J. Insect Biodivers. Syst. 09 (1), 17–32 *https://jibs.modares.ac.ir*

Tarbiat Modares University Press
Entomological Society of Iran
OPEN ACCESS
Research Article
Biodiversity
https://doi.org/10.52547/jibs.9.1.17 **ISSN**: 2423-8112
https://zoobank.org/urn:lsid:zoobank.org:45E42524-CF7F-44CB-9BBA-3435ED490CFD

Interactions between wild flora, crops, aphids (Hemiptera, Aphididae) and their natural enemies in citrus orchards

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ABSTRACT. The survey was carried out in some citrus orchards in the area of Bernalda, in the region of Basilicata, south Italy. Aphids and their natural enemies were monthly sampled from citrus tree canopies and spontaneous plants in four citrus orchards differently managed (organic and conventional with and without herb layer). Four weed species (*Rumex crispus*, *Sonchus oleraceus*, *Euphorbia peplus* and *Vicia* sp.) were reported as hosts of four non-pest aphids of citrus, which were *Myzus persciae*, *Acyrthosiphon pisum*, *Hyperomyzus lactucae* and *Aphis rumicis*, serving as preys for natural enemies including coccinellids (Coleoptera, Coccinellidae), lacewings (Neuroptera, Chrysopidae), hoverflies (Diptera, Syrphidae) and various parasitoid species (Hymenoptera, Braconidae) that were recorded on citrus canopies. Statistical analysis of collected data showed a positive correlation between weed management systems and wild plants hosting aphidophagous communities. Furthermore, organic weeding approaches had a positive effect on aphidophagous richness and abundance, whereas the conventional weeding method could cause scarcity of aphid natural enemies, but interactions among strata (entomofaunal diversity on citrus tree canopies & wild plant cover) are still unclear. Overall, this work is a further step towards the investigation of the interaction between plants, crops and arthropods in citrus orchards in the Mediterranean basin to make weed management strategy a key for aphid management in crops.

Key words: Citrus, wild flora, aphids, Basilicata, natural enemies, diversity

Received:
21 August, 2022
Accepted:
04 November, 2022
Published:
01 January, 2023
Subject Editor:
Behzad Miri

Citation: Ali-Arous, S., Meziane, M., Djelouah, K. (2023) Interactions between wild flora, crops, aphids (Hemiptera, Aphididae) and their natural enemies in citrus orchards. *Journal of Insect Biodiversity and Systematics*, 9 (1), 17–32.

INTRODUCTION

Citrus orchard hosts several pests and diseases, and some of them are very harmful to citrus trees. Aphids (Hemiptera, Aphidoidea) are an important group of insects in Italy as they are throughout the world (Addante et al., 2009). Aphids belong to the most important agricultural pest worldwide (Hulle

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et al., 2020), causing direct damage by plant feeding and indirectly as vectors of plant viruses (Conti, 1985; Blackman & Eastop, 2000; Katis et al., 2007; Yokomi et al., 2018). Citrus aphid pests are generally controlled by chemicals (Chouibani et al., 2001). Pesticides, whether synthetically or botanically derived, are powerful tools and should be used with caution (Furk et al., 1980; Sun et al., 1987; Hosoda et al., 1992). However pesticides decrease the biodiversity of a system, creating the potential for instability and future problems (Altieri, 1999; Altieri & Nicholls, 2004). Moreover chemicals acquired from the plant by the phytophagous pest can be transmitted to predators at the higher trophic level. These chemicals can affect the growth and fecundity of the beneficials (Vrienling et al., 1991).

The performance of natural enemies in agricultural systems is often limited by the absence or scarcity of essential resources (van den Bosch & Telford, 1964). Habitat management presents an opportunity to enhance the suppression of pests by natural enemies, thereby increasing the role of biological control in pest management systems (Landis et al., 2000, 2005). Arthropod communities exploiting the soil, the grass and the canopy cohabit within the orchard and contribute to its richness (Miliczcky et al., 2000). As high levels of beneficial arthropods are displayed within the herb cover, whereas a low level of predation and pest control are observed in the arboreal strata (Simon et al., 2007), strong interactions among strata are not always established in field experiments (Simon et al., 2010). There is therefore a need for basic research in arable systems to understand the links between biodiversity, ecosystem function and sustainability. The success of such efforts depends on knowledge of the pests and beneficial organisms within the cropping system (Altieri, 1991). Orchard flowering weeds enhance aphid pest control by feeding aphidophagous syrphids (Wyss, 1995). Many studies on biodiversity profits for perennial crops, including citrus trees, were associated to plant protection and they mainly relied on boosting plant diversity that favours animal diversity, including birds, mammals and arthropods (Simon et al., 2010). A higher level of pest control is thus expected, at least for some pests, through an increase in the abundance and the richness of their natural enemies, in the framework of conservation biological control (Barbosa, 1998).

Due to the lack of detailed data describing the behaviour of aphids on different weeds, manipulation of weedy host plants in cultivated areas may result in crop damage caused by aphid outbreaks (Perng, 2002). The objective of this study was to determine the relationship between aphids, their natural enemies and wild plants in differently managed citrus orchards and to provide information to aphid control and weed management programs.

MATERIAL AND METHODS

The survey was conducted from April to July 2008 in Basilicata Region. Four experimental plots were chosen in the area surrounding Bernalda in the province of Matera located at 127 meters above sea level. Two of four orchards were located in the Pantanello farm, coded as PAN1 the unweeded and as PAN2 the weeded one, together constituting the organic orchards (group A). The other two were located in the Florio farm, 5 km West of Pantanello farm (Fig. 1), coding as BER1 the weeded and as BER2 the unweeded one, together constituting the conventional orchards (group B).

The selected orchards were managed differently according to the type of farming and the current situations (pest appearance, climate, etc.). To summarize, during this year a complex fertilizer (NPK) was applied to both orchards of the Pantanello farm, followed by an application of acaricide to control citrus mites in spring, the weeding in PAN2 has been done mechanically earlier at spring using an inversion tillage technique. Orchards of the Florio farm were treated during winter with white oil against scales; the weeding in BER1 has been done mechanically, and there was not any other treatment or fertilization. Orchard characteristics are shown in Table 1. A preliminary investigation has been carried out in order to know the detailed farming practices usually carried out in the orchards (Table 1).

