Importance of the managing and the crop margins in the fluctuation of *Myzus persicae* (Hemiptera, Aphidae) and of his natural enemies in a smallholding agricultural system.

Olivo, Verónica Inés[1]; José Antonio Corronca

IEBI-Cátedra de Artrópodos. Facultad de Ciencias Naturales. UNSa. CONICET Av. Bolivia 5150. Salta capital. CP 4400; [1]veroolivo@iebi.com.ar

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Myzus persicae is a multivoltine, polyphytophagous and cosmopolitan species, vector of several viral diseases; well distributed in Argentina on a great variety of vegetables as secondary hosts. Their populations are controlled by a combination of metereological conditions and several natural enemies. Crop margins can provide several ecological advantages, contributing to maintaining a high diversity of benefic and pest arthropods. The smallholding constitutes typically more than a half of the agricultural establishments in rural Argentina. This agro-ecosystem is interest for study different agricultural situations at field. The present studied aimed to test whether the windbreak barrier surrounding a smallholding could act as a breeding and shelter area for *M. persicae* and/or its natural enemies, particularly after agrochemical applications to the cultivated smallholding plots. We carried out samplings of arthropods on vegetation every fortnight during one year in an smallholding of the North-western of Argentina, using a G-Vac. We analyze the fluctuation and movement pattern of the pest population and their natural enemies relationship with the management practices applied in this agro-ecosystem. *M. persicae* was always present in the smallholding, its abundance increased depending of crop combinations, but also on response to pesticide treatments and the reductions of natural enemies community. The windbreak barrier acted only on certain times in the year as a shelter and breeding habitat for the pest and few predators, particularly after successive pesticide applications on the crop plots of the smallholding, and it also facilitated their recolonization of the crop when conditions became favorable again.

Keywords: aphid, crop margins, predators, parasitoids, small farm.

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Myzus persicae es una especie multivoltina, polífaga y cosmopolita, vector de varias enfermedades virales. En la Argentina, se encuentra ampliamente distribuida sobre una gran variedad de hortalizas que funcionan como hospederos secundarios. Sus poblaciones pueden ser controladas por la combinación de condiciones meteorológicas y de varios enemigos naturales. En efecto los márgenes de cultivos proveen varias ventajas ecológicas y mantienen alta la diversidad de artrópodos benéficos y plagas. En nuestro país, los minifundios constituyen más de la mitad de los establecimientos rurales; este tipo de agro-ecosistema es interesante para estudiar en campo las distintas situaciones agrícolas. El objetivo de este estudio fue testear si la barrera rompeviento que rodea al minifundio actúa como área de cría y refugio de *M. persicae* y sus enemigos naturales, particularmente después de la aplicación de agroquímicos en las parcelas cultivadas del minifundio. Para ello se realizaron muestreos de artrópodos, en un minifundio de la localidad de Vaqueros, sobre la vegetación (área cultivada y márgenes) cada quince días durante un año en un minifundio del noroeste de Argentina. Se analizó la fluctuación poblacional y el movimiento de la plaga y sus enemigos naturales en relación a las prácticas de gestión aplicadas en este agroecosistema. *M. persicae* estuvo siempre presente en el minifundio, su mayor abundancia se vio incrementada según la combinación de cultivos, pero también en respuesta a los tratamientos con plaguicidas y a las reducciones de la comunidad de sus enemigos naturales. La barrera rompeviento actuó como refugio y lugar de reproducción para la plaga, sólo en ciertos momentos del año, especialmente luego de las aplicaciones sucesivas de plaguicidas en las parcelas cultivadas del minifundio, y esto facilitó la recolonización a los cultivos cuando las condiciones fueron favorables.

Palabras claves: áfido, bordes de cultivos, depredadores, parasitoides, pequeños productores.

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INTRODUCTION

Aphids are an important group of insects, responsible for high losses in several crops as a consequence of their feeding activity and their high biotic potential. They characteristically exhibit a great reproductive capability and a fast development, with numerous generations per year. Besides, combined with their ability to produce alate descendants from apterous individuals when the environmental conditions are unfavorable, allows them migrate and to disperse to less hostile areas. The green peach aphid, *Myzus persicae* (Sulzer, 1776), is a polyphagous species which can be found on a great variety of plants (Quintanilla, 1976), and is a most important vector of viral diseases; it can reach very high densities on the tissues of young plants, leading to hydric stress, withering and a reduction in the growth rate of the affected plant (Saljoqi, 2009). This cosmopolitan species (Blackman & Eastop, 1985) is well distributed in Argentina on a great variety of vegetables (secondary hosts) and fruit trees of the genus *Prunus* (primary host) (Andorno et al*.,* 2007a). *M. persicae* reproduces parthenogenetically on both wild and cultivated secondary hosts (Ortego & Carrillo, 1995), and this form of reproduction is considered to be an adaptation to unstable and disturbed environments (Moran, 1992). Its annual cycle is typical of aphids (cyclic parthenogenesis), with a sexual generation on peach trees in winter and spring, alternating with several parthenogenetic (all-female) generations during spring on peach trees, as well as several crops and wild plants in summer and autumn (Margaritopoulos et al*.,* 2009).

