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RESEARCH

Ecotoxicological Study of Insecticide Effects on Arthropods in Common Bean

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ABSTRACT. Arthropods are an important group of macroorganisms that work to maintain ecosystem health. Despite the agricultural benefits of chemical control against arthropod pests, insecticides can cause environmental damage. We examined the effects of one and two applications of the insecticides chlorfenapyr (0.18 liters a.i. ha-1) and methamidophos (0.45 liters a.i. ha-1), both independently and in combination, on arthropods in plots of common bean. The experiment was repeated for two growing seasons. Principal response curve, richness estimator, and Shannon–Wiener diversity index analyses were performed. The insecticides generally affected the frequency, richness, diversity, and relative abundance of the arthropods. In addition, the arthropods did not experience recovery after the insecticide applications. The results suggest that the insecticide impacts were sufficiently drastic to eliminate many taxa from the studied common bean plots.

Key Words: agroecosystem, common bean, insecticide, toxicity

Arthropods are an important group of macroorganisms that work to maintain soil biomass, trophic chains, and species diversity (Paris 1979, Schoonhoven et al. 2005). The main components of arthropod communities are phytophagous, predator, and detritivore species. Many phytophagous species attack common bean plants, becoming severe pests, and reducing agricultural productivity in tropical areas (Brader et al. 1974, Singh and Emdem 1979, Picanço et al. 2001, Radcliffe and Hutchison 2009). However, other phytophagous arthropods act as biological control for these pests by providing a food source for natural enemies and serving as antagonists (Price 1981, Schoonhoven et al. 2005, Radcliffe and Hutchison 2009).

The chewers are a confederated group of imported pests on soybeans and common beans, and their attack retards plant development and compromises production (Schoonhoven et al. 2005, Radcliffe and Hutchison 2009). Predators are an important group for controlling insect pests by interfering, directly or indirectly, in trophic chains (Gerling et al. 2001, Pearce and Zalucki 2006). Detritivore arthropods play important roles in organic matter mineralization, soil structure, nutrient cycling (Marasas et al. 2001, Badji et al. 2007), the control of soil nematodes and fungal plant diseases, and the regulation of microorganism populations (Badji et al. 2007). These arthropods are vertically distributed between the plant canopy and the ground and are important in the conservation of natural enemies (Tomohiro and Naoki 2005, 2006).

Despite the agricultural benefits of chemical control against arthropod pests, pesticide pollution is commonly found in soils, lakes, and growder water and can occasionally exceed levels safe in drinking water (Christensen et al. 1994, El-Kabbany et al. 2000). This pollution affects vertebrates, invertebrates, and microorganisms, which inhabitat terrestrial, soil litter, and aquatic environments (Lambert 1997, Favari et al. 2002, Relyea 2005, Badji et al. 2007). Insecticides could affect beneficial arthropods, resulting in serious environmental issues such as secondary pest outbreak and resistance (Siqueira et al. 2000, Fragoso et al. 2002). In addition, because insecticide spraying reaches the soil and affects the beneficial arthropods associated with soil litter, it can cause negative effects on soil fertility (Badji et al. 2007).

Methamidophos is an organophosphate acaricide obtained as a by-product of acephate. This insecticide possesses systemic activity and a broad spectrum of action, acting through either direct contact or ingestion by inhibiting acetylcholinesterase. The use of chlorfenapyr for pest control in common bean cultivation is relatively recent. This pesticide is analogous with pyrazole and also acts as an acaricide. The compound has a broad spectrum of action and acts through either direct contact or ingestion by inhibiting oxidative phosphorylation (Ware 2003).

The negative effects of insecticides on non-targeted arthropod communities have been reported in relatively few studies. Previous ecotoxicological considerations of insecticide effects on the agroecosystem have examined univariate dose–response or employed quantification studies of toxic waste. In addition, no previous reports have examined the impacts of methamidophos and chlorfenapyr on arthropod communities. The following work therefore aimed to evaluate the effects of one and two applications of the insecticides methamidophos and chlorfenapyr, both alone and in combination, in two growing seasons by considering the species frequency, richness, diversity, and relative abundance among arthropod communities.

Materials and Methods

Experimental Conditions. This work was conducted on a commercial common bean farm with a red–yellow Argisoil located in Coimbra, Minas Gerais, Brazil (20° 51′ 24″ S, 42° 48′ 10″ W, 648 m a.s.l.). The farm occupied a total area of 3.20 ha, and the experimental parcels on 1.00 ha of this total. A commercial mixture of herbicides (fomesafen + fluazifop) was administered at 0.8 liters ha-1 15 days after the emergence of the crop in all area (Ministério da Agricultura e Pecuária 2006). Other cultivation procedures followed those commonly used in the area (Vieira 1988).

Treatments and Experimental Structure. Two growing seasons were examined in this study: summer–autumn, or second harvest, and

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winter–spring, or third harvest (Vieira 1988). For the summer–autumn growing season, planting took place in March, and harvesting occurred in June. For the winter–spring growing season, planting took place in August, and harvesting occurred in October.

The studied insecticides were chlorfenapyr (Pirate 240 SW) (0.18 liters a.i. ha-1) and methamidophos (Tamaron 600 SL) (0.45 liters a.i. ha-1). These concentrations correspond to the recommended dosages for controlling insect pests in common bean cultivation (Ministério da Agricultura e Pecuária 2006). The insecticide applications were performed with costal pulverizers, pressurized with CO_2 to a constant pressure of 200 kPa and calibrated to apply the equivalent of 400 liters ha-1 liquid spray. The treatments were established in a 2 by 2 (number of insecticides by number of applications) factorial arrangement, with a separate control treatment, in five randomized blocks. The parcels each contained a useful area of 15 by 15 m and were separated from one another by 5 m borders. Two insecticide applications were performed in each growing season. The beginning of the pulverizations occurred at the start of flowering: 14 April 2005 and 30 April 2005 for the summer–autumn season and 3 March 2005 and 17 September 2005 for the winter–spring season.