We have also mde a general characterisation of the biotope surrounding the study areas. The landscapes surrounding each selected citrus orchard were different. The conventionally managed orchards PAN1 and PAN2 were located amid a wide cultivated area belonging to the same Pantanello farm. There were several species of fruit trees, and protected cultures (greenhouses) managed by the IPM strategy (Fig. 2). BER1 and BER2 were located in the middle of a more diversified landscape characterized by wetlands, a river, woody areas, pastures and grassland (Fig. 3).

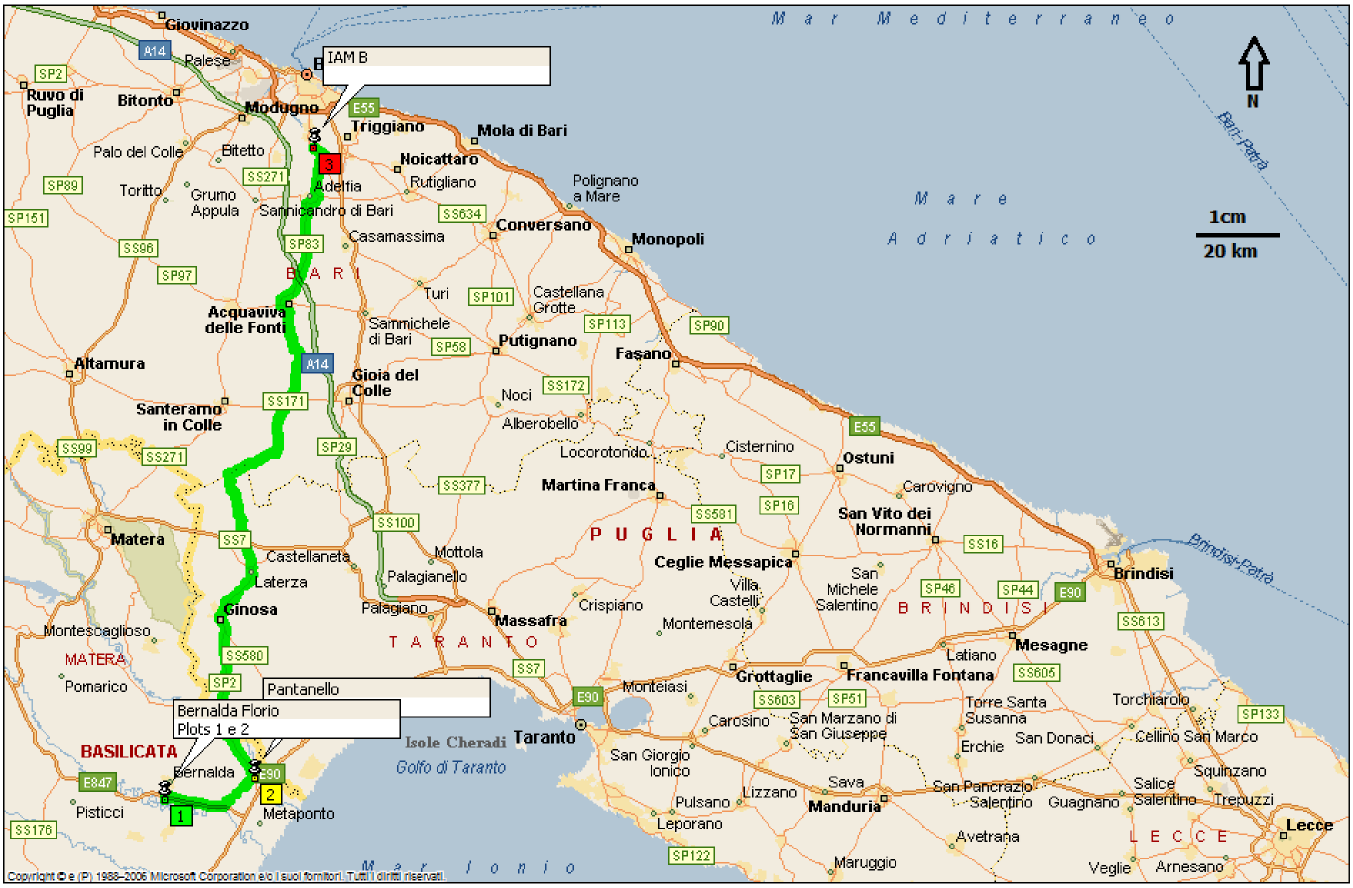

Figure 1. Map with the location of the experimental plots.