Several predatory and parasitoid, in combination with meteorological conditions (Risch, 1987) play a key role in the reduction and regulation of aphid populations (Chen & Hopper, 1997; van Emden, 1995). *M. persicae* displays a natural intrinsic growth rate higher than zero, doubling its population size within a 7-8 days period, in laboratory conditions (Duarte *et al.,* 2011), with a generational time of 2-3 days and an average life cycle of almost 21 days. Andorno et al. (2007b) found that this species possesses a highly diverse complex of regulating parasitoids (up to 7 species of aphidiinids) in organic horticultural crops in Buenos Aires province (Argentina). Due to their high reproductive capacity, chemical control is the most commonly employed for *M. persicae* control by crop growers, increasing the costs of production, pollutes the environment and can lead to an incompatibility between the harvest interval and the pesticide's quarantine period, as well as destroying a significant portion of their natural enemies.

Crop margins in agricultural landscapes can provide several ecological advantages, such as habitat and food sources for wildlife (Cederbaum et al*.,* 2004), contributing to the conservation of native fauna (Keesing & Wratten, 1997) and the maintenance of benefic arthropods (Frank & Reichhart, 2004; Gurr et al*.,* 2005). Thus, crop margins contain both benefic insects and pests, generally polyphagous phytophagous utilizing a relatively high number of host plant species. On the other hand, certain pest species need alternative host plants in different times of their life cycles, often migrating from non-cultivated to cultivated areas in particular times of the year (Marshall, 2004). Furthermore, margins adjacent to cultivated fields contribute to maintaining a high diversity of arthropods that, in turn, decrease as they move to neighboring cultivated fields (Dennis et al., 2000), constituting necessary areas for the establishment of crop fauna after a disturbance.

Agricultural activity at a small scale (up to approximately 5ha), known as a smallholding, is the most typical form of production in more than half of the agricultural farms in rural area of Argentina, with a high incidence on the agricultural structure (Manzanal et al. 2006), amounting to half the agricultural fields in Latin America (Altieri, 1999). The smallholding productive model is based on intensive agricultural activity that exerts a significant impact on the environment, thus the needed a sustainable use of natural resources and the conservation of the associated biological diversity, as well as a sustainable management of the rural environment. The Valle de Lerma (Salta) is an area orientated to a traditional intensive tobbacco crop complemented with vegetables, fodder plants, and, sometimes, vegetables crops; the latter are destining to urban consumption, and the fodder plants to the extensive and intensive animal husbandry (Pereira et al., 2001). Integrated Pest Management stresses the protection and preservation of natural control agents (Villata & Ayassa, 1994) and, among the techniques employed, conservative biological control aims to manipulate the environment and create field designs that increase the fecundity and longevity of natural enemies of pests, which makes it compatible with the sustainability of agroecosystems (Straub & Zinder, 2006). By replacing simple agroecosystems with more complex ones, or adding diversity to the existing systems, it is possible to introduce changes in habitat diversity that increase the abundance of natural enemies and their effectiveness, providing hosts/alternative prey in moments when the pest is less abundant, either through alternative food sources (pollen, nectar) for parasitoids and adult predators, or by maintaining acceptable levels of pest populations for extended periods, in order to allow the continued survival of benefic insects (Altieri, 1999).

The aim of the present study was to analyze the fluctuation of *Myzus persicae* and its natural enemies in a smallholding horticultural structure, taking into account the effects of planned cultivated plots and of the management by the producers to the agroecosystem. Certain authors have proposed that windbreak barriers can represent shelter habitats for arthropods during pesticide applications to cultivated plots (Albrecht, 2003; Asteraski et al., 2004; Wäckers, 2004; Wratten et al*.,* 2002) and that they can also exert a negative influence on pest species by providing shelter and food sources to their natural enemies (Bohlen & Barret, 1990; Capinera et al*.,* 1985; Frampton et al., 1995; Holmes & Barret, 1997). Considering all these premises, we decided to test whether the windbreak barrier surrounding a smallholding could act as a breeding and shelter area for *M. persicae* (the most relevant pest in the smallholding) and/or its natural enemies, particularly after agrochemical applications to the cultivated plots in the smallholding.

MATERIALS AND METHODS

Study area: the study was conducted in an smallholding in locality of Vaqueros (24° 43'S/ 65° 25'W) Valle de Lerma, Salta (Argentina), with a surface of approx. 3,5ha, of which 75% were occupied by two crops, strawberry (*Fragaria* sp.) and green peas (*Pisum sativum*), plus a fallow plot. Green peas were sown in June and harvested in October 2004; this area of the smallholding was unsown before and after the study, whereas strawberry remained throughout the sampling. The strawberry crop was planting on ridges that were covered by black plastic and separated by 0.75 m between them, the irrigation was by drip. Each planting ridge had two rows of strawberry plants. One plot of strawberry plot consists of plant of second year of production and the other plot with new plants. There are two windbreak barriers on an "L" formation on the periphery of the smallholding, comprised of herbaceous vegetation and trees typical of the Chaco Serrano eco-region (Fig. 1a). The tree stratus is characterized by black mulberry (*Morus nigra* L.), pacará earpod tree (*Enterolobium contortisiliquum* (Vell.) Morong), Roman cassie (*Acacia caven* (Molina)), lecherón (*Sapium haematospermum* Mull. Arg.), Indian rubber plant (*Ficus elástica* Roxb.), rosewood (*Tipuana tipu* (Benth.) Kuntze), avocado (*Persea americana* Mill.), pata de vaca (*Bauhinia argentinensis* Burkart *var. Megasiphon* (Burkart) Fortunato), chal-chal (*Allophylus edulis* A. St.-Hill, A. Juss and Cambess) *Hieron ex. Niederl*), ceibo (*Erythrina crista-galli var crista-galli* L.), creole walnut (*Juglans australis* Griseb.) and Chinese privet (*Ligustrum lucidum* W. T. Aiton); whereas the herbaceous stratus was dominated by an exotic plant, *Tithonia tubaeformis* (Jacq.) Cass.) (pasto cubano) which is widely distributed along Valle de Lerma. In the Eastern border of the smallholding, the windbreak barrier exhibits a higher diversity of species and variety of plant strata, both trees and bushes.