Arthropod Sampling. The bean-associated arthropod community in the summer–autumn growing season was evaluated 3 days before and 2, 9, 16, 28, 37, and 45 days after the first experimental pesticide application. For the winter–spring growing season, the arthropod community was evaluated 2 days before and 4, 12, 19, 26, 37, and 46 days after the first experimental pesticide application. The canopy-associated arthropod community was evaluated by beating five plants into a plastic tray [35 by 30 by 5 cm (length by width by depth)]. The tray was placed under the plants, which were shaken to dislodge the arthropods into the tray. The collected specimens were then counted (Moura et al. 2007).

Data Analysis. The number of arthropods and the frequency of each taxon were estimated in each treatment. The taxa were classified as not occurring (N, 0%), rare (R, 0.11–19.99%), intermediate (I, 20.00–49.99%), and common (C, > 50.00%).

The richness projection was obtained by the second-order Chao and first-order jackknife richness estimators, as calculated by using EstimateS Win 8.2 software (Colwell 2006). The first-order jackknife estimator (Jack 1) formula is as follows: Jack $1 = \text{Sobs} + L\ (n - 1/n)$, where Sobs is the number of species observed over all samples, L is the number of species represented in a single sample, and n is the number of samples.

The Shannon–Wiener diversity index (SW) was used to compare the diversity of the arthropod communities. The individual sample indexes were computed at each sampling time for each treatment. SW is

Table 1. Frequency (F) of arthropod species in the autumn–winter growing season

Arthropods	Control		Arthropods	Chlorfenapyr		Arthropods	Methamidophos	
	F			F			F	
Herbivore								
Aphis spp.	0.0	R	*Acalima* spp.	0.0	N	*Acalima* spp.	0.0	N
Circulifer spp.	5.7	R	*Pseudoplusia* spp.	0.0	N	Miridae	0.0	N
Simuliidae	5.7	R	Simuliidae	0.0	N	*Pseudoplusia* spp.	0.0	N
Tingidae	5.7	R	*Cerotoma* spp.	0.0	N	Tingidae	0.0	N
Miridae	5.7	R	Lagriidae	2.9	R	*Cerotoma* spp.	2.9	R
Lagriidae	8.6	R	*Liriomyza* spp.	2.9	R	Lagriidae	2.9	R
Liriomyza spp.	11.4	R	Tingidae	2.9	R	*Thrips* spp.	2.9	R
Bemisia tabaci	14.3	R	*U. proteus*	2.9	R	*U. proteus*	2.9	R
Pseudoplusia spp.	14.3	R	*Bemisia tabaci*	2.9	R	Simuliidae	5.7	R
U. proteus	14.3	R	Miridae	5.7	R	*Aphis* spp.	8.6	R
Caleothrips spp.	22.9	I	*Piezodorus guildini*	5.7	R	*Bemisia tabaci*	8.6	R
Acalima spp.	22.9	I	*Aphis* spp.	5.7	R	*Circulifer* spp.	8.6	R
Piezodorus guildini			*Circulifer* spp.	8.6	R	*Liriomyza* spp.	11.4	R
Thrips spp.	45.7	I	*Thrips* spp.	8.6	R	*Piezodorus guildini*	8.6	R
Cerotoma spp.			*Caliothrips* spp.	8.6	R	*Caleothrips* spp.	22.9	I
E. kraemeri	77.1	C	*E. kraemeri*	37.1	I	*E. kraemeri*	31.4	I
D. speciosa	82.9	C	*D. speciosa*	42.9	I	*D. speciosa*	37.1	I
Soil-dwelling								
Drosophilidae	11.4	R	Drosophilidae	5.7	R	Drosophilidae	5.7	R
Trichoptera	25.7	I	Trichoptera	5.7	R	Trichoptera	11.4	R
Collembola	82.9	C	Collembola			Collembola	28.6	I
Predator								
Micropezidae	0.0	N	Anthicidae	0.0	N	Anthicidae	0.0	N
Calosoma spp.	2.9	R	Sarcophagidae	0.0	N	*Calosoma* spp.	0.0	N
Sarcophagidae	5.7	R	*C. sanguínea*	0.0	N	Micropezidae	0.0	N
Crematogaster spp.	14.3	R	*Calosoma* spp.	2.9	R	*Solenopsis* spp.	0.0	N
Geocoris spp.	14.3	R	*Crematogaster* spp.	5.7	R	*Orius* spp.	0.0	N
Chrysoperla spp.	14.3	R	*Geocoris* spp.	5.7	R	Sarcophagidae	0.0	N
C. sanguínea	20.0	R	Micropezidae	2.9	R	*Cycloneda Sanguínea*	2.9	R
Nabis spp.	20.0	R	*Nabis* spp.	5.7	R	*Crematogaster* spp.	2.9	R
Anthicidae	20.0	R	Orius spp.	2.9	R	*Geocoris* spp.	8.6	R
Orius spp.	22.9	I	*Chrysoperla* spp.	5.7	R	*Nabis* spp.	8.6	R
Cantharidae	25.7	I	Cantharidae	8.6	R	Chrysoperla spp.	14.3	R
Solenopsis	34.3	I	Araneae	25.7	I	Cantharidae	17.1	R
Araneae	80.0	C	*Solenopsis*	34.3	I	Araneae	40.0	I
Parasitoid								
Pteromalidae	11.4	R	*Bracon* spp.	2.9	R	*Bracon* spp.	2.9	R
Trichograma spp.	11.4	R	*Aphidius* spp.	5.7	R	Pteromalidae	2.9	R
Aphidius spp.	20.0	R	*Pteromalidae*	5.7	R	*Trichograma* spp.	2.9	R
Bracon spp.	25.7	I	*Trichograma spp.*	5.7	R	*E. formosa*	8.6	R
Myrmaridae	31.4	I	*E. formosa*	14.3	R	Myrmaridae	11.4	R
E. formosa	31.4	I	Myrmaridae	11.4	R	*Aphidius* spp.	20.0	R

Not occurring (N), rare (R), intermediate (I), common (C).