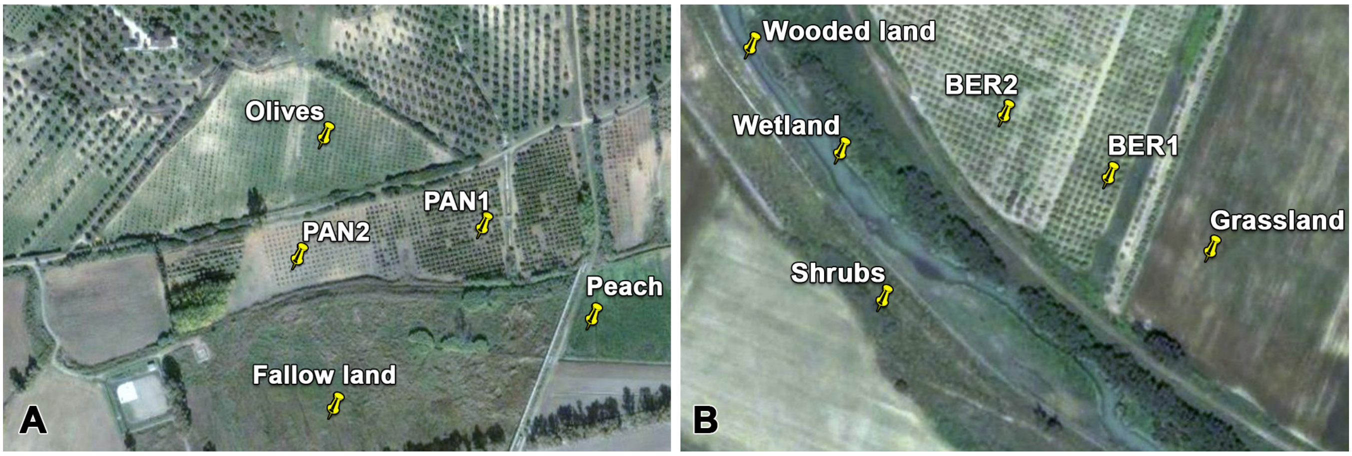

Figure 2. Details of the sampling areas. **A.** Organic weeded BER1, unweeded organic BER2; **B**. Unweeded conventional PAN1 and weeded conventional PAN2.

Table 1. Characteristics of the selected citrus orchards.

	Pantanello farm		Florio farm	
Name of orchard	Pantanello 01	Pantanello 02	Bernalda 01	Bernalda 02
Coordinates data	N 40.390, E 016.174	N 40.390, E 016.171	N 40.392, E 016.654	N 40.392, E 016.653
Code of orchard	PAN1	PAN2	BER1	BER2
Variety	Navels	Navels	Navels	Navels
Type of management	Conventional, With weeds	Conventional, Weeded	Organic, Weeded	Organic, With weeds
Type of irrigation	Drip irrigation	Drip irrigation	Drip irrigation	Drip irrigation
Soil texture	Sandy clay loam	Sandy clay loam	Clay loam	Clay loam
Age (years)	20	8	20	20
Surface (ha)	1.5	4	2	3
Planting distance (m)	5*5.5	5*6	5*5.5	5*6

Field survey and collection of plant material. The composition of the wild plant community varies in time and space, being related to soil, climatic conditions and to farming practices. To start with this kind of studies it is essential to adopt an adequate sampling design. There are mainly two different kind of sampling designs, randomised sampling and systematic one. Systematic sampling consists in considering samples taken from the same units with a regular interval of time. In our case, field surveys were performed monthly on the same sampling areas (trees) for arthropods and wild plants but obviously applying different protocols. The sampling survey were done on a surface of 1 ha per orchard choosing 5 trees falling on the diagonal line of each orchard by considering one tree and skipping the next until counting 5 trees. Because of the heterogeneous distribution of the wild plants, the tree canopies have been divided into 4 parts according to the cardinal points. We placed one quadrate of 25 x 25 cm in correspondence of each cardinal point on the soil at the base of each tree, about 50 cm away from the tree trunk and corresponding to the projection of the tree canopy (Fig. 3).

Wild plant assessments. At each site, the wild plant community was assessed monthly, from April to July. At each sampling date, the relative abundance index RAI= (Drel+Frel)/2 was calculated. The relative density (D_{Rel}= Ni x 100/N), where Ni is the ratio of the number of individuals of a plant species found in a given environment and N is the total number of individuals of all combined plant species. The relative frequency (F_{Rel}=Pi/P*100), Pi: total number of samples containing the considered plant species; P: total number of samples recorded (Dajoz, 2006). The flora species gathered were conserved in a herbarium, which included plant species of each site before being identified by botanists of the department of organic agriculture (CIHEAM-Bari, Italy).

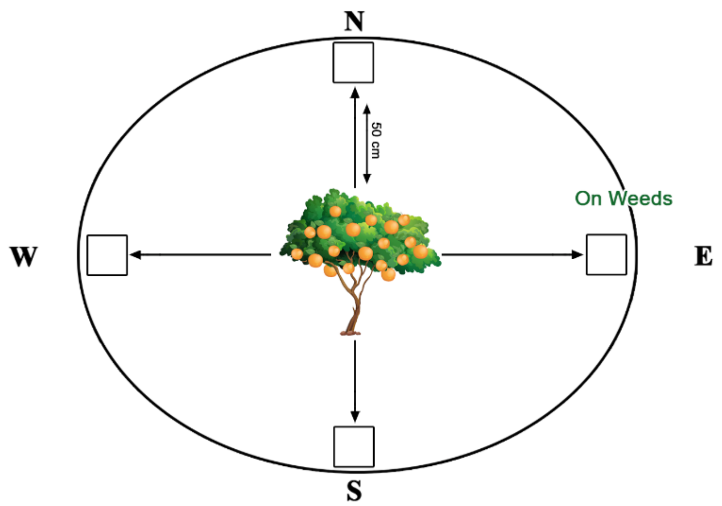

Figure 3. Placement of the quadrates used for sampling wild plant communities.

Collection of arthropods on wild plants. Both aphids and their natural enemies were collected from wild plants monthly on the 5 selected trees of each orchard. All the plants falling into each frame (sampling area) were collected and put into plastic bags. Species were kept separated by species and frame. Visual observation has been done on each sampled plant by a magnifying lens and at the laboratory by using a stereoscopic microscope. All the life stages of the arthropods were identified and recorded, thus observing: eggs, larvae, nymphs, and pupae of both aphids and beneficials. Parasitized aphids reared at room temperature under 18 hours of photoperiod for 12 days. Leaves were replaced on the fourth and seventh days until the emergence of the adults' parasitoids from the mummies. All identifications have been carried out at the Laboratory of Zoology, by Dr Rocco Addante, Università degli Studi di Bari, Department of Soil, Plant and Food Sciences. Arthropods were identified up to family, genus or species (as far as possible).

Collection of arthropods on citrus trees. On each of the five trees per orchard, eight shoots were monthly observed chosen at different height and orientations and collecting eight infested shoots per tree in case of infestation. Infested shoots have been put in polyethylene bags and examined in the laboratory, where some aphids were collected from each shoot with a smooth brush and then stored into little vials containing 70% ethanol. In each vial a label was added on which collection information and a code number related to a note-book was written (Eastop, 1972). Collected samples of aphids were mounted on slides at laboratory and identified following the protocol of Blackman & Eastop (2000); all the others were stored in the vials with ethanol.