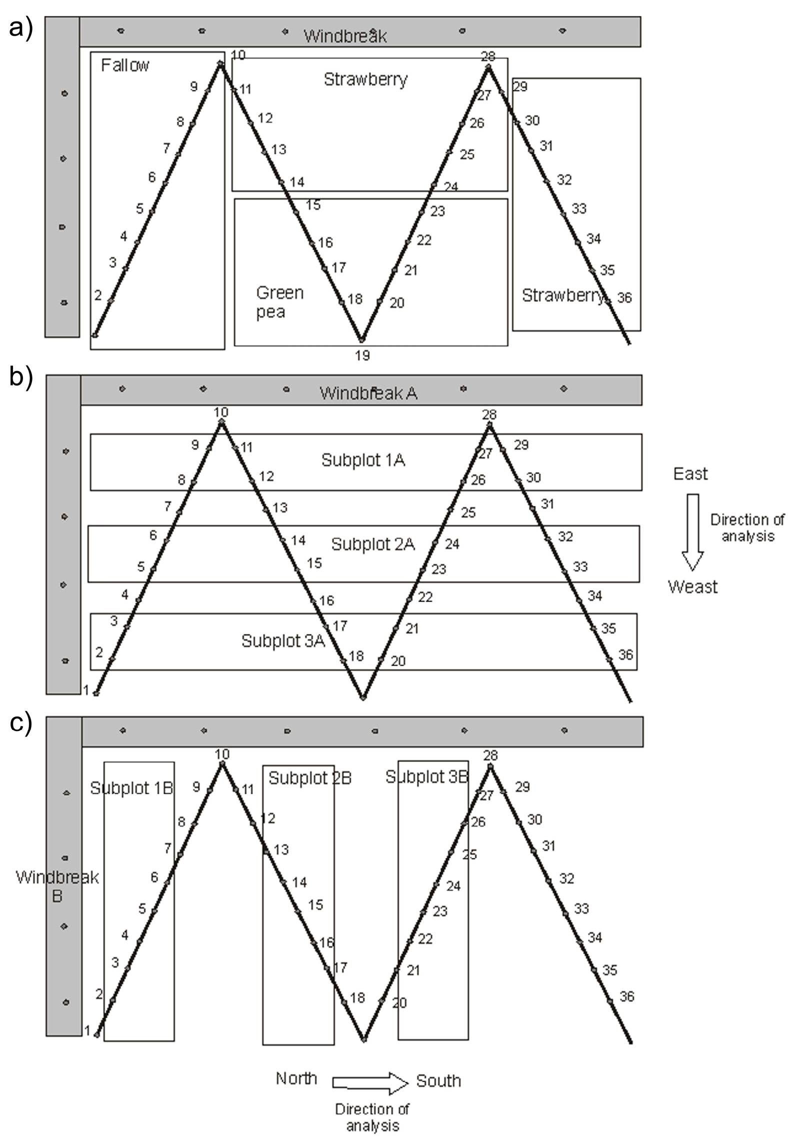

Figure 1: (a) Field diagram, (b) scheme of blocking of the smallholding for the East-West analysis of patterns of movement (c) The same for the North-South analysis of patterns of movement.

During the period of the study, the producer planned the disposition and type of crops to be implanted in the non-cultivated plots of the smallholding, and managed the cultivated plots following his own judgment, including pesticide and fertilizer applications as follows: in strawberry plots, fertilizer and Flucamil (May 14th, 2004), Cypermetrhin (Pyrethroid insecticide-Dose: 200 cm/ha) and sulfur (June 27th, 2004) and Sulphur (September 17th, 2004); in peas plots, Avermectin (insecticide and acaricide of natural origin - Dose: 75 cc/100l of water)(July 23rd, 2004); as well as a treatment with Cypermetrhin and Sulphur (August 20th, 2004) in all cultivated plots. Furthermore, herbicides were applied to the fallow plot and the windbreak barrier to the Eastern border of the smallholding on February 1st (2005), which reduced the herbaceous and bush strata. Sampling: we carried out samplings of arthropods on vegetation every fortnight from April 2004 to March 2005 using a McCullock G-Vac aspirator; every sample equaled the suction of a lineal meter during a minute, and up to a height of 2m, in windbreak barriers. The number of samples per plot was proportional to the surface of each plot, amounting to 36 inside the smallholding and 10 in the windbreak barriers. Within the smallholding we took samples from a 2,3ha strawberry plot (Fr), a 0,5ha peas plot (Ar, from June to October) and a fallow area (Fa) with weeds, which varied in surface throughout the year but extended to an average of 1ha (Fig. 1a). Samples were considered independent, labeled and identified according to the division of plots described above. The material collected was kept in refrigerated chambers until transport to the lab, where it was properly fixed in 70% ethanol, sorted out and identified, first to the species/morphospecies level using a digital image database generated using Taxis 3.5 software (Meyke, 1999-2004). Data obtained were transferred to electronic worksheets recording date and number of specimens collected. Afterwards, the material was sorted into orders, families and functional groups (phytophagous insects, predators and parasitoids). Identification to the species level of aphids and certain natural enemies was achieved thanks to the input from Agricultural Zoology professors at FCN-Salta National University and their reference collection, which allowed corroboration of diagnostic morphological characters of species. Data analysis: samples were separated for analysis into *stages* named according to the management practices applied on the smallholding: T1 (samplings 1 to 11), a period when the grower carried out several agrochemical applications; T2 (samplings 12 to 17) with no applications, and T3, all the remaining samplings, with application of herbicide and weeding of the smallholding. Considering these different stages in the smallholding, we performed a Multiple-response permutation procedure (MRPP) using the Bray-Curtis index as a similarity measure, in order to assess whether the *M. persicae* population and the natural enemies complex changed through time, using PC-ORD ver. 6.0 software (McCune & Mefford, 2011). Mean abundances per sample were graphed in order to assess the patterns of change in abundance and the temporal variations of *M. persicae* and its natural enemies. We compared the values of abundance obtained for the aphid population throughout the different stages in the smallholding with the values recorded for the windbreak barrier by means of a Kruskall-Wallis test using PAST ver 2.14 software (Hammer *et al.,* 2003) since data recorded were not normally distributed and there was no homogeneity of variances.

