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Impact of some alternative methods to chemical control in controlling aphids (Hemiptera: Sternorrhyncha) and their side effects on natural enemies on young Moroccan citrus groves

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Abstract Aphid control in Moroccan citrus orchards is based mainly on carbamate and neonicotinoid sprays, especially methomyl and imidacloprid. The extensive use of these insecticides may have side effects on natural enemies and environment quality and raises human health concerns. This research aimed to assess the control of aphids with insecticidal soap, kaolin and augmentative biological control using the indigenous predator *Adalia decempunctata* L. (Coleoptera: Coccinellidae). The insecticides were applied and the predators were released in April 2009 and 2010. Under field experimentation, the methomyl and imidacloprid foliar pulverization were very effective against aphids. In contrast, the insecticidal soap and kaolin application were less efficient while *A. decempunctata* adults were effective only in the first week after release. The side effects on beneficial insects were also assessed and discussed. The possibility of employing *A. decempunctata* in an integrated pest management package in citrus groves is discussed in relation to effectiveness and side effects on beneficial arthropods.

Keywords *Adalia decempunctata* · Aphididae · Beneficial species · Biological control · Imidacloprid · Kaolin · Soaps

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Introduction

In Morocco, the citrus industry plays a very important socio-economic role with a total acreage of approximately 105,000 ha and an estimated production of 1,500,000 tons per year. In addition, the citrus industry provides an important source of foreign currency, amounting to approximately 0.27 billion euros per year (MAPM 2008). It also generates important employment of about 21 million work-days per year including 12 million in orchards and 9 million in the packing and processing segments and many other related industries. The last agreement between the government and citrus growers on the development of the citrus industry was to implement a program aiming to renew old citrus plantations and extend new plantings to 50,000 ha (MAPM 2008).

In Morocco, several pests limit citrus production and can cause significant damage when conditions are favorable for the pests. Besides scales, medfly, mites and snails, aphids also are major pests, with negative effects on citrus productivity (Mazih 2011). In Morocco, the aphid species that infest citrus orchards are: spirea aphid *Aphis spiraecola* Pach, black citrus aphid *Toxoptera aurantii* Boyer de Fonscolombe, melon aphid *Aphis gossypii* Glover, green peach aphid *Myzus persicae* Sulzer, black bean aphid *Aphis fabae* Scopoli, and cowpea aphid *Aphis craccivora* Koch (Hemiptera : Aphididae) (Sekkat 2008; Smaili *et al.* 2001, 2008; Vittorio & Delucchi 1964). However, the brown citrus aphid *Toxoptera citricida* Kirkaldy (Hemiptera: Aphididae), which is a major citrus aphid pest in the northern part of the Mediterranean zone, mainly in Portugal and Spain (Nieto-Nafría *et al.* 2005; EPPO 2006; Ilharco and Sousa-Silva 2009), currently does not exist in Morocco. In the Gharb area (northwest of Morocco), only the first three species are considered the most important citrus pests (Smaili *et al.* 2009). When conditions are favorable, these species can cause significant damage, especially to young citrus plantations, causing falling and growth stunting (Michaud & Browning 1999). The two species *T. citricida* and *A. gossypii* are the main vector of CTV (*Citrus tristeza closterovirus* (Closterovirus: Closteroviridae) (EPPO 2004; Nieto-Nafría *et al.* 2005). However, *A. spiraecola* and *T. aurantii* can also, to a lesser extent, be CTV vectors (Yokomi & Garnsey 1987).

In the Gharb area and during certain years, aphids were considered as secondary pests in the old citrus orchards because the shoot infestations were very low (Smaili *et al.* 2009), whereas in young citrus plantations aphids are considered primary pests and damage often is visible – requiring several chemical applications during the same year. In Morocco, an insecticide mix based on imidacloprid and methomyl (and sometimes with endosulfan), is currently used to control aphids in citrus groves. Methomyl belongs to the carbamate class, widely used for controlling insects by inhibiting the enzyme acetylcholinesterase which hydrolyzes the neurotransmitter acetylcholine. Imidacloprid is a neonicotinoid substance which acts agonistically on the insect nicotinic acetylcholine receptor as molecular target and works by interfering with the transmission of nerve impulses in insects (Mencke & Jeschke 2002).

In Morocco, these products are listed among the active ingredients recommended for controlling citrus aphids (AMPP 2013). However, many efforts have been made to switch from chemical control to integrated pest management (IPM) on citrus. In this context, several so-called natural and commercial products compatible with IPM often are considered to be effective and recommended in controlling aphids in young citrus plantations, without taking into account their side effects and selectivity on the natural enemies. This is the case with insecticidal soap which acts on foliar insects by contact, dissolving their outer envelopes and causing the insect to dry up and die. It is also the case of kaolin, a natural mineral product in the form of fine white powder, which was reported as effective against several pest Lepidoptera (Jaastad *et al.* 2006; Sackett *et al.* 2005), beetles (Showler 2002), mites (Jaastad *et al.* 2006), fruit flies (Braham *et al.* 2007; Mazor & Erez 2004; Saour & Makee 2004; Villanueva & Walgenbach 2007), thrips (Larentzaki *et al.* 2008) and aphids (Karagounis *et al.* 2006; Wyss & Daniel 2004). On the other hand, an augmentative biological control technique using especially native species often has been reported as a potential method to control some pests (Cock *et al.* 2009; Crowder 2007; Iperti 1999; Michaud 2001; Van Lenteren & Bueno 2003).

This work is part of an IPM program against citrus aphids and other pests in the Gharb region, and has two objectives: to evaluate the efficacy of insecticidal soap, kaolin and augmentative biological control using *A. decempunctata* on young citrus plantations; and to assess side effects on beneficial insects under field trial.

Materials and methods

Area and field trial The Gharb region is located in the northwestern part of Morocco. The climate is Mediterranean with an average annual rainfall ranging from 430 mm to 520 mm and mean temperatures between 13 °C in winter and 27 °C during the summer. The experiment was conducted in a 1.1 ha citrus grove of 5-year-old clementine trees (*Citrus reticulata* Blanco), planted at a spacing of 4 m x 5 m (354 trees ha^{-1}), on a sandy soil located 9 km from the city of

Kenitra (Gharb zone). The grove was drip irrigated (daily watering) and received routine fertilizer.

