Ecotoxicological Study of Insecticide Effects on Arthropods in Common Bean

Emerson Cristi de Barros,1,2 Hudson Vaner Ventura,3 Pablo Costa Gontijo,4 Renata Ramos Pereira,5 and Marcelo Coutinho Picanço3

1Institute of Biodiversity and Forests, Federal University of Western Para, Santarém, 68005-050 Para, Brazil
2Corresponding author, e-mail: emersoncristi@gmail.com
3Department of Entomology, Federal University of Viçosa, Viçosa, 36571-000, Minas Gerais, Brazil
4Agricultural Research Center, Kansas State University, Hays, KS 66506
5Department of Phytotechny, Federal University of Viçosa, Viçosa, 36571-000 Minas Gerais, Brazil

Subject Editor: T.-X. Liu

J. Insect Sci. 15(14): 2015; doi: 10.1093/jisesa/jeu172

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 inhabit 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 byproduct 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 Argisol 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...
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 CO2 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 first growing season. 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: 

$$L = \frac{1}{n} S_{obs} + \frac{1}{n(n-1)} L$$

where $S_{obs}$ 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.

### 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   | Pseudoplopus spp. | 0.0 N | Miridae | 0.0 N |
| Simulidae        | 5.7 R   | Simulidae   | 0.0 N        | Pseudoplopus 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 |
| Pseudoplopus spp.| 14.3 R  | Bemisia tabaci | 2.9 R | Bemisa tabaci | 8.6 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 | Pteromalidae | 2.9 R |
| Alcama spp.      | 22.9 I  | Aphis spp. | 5.7 R        | Circulifer spp. | 8.6 R |
| Piezodorus guildini | 45.7 I   | Thrips spp. | 8.6 R   | Liriomyza spp. | 11.4 R |
| Cerotoma spp.    | 77.1 C  | Calothrips spp. | 8.6 R | Calothrips spp. | 22.9 I |
| E. kraemefi      | 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 |
| Collemboala      | 82.9 C  | Collemboala | 5.7 R        | Collembola | 28.6 I |
| Predator         |         |            |              |            |               |
| Micropezidae     | 0.0 N   | Anthicidae | 0.0 N        | Anthicidae | 0.0 N |
| Calosoma spp.    | 2.9 R   | Calosoma spp. | 0.0 N    | Calosoma spp. | 0.0 N |
| Sarcopephagidae  | 5.7 R   | C. sanguinea | 0.0 N     | Micropezidae | 0.0 N |
| Crematogaster spp.| 14.3 R  | Crematogaster spp. | 2.9 R | Crematogaster spp. | 2.9 R |
| Geocoris spp.    | 14.3 R  | Geocoris spp. | 5.7 R | Geocoris spp. | 8.6 R |
| Chrysoperla spp. | 14.3 R  | C. sanguinea | 5.7 R    | Cyclone Sanguinea | 2.9 R |
| C. sanguinea     | 20.0 R  | Micropezidae | 2.9 R | Cyclone Sanguinea | 2.9 R |
| Nabis spp.       | 20.0 R  | Nabis spp. | 5.7 R        | Nabis spp. | 8.6 R |
| Anthicidae       | 20.0 R  | Orius spp. | 2.9 R        | Orius spp. | 8.6 R |
| Orius spp.       | 22.9 I  | Chrysoperla spp. | 5.7 R | Chrysoperla spp. | 14.3 R |
| Cantharidae      | 25.7 I  | Cantharidae | 8.6 R        | Cantharidae | 17.1 R |
| Solenopsis       | 34.3 I  | Araneae    | 25.7 I       | Araneae    | 40.0 I |
| Araneae          | 80.0 C  | Solenopsis | 34.3 I       | Solenopsis | 34.3 I |

Not occurring (N), rare (R), intermediate (I), common (C).
calculated by the function $H' = -\sum (f_i \ln f_i)$, where $f_i$ is the relation of individuals belonging to the $n$th species and $In$ is the Naperian 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 ($\text{Cdt}$) 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 ($\geq 1$) 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 $\exp [\text{arthropod weight (bk) } \times \text{first canonical coefficient (cdt)}]$ 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 ($x + 2$) transformed for normality assumption.