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calculated by the function $H' = -\sum(fi) \ln (fi)$, where *fi* is the relation of individuals belonging to the *n*th species and *ln* is the Napierian logarithm (Pielou 1975). The means and standard errors of the diversity index were then determined for each treatment.

To evaluate the impacts of the pesticides on relative abundance, we employed principal response curves (PRC) calculated using the statistical software *CANOCO 4.0* (Ter Braak and Smilauer 1998). This technique is a redundancy analysis in delineation with repeated observations. PRC represents a direct gradient analysis based on a linear distribution model (Van den Brink and Ter Braak 1999). The first canonical axis is used for this method. Moreover, PRC allows the xenobiotic effects in the arthropod community to be summarized in a simple diagram. In this diagram, the *x*-axis corresponds to time, and the *y*-axis is the PRC coefficient (Cdt) for each treatment. PRC yields eigenvalues, which explain the variance in percentage, in addition to significance values for the first canonical axis.

This multivariate analysis also yields taxon weights (*bk*), which indicate the relative contributions of each taxon to the curve response. These weights may be used to identify which taxon was most affected by the treatment. Taxa with high positive weight (≥ 1) likely follow the pattern of the PRC curve, while those with negative weights likely contribute to the pattern in the opposite direction. Taxa with weights close to 0 (between -0.5 and 0.5) do not show responses.

Furthermore, the proportion contributed by each taxon to the total variance of the dataset is listed in the PRC. These values may be calculated by either the time $1 -$ (sum of all unconstrained eigenvalues) or by the chemical treatment influence (sum of all canonical eigenvalues) $\times$ 100. Finally, the percentage of variance explained by the treatment may be calculated as (canonical eigenvalues of the first axis/sum of all canonical eigenvalues) $\times$ 100. The expression exp [arthropod weight (*bk*) $\times$ first canonical coefficient (*cdt*)] may be applied to every *k* species in the treatments sampled at each date to evaluate quantitatively the degree to which taxon density was reduced in the treatments in relation to the control group (Van den Brink and Ter Braak 1999).

The axis probabilities are determined by the Monte Carlo permutation test (Van den Brink and Ter Braak 1999). In this analysis, the null hypothesis is that the coefficients are equal to 0 or are not different from the control group. The level of significance was calculated by the proportion of *F* values equal or superior to those based on the original dataset. The dataset is log $(x + 2)$ transformated for normality assumption.

Table 2. Frequency (F) of arthropod species in the spring–summer growing season

Arthropods	Control		Arthropods	Chlorfenapyr		Arthropods	Methamidophos	
	F			F			F	
Herbivore								
Calaspis spp.	0.0	N	*Calaspis* spp.	0.0	N	*Acalima* spp.	0.0	N
Acari	2.9	R	*Franklinothrips* spp.	0.0	N	Alydidae	0.0	N
Alydidae	2.9	R	*U. proteus*	0.0	N	*Circulifer* spp.	0.0	N
Franklinothrips spp.	2.9	R	*Bemisia tabaci*	2.9	R	Cerotoma spp.	0.0	N
U. proteus	5.7	R	*Cerotoma* spp.	2.9	R	Simuliidae	0.0	N
Circulifer spp.	8.6	R	Miridae	2.9	R	*Piezodorus guildini*	0.0	N
Bemisia tabaci	8.6	R	*Mysus percicae*	2.9	R	*Franklinothrips* spp.	0.0	N
Liriomyza spp.	8.6	R	Acari	5.7	R	*Calaspis* spp.	2.9	R
Simuliidae	11.4	R	Alydidae	5.7	R	Lagriidae	2.9	R
Piezodorus guildini	11.4	R	*Circulifer* spp.	5.7	R	Miridae	2.9	R
Myzus percicae	14.3	R	*Liriomyza* spp.	8.6	R	Acari	5.7	R
Pseudoplusia spp.	17.1	R	*Acalima* spp.	11.4	R	*Bemisia tabaci*	5.7	R
Aphis spp.	17.1	R	Simuliidae	11.4	R	*Mysus persicae*	5.7	R
Lagriidae	20.0	R	*Pseudoplusia* spp.	11.4	R	*U. proteus*	8.6	R
Miridae	20.0	R	*Piezodorus guildini*	11.4	R	*Pseudoplusia* spp.	11.4	R
Thrips spp.	22.9	I	*Aphis* spp.	11.4	R	*Liriomyza* spp.	11.4	R
D. speciosa	25.7	I	*Thrips* spp.	11.4	R	*Caliothrips* spp.	11.4	R
Acalima spp.	34.3	I	Lagriidae	17.1	R	*Aphis* spp.	14.3	R
Caliothrips spp.	80.0	C	*D. speciosa*	22.9	I	*Thrips* spp.	17.1	R
Cerotoma spp.	71.4	C	*Caliothrips* spp.	31.4	I	*D. speciosa*		
E. kraemeri	91.4	C	*E. kraemeri*	65.7	I	*E. kraemeri*		
Soil-dwelling								
Drosophilidae	2.9	R	Drosophilidae	0.0	N	Collembola	0.0	N
Trichoptera	5.7	R	Trichoptera	2.9	R	Trichoptera	0.0	N
Collembola	62.9	C	Collembola	11.4	R	Drosophilidae	2.9	R
Predators								
Dolichopodidae	0.0	N	Carabidae	0.0	N	Araneae	0.0	N
Carabidae	2.9	R	Dolichopodiae	0.0	N	Carabidae	0.0	N
Sarcophagidae	2.9	R	*Crematogaster* spp.	0.0	N	*Chrysoperla* spp.	0.0	N
Cantharidae	8.6	R	*Geocoris* spp.	0.0	N	*Crematogaster* spp.	0.0	N
Vespidae	8.6	R	Sarcophagidae	0.0	N	Geocoris SPP.	0.0	N
Micropezidae	11.4	R	Vespidae	0.0	N	Reduviidae	0.0	N
Crematogaster sp.	14.3	R	*Calosoma* spp.	2.9	R	Sarcophagidae	0.0	N
Staphinelidae	17.1	R	*Nabis* spp.	2.9	R	Anthicidae	2.9	R
Solenopsis spp.	20.0	R	Reduviidae	5.7	R	*Calosoma* spp.	2.9	R
Reduviidae	20.0	R	Micropezidae	8.6	R	Dolichopodidae	2.9	R
Anthicidae	22.9	I	Anthicidae	11.4	R	Micropezidae	2.9	R
Geocoris spp.	22.9	I	Cantharidae	11.4	R	Staphinelidae	2.9	R
Calosoma spp.	25.7	I	*Solenopsis* spp.	14.3	R	Cantharidae	5.7	R
Orius spp.	25.7	I	Staphinelidae	14.3	R	*Orius* spp.	5.7	R
Nabis spp.	34.3	I	*Orius* spp.	20.0	R	Vespidae	5.7	R
Chrysoperla spp.	54.3	C	*Chrysoperla* spp.	25.7	I	*Nabis* spp.	8.6	R
Araneae	62.9	C	Araneae	34.3	I	*Solenopsis* spp.	11.4	R