Treatment description Lannate 25WP (25 % methomyl, Amaroc SA, Casablanca, Morocco) was sprayed at a dose of 250 cc hl^{-1}. Confidor (200 g^{-1} imidacloprid, Bayer Crop Science, Casablanca, Morocco) was applied at a dose of 50 cc hl^{-1}. Black soap, a natural product derived from olive oil production (soap traditionally produced in Marrakech, Morocco), was used at ~0.2 kg hl^{-1}. The kaolin-based powdery product is a non-toxic white concentrated fine powder $Al_2[(OH)_2,Si_2O_5]$ (Kaolin formulated product, Agriman Firm, Casablanca, Morocco); ~2000 *l* ha^{-1} was applied at a dose of 1.4 %. Augmentative biological control involved the release of *A. decempunctata* adults less than one week old with one adult per tree (d1) and four adults per tree (d2) during April of 2009 and 2010, respectively. *A. decempunctata* larvae were picked *in situ* from other citrus orchards in the Gharb area where their abundance was high. They fed on aphids (*A. spiraecola* and *T. aurantii*) infesting clementine shoots cv 'Cadoux' inside a Plexiglas container (50 cm x 51 cm x 40 cm) in the entomology laboratory of the Regional Agricultural Research Center (Kenitra, Morocco). They are then kept in a rearing cage until adult emergence. Infested citrus shoots were transplanted into moistened soil to retain their turgor under controlled conditions (25 ±1 °C, 70 % r.h.) with natural lighting. Shoots showing signs of weakness were replaced by new ones. Before release in the field, *A. decempunctata* adults were placed separately and kept without aphid food in the Plexiglas container for 24 h, in order to maximize their predatory reflex toward aphids under the same controlled conditions mentioned above.

Field assays Trials were conducted from March to June in 2009 and 2010. The experiment was conducted as a randomized complete block design, with three blocks. Each block consisted of five treatments which included: methomyl (2009)/imidacloprid (2010): plots with trees sprayed with methomyl (2009) or imidacloprid (2010); insecticidal soap: plots with trees sprayed with the soap; kaolin: plots with trees sprayed with kaolin; and adalia/d1 (2009) or adalia/d2 (2010): plots with trees where *A. decempunctata* adults were released with a dose d1 or d2 mentioned above, during 2009 and 2010, respectively; Control: plots with trees sprayed only with water. In each block, each treatment consisted of 14 trees with two rows, of which four were randomly selected. Then on those trees, eight shoots per tree were selected again (32 seedlings per treatment x 3 replications). The young citrus shoot, noted here by "shoot", is easily recognizable by its green color and clear flush or young leaves, which are infested with early and newly formed aphid colonies. In contrast, old citrus shoots are wounded, with a dark green color and are already infested with aphid colonies. The treatments applied were foliar pulverization with a conventional 120*l* air blaster ground sprayer (Agriman Firm), pulled by a mini tractor (Mark Victor BCS AR 500, 45 HP, Ramioui Firm Sarl, Casablanca, Morocco). One foliar spray of each product listed above was applied in approximately 5–6*l* per tree during the mornings of April 7, 2009 and April 6, 2010. For each treatment, all rows and trees were covered by the product. This period often coincides with a high number of aphid colonies and citrus flush is very attractive. To avoid interference between treatments, the plots were separated by one row of guard trees. No other insecticide treatments were applied while the trial was performed in the clementine grove.

Monitoring and assessment Aphids: A total of six variables belonging to two categories were recorded at four dates (5, 7, 14 and 21 days) after treatment. The first category referred to the density of aphids (*T. aurantii*, *A. spiraecola* and the two species grouped together), and was estimated by the number of aphids per shoot. The second category referred to the level of shoot infestation by aphids (*T. aurantii*, *A. spiraecola* and the two species grouped together), and was estimated by dividing the number of infested shoots by the total number of shoots observed (per tree). Each shoot was considered infested when it hosted one or more colonies of *T. aurantii*, *A. spiraecola* or both species. Other important aphid species such as *M. persicae* or *A. gossypii* were absent during these field trials.

Natural enemies were monitored using different methods: On citrus shoots, for each treatment, the number of natural enemies was counted on each citrus shoot used for aphids sampling. Many species of beneficial insects were recorded on Moroccan citrus groves (Smaili *et al.* 2009, 2010, 2013). The main groups of these beneficial species were the parasitoids (Aphelinidae, Braconidae, Encyrtidae and Eulophidae) and the predators (Coccinellidae, Syrphidae, Nitidulidae, Chrysopidae, Cecidomyiidae, Coniopterygidae and Phytoseiidae).

The density of each species was estimated by recording the total number on eight shoots (4 observations x 3 replicates). Parasitism was estimated by dividing the number of parasitized aphids by the total number of aphids recorded on eight citrus shoots. With the beating method, in each treatment 12 branches randomly selected were beaten (12 x 4 branches per treatment). To standardize the method, each branch was stricken ten times by a stick fitted at its end with a rubber cover. The natural enemies fell in the jar of the "umbrella trap" containing 70 % alcohol. The density of each species was estimated by counting the total number of species found on the 12 branches (4 observations x 3 replicates). The yellow sticky traps were used to follow the hymenoptera species. In each treatment, one trap (20 x 6 cm^2) was suspended on the south side of the tree. The number of species caught in the trap was counted in the laboratory under a binocular microscope. The density of each species caught was estimated by counting the total number in each trap (one observation x 3 replicates). The visual observation method was used for monitoring the hoverfly *Episyrphus balteatus* DeGeer (Diptera: Syrphidae). Its density was estimated by counting the number of hoverflies moving side by side to each sampling tree during a 15-min period (4 observations x 3 replicates).

Treatment effect and percentage efficacy Effect of treatment was estimated by the rate of reduction (% Ri) using the following formula: $R_i\%=(1-T_i/T0_i) \times 100$ (Abbott 1925; Ullah *et al.* 2005), where T_i is the average of the studied variable "i" (density or infestation) in the treated plots; $T0_i$ is the average of the studied variable "i" in the untreated control plots. The percentage efficacy control ($E_i\%$) was estimated and computed using the following formula (Henderson & Tilton 1955) : $E_i\%=[(1- T0_i$ before treatment x Ti after treatment)/($T0_i$ after treatment x T_i before treatment)] x 100; with $T0_i$ being average of the studied variable "i" for the control; and T_i being the average of the studied variable "i" in the treated plots.

Statistical analysis At each date, ANOVA was used to compare the effect of the treatment on the variables; density of *T. aurantii*; *A. spiraecola* and aphids; the infestation of shoots per *T. aurantii, A. spiraecola* and aphids; and finally the densities of different beneficial species recorded. Separation of homogeneous groups (levels of the factor treatment) was made by t-test (LSD at the $P=0.05$ level using the SAS software version 9.1.3 (SAS Institute 2005). Square-root and arcsin (square-root) transformation of the number of aphids and transformation and the infestation of shoots were used to normalize the data.

Results

Aphid density and shoot infestation During 2009, there was a difference among the mean densities of aphids in the various treatments (Table 1). Five days after product application, the mean aphid density was significantly much lower in the methomyl treatment than in all others. However, this density was similar in the plots sprayed with insecticidal soap, kaolin and the untreated control. The aphid density was also increased in the adalia/d1 treatment to ~99.63±96.32. Seven days later, the mean aphid density was significantly lower in the insecticidal soap, kaolin and adalia/d1 treatments than in the untreated control. Although we note that aphids were recorded on shoots previously sprayed with methomyl and aphid density was less in adalia/d1 treatment than others, this reduction was not statistically different among treatments. The mean of shoot infestation was statistically different among treatments during 2009 (Table 2). Five days after product application, shoot infestation increased in the kaolin and adalia/d1 treatments, whereas there were no infested shoots in the methomyl treatment. Two days later, mean shoot infestation was null and low for methomyl and adalia/d1 treatment, respectively (for *T. aurantii*). At other sampling dates, mean shoot infestation was similar for all treatments.