The most abundant natural enemies in the samples were Braconidae parasitoids, spiders and three species of Coccinellidae predators (Coleoptera, Coccinellidae): *Eriopis connexa* (Germar, 1824), *Hippodomia convergens* Guerin and *Cycloneda sanguinea* (Linnaeus, 1743). In order to compare patterns of movement between barriers and plots in the smallholding, we assessed abundance in relation to distance, according to Duelli & Obrist (2003). For this purpose, we considered the abundance values obtained for *M. persicae* and the dominant natural enemy species, *Oxyopes salticus* Hentz, 1845 (Araneae, Oxyopidae), an unidentified anyphaenid species (Araneae, Anyphaenidae) and the parasitoids *Aphidius* sp., *Diaeretiella rapae* (M'Intosh, 1855) and an unidentified braconid species (Hymenoptera, Braconidae), as well as the Coccinellidae coleopterans mentioned above.

We followed the classification proposed by Duelli & Obrist (2003), dividing them into 5 types according to the distribution of their abundance in agroecosystems: "stenotopic" species (100% of the individuals collected at the barriers), "dispersers" (more than 50% of the individuals collected within 20% of the length of the barrier), "ecotone" (species found in the interphase barrier-plot border), "cultural" (pest species, increasing in numbers with increasing distance to the barrier) and "ubiquits" (species found both in barriers and plots). For this analysis we used the mean abundance values recorded by the G-Vac samples in each subplot, performing an analysis from east to west and north to south from the windbreak barrier to the center of the smallholding. Thus we considered, from East to West (Fig. 1b) 6 samples in the barriers and those from the subplots 1A, 2A and 3A, and from North to South, 4 samples in the barrier and those from subplots 1B, 2B and 3B (Fig. 1c).

RESULTS

We collected 13,305 *M. persicae* individuals (not-parasitized) from the strawberry plots (n_{Fr}=1288), peas plots (n_{Ar}=2025), fallow plots (n_{Fa}=1144) and windbreak barrier (n_B=8848), whereas of 1719 natural enemy individuals from cultivated areas and 970 from the barrier, 1977 were spiders of 118 species, 636 were braconids of 14 species and 76 individuals were coleopterans: *Eriopis connexa* (n=24), *Hippodomia convergens* (n=42) and *Cycloneda sanguinea* (n=10). We noted that the populations of both *M. persicae* and its natural enemies changed throughout time in the different stages of the smallholding (T1-T3), with significant differences when we performed the MRPP between groups per stage (A=0.0726, p=0.0008), as well as comparing the similarity in composition of natural enemies accompanying the aphid species throughout the stages of the smallholding (T1*vs*T2, A=0.0314, p=0.05; T1*vs*T3, A=0.085, p=0.018 and T2*vs*T3 A=0.0057, p=0.04).

The comparison of population abundance of *M. persicae* between the smallholding plots and the windbreak barrier showed significant differences (H=4.075; Hc=4.094; P=0.04). The population of *M. persicae* exhibited changes in abundance in the cultivated plots when compared to the barrier, with a higher increase by the end of stage 1 (T1), when the grower sowed peas and carried out several agrochemical applications in the cultivated plots (Fig. 2a). We recorded two instances of increased abundance of the aphid population in the windbreak barrier, the first coinciding with that recorded within the smallholding, and a second, very marked one, during the first samplings performed after agrochemical applications in the cultivated plots (August-October) (Fig.2a). The application of agrochemicals to cultivated plots, in different times in the different plots, resulted in fluctuations in the aphid population, which showed a quick recovery in abundance, particularly in the peas and the fallow plot, whereas in the strawberry plot the increase in abundance was recorded mainly at the end of T1 stage (September, Fig. 3). The abundance of the aphid population peaked in the cultivated plots between July and October, with cyclic fluctuations of low abundance in summer on strawberry, which was the only crop remaining in the smallholding in that season (Fig. 3).