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

| Arthropods          | Control F | Arthropods F | Chlorfenapyr F | Arthropods F | Methamidophos F |
|---------------------|-----------|--------------|----------------|--------------|-----------------|
| **Herbivore**       |           |              |                |              |                 |
| Calaspis spp.       | 0.0 N     | Calaspis spp. | 0.0 N          | Acalima spp. | 0.0 N           |
| Acari               | 2.9 R     | Franklinthrips spp. | 0.0 N          | Acari         | 5.7 R           |
| Alydidae            | 2.9 R     | U. proteus   | 0.0 N          | Alydidae     | 0.0 N           |
| Franklinthrips spp. | 2.9 R     | Bemisia tabaci | 2.9 R          | Cubilform spp. | 0.0 N          |
| U. proteus          | 5.7 R     | Cerotoma spp. | 2.9 R          | Cerotoma spp. | 0.0 N           |
| Circulifer spp.     | 8.6 R     | Miridae      | 2.9 R          | Simulidae    | 0.0 N           |
| Bemisia tabaci      | 8.6 R     | Mysus percicla | 2.9 R         | Piezodorus guildini | 0.0 N |
| Liriomyza spp.      | 8.6 R     | Acari        | 5.7 R          | Calaspis spp. | 2.9 R           |
| Simulidae           | 11.4 R    | Alydidae    | 5.7 R          | Lagriidae    | 2.9 R           |
| Piezodorus guildini | 11.4 R    | Cubilfom spp. | 5.7 R          | Miridae      | 2.9 R           |
| Myzus percicla      | 14.3 R    | Liriomyza spp. | 8.6 R        | Acari        | 5.7 R           |
| Pseudoplusia spp.   | 17.3 R    | Calaspis spp. | 11.4 R      | Mysus percicla | 5.7 R           |
| Aphis spp.          | 17.1 R    | Simulidae    | 11.4 R        | U. proteus   | 8.6 R           |
| Lagriidae           | 20.0 R    | Pseudoplusia spp. | 11.4 R  | Pseudoplusia spp. | 11.4 R       |
| Miridae             | 20.0 R    | Piezodorus guildini | 11.4 R | Liriomyza spp. | 11.4 R         |
| Thrips spp.         | 22.9 R    | Aphis spp.   | 11.4 R       | Liriomyza spp. | 11.4 R         |
| D. speciosa         | 25.7 i    | Thrips spp.  | 11.4 R      | Calothrips spp. | 11.4 R       |
| Acalima spp.        | 34.3 i    | Larioidae   | 17.1 R         | Aphis spp.   | 14.3 R         |
| Calothrips spp.     | 80.0 C    | D. speciosa | 22.9 I       | Thrips spp.  | 17.1 R         |
| Cerotoma spp.       | 71.4 C    | Calothrips spp. | 31.4 I     | D. speciosa | 11.4 R         |
| E. Kraemer i        | 91.4 C    | E. kraemer | 65.7 I         | E. kraemer |                 |
| **Predators**       |           |              |                |              |                 |
| Dolichopodidae      | 0.0 N     | Carabidae    | 0.0 N          | Anitidae     | 0.0 N           |
| Carabidae           | 2.9 R     | Dolichopodidae | 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     | Georics spp. | 0.0 N          | Crematogaster spp. | 0.0 N           |
| Vesipidae           | 8.6 R     | Sarcophagidae | 0.0 N         | Georics spp. | 0.0 N           |
| Micropedidae        | 11.4 R    | Vesipidae    | 0.0 N          | Reduviidae   | 0.0 N           |
| Crematogaster sp.   | 14.3 R    | Calosoma spp. | 2.9 R        | Sarcophagidae | 0.0 N           |
| Staphiniledae       | 17.1 R    | Nabis spp.   | 2.9 R          | Anthidiae    | 2.9 R           |
| Solenopsis spp.     | 20.0 R    | Reduviedae   | 5.7 R          | Calosoma spp. | 2.9 R           |
| Reduviedae          | 20.0 R    | Micropedidae | 8.6 R         | Dolichopodidae | 2.9 R         |
| Anthidiae           | 22.9 i    | Anthidiae    | 13.4 R        | Micropedidae | 2.9 R           |
| Georics spp.        | 22.9 i    | Cantharidae  | 11.4 R         | Staphiniledae | 2.9 R           |
| Calosoma spp.       | 25.7 I    | Solenopsis spp. | 14.3 R   | Cantharidae | 5.7 R           |
| Orits spp.          | 25.7 I    | Staphiniledae | 14.3 R     | Orits spp. | 5.7 R           |
| Nabis spp.          | 34.3 i    | Orits 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).
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* (Gemar) (Coleoptera: Chrysomelidae) changed from C to I after the chlorfenapyr and methamidophos treatment. *Cerotoma* spp. (Coleoptera: Chrysomelidae) was N after chlorfenapyr treatment and R
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 sanguinea* (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. kraemer* 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* spp. and *Acalima* spp. became R after chlorfenapyr treatment, and *Acalima* spp. were N after methamidophos. *Franklinthrips* spp. (Thysanoptera: Thripidae) and *Urbanus proteus* (Linnaeus) (Lepidoptera: Hesperiidae) were N after chlorfenapyr treatment, and *Franklinthrips* 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. 3. PRC and weights of the arthropod 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.
methamidophos. Among I species, the family Anthicidae, Calosoma spp., Orius spp., and Geocoris spp. (Heteroptera: Nabidae) became R, and the families Sarcophagidae (Diptera) and Vespidae (Hymenoptera) became N after 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 40.66 (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).