During 2010, mean aphid density varied among the treatments (Table 3). Five days after treatment application, the mean aphid density in adalia/d2 was similar to the insecticidal soap and kaolin treatments, but statistically less than the control. Seven days later, the aphid density was lower in the adalia/d2 treatment than in the insecticidal soap and kaolin treatments. Two weeks later, imidacloprid and adalia/d2 treatments scored similarly, and were different from kaolin, the insecticidal soap and the untreated control. For the other sampling date, the density was lower in the imidacloprid and adalia/d2 treatments than other treatments, but was not statistically significant compared with the untreated control. Also differences in the mean shoot infestation among treatments were significant (Table 4). Five days

Table 1 Average aphid density (number/shoot/date±SE) on a young citrus plantation during 2009. A one-way ANOVA was used to compare aphid density: *Toxoptera aurantii* and *Aphis spiraecola* [Bt=before treatment; dat=days after treatment]

		Methomyl	Soap	Kaolin	Adalia/d1	Control
Bt	*Toxoptera aurantii (F= 5.06;df:4; P= 0.0005)*	21.23±21.81ab	15.01±17.68bc	30.73±37.63a	17.98±21.76bc	12.71±17.05c
	Aphis Spiraecola (F= 3.37;df:4; P= 0.0099)	55.40±64.07b	54.35±68.91b	95.23±108.67a	58.85±78.17b	46.77b±59.23
	Both aphid species *(F= 3.58;df:4; P= 0.0068)*	76.64±78.98b	69.36±83.29b	125.97±136.15a	76.84±94.21b	59.48±70.67b
5 dat	*Toxoptera aurantii (F:27.80;df:4; P< 0.0001)*	0.00±0.00b	15.66±18.49a	16.87±20.14a	21.46±25.80a	18.52±25.39a
	Aphis spiraecola (F= 37.26;df:4; P< 0.0001)	0.00±0.00c	53.50±54.55b	43.90±43.82b	78.16±82.07a	55.27±62.32b
	Both aphid species *(F= 39,12;df:4; P< 0.0001)*	0.00±0.00c	69.16±70.42b	60.78±56.01b	99.63±96.32a	73.79±80.78b
7 dat	*Toxoptera aurantii (F= 26.70;df:4; P< 0.0001)*	0.00±0.00d	7.78±8.63b	7.54±10.09bc	5.57±9.35c	14.69±21.45a
	Aphis spiraecola (F= 43.51;df:4; P< 0.0001)	0.00±0.00c	20.73±22.29b	15.36±17.21b	18.57±23.92b	51.57±49.11a
	Both aphid species *(F= 43.06;df:4; P< 0.0001)*	0.00±0.00c	28.52±28.71b	22.90±25.04b	24.14±29.37b	66.27±64.15a
14 dat	*Toxoptera aurantii (F= 0.70;df:4; P= 0.5950)*	0.62±1.85a	0.67±1.65a	1.01±3.36a	1.12±2.94a	0.86±1.79a
	Aphis spiraecola (F= 2.88;df:4; P= 0.0226)	2.20±5.13b	3.95±10.78ab	7.09±13.82a	4.47±9.49ab	6.64±14.40a
	Both aphid species *(F= 2.61;df:4; P= 0.0351)*	2.83±6.14b	4.63±11.57ab	8.10±15.55a	5.60±10.71ab	7.510±15.38a
21 dat	*Toxoptera aurantii (F= 3.03;df:4; P= 0.0175)*	0.43±0.99b	1.08±2.46ab	0.93±1.73ab	1.71±3.43a	0.94±1.73ab
	Aphis spiraecola (F= 2.13;df:4; P= 0.0767)	0.21±0.60b	0.69±1.75a	0.72±1.59a	0.73±1.66a	0.64±1.39a
	Both aphid species *(F= 2.79;df:4; P= 0.0260)*	0.65±1.47b	1.78±3.93ab	1.66±2.93a	2.45±4.62a	1.59±2.71a

Within each row, values followed by a common letter do not differ significantly at *P*<5 %; LSD test

Table 2 Mean citrus shoot infestation (%±SE) on a young citrus plantation during 2009. A one-way ANOVA was used to compare shoot infestation; *Toxoptera aurantii* and *Aphis spiraecola* [Bt=before treatment; dat=days after treatment]

		Methomyl	Soap	Kaolin	Adalia/d1	Control
Bt	*Toxoptera aurantii* (*F*= 0.80; *df*:4; *P*= 0.5294)	54.16±20.87a	48.95±11.25a	59.37±10.82a	53.12±5.65a	48.95±17.23a
	Aphis Spiraecola (*F*= 1.39; *df*:4; *P*= 0.2542)	54.16±18.71a	48.95±11.25a	60.41±10.43a	53.12±9.42a	52.08±7.21a
	Both aphid species (*F*= 2.73; *df*:4; *P*= 0.0406)	59.37±12.06a	48.95±11.25b	60.41±10.43a	54.16±8.14ab	53.12±7.76ab
5 dat	*Toxoptera aurantii* (*F*= 144.96; *df*:4; *P*< 0.0001)	0.00±0.00d	61.45±11.25bc	67.70±16.39ab	71.87±13.19a	55.20±6.43c
	Aphis Spiraecola (*F*= 119.05; *df*:4; *P*< 0.0001)	0.00±0.00d	61.45±11.25bc	65.62±18.55ab	72.91±14.91a	55.20±6.43c
	Both aphid species (*F*= 127.26; *df*:4; *P*< 0.0001)	0.00±0.00d	62.5±10.66bc	67.70±16.39ab	72.91±14.91a	55.20±6.43c
7 dat	*Toxoptera aurantii* (*F*= 85.88; *df*:4; *P*< 0.0001)	0.00±0.00c	62.5±14.10a	62.5±9.23a	41.66±20.17b	53.12±9.42a
	Aphis Spiraecola (*F*= 158.00; *df*:4; *P*< 0.0001)	0.00±0.00b	62.5±14.10a	61.45±9.91a	59.37±12.06a	59.37±12.06a
	Both aphid species (*F*= 145.90; *df*:4; *P*< 0.0001)	0.00±0.00b	62.5±14.10a	64.58±10.43a	59.37±12.06a	62.50±15.07a
14 dat	*Toxoptera aurantii* (*F*= 0.18; *df*:4; *P*= 0.9483)	16,66±13.41a	18.75±16.42a	19.79±18.04a	21.87±16.96a	15.62±13.19a
	Aphis Spiraecola (*F*= 1.22; *df*:4; *P*= 0.3159)	22,91±11.71a	23.95±12.45a	34.37±13.19a	29.16±20.87a	31.25±13.58a
	Both aphid species (*F*= 1.26; *df*:4; *P*= 0.3000)	25.00±14.10a	27.08±11.71a	35.41±13.93a	37.50±15.99a	31.25±13.58a
21 dat	*Toxoptera aurantii* (*F*= 1.84; *df*:4; *P*= 0.1380)	19.79±12.45a	22.91±14.91a	32.29±6.43a	27.08±14.91a	30.20±8.35a
	Aphis Spiraecola (*F*= 3.13; *df*:4; *P*= 0.0237)	13.54±12.45b	19.79±12.45ab	28.12±7.76a	27.08±14.91a	27.08±8.97a
	Both aphid species (*F*= 1.95; *df*:4; *P*= 0.1188)	19.79±12.45b	22.91±14.91ab	32.29±6.43a	27.08±14.91ab	31.25±8.42a