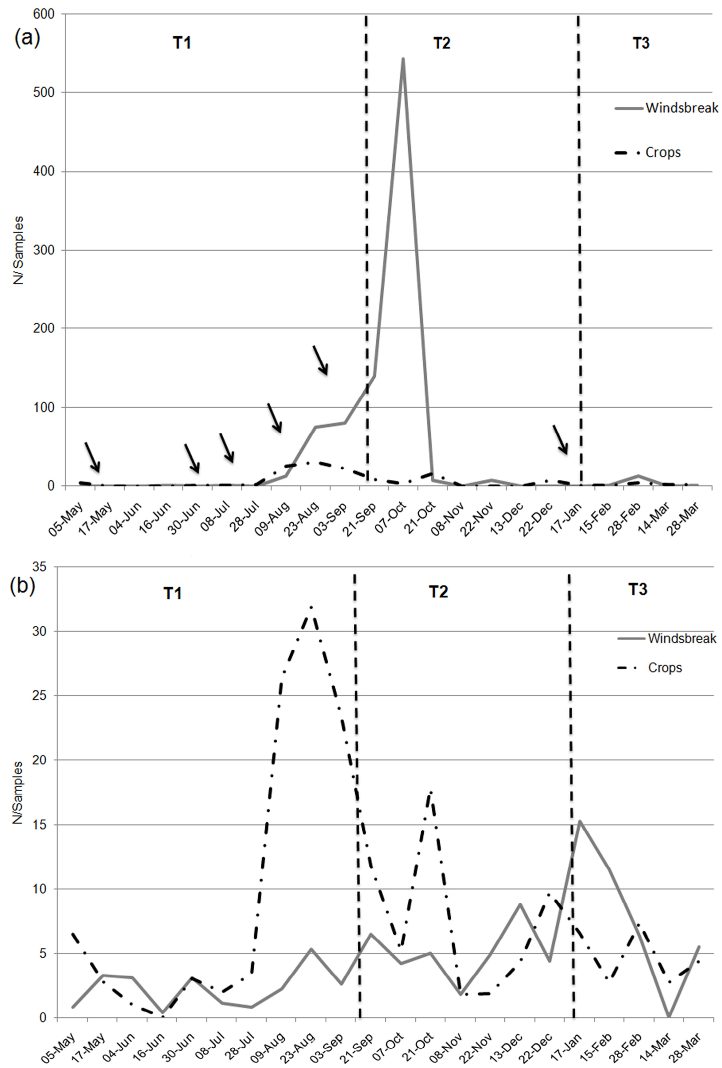

Figure 2: (a) Temporal variation of M. persicae; and (b) of the natural enemies considering the windbreak and cultivated plots. Arrows indicate applied management practices over the smallholding

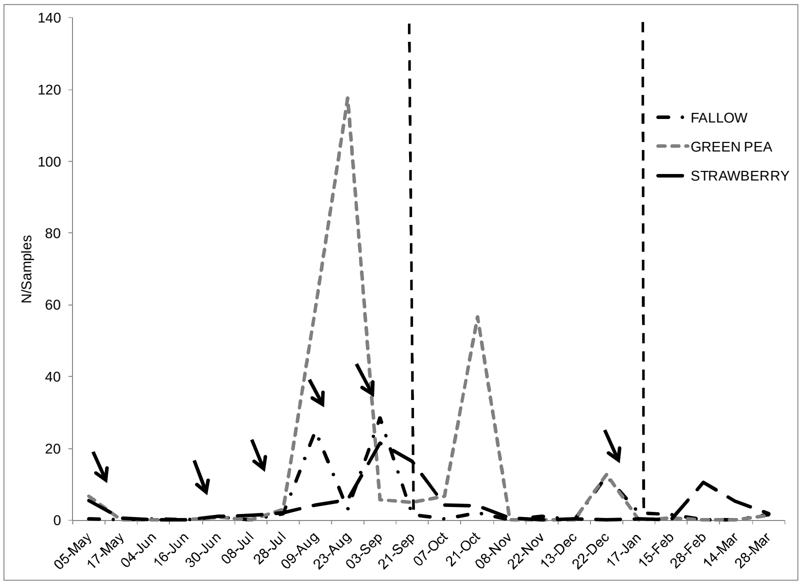

Figure 3. Temporal variation of M. persicae on fallow, strawberry and pea plots. Arrows indicate applied management practices on each situation.

Natural enemies in the smallholding exhibited an increased abundance during the months when peas were present (Fig. 2b). The abundances of the different groups of natural enemies in the smallholding fluctuated through time, with changes in abundance that coincided with the management practices applied to the cultivated plots, and with spiders being the most affected group (Fig. 4a). As long as peas remained, the abundance of parasitoids markedly increased in the smallholding, although they were affected by pesticide applications (Fig. 4a). In peas plots, 87% of natural enemies were represented by braconid parasitoids (Fig. 5a), with fluctuations that accompanied those of *M. persicae*. On the other hand, both in the strawberry and fallow plots spiders amounted to 87% and 80% of the total natural enemies, respectively, and we noted that any agrochemical application on the cultivated plots in the smallholding affected their community, resulting in changes in their abundance (Fig. 5b and c). Only in strawberry (Fig. 5c) the complex of predatory coleopterans fluctuated with increases in abundance, which was delayed with respect to the aphid. The fallow plot exhibited a pattern of natural enemies abundance almost similar to that of the windbreak barrier, mainly for spiders and coleopterans (Figs. 4b and 4c), whereas braconids were more abundant in the barrier, with fluctuations in abundance throughout time. Spiders were the most abundant natural enemies in the windbreak barrier, particularly in summer, whereas the abundance of parasitoids lightly increased between August and October (Fig. 4b). When we analyzed the movement patterns of *M. persicae* within the smallholding and the windbreak barrier, we found it to be a cultural species in North-South analysis, although it behaved as a disperser species in East-West analysis, that is, from the windbreak barrier to the cultivated plots in the smallholding, which stresses its relevance to the aphid. This same behavior was evident for *D. rapae* in the analysis from the barrier to within the smallholding (E-W direction). The remaining dominant natural enemies considered were cultural species in both directions of the analysis, with the exception of the spider *O. salticus*, which was ubiquitous in the E-W direction.

