pair-wises test		**df**	**t**	**Dissimilarity**
May: Cover crop vs. bare ground		1	2.03*	37.42
June: Cover crop vs. bare ground		1	1.78*	50.82
July: Cover crop vs. bare ground		1	1.46	33.30

* $p < 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$. SW = sampling week.

to dissimilarity of communities between cover crop and bare ground were *Macrosteles variatus* (Fallén, 1806), *Platymetopius* sp., *Allygus mixtus* (Fabricius, 1794) and *Euscelidius variegatus* (*Kirschbaum*, 1858), which contribute to dissimilarity with a 46.32%, 16.42%, 16.17 and 9.45% respectively.

Environmental factors affecting the Cicadomorpha communities

The sequential test performed by means of the first DistLM indicated that eight environmental variables had a significant effect on the structure and composition of Cicadomorpha communities and that they should be included as possible candidates with which to build a model (moisture average SW, ET_o SW, moisture average PW, solar irradiation PW, linear meters of vegetation, ET_o PW, temperature average PW and precipitation SW) (Table 4).

The second DistLM, which was performed with the eight environmental variables mentioned above, indicated that the best model excluded just one of these environmental variables: precipitation SW (probably owing to its low occurrence in Mediterranean hot-dry summers). The model composed of the seven remaining variables had an AICc value of 983.3 and its first two axes explained 86.5% of the fitted variation and 38.4% of the total variation, respectively (Fig. 2).

Table 4. Results of sequential test of distance-based linear model (DistLM) for selection of environmental variables that could be included in the best model.

Variable	R^2	SS (trace)	Pseudo-F	*p*-value
Moisture average SW	0.24	52853	47.04	0.001
ET_o SW	0.28	7171	6.63	0.001
Moisture average PW	0.33	10749	10.62	0.001
Solar irradiation PW	0.36	7222	7.47	0.001
Linear meters of vegetation	0.39	5897	6.33	0.001
ET_o PW	0.42	5543	6.17	0.001
Temperature average PW	0.44	4773	5.49	0.004
Precipitation SW	0.46	3509	4.13	0.008
Temperature average SW	0.46	601	0.70	0.563
Distance	0.46	921	1.08	0.359
Solar irradiation SW	0.46	-4.82E-11	0	1

PW: previous week. SW: sampling week.

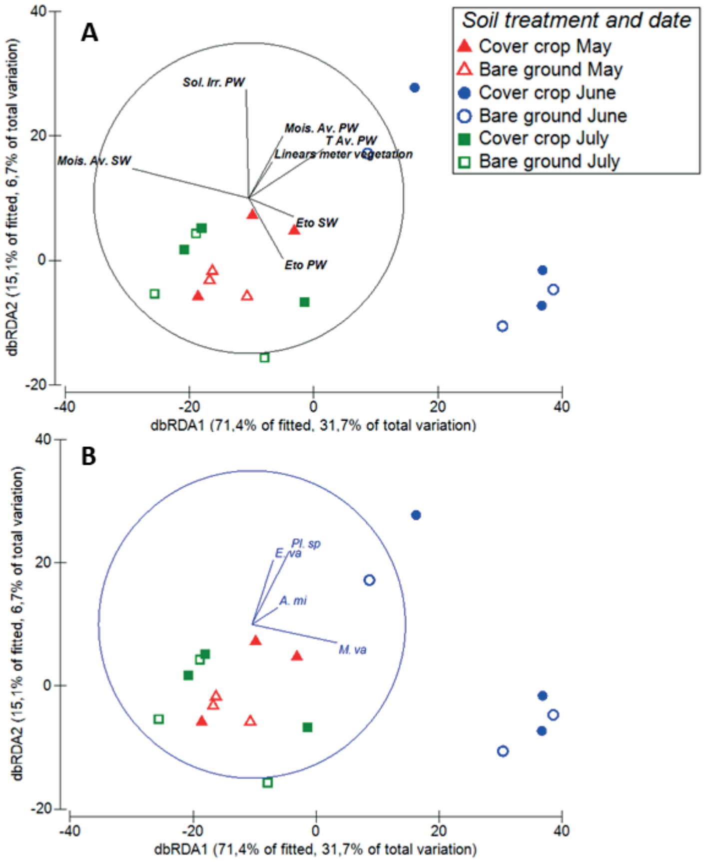

Figure 2. Distance-based redundancy analysis (dbRDA) of community responses to soil treatment and sampling date showing (a) vector overlays of predictor variables and (b) vector overlays of species responses. *Sol. Irr. PW,* solar irradiation previous week; *Mois. Av. PW,* moisture average previous week; *Mois. Av. SW,* moisture average sampling week; *T AV. PW,* temperature average previous week. Pl. sp, *Platymetopius* sp.; E. va, *Euscelidius variegatus;* A. mi, *Allygus mixtus;* M. va, *Macrosteles variatus;* P. sp, *Paramesus* sp.