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 be 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
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., Solenopsis 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, Reza 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 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 chlorfenapyr affect negatively the diversity, relative abundance and richness of arthropod communities.

Acknowledgments

This research was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

References Cited

Araújo, R. A., C. A. Badji, A. S. Corrêa, A. J. Ladeira, and R. N. C. Guedes. 2004. Impacto causado por deltametrina em coleópteros de superfície do solo associados à cultura do milho em sistemas de plantio direto e convencional. Neotrop. Entomol. 33: 379–385.

Badji, C. A., R. N. C. Guedes, A. A. Silva, A. S. Corrêa, M. E. L. R. Queiroz, and M. Michereff-Filho. 2007. Impacto causado por deltametrina e metamidophos sobre duas espécies de acaros predadores (Acari: Phytoseiidae) em cultivos irrigados sob pivot central, pp. 275–324. In L. Zambolim (ed.), Manejo Integrado; Fitossanidade; Cultivo Protegido, Pivo ˆcentral e Plantio direto. UFV, Viçosa, Brazil.

Peloue, E. C. 1975. Ecological diversity. John Wiley & Sons, New York, NY.

Price, P. W. 1981. Semiochemicals in evolutionary time, pp. 251–279. In D. A. Nordlund, R. L. Jones, and W. J. Lewis (eds.), Semiochemicals—their role in pest control. John Wiley and Sons, New York, NY.

Radcliffe, E. B., and W. D. Hutchinson 2009. Integrated pest management: concepts, tactics, strategies and case studies. Cambridge University Press, Cambridge, UK.

Reis, P. R., and E. O. Sousa. 2001. Seletividade de chlorfenapyr e fenbutatin oxide sobre duas espécies de acaros predadores (Acari: Phytoseiidae) em cultivos irrigados sob pivô central, pp. 275–324. In L. Zambolim (ed.), Manejo Integrado; Fitossanidade; Cultivo Protegido, Pivo ˆcentral e Plantio direto. UFV, Viçosa, Brazil.

Schneider, H. A. A., R. N. C. Guedes, and M. C. Picasso. 2000. Insecticide resistance in populations of Tuta absoluta (Lepidoptera: Gelechiidae). Annu. Rev. Entomol. 45: 123–139.

Stark, J. D. 1992. The ant fauna of a tropical rain forest: estimating species richness in three different ways. Ecology 83: 689–702.

Marasas, M. E., S. J. Sarandon, and A. C. Cicchino. 2001. Changes in soil arthropod functional group in a wheat crop under conventional and no tillage systems in Argentina. Appl. Soil Ecol. 18: 61–68.

Ministério da Agricultura e Pecuária. 2006. AGROFIT. www.agrofit.org.br (accessed 16 January 2012).

Moura, M. F. M. C. Picasso, R. N. C. Guedes, E. G. F. Morais. 2007. Conventional sampling plan for the green leaf hopper Empoasca kraeuteri in common beans. J. Appl. Entomol. 131: 215–220.

Paris, V. 1979. Biologia y ecología del suelo. Blume, Barcelona.

Fragoso, D. B., P. F. Jusselino, A. F. Pallini, and A. C. Badji. 2002. Action of pyrethroids on Plutella xylostella (Lepidoptera: Plutellidae) in the canopy and soil habitat of a Cryptomeria japonica plantation. Pedobiologia 54: 507–510.

Tomohiro, Y., and H. Naoki. 2006. Vertical distribution and seasonal dynamics of arboreal collembolan communities in a Japanese cedar (Cryptomeria japonica D. Don) plantation. Pedobiologia 49: 425–434.

Tomohiro, Y., and H. Naoki. 2006. Vertical distribution and seasonal dynamics of arboreal collembolan communities in a Japanese cedar (Cryptomeria japonica D. Don) plantation. Pedobiologia 49: 425–434.
Torres, F. Z. V., G. A. Carvalho, J. R. Souza, and L. C. D. Rocha. 2007. Seletividade de inseticidas a Orius insidiosus. Bragantia 66: 433–439.

Toti, D. S., F. A. Coyle, and J. A. Miller. 2000. A structured inventory of Appalachian grass bald and heath bald spider assemblages and a test of species richness estimator performance. J. Arachnol. 28: 329–345.

Van Den Brink, P. J., and C. J. F. Ter Braak. 1999. Principal response curves: analysis of time-dependent multivariate responses of biological community to stress. Environ. Toxicol. Chem. 18: 138–148.

Vieira, C. 1988. Doenças e pragas do feijoeiro. UFV, Viçosa, BR.

Ware, G. W. 2003. The pesticide book. W.T. Thompson, Fresno, CA.

Received 3 May 2012; accepted 14 October 2014.