DISCUSSION

Myzus persicae was present in the smallholding throughout the year in the cultivated area, but its population was markedly increased when the peas plot was sown, one of the crops where it is considered an important pest (Kraft & Pfleger, 2001; Ochieng & Nderitu, 2011). There, the population exhibited outbreaks, possibly due to the successive pesticide treatments, which is in agreement with reports by several authors who found that repeated pesticide treatment lead to the development of resistance in pest populations, as well as resurgence and substitution of pest species, not to mention the lethal effects on other organisms, man included, as well as environmental pollution (Norris *et al.,* 2003). Several authors (Casals & Silva, 1999; Devonshire et al*.,* 1998; Fuentes-Contreras et al., 2004) have reported resistance in this species to several pesticides, including pyrethroids.

The strawberry plot acted as a secondary host to the aphid, since on this crop this and other aphid species are not an important pest (Cédola & Greco, 2010); therefore, in our study the aphid population exhibited cyclic changes in low abundance throughout time. On the other hand, although it was present for most of the year at very low densities in the fallow plot, its population reached higher abundances in two instances, following pesticide treatment in cultivated plots. Thus, the fallow plot acted as an alternative habitat and shelter for the pest until the effect of the pesticide application decreased in the crops; furthermore, *M. persicae* has been reported to survive winter on weeds (Fisken, 1959).

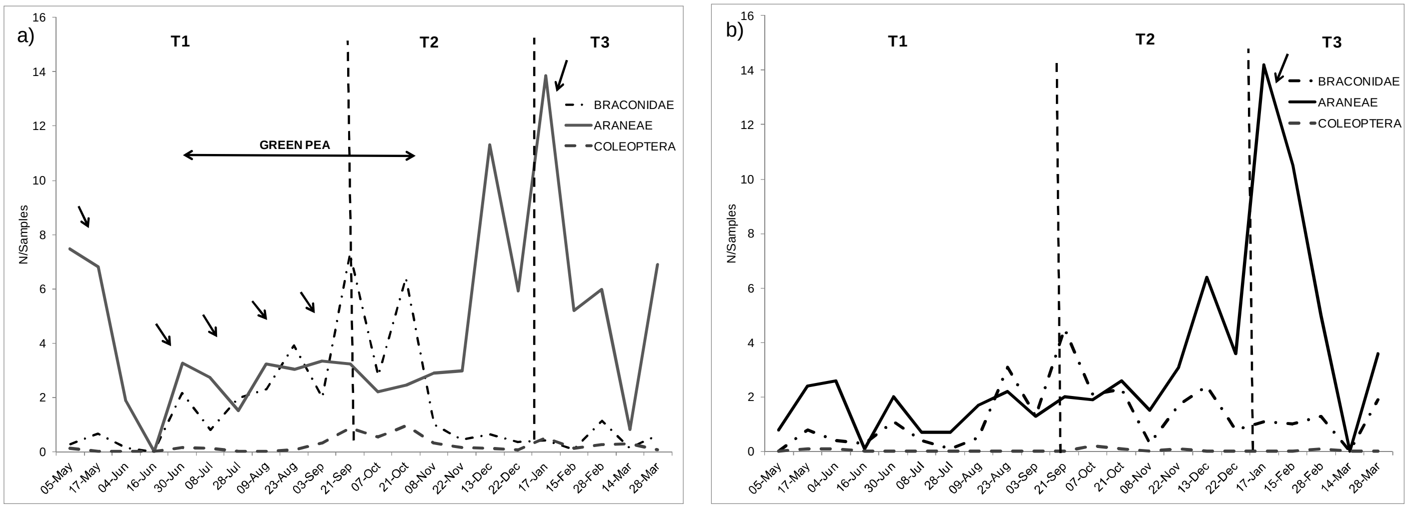

Figure 4: Temporal variation of natural enemies on (a) cultivated plot; and (b) windbreak. Arrows indicate management practices.