Not occurring (N), rare (R), intermediate (I), common (C).

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Table 3. Continuation of Table 2

Arthropods	Control		Arthropods	Chlorfenapyr		Arthropods	Methamidophos	
	F			F			F	
Parasitoids								
Ichenoumonidae	0.0	N	Chalcididae	0.0	N	Chalcididae	0.0	N
Chalcididae	2.9	R	*Trichograma* spp.	2.9	R	*Trichograma* spp.	0.0	N
Trichograma spp.	8.6	R	Ichneumonidae	5.7	R	Ichneumonidae	2.9	R
Bracon spp.	22.9	I	Myrmaridae	8.6	R	*E. formosa*	8.6	R
Myrmaridae	22.9	I	Pteromalidae	14.3	R	*Bracon* spp.	8.6	R
Pteromalidae	22.9	I	*E. formosa*	17.1	R	*Aphidius* spp.	8.6	R
E. Formosa	34.3	I	*Bracon* spp.	22.9	I	Pteromalidae	8.6	R
Aphidius spp.	37.1	I	*Aphidius* spp.	22.9	I	Myrmaridae	14.3	R

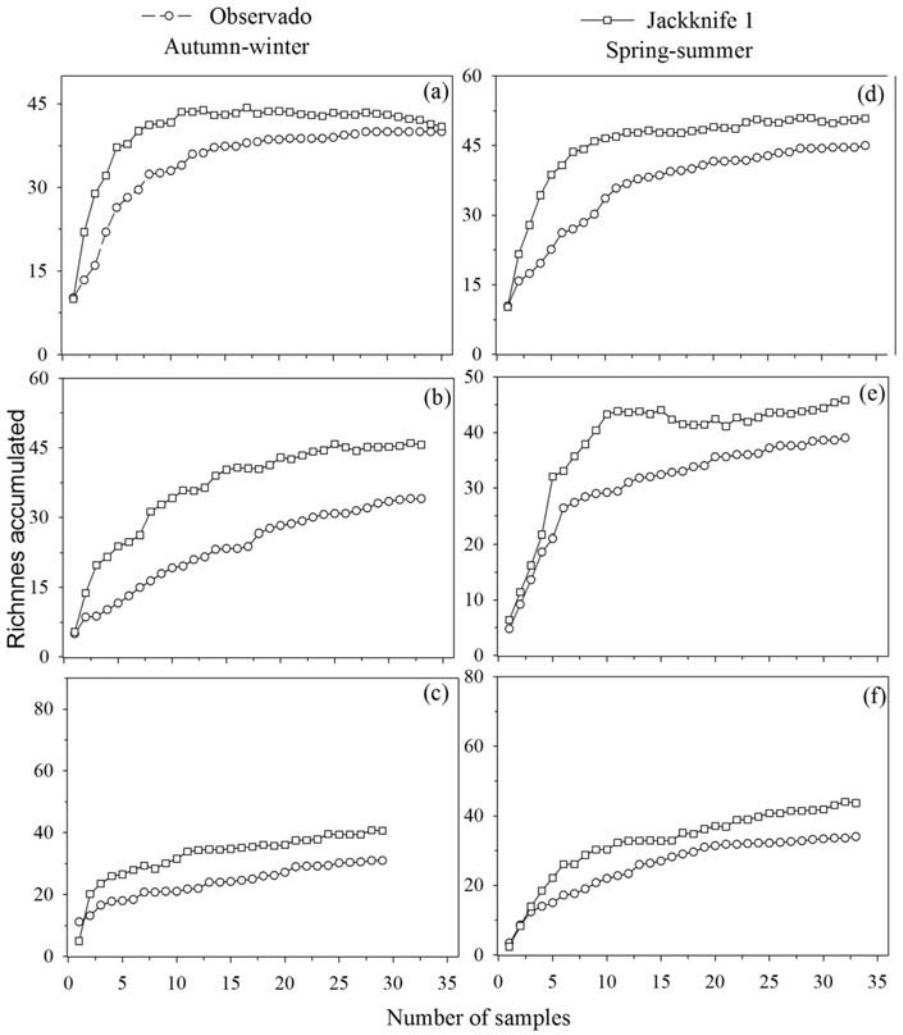

Fig. 1. Species richness estimates for the common bean agroecosystem. In the autumn–winter growing season, a = control, b = chlorfenapyr, and c = methamidophos; in the spring–summer growing season, d = control, e = chlorfenapyr, and f = methamidophos.

Results

The insecticides were found to have generally adverse effects on arthropod frequencies. In the autumn–spring growing season, the numbers of N arthropods were 5, 11, and 14 for the control, chlorfenapyr, and methamidophos treatments, respectively. The number of R arthropods was 23 for the control, 27 for chlorfenapyr, and 25 for methamidophos. The number of I arthropods was 11 for the control, 5 for chlorfenapyr, and 5 for methamidophos. The control treatment alone contained C arthropods, with five taxa in this class. In the spring–summer growing season, the number of N arthropods was three for the control, 10 for chlorfenapyr, and 15 for methamidophos. The number of R arthropods was 27 for the control, 31 for chlorfenapyr, and 29 for methamidophos. The number of I arthropods was 14 for the control, 7 for chlorfenapyr, and 2 for methamidophos. Only the control treatment presented C arthropods, with five taxa in this category.

In the autumn–spring growing season, the taxa *Empoasca kraemeri* (Ross and Moore) (Heteroptera: Cicadellidae) and *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae) changed from C to I after the chlorfenapyr and methamidophos treatment. *Cerotoma* spp. (Coleoptera: Chrysomelidae) was N after chlorfenapyr treatment and R