Within each row, values followed by a common letter do not differ significantly (P<5 %; LSD test)

Table 3 Average aphid density (number/shoot/date±SE) on a young citrus plantation during 2010. A one-way ANOVA was used to compare aphid density; *Toxoptera aurantii* and *Aphis spiraecola* [Bt=before treatment; dat=days after treatment]

		Imidacloprid	Soap	Kaolin	Adalia/d2	Control
Bt	*Toxoptera aurantii* *(F=2.84; df:4; P=0.0241)*	16.95±27.02a	11.89±26.92bc	16.90±28.89a	9.34±18.12c	15.12±22.66ba
	Aphis spiraecola *(F=1.44; df:4; P=0.2196)*	36.65±57.15a	25.53±42.22a	40.21±62.58a	38.35±55.79a	35.53±50.69a
	Both aphid species *(F=1.89; df:4; P=0.1110)*	53.61±69.69a	37.42±53.48b	57.12±74.17a	47.69±62.74ab	50.65±61.66ab
5 dat	*Toxoptera aurantii* *(F=8.79; df:4; P<0.0001)*	0.76±3.09d	7.13±14.24ab	9.66±37.74bc	2.98±8.84 dc	9.72±19.49a
	Aphis spiraecola *(F=13.68;df:4; P<0.0001)*	2.63±7.49c	23.91±38.95a	16±38.50b	16.86±29.05ab	23.53±35.75a
	Both aphid species *(F=14.57;df:4;P<0.0001)*	3.39±10.35d	31.05±50.2ab	25.66±72.42c	19.67±32.86bc	33.26±50.02a
7 dat	*Toxoptera aurantii* *(F=11.34; df:4; P<0.0001)*	0.04±0.28b	3.89±11.04a	3.42±7.67a	0.07±0.39b	4.97±13.95a
	spiraecola *(F=8.37; df:4; P<0.0001)*	0.35±1.42b	13.17±31.29a	8.37±20.31a	1.76±6.92b	13.43±31.66a
	Both aphid species *(F=15.88;df:4; P<0.0001)*	0.39±1.44b	17.07±38.18a	11.80±26.22a	1.83±6.93b	18.41±42.19a
14dat	*Toxoptera aurantii* *(F:7.17; df:4; P<0.0001)*	0.06±0.51b	1.80±6.62a	1.60±6.09a	0.11±0.59b	0.18±0.96b
	Aphis spiraecola *(F=6.36; df:4; P<0.0001)*	0.66±2.00b	3.5±7.72a	3.84±11.09a	1.03±4.69b	1.27±4.63b
	Both aphid species *(F=8.06; df:4; P<0.0001)*	0.72±2.04b	5.30±12.16a	5.44±16.64a	1.14±4.70b	1.45±5.47b
21dat	*Toxoptera aurantii* *(F=1.51; df:4; P=0.1983)*	0.01±0.10a	0.06±0.31a	0.02±0.14a	0.04±0.24a	0.09±0.38a
	Aphis spiraecola *(F=3.61; df:4; P=0.0065)*	0.04±0.32b	0.40±1.48a	0.01±0.10b	0.14±0.73b	0.17±0.63ab
	Both aphid species *(F=4.46; df:4; P=0.0015)*	0.05±0.36c	0.46±1.50a	0.03±0.17c	0.18±0.77bc	0.27±0.77ab

Within each row, values followed by a common letter do not differ significantly (*P*<5 %; LSD test)

Table 4 Mean citrus shoot infestation (%±SE) on a young citrus plantation during 2010. A one-way ANOVA was used to compare shoot infestation; *Toxoptera aurantii* and *Aphis spiraecola* [Bt=before treatment; dat=days after treatment]

		Imidacloprid	Soap	Kaolin	Adalia/d2	Control
Bt	*Toxoptera aurantii* *(F= 2.58;df:4; P= 0.005)*	46.87±26.17abc	34.37±24.49bc	58.33±28.86a	37.5±30.15c	55.20±26.35ab
	Aphis Spiraecola *(F= 0.84;df:4; P= 0.5100)*	60.41±29.59a	51.04±23.51a	64.58±30.54a	68.75±28.94a	62.50±29.19a
	Both aphid species *(F= 1.19;df:4; P= 0.3266)*	67.70±30.36a	59.37±17.77a	78.12±32.03a	72.91±30.07a	71.87±25.07a
5 dat	*Toxoptera aurantii* *(F= 4.00;df:4; P= 0.0074)*	11.45±15.50b	37.5±28.70a	25.00±27.69ab	25.00±24.42ab	41.66±35.48a
	Aphis spiraecola *(F= 2.76;df:4; P= 0.0391)*	30.52±20.99b	56.25±42.80ab	33.33±37.05b	53.12±28.76ab	61.45±30.36a
	Both aphid species *(F= 4.41;df:4; P= 0.0043)*	31.25±19.58c	62.5±37.31a	38.54±33.90bc	59.37±27.75ab	66.66±30.30a
7 dat	*Toxoptera aurantii* *(F= 7.53;df:4; P< 0.0001)*	2.08±4.86b	31.25±35.55a	31.25±26.91a	4.16±6.15b	22.91±27.61a
	Aphis spiraecola *(F= 2.68;df:4; P= 0.0437)*	15.62±15.19b	42.70±38.97a	33.33±25.18ab	16.84±18.12b	40.62±33.76a
	Both aphid species *(F= 3.31;df:4; P= 0.0184)*	17.70±18.81c	45.83±39.64a	45.83±27.86a	19.79±18.04bc	43.75±34.74ab
14 dat	*Toxoptera aurantii* *(F= 1.93;df:4; P= 0.1225)*	7.29±11.25a	19.79±23.51a	13.54±31.73a	5.20±8.35a	4.16±11.09a
	Aphis spiraecola *(F= 1.53;df:4; P= 0.2092*	16.66±9.73a	33.33±32.12a	20.83±35.48a	11.45±17.23a	16.66±20.87a
	Both aphid species *(F= 1.37;df:4; P= 0.2602)*	16.66±9.73a	36.45±33.90a	21.70±37.73a	16,66±17.94a	16,66±20.87a
21 dat	*Toxoptera aurantii* *(F= 2.06;df:4; P= 0.1026)*	0.00±0.00a	5.20±6.43a	1.04±3.60a	3.12±5.65a	2.08±4.86a
	Aphis spiraecola *(F= 5.35;df:4; P= 0.0013*	1.04±3.60b	11.45±9.91a	1.04±3.60b	5.20±8.35b	3.12±7.76b
	Both aphid species *(F= 5.34;df:4; P= 0.0013)*	1.04±3.60c	15.62±14.22a	2.08±4.86bc	8.33±11.09ab	5.20±9.91bc

Within each row, values followed by a common letter do not differ significantly (P<5 %, LSD test) later, no difference was observed among imidacloprid, kaolin, insecticidal soap and adalia/d2 treatments. Two days later, shoot infestation was similar for adalia/d2 and imidacloprid treatments, but statistically lower than others. At the other sampling dates, a heavy shoot infestation was recorded in the plots treated with insecticidal soap and kaolin, but not significantly different from that registered on other treatments.