With regard to the environmental variables, it is possible to see a negative relationship between the first axis and the average amount of moisture in the sampling week (Fig. 2a). Some environmental variables, such as linear meters of vegetation, average temperature PW and ET_o SW, meanwhile, had a positive relationship with the first axis. The second RDA axis was related to solar irradiation PW (positive relationship) and ET_o PW (negative relationship), as shown in Fig. 2a.

The superimposition of the vector representing the relationship between the Cicadomorpha species and the dbRDA axes is owing to the strong relation between *M. variatus* and the first axis (Fig. 2b). The vectors that represent the species *A. mixtus, Platymetopius* spp and *E. variegatus* (Fig. 2b) have a similar direction and position to the vector of average moisture PW, linear meters of vegetation and the average of temperature PW (Fig. 2a), thus underlining possible relations between these variables and species.

Discussion

Of the 1379 specimens identified, only one is characterised as being a xylem-feeder (one specimen of *Cercopis sanguinolenta, Kirschbaum,* 1868) being phloem-sap feeding insects the remaining species. Olive groves with cover crops had the highest abundance of Cicadomorpha (phloem-fluid feeding), but this was not the case for species richness. Environmental variables, structural complexity (e.g. hedge or ditches), along with the presence of a cover crop increased the abundance of Cicadomorpha. Interestingly, the distance to vegetation showed a positive relation with the abundance (i.e.

a lower abundance close to hedges with remnants of natural vegetation).

Effect of cover crop and hedges and environmental factors on the abundance and species richness

The relationship between plants and arthropod communities is complex. Bengtsson *et al.* (2005) found that organic farms (on which a large number of weed communities are still present) have a higher abundance of arthropod predators, while non-predatory insects and pests did not increase. Predatory and parasitic arthropod communities are often dependent upon the food that is available during different insect stages. Many predators and parasitic arthropods feed on non-prey foods, such as pollen, during their adult phase (Coll & Guershon, 2002), which provide some additional nutrients to those obtained from their host (Zhong-Xian *et al.,* 2014). In our study plots, we found that the frequency of occurrence of Cicadomorpha was positively influenced by the presence of vegetation cover, which agree with previous studies carried out in agricultural landscapes (McClure, 1982; Altieri *et al.,* 1985; Masters, 1998; Körösi *et al.,* 2012; Helbing *et al.,* 2017). Shelter such as bushes or shrubs have been identified as key habitat resources that lead to an increase in the abundance of Cicadomorpha (Redak *et al.,* 2004). On the contrary in this study we interestingly found lower Cicadomorpha abundance close to edges and shrubs. Our results showed that the main factor to negatively affect the abundance of the Cicadomorpha species is the presence of remnants of natural vegetation. Traps located close to the edges captured fewer specimens than those placed in central areas of the olive orchards. The lower abundance of Cicadomorpha close to hedges may be the result of a higher abundance of predation on insects. Castro-Caro *et al.* (2015) found that the abundance of insectivorous songbirds in olive orchards was highly correlated with the percentage of hedge cover in a short radius (up to 50 m) around the sampling spots. Another possible cause of the low abundance of Cicadomorpha could be that the sticky traps were not located out in the vegetation cover, where the abundance of the cicadomorpha is high during spring (Morente & Fereres, 2017).

All Cicadomorpha species captured (except one specimen of *Cercopis sanguinolenta*) were phloem-sap feeding insects and it is, therefore, unlikely that they transmit the *X. fastidiosa* bacterium. Our results on the absence of *X. fastidiosa* vectors are noteworthy, since the use of herbicides to control *X. fastidiosa* vectors (which is currently mandatory in Apulia, where the olive infection is now firmly established) is inadvisable, or at least when there is no empirical evidence of *X. fastidiosa* vectors. Moreover, previous studies have shown that olive groves with bare ground can reduce the diversity of arthropods owing to the explosion of certain dominant groups, while arthropod diversity is positively affected by cover crops (Carpio *et al.,* 2019).