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after methamidophos. Among the I herbivores, *Acalima* spp. (Coleoptera: Chrysomelidae) became N after the chlorfenapyr and methamidophos treatment, *Caliothrips* spp. (Thysanoptera: Thripidae) became R after chlorfenapyr, and *Piezodorus guildinii* (Westwood) (Hemiptera: Pentatomidae) and *Thrips* spp. (Thysanoptera: Thripidae) became R after chlorfenapyr and methamidophos. Among the R herbivores, the family Simuliidae (Diptera) were not present after chlorfenapyr treatment, the family Tingidae (Heteroptera) were N after methamidophos, and *Pseudoplusia* spp. (Lepidoptera: Noctuidae) were N after chlorfenapyr and methamidophos. The C detritivore order Collembola (Hexapoda) changed to I after chlorfenapyr and methamidophos treatment (Table 1).

The C predator order Araneae (Arachnida) became intermediate after all of the insecticide treatments. Among the I arthropods, the Cantharidae (Coleoptera) and *Orius* spp. (Heteroptera: Anthocoridae) became R after chlorfenapyr treatment, while *Orius* spp. and *Solenopsis* spp. (Hymenoptera: Formicidae) became N after methamidophos. Among the R arthropods, the family Anthicidae (Coleoptera), *Cycloneda sanguínea* (Linnaeus) (Coleoptera: Coccinellidae), and Sarcophagidae (Diptera) became N after chlorfenapyr treatment; the Anthicidae, *Calosoma* spp. (Coleoptera: Carabidae), Micropezidae (Diptera), and Sarcophagidae changed to N after methamidophos. The I parasitoids *Bracon* spp. (Hymenoptera: Braconidae), *Encarsia formosa* (Gahan) (Hymenoptera: Aphelinidae), and the Mymaridae (Hymenoptera) became R after all of the insecticide treatments (Table 1).

For the spring–summer growing season, the C herbivores *Cerotoma* spp. and *E. kraemeri* became intermediate and rare, respectively, after chlorfenapyr treatment, while Caliothrips spp. became N after chlorfenapyr and *Cerotoma* spp. N after methamidophos. Among the I arthropods, *Thrips* ssp. and *Acalima* spp. became R after chlorfenapyr treatment, and *Acalima* spp. were N after methamidophos. *Franklinothrips* spp. (Thysanoptera: Thripidae) and *Urbanus proteus* (Linnaeus) (Lepidoptera: Hesperiidae) were N after chlorfenapyr treatment, and *Franklinothrips* spp. was N after methamidophos. The C detritivore order Collembola became rare after chlorfenapyr treatment and was N after methamidophos. Among R detritivores, the family Drosophilidae (Diptera) was N after chlorfenapyr treatment, and the order Trichoptera (Hexapoda) was N after methamidophos (Table 2).