Identification of aphids and their natural enemies. Identification is a task of taxonomists. Nevertheless an identification of citrus aphids up to genus or species (when possible) level was made at the University Aldo Moro of Bari using the keys of Blackman & Eastop (2000). In same way different natural enemies species were identified at Bari University.

Statistical analysis. Prior to start the statistical analysis we have merged the data of the four cardinal points. This decision has been taken based on a preliminary multivariate analysis with the programme CANOCO that showed no correlation of the effect of the cardinal orientation on the spontaneous plant composition and density. Bartlett's test was performed first to ascertain homogeneity of variances, and appropriate data transformation was performed on the variables that had no homogenous variances. To compare the effect of management on the tested variables One Way Completely Randomized ANOVA has been used. When ANOVA showed significant differences between the studied variables Fisher's LSD (Least Significant Difference) test was performed ($P \leq 0.05$) to group treatment means. Statistical analyses of various parameters studied have been illustrated in charts. Significant differences obtained between management types and tested parameters during sampling dates have been shown in the graphs by means of the appropriate letters, considering that variables marked by the same letter did not show significant differences for $P \leq 0.05$. During this statistical analysis, we gave the name "host plants" for the four species *Rumex crispus* L., *Sonchus oleraceus* L., *Vicia* sp., and *Euphorbia peplus* L. This means that the mentioned species were found able to host the aphid species and their natural enemies in the citrus orchards.

RESULTS

Wild plants in the selected citrus orchards. In the four citrus orchards, 32 plant species were recorded, which belonged to 20 botanical families. Two of these families were monocotyledonous (including 6 species) and 18 were dicotyledonous (including 26 species). The complete list of wild plant species retrieved in the orchards is provided in Table 2.

Wild flora wealth in the four orchards. The mean RAI (Relative Abundance Index) of each wild plant species per orchard of the four sampling date altogether are presented in the Table 3.

Table 2. Classification of the wild plant species recorded in the citrus orchards.

Group	Family	Species
Dicotyledonous	Oxalidaceae	*Oxalis pes-caprae*
	Polygonaceae	*Rumex crispus*
	Umbelliferae	*Aethusa cynapium*
	Asteraceae	*Calendula arvensis; Chrysanthemum segetum; Conyza canadensis; Picris hieracioides; Sonchus oleraceus*
	Scrophulariaceae	*Veronica cymbalaria*
	Equisetaceae	*Equisetum hyemale*
	Rubiaceae	*Galium aparine*
	Orobanchaceae	*Orobanche uniflora*
	Fabaceae	*Hedysarum* sp.; *Medicago polymorpha; Ornithopus compressus*; *Vicia* sp.;
	Araceae	*Arisarum vulgare*
	Euphorbiaceae	*Euphorbia peplus*
	Primulaceae	*Anagallis arvensis*
	Papaveraceae	*Papaver rhoeas*
	Malvaceae	*Malva parviflora*
	Convolvulaceae	*Convolvulus arvensis*
	Chenopodiaceae	*Chenopodium album; Chenopodium quinoa*
	Solanaceae	*Solanum nigrum*
	Portulacaceae	*Portulaca oleracea*
Monocotyledonous	Poaceae	*Avena* sp.; *Cynodon dactylon*; *Lolium perenne*; *Lolium* sp.; *Phalaris* sp.
	Cyperaceae	*Cyperus rotundus*

Sonchus oleraceus was the main dicotyledonous species in BER1 (RAI = 10), it ranked second in BER2 (RAI = 10.40) and PAN1 (RAI = 9.26), whereas PAN2 was almost clean of wild plants. *R. crispus* was the most abundant dicotyledonous species in BER2 (RAI = 11.07) but less frequent in BER1, PAN 1 and PAN 2. *O. pes-caprae* was the main dicotyledonous species in PAN1 (RAI = 13.37), but less represented in BER2 (RAI = 8.27) and BER1 (RAI = 3.32). The presence of *Vicia* sp., and *E. peplus* was scarce. The rest of the dicotyledonous species were moderately represented.

Identification of aphids and related antagonists. During the investigation on the four orchards, many aphid species and antagonists were found associated with wild plants and citrus trees. Table 4 shows the aphid guild recorded on citrus and weeds. In citrus orchards, *A. gossypii* Glover, 1877 and *A. spiraecola* Patch, 1914 were the most commonly recorded aphid species, in addition to *A. fabae* Scopoli, 1763 which has been encountered on citrus in April only. While, in plants naturally occurring in the citrus crop, *Rumex crispus* served as host for *Aphis rumicis* (Linnaeus, 1758), whereas *Sonchus oleraceus, Euphorbia peplus* and *Vicia* spp. hosted *Acyrthosiphon pisum* (Harris, 1778), while *Myzus persciae* (Sulzer, 1776) and *Hyperomyzus lactucae* (Linnaeus, 1758) were found on *Sonchus oleraceus*.

Effects of management systems on plants, aphids and natural enemies. ANOVA applied to the relative density of wild plants hosting aphids showed significant differences between the unweeded and weeded conventional citrus orchards, respectively (PAN1 and PAN2) and weeded and unweeded organic citrus orchards, respectively (BER1 and BER2) (Fig. 4A).

Table 3. Mean RAI* of each wild plant species per orchard (averaged across sampling periods) in the four orchards.