The sampling date also had an effect on the frequency of cicadellids, with a high frequency of occurrence in June owing to the phenology of *M. variatus,* the most abundant species collected in that month (88% of the specimens were recorded in June) as also found in German vineyards by Riedle-Bauer *et al.* (2006), who mainly captured this species in June-August. What is more, La Spina *et al.* (2005) found a higher abundance of another species of the same genera, *Macrosteles quadripunctulatus* (*Kirschbaum*, 1868), during the same period.

With regard to the environmental variables, we found that average moisture SW, average temperature SW and ET_o SW were negatively related to the abundance of Cicadomorpha.

With respect to the insect-plant assemblages, our results coincide with those found previously as regards the abundance of both leafhopper species (Brown *et al.,* 1992) and other groups of insects, showing the great influence of the composition and physical structure of vegetation at a local scale (Andrzejewska, 1965; Biedermann *et al.,* 2005; Hollier *et al.,* 2005). However, Altieri *et al.* (1985) found a higher abundance of leafhoppers in monospecific clover mulch when compared to those with a more diverse weed cover.

The average moisture reduced the Cicadomorpha abundance; however, this environmental variable had beneficial effects to Cicadomorpha species richness. Our findings showed only a positive relation of species richness with average moisture SW and ET_o SW. However, the results did not show any positive relation between species richness and cover crop or habitat variables. This may be owing to the fact that moisture and ET_o have a similar effect on species richness because ET_o is related to environmental variables such as temperature and moisture. In Mediterranean agroecosystems, which have extremely high temperatures in summer, high values of moisture may reduce the limiting influence of temperature on the development of some species. What is more, higher moisture values allow the development of more plant species that can provide shelter and a food source for a greater number of Cicadomorpha species. Nickel & Achtziger (2005) described the key role of moisture for the recovery of leafhopper communities in meadows with extensive land use. However, the same authors did not find any relationship between the number of leafhopper species and plant communities, as occurred in the present study.

Effect of the cover crop and hedges on Cicadomorpha community assemblage

Our results show that abundance and distance to remnants of natural vegetation, along with the sampling date and cover crop and their interactions, influenced community assemblage. However, only one environmental variable, the average moisture in SW, affected the insect community sampled. Olives with cover had twice the number of specimens and three species more when compared to olive groves with bare ground. The main species of Cicadomorpha communities indicated by the SIMPER procedure (*M. variatus, Platymetopius spp, A. mixtus* and *E. variegatus*) were found in higher abundance in olive groves with cover crops than in those with bare ground (see Table 1). These results highlight the benefits of the presence of plant communities for Cicadomorpha, as described in previous studies (Murdoch *et al.,* 1972; Denno & Roderick, 1991; Denno, 1994). The strong and fast response of Cicadomorpha communities to the management of grasslands (such as cutting, grazing and fertilizing) led Nickel & Hildebrandt (2003) to employ them as indicators of disturbance in grasslands. The same authors state that species' life strategies are correlated with the level of perturbation in ecosystems, with generalist species being more abundant in disturbed ecosystems, and the specialist species in low disturbed ecosystems. This observation is supported by the influence of vegetal variables on Cicadomorpha communities. The influence of the sampling date on the composition of the Cicadomorpha community is mainly related to the peak of the *M. variatus* population recorded in June for olive orchards with both cover crops and bare ground. Of the other species, *E. variegatus* and *Platymetopius* sp. also underwent an increase in June when compared to May and July. Changes in Cicadomorpha communities on a small-time scale were also observed by Brown *et al.* (1992), although they observed a peak of populations in the period late July-early August. They attributed these changes in abundance and community composition to a successive process. However, the main change to take place in the Cicadomorpha community in June occurs in the case of the *M. variatus* and coincides with half the flowering period of *U. dioica* (from May to July), its nutritional plant (Taylor, 2009). *U. dioica* is a species that is associated with an anthropogenic environment, typical of urban riparian habitats that are highly disturbed, and is commonly found in olive crops (Maskell *et al.,* 2006; Perrino *et al.,* 2014).

In conclusion, Cicadomorpha richness and abundance were affected by structural complexity provided by cover crops (positive effect) and live hedges (negative effect), which may be owing to the higher food abundance and shelter when cover crops are present, whereas higher insect predation may occur close to hedges, probably owing to insectivorous song birds. However, further research should be done considering different weather conditions (humid or dry years), different cover crop species and managements or different sampling dates.

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