Among C predators, the order Araneae and *Chrysoperla* spp. (Neuroptera: Chrysopidae) became I after chlorfenapyr treatment, while *Chrysoperla* spp. became R and the Araneae N after

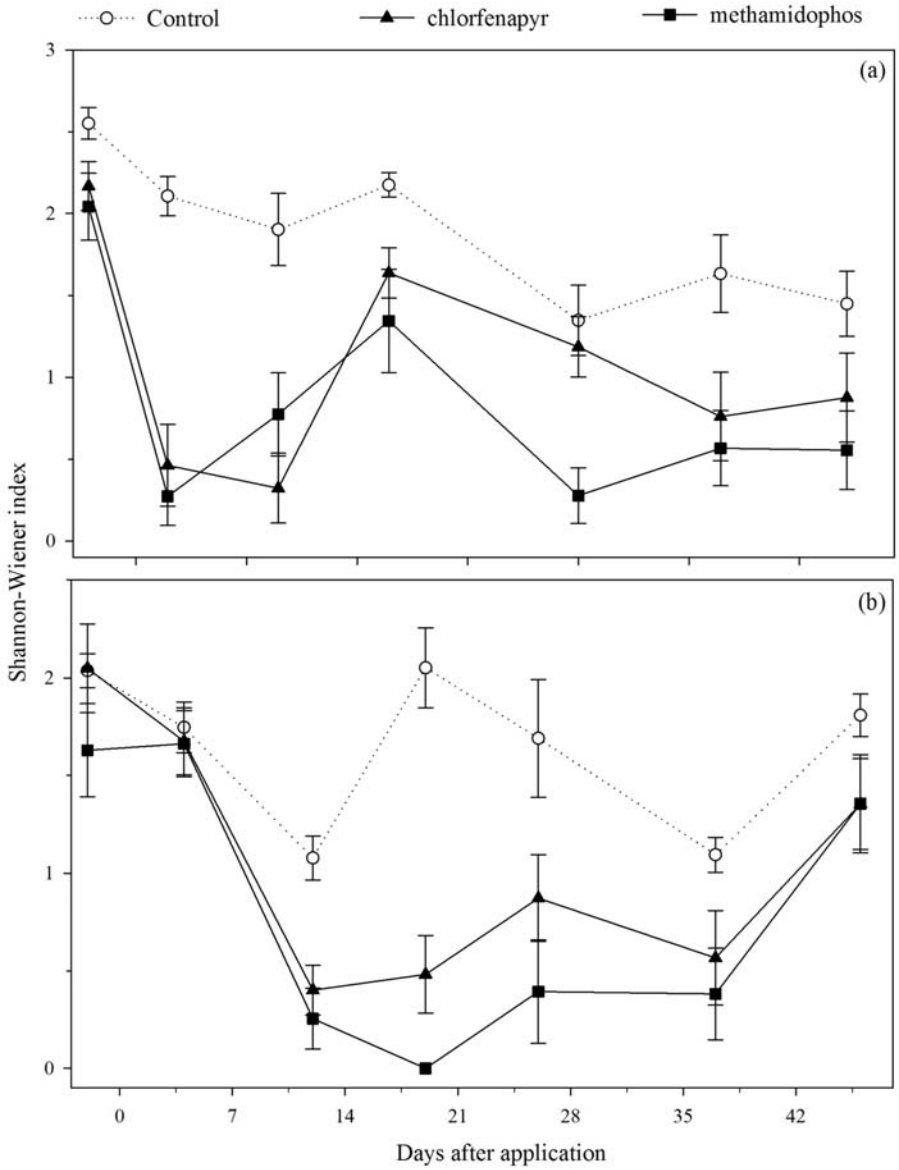

Fig. 2. SW index of arthropods in the common bean agroecosystem for the autumn–winter (a) and spring–summer (b) growing seasons.

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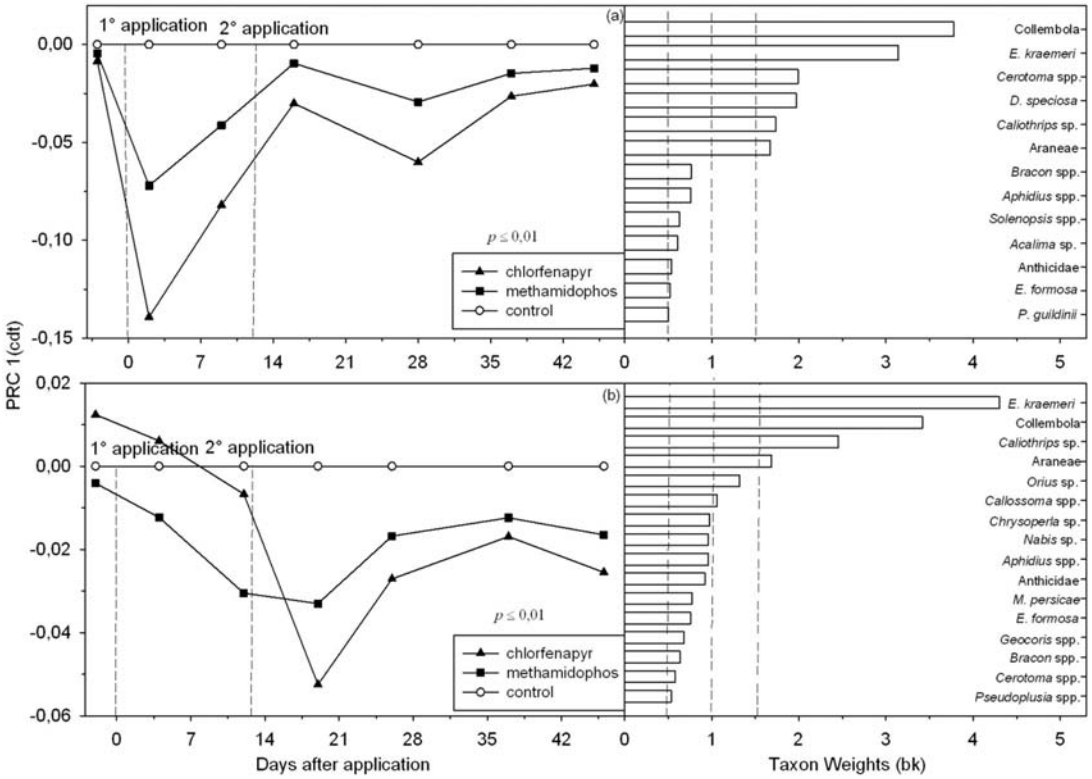

Fig. 3. PRC and weights of the arthropods communities treated with methamidophos and chlorfenapyr compared with the control for the autumn–winter (a) and spring–summer (b) growing seasons.