Wild Plants Species	MEAN* RAI			
	BER1	BER2	PAN1	PAN2
Oxalis pes-caprae	3.32	8.27	13.37	0.00
Rumex crispus	1.02	11.07	0.00	0.00
Aethusa cynapium	0.00	2.25	0.00	0.00
Sonchus oleraceus	10.00	10.40	9.26	0.00
Calendula arvensis	1.55	3.19	0.00	3.53
Chrysanthemum segetum	0.00	0.00	2.06	0.00
Equisetum hyemale	1.46	0.00	0.00	0.00
Galium aparine	0.69	0.00	0.00	0.00
Orobanche uniflora	2.84	0.69	0.00	0.00
Medicago polymorpha	5.74	0.00	1.12	1.19
Vicia sp.	2.24	0.00	0.00	0.00
Ornithopus compressus	3.24	0.00	5.04	0.00
Arisarum vulgare	1.61	0.00	0.00	0.00
Euphorbia peplus	0.00	0.00	2.98	0.00
Anagallis arvensis	2.14	1.43	0.81	0.00
Papaver rhoeas	1.33	0.00	0.00	2.81
Picris hieracioides	1.88	0.00	1.88	0.00
Malva parviflora	4.68	0.00	0.00	0.00
Convolvulus arvensis	4.35	1.09	3.32	5.13
Solanum nigrum	4.33	0.52	1.54	0.00
Portulaca oleracea	0.83	5.77	0.00	0.00
Lolium sp.	2.20	7.77	16.20	8.91
Cynodon dactylon	22.45	19.69	21.50	12.60
Phalaris sp.	9.95	8.89	13.50	0.00
Avena sp.	7.62	5.93	7.36	11.84
Lolium perenne	0.90	0.00	0.00	0.00
Hedysarum sp.	0.90	0.00	0.00	0.00
Conyza canadensis	0.86	0.63	0.00	0.00
Cyperus rotundus	0.86	0.00	0.00	8.36

RAI= $(D_{rel} + F_{rel})/2$, D_{rel}= Relative density, F_{rel}= Relative frequency (Dajoz, 2006)

Table 4. Aphids and their natural enemies associated with wild plants and citrus in the four citrus groves.

Categories	Species names	Host plants
Aphids in Orchard	*Aphis gossypii*; *Aphis spiraecola*; *Aphis fabae*	*Citrus* spp.
Aphids on weeds	*Myzus persicae* *Hyperomyzus lactucae* *Acyrthosiphon pisum* *Aphis rumicis*	*Sonchus oleraceus* *Sonchus oleraceus Euphorbia peplus* *Vicia* sp. *Rumex crispus*
Beneficials	*Adalia bipunctata*; *Adonia variegata*; *Chrysoperla carnea*; *Coccinella septempuctata*; *Scymus* sp.; *Syrphus* sp.; Braconids	*Citrus* spp.; *Rumex crispus*; *Euphorbia peplus*; *Sonchus oleraceus*; *Vicia* sp.

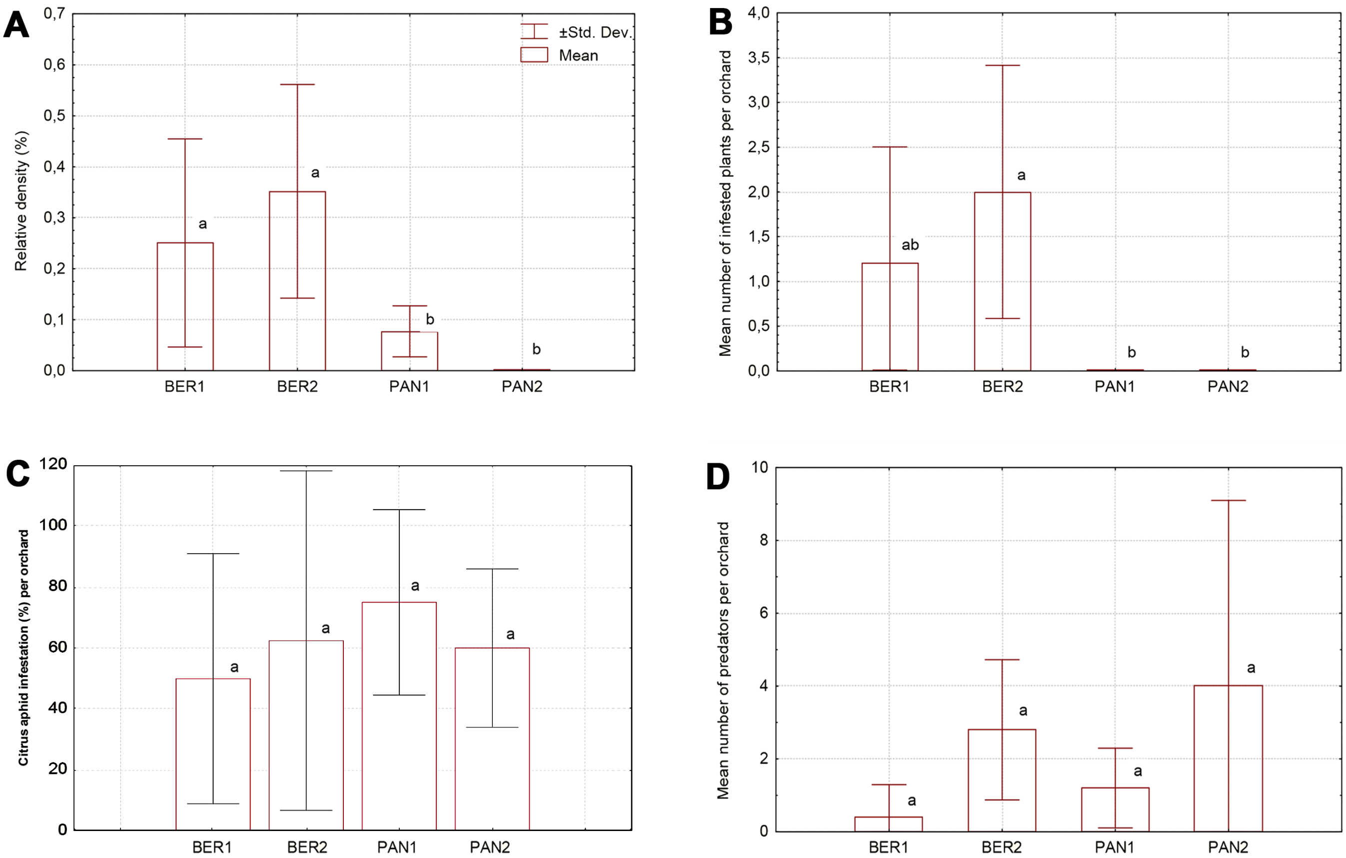

Figure 4. Results of ANOVA applied to: **A.** Mean relative density of host plant; **B.** Mean number of colonized host plants; **C.** Percentage of citrus aphid infestation; **D.** Mean number of predators on citrus, in the four citrus orchards (organic weeded BER1, unweeded organic BER2; and (unweeded conventional PAN1 and weeded conventional PAN2).