Effect of treatment Considering mean aphid density, reduction for the methomyl treatment was higher one week after (100 %) and further decreased (around 60 %) during 2009 (Table 5). Reduction for the insecticidal soap treatment was very low at first (6.26 %) and varied later (38 % to 57 %), but became negative for the last sampling. For kaolin, reduction did not exceed 65.4 % for the first week and became negative afterwards. Reduction in the adalia/d1 treatment was ~63.5 % one week later and then became negative. During 2010, reduction was always above 50 % for imidacloprid treatment. Reductions for insecticidal soap and kaolin treatments were low or negative, except for kaolin treatment in the last sampling. Adalia/d2 treatment allowed a great reduction (90.04 %) one week after *A. decempunctata* was released. However, a small reduction was found later, ranging between 21.42 % and 30.76 %. Considering mean shoot infestation, reduction for methomyl application was higher (100 %) after one week compared with 2009. This reduction decreased at later dates (20 % and 36.66 %). During 2010, reduction was variable for the imidacloprid treatment (0 % and 80 %) (Table 6). The insecticidal soap application showed a low or negative reduction at one week, but an increase of shoot infestation was recorded afterwards. However, in kaolin and adalia/d2 treatments, reduction was low only after one week.

Percentage of efficacy control Considering mean aphid density, methomyl and imidacloprid treatments were very effective during the first sampling date (Table 5). Application of insecticidal soap and kaolin during 2009 had a maximum efficiency of ~63.1 % and 83.6 %, respectively, one week after their spreading. However, during 2010, these two products did not seem very effective against aphids (except the last date for kaolin). The efficacy of adalia/d1 and adalia/d2 ranged between 71.7 % and 89.42 % for the first week after *A. decempunctata* release. Regarding shoot infestation, methomyl and imidacloprid were very effective (100 %) and ranged between 57 % and 78.7 %, respectively, during the first week. Insecticidal soap and kaolin treatments were not effective in 2009 (13 % and 20 %) (Table 6). The same was noted during 2010, with a negative efficacy for the insecticidal soap and kaolin treatments. Adalia/d1 treatment was not very effective in 2009 (<15 %). However, efficacy of the adalia/d2 treatment should be considered (55.40 %) but only one week after the release of *A. decempunctata*. Effectiveness and percentage reduction varied qualitatively among treatments (Table 7). Methomyl and imidacloprid treatments were very effective followed by the adalia/d2 treatment.

Table 5 Reduction (R%) and Effectiveness (E%) treatments applied to the density of aphids: *Toxoptera aurantii* and *Aphis spiraecola* [dat=days after treatment]

	5 dat		7 dat		14 dat		21 dat	
	R	E	R	E	R	E	R	E
Methomyl	100*	100	100	100	62.27	70.71	58.82	68.04
Imidaclopride	89.79**	90.35	97.85	97.96	50.00	52.75	80.76	81.83
Soap	6.26	19.60	56.96	63.09	38.28	47.06	-11.76	4.14
	6.63	-26.36	7.29	-25.47	-263.57	-392.08	-73.07	-134.25
Kaolin	17.63	61.10	65.43	83.67	-7.90	49.04	-4.57	50.61
	22.83	31.56	35.91	43.17	-273.57	-231.26	88.46	89.76
Adalia/d1	-35.02	-4.52	63.56	71.79	25.28	42.23	-54.24	-19.41
Adalia/d2	40.83	37.17	90.04	89.42	21.42	16.55	30.76	26.47

*; **: Values in 2009 and 2010, respectively. See text for definition and formula of Reduction percentage and Effectiveness percentage

Table 6 Reduction (R%) and Effectiveness (E%) treatments applied for shoot infestation [dat=days after treatment]

	5 dat		7 dat		14 dat		21 dat	
	R	E	R	E	R	E	R	E
Methomyl	100*	100	100	100	20.00	28.42	36.66	43.33
Imidaclopride	53.01**	50.24	59.05	57.03	0.00	-6.15	80	78.76
Soap	-13.20	-22.84	0.00	-8.51	13.33	5.95	26.66	20.42
	6.25	-13.48	-4.76	-26.81	-118.75	-164.80	-200	-263.15
Kaolin	-22.64	-7.83	3.33	9.13	-13.33	0.34	-3.33	9.13
	42.18	46.81	-4.76	3.61	-13.25	-20.75	60	63.20
Adalia/d1	-32.07	-29.53	5.00	6.82	-20.00	-17.69	13.33	15.00
Adalia/d2	10.93	12.20	54.76	55.40	0.00	1.42	-60	-57.71

*; ** Values in 2009 and 2010, respectively. See text for definition and formula of Reduction percentage and Effectiveness percentage

Natural enemies Differences among treatments in the density of beneficial species at each sampling date were significant throughout the monitoring period (Tables 8 and 9). During 2009, the methomyl application reduced the number of natural enemies compared with the other treatments. Coccinellid density was higher in the adalia/d1 treatment than in the control after one week. The same observation was made for the lacewing *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) in adalia/d1. No difference was observed among treatments in the density of the syrphid *E. balteatus,* although the density was relatively higher in the untreated control and adalia/d1. During 2010, the coccinellid density was lower in imidacloprid-treated trees than in the control. However, if species are considered separately, this density is not significant for all treatments. The density of the lacewing *C. carnea* was similar for adalia/d2, kaolin and control treatments. The density of spiders was higher for adalia/d1 and control treatments during the first week. Parasitized aphids were not observed in our samples during 2009. Except for a maximum of 25.44 % noted at the insecticidal soap treatment, no significant difference was observed among all treatments. During 2010, the hymenoptera density was higher in adalia/d2 and control treatment than in the others.