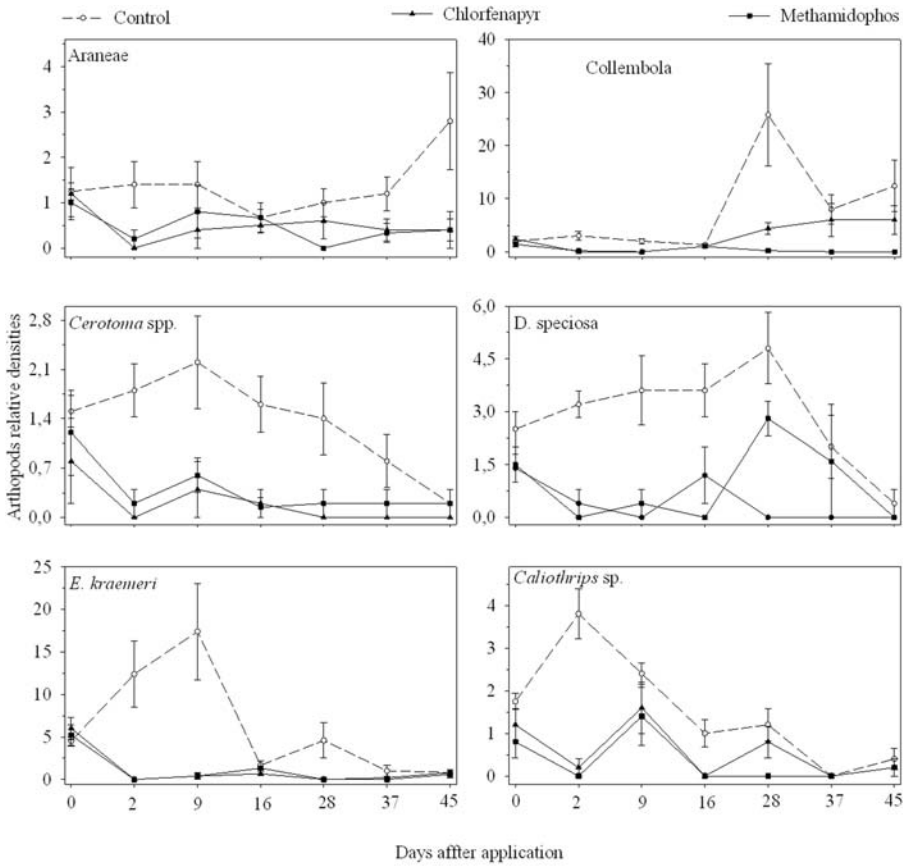

Fig. 4. Relative abundance of arthropods in the autumn–winter growing season after insecticide treatment.

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methamidophos. Among I species, the family Anthicidae, *Calosoma* spp., *Orius* spp., and *Nabis* spp. (Heteroptera: Nabidae) became R, and *Geocoris* spp. (Heteroptera: Lygaeidae) N, after all of the insecticide treatments. Among the R arthropods, the family Carabidae (Coleoptera), *Crematogaster* spp., (Hymenoptera: Formicidae), and the families Sarcophagidae (Diptera) and Vespidae (Hymenoptera) became N after chlorfenapyr treatment, while the Carabidae, *Crematogaster* spp., and Sarcophagidae became N after methamidophos. In addition, the family Reduviidae (Heteroptera) was N after methamidophos treatment (Table 3). Among the I parasitoids, the family Myrmaridae, *E. formosa*, and the family Pteromalidae (Hymenoptera) became R after all of the insecticide treatments, and *Aphidius* spp. (Hymenoptera: Aphidiidae) and *Bracon* spp. became rare after methamidophos (Table 3).

The richness analysis also indicated the adverse impacts of the treatments. In the autumn–winter growing season, the total richness estimation generated by the observed in the control 40 and first-order jackknife 40.97 (Fig. 1a). In the chlorfenapyr treatment, the total richness estimation generated by the observed in the control 34, first-order jackknife 45.60 (Fig. 1b). Methamidophos presented a total richness, generated by the observed in the control 31, first-order jackknife 40.66 (Fig. 1c). In the spring–summer growing season, the total richness estimation generated by the observed in the control 39, first-order jackknife 45.78 (Fig. 1d). The estimation in the chlorfenapyr treatment generated by the observed was 34, first-order jackknife 43.7 (Fig. 1e). The total richness estimation in the methamidophos treatment generated by the observed in control 34.00, first-order Jackknife 43.7 (Fig. 1f). Moreover, SW was calculated in the taxa diversity study. The treatments presented differences in relation to diversity, with the insecticide treatments presenting much lower values in both of the evaluated growing seasons (Fig. 2).

The negative impacts of the insecticide treatments on relative abundance are shown in the PRC diagram (Fig. 3). Two significant axes are estimated for each growing season in the PRC, but only the first significant axis was used in the present analysis. The PRC calculated for the autumn–winter season (Fig. 3a) revealed that 18.90% of the total variance of the dataset could be explained by time and that 28.70%, by the chemical treatments. The first canonical axis captured a significant part (54.10%) of the variance using the Monte Carlo permutation test with 999 permutations and $P \leq 0.01$. In the spring–summer season (Fig. 3b), the PRC revealed that 18.90% of the total variance could explained by time of 21.10% and by the chemical treatments of 28.20%. The first canonical axis captured 49.00% of the variance using the Monte Carlo permutation test with 999 permutations and $P \leq 0.01$.