The systematic sampling method with random collection of citrus shoots and herb layer species that was adopted for this research work in addition to the irregular distribution of both naturally occurring plant cover and arthropods either on citrus or under canopies have led to the data values heterogeneity translated by the standard deviation high values. As shown in Fig. 4B, ANOVA pointed out a clear effect of farming management on "host plants" colonized by non-pest citrus aphids (*P>0.05*). The mean number of "host plants" colonized was 2 for BER2, and 1.2 for BER1, whereas in PAN1 and PAN 2 no "host plant" was found colonized by aphids, so the two conventional managing orchards were completely free from primary consumers (aphids) which can support communities of natural enemies. ANOVA didn't show a positive correlation between neither farming systems nor weeding systems (*P>0.05*), although the infestation rate of citrus aphids *A. spiraecola* and *A. gossypii* was different at each citrus orchard, independent of management approaches as shown in Fig. 4C. ANOVA performed to compare the effect of the farming management types on the mean number of predators on citrus did not show a significant difference between the four fields (Fig. 4D).

Statistical analysis applied to the mean number of predators living on wild plants did not show significant differences among the four citrus orchards (*P>0.05*) due to the different farming management (organic and IPM) (Fig. 5). However the highest values for the occurrence of predators on "host plants" was found in the organic unweeded citrus orchard BER2 (1.8) followed by the weeded organic citrus orchard BER1 (0.6), and at last the weeded citrus orchard PAN2 (0.4).

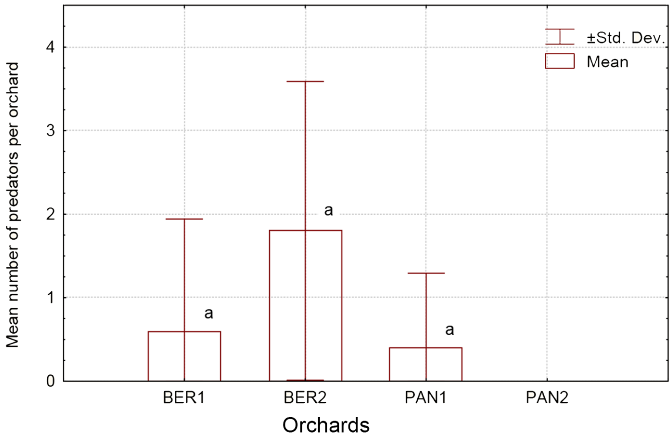

Figure 5. Mean number of predators on "host plants" in the four selected orchards (organic weeded BER1, unweeded organic BER2; and (unweeded conventional PAN1 and weeded conventional PAN2).

DISCUSSION

Overall, including monocotyledons, the summer-growing perennial weed *C. dactylon* was the dominant species recorded during this work that showed its well known suffocating effect (Barbagallo, 1966; Marshall et al., 2002). The remaining wild plants do not significantly compete with the citrus trees and can bring benefits to the plantation (*Oxalis* spp., *Poa* spp.) (Barbagallo, 1966). During this monitoring work we have observed an imbalance in term of spontaneous plant distribution, for instance *R. crispus* was very abundant between rows but rare in shaded areas specifically under citrus tree canopies. We suppose that light is a determinant factor upon curly dock growing capacity. *Cynodon dactylon,* the most important weed species that concern citrus growers (Viggiani & Angelini, 2003). Floristic diversity in the studied areas was high with a specific richness of 32 species. Among them four species: *R. crispus*, *S. oleraceus*, *Vicia* sp., and *E. peplus* might provide habitats, food sources, reproduction sites, or over-wintering shelters for several species of aphids and many beneficial belonging to several orders (Kozàr et al., 1994; Simões et al., 2004) (Table 4). During the sampling dates, four aphid species and several aphidophagous species including predators and parasitoids and belonging to four different orders have been recorded on naturally occurring plants in the studied citrus orchards.

Aphis gossypii and *A. spiraecola* were the dominant aphid species in all studied citrus orchards. According to Blackman and Eastop (2006), the majority of species belonging to the genus *Aphis* were reported on herbaceous plants, more rarely are the species that live on perennial plants. *A. gossypii* and *A. spiraecola* are part of this minority. They are the main aphid species on citrus in Algeria (Labdaoui et al., 2018; Labdaoui, 2019). They become a serious threat when their population densities exceed the economic threshold (Patti, 1996; Patti & Barbagallo, 1998; Blackman & Eastop, 2000). Many studies demonstrated the efficiency of both species to transmit various Italian strains of *Citrus Tristeza Virus* including virulent ones (Campolo et al., 2014; Yahiaoui, 2010). While *Aphis fabae* which is a very polyphagous species, anholocyclic on secondary hosts in Northern Africa and the Middle East, found particularly on Solanaceae (Müller, 1982), it is a secondary pest on citrus (Blackman & Estop, 2000), it was retrieved once, earlier in spring on citrus young shoots of one citrus tree. We have to emphasize that *T. aurantii* was not found during the four months of samplings of this work although it is a common aphid pest on Italian citrus (Addante et al., 2009). On wild plant cover, several aphid species not harmful to citrus have been identified. They were recorded from four spontaneous plants (Table 4). These aphid species may in fact be providing some control of the weeds, serving as an alternate resource for aphid predators and parasitoids (Jadot & Roland, 1971; Wyss, 1995). All observed relationships between aphid-host plant have been reported by Blackman and Eastop (2006). Several aphid natural enemies have been recorded during this work on both citrus and host plants. Aphidophagous ladybeetles (Coleoptera, Coccinellidae) were the most numerous species that have been found living on “host plants” under several stages (larvae, pupae, and adults). These generic predators were the most important aphid natural enemies occurring on citrus, *R. crispus*, and *S. oleraceus* in BER1, BER2, however in PAN2, citrus and *E. peplus* were harbouring most aphidophagous.