Discussion

The imidacloprid and methomyl foliar spray reduced the aphid populations and shoot infestation in young citrus groves compared with untreated control. These products are very effective for controlling aphids, but they reduced the density of the most beneficial species. Methomyl is known for having side effects on several

Table 7 Percentage reduction (R) and Effectiveness (E) classified arbitrarily qualitatively

	Methomyl/Imidacloprid		Adalia/d1/Adalia/d2		Kaolin		Soap	
	R	E	R	E	R	E	R	E
Aphid density								
2009	+++	+++	+	+	+	++	+	+
2010	+++	+++	++	++	++	+	+	-
Shoots infestation								
2009	++	++	0	0	0	+	+	+
2010	+	+	++	++	+	+	0	0

Effectiveness and percentage reduction classified arbitrarily qualitatively in decreasing order (+++, ++, + and 0) according to predefined thresholds. See text for definition and formula of Reduction percentage and Effectiveness percentage

Table 8 Average abundance of natural enemies (number/trap, observation, beating or shoot, ± SE) and rate of parasitism (%±SE) in a young citrus plantation during 2009. A one-way ANOVA was used to compare natural enemies abundance and rate of parasitism. *C. carnea; E. balteatus; Coccinella septempunctata* L. (Coleoptera: Coccinellidae); *A. decempunctata* [dat=days after treatment]

		Methomyl	Soap	Kaolin	Adalia/d1	Control
5 dat	Hymenoptera/sticky trap *(F= 114.06 df:4; P< 0.0001)*	0.00±0.00b	0.00±0.00b	0.00±0.00b	2±0.00a	2.33±0.57a
	C. carnea/beating *(F= 15.22 df:4; P< 0.0001)*	0.00±.0.00b	0.00±0.00b	0.00±0.00b	1.58±1.16a	1.33±1.15a
	E. balteatus/observation	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
	C. septempunctata/beating *(F= 4.43; df:4; P< 0.0042)*	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.33±0.49a	0.42±0.51a
	A. decempunctata/beating *(F= 2.84; df:4; P< 0.0348)*	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.5±0.79a	0.42±0.9ab
	Coccinellidae/beating *(F= 5.50; df:4; P< 0.0011)*	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.83±1.26a	0.83±0.93a
	Coccinellidae/shoots *(F= 28.72; df:4; P< 0.0001)*	0±0.00c	3±3.27c	4.92±2.60b	9.5±3.91a	6.67±2.90b
	Spiders/beating *(F= 3.63; df:4; P= 0.0119)*	0.33±0.89b	1.16±1.11ab	1.41±1.00a	2±1.48a	1.66±1.5a
	Parasitism	0.00±.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
7 dat	Hymenoptera/sticky trap *(F= 36.40 df:4; P< 0.0001)*	0±0.00b	0±0.00b	0±0.00b	3±0.00a	3.33±1.52a
	C. carnea/ beating *(F= 5.50; df:4; P= 0.011)*	0.16±0.38b	0.41±0.66b	0.58±0.90b	0.83±1.11b	2.16±1.74a
	E. balteatus/observation *(F= 1.03 df:4; P= 0.4034)*	0.00±0.00a	0.16±0.39a	0.16±0.39a	0.33±0.65a	0.33±0.65a
	A. septempunctata/beating *(F= 10.12; df:4; P< 0.0001)*	0.08±0.28 b	0.00±0.00b	0.00±0.00b	0.58±0.51a	0.83±0.71a
	A. decempunctata/beating *(F= 1.95; df:4; P= 0.1180)*	0.41±0.99b	0.83±1.19 ab	0.83±0.93ab	1.58±1.16a	1.16±1.11ab
	Coccinellidae/beating *(F= 4.05; df:4; P= 0.0068)*	0.5±1.00b	0.83±1.19b	0.83±0.93b	2.16±1.40a	2±1.59a
	Coccinellidae/shoots *(F= 17.84; df:4; P< 0.0001)*	0±0.00d	1.58±1.97bc	1.17±1.19c	4±2.13a	15.9±14.14ab
	Spiders/beating *(F= 1.23; df:4; P= 0.3130)*	0.66±0.89a	1.75±1.42a	0.91±1.56a	1.41±2.11a	2±2.41a
	Parasitism	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
14 dat	Hymenoptera/sticky trap *(F= 26.75 df:4; P= 0.0001)*	0.00±0.00c	0.00±0.00c	0.66±0.57b	2±1.00a	2.66±0.57a
	C. carnea/beating *(F= 1.16; df:4; P= 0.3423)*	0.33±0.77a	0.41±0.79a	0.00±0.00a	0.16±0.38a	0.41±0.66a
	E. balteatus/observation	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
	C. septempunctata/beating	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00 a
	A. decempunctata/beating *(F= 0.76; df:4; P= 0.5588)*	0.75±1.28a	1±1.59a	1.08±2.31a	0.16±0.38a	0.75±0.86a
	Coccinellidae/beating *(F= 0.76; df:4; P= 0.5588)*	0.75±1.28a	1±1.59a	1.08±2.31a	0.16±0.38a	0.75±0.86a
	Coccinellidae/shoots *(F= 5.65; df:4; P< 0.0009)*	0.00±0.00b	0.08±0.28b	0.00±0.00b	2.33±4.39a	0.42±0.79b
	Spiders/frappage *(F= 4.65 ; df :4 ; P :0.0031)*	1±1.28ab	1.83±1.59a	0.33±1.15b	1.91±1.56a	1.91±1.44a
	Parasitism	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
21 dat	Hymenoptera/sticky trap *(F= 13.01 df:4; P= 0.0014)*	0±0.00b	0±0.00b	0±0.00b	2±1.00a	2.33±1.52a
	C . carnea/beating *(F= 7.20; df:4; P= 0.0001)*	0.41±0.66b	0.16±0.38b	0.66±0.88b	0.91±0.99b	2.5±3.06a
	E. balteatus/observation *(F= 2.00; df:4; P= 0.1107)*	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.25±0.45a	0.17±0.39ab
	C. septempunctata/beating *(F= 3.16; df:4; P= 0.0226)*	0.00±0.00b	0.25±0.45ab	0.00±0.00b	0.42±0.66a	0.5±0.52a
	A. decempunctata/beating *(F= 5.79; df:4; P= 0.0008)*	0.5±0.79b	0.5±0.79b	0.5±1.24b	0.66±0.65b	1.66±0.65a
	Coccinellidae/beating *(F= 6.31; df:4; P= 0.0004)*	0.5±0.79b	0.75±1.13b	0.5±1.24b	1.08±1.16b	2.16±0.71a
	Coccinellidae/shoots	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
	Spiders/beating *(F= 2.59; df:4; P= 0.0493)*	0.25±0.45b	1.25±0.87a	0.83±0.72ab	0.75±0.87ab	0.75±0.75ab
	Parasitism	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a

Within each row, values followed by a common letter do not differ significantly (P<5 %; LSD test)

beneficial species, especially Hymenoptera (Cerillo *et al.* 2005; Krespi *et al.* 1991; Schuster 1994). The Environment Protection Agency (EPA), the European Chemical Classification (ECC) and the World Health Organization (WHO) classify methomyl as very toxic and hazardous (Mohamed 2009). Imidacloprid is known for its side effects on natural enemies such as coccinellids (Smith & Krischik 1999), Hymenoptera:

Table 9 Average abundance of natural enemies (number/trap, observation, beating or shoot, ± SE) and rate of parasitism (%±SE) on a young citrus plantation during 2010. A one-way ANOVA was used to compare natural enemies abundance and rate of parasitism. *C. carnea; E. balteatus; C. septempunctata; A. decempunctata*; *Rodolia cardinalis* (Mulsant); *Stethorus punctillum* (Weise) and *Scymnus sp* (Coleoptera: Coccinellidae) [dat=days after treatment]

		Imidacloprid	Soap	Kaolin	Adalia/d2	Control
5 dat	Hymenoptera/sticky trap *(F= 0.05 df:4; P= 0.9936)*	0.33±0.57a	0.66±1.15a	0.66±1.15a	0.66±1.15a	0.66±0.57a
	C. carnea/beating *(F= 5.10; df:4; P= 0.0018)*	0.00±0.00c	0.08±0.28bc	0.41±0.51ab	0.66±0.79ab	1±0.62a
	E. balteatus/observation	nr*	nr	nr	nr	nr
	C. septempunctata/beating *(F= 1.92; df:4; P= 0.01242)*	0.16±0.57b	0.75±0.96ab	0.83±1.19ab	0.75±1.13ab	1.33±2.14a
	A. decempunctata/beating *(F= 3.03; df:4; P= 0.0271)*	0.33±0.49b	1.08±0.99ab	2.58±3.47a	1.58±1.78ab	2.25±2.17a
	S. punctillum/beating	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
	R. cardinalis/beating *(F= 1.33; df:4; P= 0.2723)*	0.00±0.00a	0.00±0.00a	0.08±0.28a	0.16±0.38a	0.00±0.00a
	Scymnus sp. *(F= 1.03; df:4; P= 0.4036)*	0.16±0.39a	0.33±0.65a	0.58±1.08a	0.16±0.39a	0.58±0.9a
	Coccinellidae/beating *(F= 5.45; df:4; P= 0.0012)*	0.66±1.07c	2±1.27b	4.08±4.69ab	2.66±2.10ab	4.16±3.97a
	Coccinellidae/shoots *F= 1.75; df:4; P= 01552)*	0.25±0.26a	0.33±0.77a	0.58±1.50a	1.33±1.43a	0.75±1.21a
	Spiders/beating *(F= 3.75; df:4; P= 0.0103)*	0.5±0.52c	0.83±0.83bc	1.16±0.94bc	2.41±1.83a	1.83±1.85ab
	Parasitism *(F= 0.88; df:4; P= 0.4839)*	0.52±1.80a	25.44±86.46a	3.13±5.89a	1.25±1.70a	0.83±0.94a
7 dat	Hymenoptera/sticky trap *(F= 0.80 df:4; P= 0.5553)*	0.00±0.00a	1.33±2.30a	0.00±0.00a	2±1.73a	1.33±2.30a
	C. carnea/beating *(F= 0.19; df:4; P= 0.9415)*	0.33±0.49a	0.58±1.44a	0.33±0.49a	0.41±0.79a	0.25±0.62a
	E. balteatus/observation	nr	nr	nr	nr	nr
	C. septempunctata/beating *(F= 1,18; df:4; P= 0.3328)*	0.33±0.88a	0.008±0.28a	0.33±0.88a	0.58±0.90a	0.58±0.79a
	A. decempunctata/beating *(F= 0.88; df:4; P= 0.4819)*	0.25±0.62a	1.33±2.06a	1.16±2.03a	0.83±1.26a	1±2.13a
	S. punctillum/beating	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
	R. cardinalis/beating *(F= 0.79; df:4; P= 0.5405)*	0.00±0.00a	0.16±0.57a	0.00±0.00a	0.00±0.00a	0.08±0.28a
	Scymnus sp./ beating *(F= 2.06; df:4; P= 0.1020)*	0.00±0.00a	0.41±0.90a	0.00±0.00a	0.58±0.99a	0.08±0.28a
	Coccinellidae/beating *(F= 1.40; df:4; P= 0.2497)*	0.58±0.99b	2±2.95ab	1.5±2.27ab	2±1.75a	1.75±2.30ab
	Coccinellidae/shoots *(F= 1.79; df:4; P= 0.1479)*	0.167±0.38a	0.75±1.35a	1 .25±1.42a	1±1.12a	1 .17±1.80a
	Spiders/beating *(F= 0.37; df:4; P= 0.8260)*	0.83±1.11a	1.33±1.83a	0.75±1.14a	1.16±1.53a	0.83±1.34a
	Parasitism *(F= 2.64; df:4; P= 0.0457)*	0.00±0.00b	0.25±0.47ab	0.33±0.70ab	0.00±0.00b	0.61±1.11a
14 dat	Hymenoptera/sticky trap *(F= 2.44 df:4; P= 0.1319)*	0.00±0.00a	2.0±0.00a	0.00±0.00a	0.33±0.57a	1.33±2.30a
	C. carnea/beating *(F= 1.1; df:4; P= 0.3694)*	0.00±0.00a	0.16±0.38a	0.25±0.62a	0.00±0.00a	0.25±0.62a
	E .balteatus/observation	nr	nr	nr	nr	nr
	C. septempunctata/beating *(F= 0.75; df:4; P= 0.5632)*	0.25±0.99a	0.16±0.38a	0.25±0.45a	0.00±0.00a	0.66±2.01a
	A. decempunctata/beating *(F= 1.61; df:4; P= 0.1894)*	0.08±0.28a	0.75±1.35a	0.33±1.15a	0.16±0.57a	0.08±0.28a
	S. punctillum/beating	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
	R. cardinalis/beating	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
	Scymnus sp./beating *(F= 0.5; df:4; P= 0.7358)*	0.00±0.00a	0.83±0.28a	0.83±0.28a	0.83±0.28a	0.00±0.00a
	Coccinellidae/beating *(F= 0.65; df:4; P= 0.6305)*	0.5±1.00a	1±1.59a	0.66±1.15a	0.25±0.86a	0.75±2.00a
	Coccinellidae/shoots *(F= 1.80; df:4; P= 0.1458)*	0.16±0.38a	0.5±0.90a	0.00±0.00a	0.08±0.28a	0.17±0.38a
	Spiders/beating *(F= 0.84; df:4; P= 0.5079)*	0.25±0.62a	0.66±1.07a	1.08±1.16a	0.83±1.64a	0.58±0.79a
	Parasitism	0.00±0.00a	0.33±1.15a	0.00±0.00a	0.00±0.00a	0.00±0.00a
21 dat	Hymenoptera/sticky trap *(F= 1.91 df:4; P= 0.2019)*	0.00±0.00a	0.00±0.00a	0.00±0.00a	1±1.00a	0.66±1.15a
	C. carnea/beating *(F= 3.59; df:4; P= 0.0127)*	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.08±0.28b	0.41±0.66a
	E. balteatus/observation	nr	nr	nr	nr	nr
	C. septempunctata/beating *(F= 2.46; df:4; P= 0.0591)*	0.00±0.00b	0.5±0.90a	0.33±0.77ab	0.00±0.00b	0.16±0.38ab
	A. decempunctata/beating *(F= 0.12; df:4; P= 0.9747)*	0.25±0.86a	0.16±0.38a	0.08±0.28a	0.16±0.38a	0.16±0.38a
	S. punctillum/beating *(F= 0.32; df:4; P= 0.8622)*	0.16±0.57a	0.00±0.00a	0.08±0.28a	0.08±0.28a	0.16±0.57a