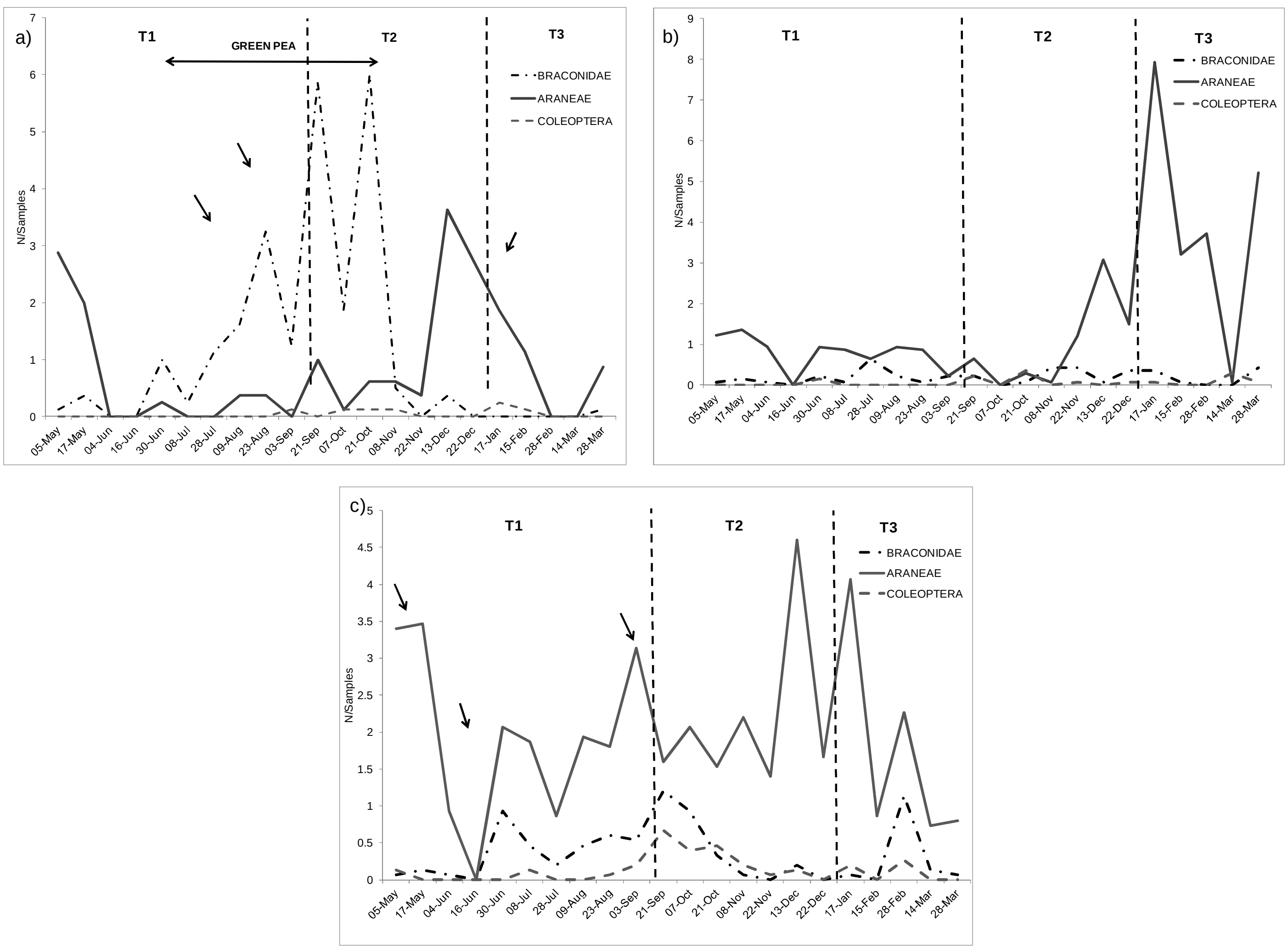

Figure 5: Temporal variation of natural enemies on (a) green pea; (b) fallow; and (c) strawberry plots. Arrows indicate management practices applied on each situation.

In the windbreak barrier, the abundance of *M. persicae* increased not only after sowing the peas plot, but also following pesticide treatments in the cultivated areas of the smallholding. This suggests that on such occasions the windbreak barrier acted as a shelter habitat for the pest, where it reproduced asexually, resulting in a distinct peak in abundance on the first fortnight of October (Fig. 3). Our results agree with reports of windbreak barriers acting as shelter habitats to insects after pesticide treatments on cultivated plots (Dyer & Landis, 1997; Powell, 1986), provided that the structure of the barrier is such that it can support a high number of the pest, as seems to have occurred in our study. On the other hand, the pronounced decrease in abundance in the barrier in late October, with a concomitant increase in the cultivated area, particularly in peas before harvest (Fig. 2a) seems to support the hypothesis of a recolonization from the barrier into cultivated plots following a reduction in the effect of the pesticide treatment. Our results show that *M. persicae* behaved as a disperser species from the barrier (East-West direction) to the cultivated plots in the smallholding, which supports the idea of a recolonization. The abundance of the pest significantly decreased in the windbreak barrier after the harvest and tilling in the peas plot. This result provides further confirmation to the windbreak barrier acting as a shelter, reproduction and recolonization area only on particular occasions.

After the harvest in the peas plot, the fallow plot became an alternative habitat for the aphid, and the same was observed for the strawberry plot (Fig. 3), with cyclic fluctuations. Herbicide applications to these fallow areas in the smallholding not only markedly reduced the vegetation and the herbaceous stratus in the windbreak barrier, but also the aphid population as well. *M. persicae* has been reported to use weeds close to the cultivated areas as alternative hosts for its immature and alate stages, as well as sites overwinter sites, increase their population, and from which to migrate to cultivated areas (Annis et al., 1981; Manfrino et al., 2011; Norris & Kogan, 2000). Although most herbicides have very low direct effects on arthropod populations (Norris & Kogan, 2000), by killing host plants they can indirectly reduce phytophagous populations using them as food or shelter sources.