Based on arthropod weight, in the autumn–winter growing season, high pesticide impacts were observed for the herbivores *Caliothrips* spp., *Cerotoma* spp., *D. speciosa*, and *E. kraemeri*, the detritivore order Collembola, and the predator order Araneae (Figs. 3a and 4). Conversely, in the spring–summer growing season, high impacts were observed on the herbivores *E. kraemeri* and *Caliothrips* spp., the detritivore order Collembola, and the predator order Araneae (Figs. 3b and 5).

Discussion

Overall, the insecticide treatments had evident impacts on arthropod species frequency, richness, diversity, and relative abundance. The insecticides affected populations of both high and low density. These effects were sufficiently drastic to eliminate taxa from the treatment plots. The jackknife estimators were used, as these methods provide more accurate and less biased valuations of datasets with smaller sample sizes (Colwell 2006). The jackknife estimators in this study were not close to the observed estimators and did not reach the asymptote. This situation occurs when the proportion of rare taxa in the dataset is high (Toti et al. 2000, Longino et al. 2002).

The PRC analysis considers time and treatment effects on the taxa. The reduction of natural enemy populations was expected to result from insecticide application due to the lower availability of shelter and

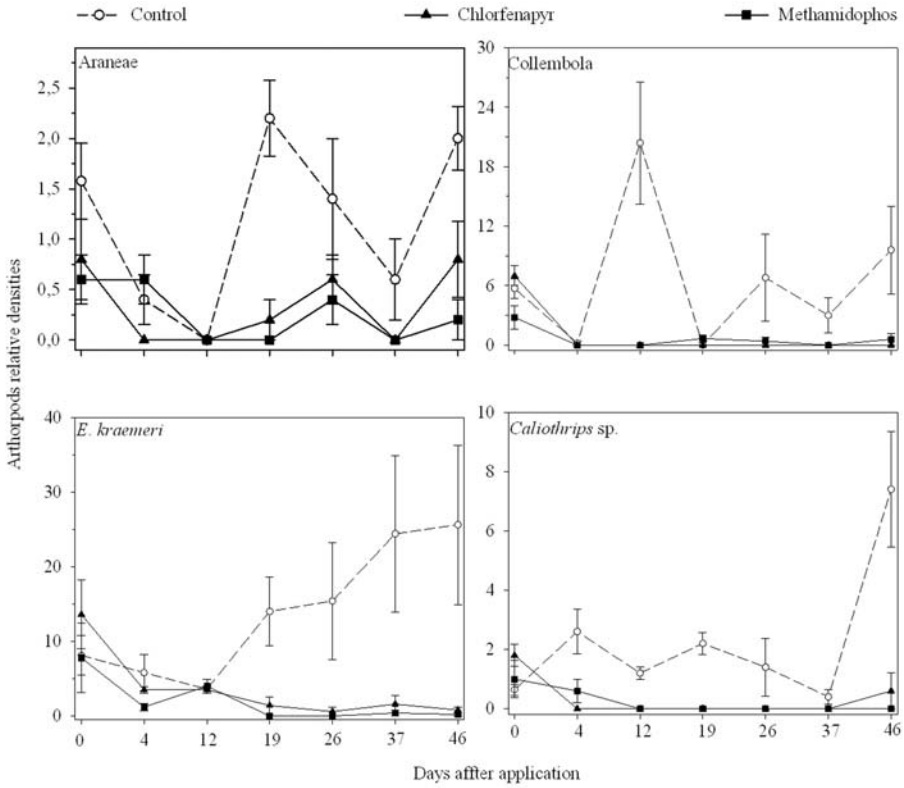

Fig. 5. Relative abundance of arthropods in the winter–spring growing season after insecticide treatment.

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food (Parra et al. 2002, Araújo et al. 2004). In addition, chlorfenapyr and methamidophos are targeted to the herbivores examined in this article (Ministério da Agricultura e Pecuária 2006). Similarly, the xenobiotic effect against the detritivore community, including the Collembola, has been widely discussed in the literature. Several authors have reported the deleterious effects of these insecticides on these communities (Stark 1992, Frampton 1999, Araújo et al. 2004, Badji et al. 2007). These observations suggest that the Collembola are highly susceptible to the effects of these insecticides.

Regarding predators and parasitoids, the family Anthicidae, the order Araneae, *Calosoma* spp., *Chrysoperla* spp., *Nabis* spp., *Orius* spp., *Solenopis* spp., *Bracon* spp., *E. formosa*, and *Aphidius* spp. were most affected by the treatments. Several studies have identified the injurious effects of insecticides on predators and parasitoids (Gonring et al. 1999, Reis and Sousa 2001, Haseeb et al. 2005, Torres et al. 2007, Rezac et al. 2010).

Apart from the toxicity, some arthropods have resilience against disturbed environments. Resilience may be associated with the physiological or ecological selectivity of the insecticides employed in the treatments. Therefore, ecological interactions may have also contributed to the observed results. Intraspecific and interspecific competition among arthropods has adverse effects on both individuals involved in the interaction, including decreased fertility, longevity, size, and weight (Schoonhoven et al. 2005).

In conclusion, overall, insecticides affect the common taxa and also the taxa that survive in low density. In addition, methamidophos and chlorphenapyr affect negatively the diversity, relative abundance and richness of arthorpods community.

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