The sampling of April was characterised by the relatively high number of parasitoid wasps (Hymenoptera, Braconidae) found in BER2 on *S. oleraceus* and *R. crispus* in comparison with other beneficials, as green lacewing predators (Nevropetra, Chrysopidae), which were recorded only on citrus, and hoverflies (Diptera, Syrphidae) found on *S. oleraceus* (Table 4). Simões et al. (2004) have led a similar work in citrus orchards in Terceira Island, Azores (Portugal) concluding that aphid parasitoids prefer *S. oleraceus* and *R. crispus* as hosts, whereas hoverflies larvae have been observed mainly on *Sonchus sp* and green lacewings larvae were strongly related to citrus trees. On the contrary on May and June ladybeetles were higher than all other natural enemies followed by green lacewings and hoverflies, all attracted to the plants by the high rate of aphid infestation. These observations agree with the study carried out by Hodek (1966) and Foott (1973) reporting that ladybeetles prefer to occupy an area when the aphid density is sufficiently high. The green lacewings and parasitoids respond to odours emitted by aphids and/or honeydew at long range, therefore they should be able to find aphid-infested habitats even if these are not immediately visible (Hodek, 1966; Foott, 1973). During the sampling of July, the density of aphids and their natural enemies has dropped drastically because very likely to the high temperatures.

In BER1, despite it was a weeded orchard, the relative density of “host plants” was considerable because the ploughing was superficial thus weed seeds were partially buried and hence they easily germinated giving origin to established plants. Whereas, in the unweeded citrus orchard BER2, which had an abandoned herb layer, the relative density was higher, and the “host plant” community had a marked effect on the natural enemies retention in the orchard. The relative density dropping off in weedy orchard PAN1 was probably due to the distribution of *R. crispus* in the orchard. As we have stressed previously the curly dock has grown intensively between the rows rather than under canopies hence, it escaped from the sampling. In weeded citrus orchard PAN2, where inversion tillage has been done, the floristic richness has remained low, except for the growth of some Graminaceae near citrus tree trunks. The above-mentioned differences in the density of “host plants” gave us only a slight idea about the role that weeds can play in order to enhance the farm biodiversity as a tool to manage pests. However we need to deepen our understanding of the consequences that the use of such manipulation in implementing an effective pest management strategy, by considering agricultural areas i.e citrus orchards as functional ecosystems that include natural and managed components (Norris & Kogan, 2000; Fischer et al., 2006). Variation in aphid-colonized host plants, might be linked to the hypothesis of apparency (Chew & Courtney, 1991), since BER1 and BER2 had an acceptable rate of “host plants” the apparency was high, so “host plants” were likely to be attacked by the identified non-pest aphids. The study has revealed many weed-aphid relationships. For instance, *A. rumicis* is one of the most common species of aphids we have found on the curly dock (Table 4), it can represent a serious pest on Swiss chard (*Beta vulgaris*) as reported by Bayhan et al. (2006) in Turkey and other Mediterranean regions, but is completely harmless for citrus trees. *Vicia sp* hosted the pea aphid *A. pisum*, usually forming colonies on young growth and developing pods of many herbaceous and some shrubby leguminous. *M. persicae* was found on *S. oleraceus* (Table 4), it is a very well-known holocyclic species that usually has *Prunus persica* (L.) Batsch as the primary host, while the secondary hosts belong to over 40 different plant families (Blackman & Eastop, 2006). The currant-sowthistle aphid *H. lactucae* was also found on *S. oleraceus*, which represents one of its secondary hosts, whereas *Ribes spp*. are the primary one (Blackman & Eastop, 2006). Fortunately, we did not record any aphid species colonizing the “host plants” which could become harmful to citrus trees, even though some of this insight pushes. Valorisation of host plant species identified by the current study, may lead to a beneficial effect on the aphid citrus pest, manipulation of those naturally occurring plants in citrus orchards should be assessed by experiments because weed manipulation can result in positive or detrimental consequences for orchard pest control (Boller et al., 2004; Debras et al., 2007). Although ANOVA didn't show a significant effect of both farming and weed management on the density of aphid predators (ladybeetles, hoverflies, and green lacewings) on citrus, the mean number of predators occurring in the organic unweeded citrus orchards BER2 was higher compared to the conventional unweeded citrus orchard PAN1, with 2.8 and 1.2 predators per orchard respectively (Fig. 4D). In contradiction to the mean number of predators in the weeded citrus orchard either organic or conventional was low, which can be probably explained by the hypothesis of resources concentration. In fact, the infestation of *A. gossypii* and *A. spiraecola* in BER2 and PAN1 was high enough to attract predators on the trees (Fig. 4C). These predators prefer to occupy an area only if prey density is sufficiently high (Honek, 1994; Dixon, 2000). On naturally occurring plants, especially on "host plants", the number of predators on wild plants increased in accordance with the relative density of "host plants" (Fig. 5). The "host plants" and aphid populations feeding on them might have attracted the predators occurring within or outside the orchards. Many authors have strengthened this hypothesis revealing that weeds influence the abundance of coccinellids in the fields, including the timing of colonization of the field by the predators in addition to the density of aphids (Coderre & Tourneur, 1986; Cottrell & Yeargan, 1998b; Wu et al., 2010). While, others reported that as high levels of beneficial are displayed within the herb cover, whereas low level of predation and pest control are observed in the arboreal strata (Simon et al., 2007). A similar observation was observed in the organic unweeded organic citrus orchard BER2, where the severe attack of aphid pest species was recorded on citrus new shoots, although, various aphidophagous species (coccinellids, lacewing and hoverflies) were abundant on host plants (Figs 4C & 5). The lack of concrete results of interactions among strata in field experiments (Simon et al. 2010), enhanced controversial hypothesis that diversity in arable areas is structural rather than functional (Horton et al., 2002). The latter hypothesis was supported by the amazing number of predators on citrus trees of the conventional weeded citrus orchard PAN2, compared to the organic unweeded citrus orchard BER2; it was the highest, in the absence of herb layer and therefore of host plants, likely attracted by the large colonies of citrus aphid populations as mentioned above (Figs 4C–4D). The high rate of ladybeetles registered in PAN2 was probably due to the landscapes surrounding orchards which are probably serving as hibernation sites (Fig. 2).