Table 9 (continued)

	Imidacloprid	Soap	Kaolin	Adalia/d2	Control
R. cardinalis/beating	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a
Scymnus sp./beating *(F=0.75; df:4; P=0.5632)*	0.00±0.00a	0.08±0.28a	0.00±0.00a	0.00±0.00a	0.08±0.28a
Coccinellidae/beating *(F=0;68; df:4; P=0,6123)*	0.41±0.99a	0.75±1.21a	0.5±0.79a	0.25±0.62a	0.58±0.79a
Coccinellidae/shoots *(F=0.50; df:4; P=0.7381)*	0.00±0.00a	0.17±0.57a	0.17±0.38a	0.17±0.38a	0.08±0.28a
Spiders/beating *(F=0.29; df:4; P=0.8817)*	0.58±0.79a	0.66±1.22a	0.25±0.78a	0.58±1.08a	0.66±1.30a
Parasitism	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a	0.00±0.00a

Within each row, values followed by a common letter do not differ significantly (*P*<5 %; LSD test). **nr* not realized

Apidae, in the laboratory (Schmuck *et al.* 2001); Coccinellidae on peach groves (Karagounis *et al.* 2006; Kourdoumbalos *et al.* 2006); the Neuroptera Hemerobiidae on lettuce (Cole and Horne 2006); and predatory beetles on okra (Solangi & Lohar 2007); and some pollinator insects of wild flowers (Mommaerts *et al.* 2010).

In a field trial, insecticidal soap and kaolin foliar spray reduced aphid density for one week. In contrast, they do not seem very effective in reducing citrus shoot infestations. In a previous study, three products allowed in organic farming (kaolin, mineral oil and insecticidal soap) were applied for the control of *M. persicae* in a peach orchard (Karagounis *et al.* 2006). According to this study, all products showed good control in the first year, but in the next year they were less effective. However, a study examining the effects of kaolin particle film treatments on some pests in apple cv. 'Golden Delicious' orchards in Europe showed that there was no effect on the number of colonies of rosy leaf-curling aphid *Dysaphis devecta* Walker (Marko *et al.* 2008). According to that study the level of infestation of rosy apple aphid *Dysaphis plantaginea* Passerini and the woolly apple aphid *Eriosoma lanigerum* Hausmann increased in the kaolin-treated plots. Under our conditions, aphid density and citrus shoot infestation were reduced one week after *A. decempunctata* release. Ladybirds were effective during this week, probably because the *A. decempunctata* adults released had at first a great capacity for search and predation, but after the first week the predation was low. Two possible hypotheses can explain this; first, the low number of *A. decempunctata* adults released (both for d1 and d4), and second the presence of ants in this citrus orchard after this first week influenced coccinellids predation of aphids.

Under citrus field conditions, methomyl, imidacloprid and insecticidal soap also showed lower densities of natural enemies compared with kaolin treatment and *A. decempunctata* release. The density of coccinellids was higher in adalia/d1 and adalia/d2 plots for one week. However, in the second year, the mean density of each species taken separately was similar for all treatments, except for imidacloprid, which was much lower. On apples, spraying kaolin once a week for 4 weeks against *Choristoneura rosaceana* Harris (Lepidoptera: Tortricidae), altered the composition of generalist predators and reduced the abundance of some families such as the coccinellids (Sackett *et al.* 2005). In olive groves, kaolin revealed during 3 years a significant deleterious effect on the natural enemy arthropod community such as *Scymnus mediterraneus* Iablokoff-Khnzorian, *Stethorus punctillum* Weise and *Hyperaspis reppensis* Herbst (Pascual *et al.* 2010). However, the previous study on *M. persicae* in a peach orchard showed that insecticidal soap and kaolin had little or no adverse effects on Coccinellidae (Karagounis *et al.* 2006; Kourdoumbalos *et al.* 2006). In contrast, insecticidal soaps application may be compatible with biological control of the Asian citrus psyllid (ACP), *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae), by adult coccinellids like *Cycloneda sanguinea* (L.) (Coleoptera: Coccinellidae), but not the parasitoid *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) (Hall & Richardson 2013).

Chrysopidae species are known as generalist predators that greatly contribute to the natural control of pest species in citrus orchards such as aphids, citrus leafminer and whiteflies (Michaud 1999, 2001). In our study, *C. carnea* density was high during the first week for dalia/d1 and untreated control treatments during 2009 and for adalia/d2, kaolin and untreated control treatments during 2010. However, in apple groves, despite the fact that the aphid prey supply was substantially higher, Chrysopidae adults did not aggregate in the kaolin-treated plots (Marko *et al.* 2008). In olive fields, the number of Chrysopidae adults was lower in the kaolin plot than in the untreated control plot over the 3 years of study (Pascual *et al.* 2010). The spiders Araneidae, Philodromidae and Salticidae were the most numerous family, with predation as their main behavior. During the 2 years, spider densities were similar for all treatments, although slightly higher in adalia/d1 and adalia/d2 treatments. On apples, spraying kaolin altered and reduced the abundance of the spiders Salticidae and Philodromidae (Marko *et al.* 2008; Sackett *et al.* 2005). In olive groves, the family Philodromidae was the most vulnerable to kaolin spraying (Pascual *et al.* 2010). In our field trials, hoverfly *E. balteatus* densities were similar for all treatments, although their density was relatively high in the plots where *A. decempunctata* was released and in the untreated control. In apple, kaolin spraying reduced the abundance of polyphagous predators like predaceous Heteroptera and the red velvet mite *Allothrombium fuliginosum* Hermann (Marko *et al.* 2008). Except for a maximum of 25.44 % noted for the insecticidal soap treatment, the parasitism seemed to be similar for all treatments. However, the hymenoptera recorded in the sticky traps were more numerous in the plots where *A. decempunctata* were released and the untreated plot.

It appears that a single foliar application with kaolin, insecticidal soap and both densities of *A. decempunctata* release is not sufficient to control aphids in young citrus groves. A single foliar spraying with kaolin and insecticidal soap did not prove to be a suitable solution to control aphids. However, frequent releases with higher doses than those experimented with of *A.decempunctata,* are considered as a promising and potential alternative method to control aphids. The same holds true for *Scymnus subvillosus* Goeze and *C. septempunctata*, species very abundant and with low dispersal behavior in most citrus orchards in Morocco (M. C. Smaili, personal observation).

This trial provided information about which safe natural products (insecticidal soap and kaolin) merit consideration and also about the possibility to incorporate indigenous natural enemies such as *A. decempunctata* into an integrated management strategy for controlling aphids in young citrus groves.

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