Our results show that the community of natural enemies accompanying *M. persicae* in the smallholding throughout time was affected by the management practices employed, since its composition varied significantly between the different stages of the smallholding. The decreasing abundance of natural enemies might be due to their sensitivity to pesticides (Jacas & Gómez, 2002; Massaro et al., 2005; Smith et al., 1997; Van Driesche & Bellows, 1996), and in particular to pyrethroids, the chemical group that includes cypermethrin, which has been reported to exert a marked negative effect on the diversity of natural enemies, often greater than the effect on its target pest. Since the abundance of natural enemies in the smallholding did not increase in the windbreak barrier following pesticide applications in cultivated plots, we may infer that there was no possibility of movement towards it in search for shelter. An increase of natural enemies in the windbreak barrier was recorded particularly in summer, a time usually related to the reproductive season, as well as a higher abundance of resources. In this case, the windbreak barrier acted as a reservoir habitat for some natural enemies that constantly invade and recolonize cultivated plots in search of prey, as seen for *Oxyopes salticus* and *D. rapae*, among the dominant species with records of movement between the barrier and the smallholding. This would be further supported by the marked increase they exhibited from late July to October, a period in which the peas plot was sown, and when we recorded the highest abundance of *M. persicae*.

The parasitoids behaved differently in the different plots analyzed; although they followed the population increase of *M. persicae* more closely in the peas plot than in the windbreak barrier, they do not seem to have been effective controllers due, on one hand, to parasitoidism markedly decreasing at high host densities (Thies et al., 2005). Insecticides may alter the action of parasitoids, terminally reducing the local population and limiting recolonization from cultivated areas (Desneux et al., 2005). The dominant species in the smallholding, *D. rapae*, is capable of limiting aphid populations even in the presence of pesticide applications, and of pyrethroid residues (Desneux et al., 2005), although it is likely that, due to the great abundance of *M. persicae* in the barrier, it was unable to exert a proper control, since this species has been shown to be more effective against reduced aphid populations (Rabasse & Van Steenis, 1999). Furthermore, there may be alterations in the host-search behavior and flight patterns when plants are treated with pyrethroid or carbamate insecticides (Jiu & Waage, 1990; Longley & Japson, 1996; Unoru et al., 1996). *D. rapae* also behaved as a dispersers species in one of the directions of analysis, and parasitoid recolonization may have depended on its ability to protect itself from the effect of insecticides during the pupal phase (mummy) (Jansen, 1996; Krespi et al., 1991), and the number of parasitoidized hosts outside the cultivated area (Desneux, 2006). Spiders, on the other hand, were benefited by the environmental heterogeneity, both in the windbreak barrier and the fallow plot and weeded areas (Maloney et al., 2003), as well as the presence of an annual crop such as strawberry. Thus, the proportion of perennial crops in an agricultural landscape may have a significant effect on the density of some spider groups, and several studies have shown that a high proportion of perennial crops and/or non-cultivated areas in the landscape surrounding a crop has a positive effect on predators in crops (Bianchi et al., 2006; Clough et al., 2005; Halley et al., 1996; Schmidt & Tscharntke, 2005 a, b; Thorbek & Topping, 2005). They were the dominant natural enemies group in the smallholding, and this results is coincident with those found by Wise (1993) and Entling et al. (2007), where the spiders shown to be the most abundant generalist predators in agroecosystems, with high species richness, high dispersal potential and several degrees of specialization regarding habitats. On the other hand, in our study management practices applied to the cultivated plots reduced the abundance of the spider community, as observed by Pommeresche (2004). The dominant species in the smallholding was *O. salticus*, which can feed on different aphid species, although it is an important predator of lepidopteran larvae (Armendano & González, 2011). The ubiquitous status of this species in the smallholding might be related to its habit of actively wandering around leaves and stalks in search for prey, both in crops and barrier vegetation.

Predatory coleopterans were scarcely represented in the smallholding, with a higher presence in the strawberry plot. This difference with respect to other natural enemies in the windbreak barrier may be due to the structure and composition of the vegetation, agreeing with Molinari (2005), who states that the benefic fauna is less dependent on pests than on the feeding possibilities offered by the windbreak barrier, as well as shelter from extreme conditions, wintering places, etc. Therefore, the effects of windbreak barriers on crop pests and their natural enemies cannot be generalized, since they depend on the specificity of the arthropods, the structure and location of the barrier, and the type of application performed by crop growers (Girma et al., 2000).

CONCLUSIONS

We can conclude that *M. persicae* is always present in the smallholding, but its increase in abundance, and concomitant elevation to the status of pest in the smallholding, depends not only on the combination of crops planned for it, but also on the response to pesticide treatments that may induce pest outbreaks and reductions in the populations of natural enemies limiting the pest population in the agroecosystem. The windbreak barrier acted only on certain times in the year as a shelter and breeding habitat for *M. persicae*, particularly after successive pesticide applications, and it also facilitated the recolonization of the crop by the pest when conditions became favorable again. Although the windbreak barrier is the natural habitat of certain groups of natural enemies, from where they can recolonized the cultivated plots in the smallholding, the non-cultivated plots are also important at certain times of the year as shelter zones, not only for pests, but also for certain natural enemies.

The diversification of crops and planning of plot design in an agricultural system is important in reducing the effects of pests and potentiating the effect of natural enemies, in order to achieve a greater sustainability in the system. Our results show that the crop diversification and management practices applied failed to benefit natural enemies, and actually induced the resurgence of *M. persicae* as a pest. This aphid species was present in the smallholding at a low density, but the inclusion in the system of a preferred crop lead to a marked increase in its population. This leads us to suggest that the planning of diversified crops and the design of cultivated plots in a smallholding must be carried out with great care, assessing *a priori* the different phytophagous species present in order to avoid associations of crops that may potentiate the resurgence of a pest, so that growers may reduce the treatments with pesticides that might deter the regulating effect of natural enemies on the pests in that agroecosystem.

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