The survey work has ended revealing some interesting conclusions. 32 plant species have been recorded in the four orchards belonging to 20 families. All the plant species we have found were reported by Barbagallo (1966), therefore no alien species was found. *Cynodon dactylon* was the most abundant and it is the most harmful among the weed species range occurring in the citrus orchards. *Aphis gossypii* and *Aphis spiraecola* were the main aphid pest species occurring in citrus orchards whereas three aphid species absolutely harmless on citrus *Aphis rumicis, Acyrthosiphon pisum,* and *Hyperomyzus lactucae* were serving as natural limitation agents of four weed species currently occurred in citrus orchards *Rumex crispus, Sonchus oleraceus, Euphorbia peplus* and *Vicia* sp. The latter have provided habitats for several aphidophagous insects. From these results we can say that the enhancement of aphid natural enemies by ensuring them wild plants which serve as hosts using selective weed management could be very powerful. Furthermore the comparative study on the effect of different farming management has shown that organic farming is more able to provide habitats and preys for beneficials in the citrus agroecosystem. Citrus agroecosystem showed an interesting biodiversity potential hence this work is a further step toward the investigation of the interactions between plants, crops and arthropods in citrus orchards of the Mediterranean Basin. Actually, we will never understand all interactions occurring in an agroecosystem because of their high number. Thus, answering such complex questions through a survey of few months will be subjective. The implementation of long-period experiments on crop-wild flora-arthropod's functional groups is a unique way to find out consistent interactions that could be applicable in the field. Then, we will succeed to give objective guidelines to citrus growers in order to manage aphids using farm biodiversity.

AUTHOR'S CONTRIBUTION

The authors confirm their contribution in the paper as follows: S. Ali-Arous: Sampling, identification, statistical analysis and interpretation; M. Meziane: Data analysis and text redaction; K. Djelouah: Contribution to data analysis, interpretation and English proofreading; All authors read and approved the final version of the manuscript.

FUNDING

This work was supported by the Mediterranean Agronomic Institute of Bari, CIHEAM Bari. Italy [506].

AVAILABILITY OF DATA AND MATERIAL

Not applicable.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

ACKNOWLEDGMENTS

We thank Dr Rocco Addante (Università degli Studi di Bari, Department of Soil, Plant and Food Sciences), for assistance in insect's identification.

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برهم‌کنش فلور وحشی، گیاهان کشت‌شده، شته‌ها و دشمنان طبیعی آنها در باغات مرکبات

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| **تاریخ دریـافت:** ۳۰ مرداد ۱۴۰۱ | **تاریخ پذیرش:** ۱۳ آبان ۱۴۰۱ | **تاریخ انتشار:** ۱۱ دی ۱۴۰۱ |

چکیـــده: این مطالعه در بخش‌هایی از باغ‌های مرکبات ناحیه برنالدا در منطقه باسیلیکاتا در جنوب ایتالیا انجام شد. شته‌ها و دشمنان طبیعی آنها از روی کانوپی درختان و گیاهان مجاور آنها در چهار باغ مرکبات که به روش‌های متفاوت (ارگانیک و سنتی، با و بدون پوشش علفی) مدیریت می‌شدند، جمع‌آوری شد. چهار گونه گیاه علفی (*Rumex cripsus*، *Sonchus oleraceus*، *Euphorbia peplus* و *Vicia* sp.) به عنوان میزبان چهار گونه شته غیر آفت روی مرکبات شناسایی شدند. این شته‌ها شامل *Myzus persciae*، *Acyrthosiphon pisum*، *Hyperomyzus lactucae* و *Aphis rumicis*، خود طعمه حشرات شکارچی شامل کفشدوزک‌ها (Coleoptera, Coccinellidae)، بالتوری‌ها (Neuroptera, Chrysopidae)، مگس‌های سیرفید (Diptera, Syrphidae) و انواع پارازیتوییدها (Hymenoptera, Braconidae) که در کانوپی درختان مرکبات فعالیت دارند هستند. بررسی آماری داده‌های جمع‌آوری شده نشان‌دهنده رابطه مثبت بین سیستم‌های مدیریت علف‌های هرز و گیاهان وحشی که میزبان جمعیت شته‌خواران هستند، بود. به‌علاوه، رویکرد مدیریت ارگانیک علف‌های هرز تاثیر مثبتی بر فراوانی و غنای گونه‌ای شته‌خوارها داشت. در صورتی‌که روش سنتی مدیریت علف‌های هرز منجر به زوال دشمنان طبیعی می‌گردد. در عین حال، برهم‌کنش بین لایه‌های مختلف (تنوع فون حشرات روی کانوپی درختان مرکبات و پوشش گیاهی منطقه) کماکان نامشخص است. به طور کلی، این مطالعه قدمی در جهت بررسی برهم‌کنش بین پوشش گیاهی طبیعی و گیاهان کشت‌شده و بندپایان مستقر در باغات مرکبات حوضه مدیترانه بوده که بر اساس آن می‌توان راهبرد مدیریت علف‌های هرز را به عنوان راه حل کلیدی مدیریت شته‌های آفت محصولات کشاورزی در نظر گرفت.

واژگــان کلیدی: مرکبات، فلور وحشی، شته‌ها، باسیلیکا، دشمنان طبیعی، تنوع گونه‌ای