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# Non-target impact of deltamethrin on soil arthropods of maize fields under conventional and no-tillage cultivation

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**Abstract:** Deltamethrin is a commonly used insecticide for controlling its key maize pest, the fall armyworm *Spodoptera frugiperda* (Lep., Noctuidae). Its toxicological profile is well known, but its impact on arthropods widely reported as bioindicators, mainly springtails (Collembola) and mites (Oribatida), is yet to be assessed in tropical maize fields. The treatments used to circumvent this shortcoming were conventional cultivation and no-tillage cultivation (with a pre-sowing application of 2,4-D and glyphosate) systems with or without deltamethrin spraying. The deltamethrin residue analysis of soil samples by gas chromatography did not detect the insecticide 24 h after it was sprayed on the maize fields. There was no significant overall effect of deltamethrin based on principal component analysis. However, repeated-measures analyses of variance detected significant impact of deltamethrin in a species of Nitidulidae (Coleoptera). The cultivation system also provided significant impact on Oribatida and Gamasida soil mites and on the same Nitidulidae species referred above, which were more abundant in the conventional cultivation system. Springtails were also significantly affected by the cultivation system showing greater abundance in the conventional system, except Podumorpha. Analyses using only high taxonomic levels did not allow the detection of impact in the ant assemblage assessed. The results suggest that the impact of deltamethrin on soil arthropods from tropical fields varies among species and is lower than expected. The cultivation system imposes more drastic effects on arthropod assemblage.

**Key words:** ants, bioindicators, Collembola, environmental impact, principal component analysis, soil mites

## 1 Introduction

The fall armyworm, *Spodoptera frugiperda* (Smith) (Lep., Noctuidae), is one of the main pests of maize, particularly in Neotropical America (Cruz 1997). Infestations by this pest species are higher and lead to major losses when maize is sown late in late summer (January–March). Cultivation in this period is in current expansion in Brazil and it coincides with high temperature and dry weather conditions (Fornasieri 1992; Companhia Nacional de Abastecimento 2005). The consequence of such infestations is the increased use of insecticides (Ghidiu and Drake 1989; Cruz 1997).

Insecticide spraying on the maize canopy invariably reaches the soil and may affect the epigeic arthropods, which are associated with the more superficial soil layers and litter (van der Werf 1996; Frampton 1997; Peck et al. 1998; Behan-Pelletier 1999). These arthropods have important roles in structuring tropical agroecosystems, as they affect soil accumulation of organic matter, action of decomposer micro-organisms, soil structure and nutrient cycling, incidence of soil nematodes and fungi plant diseases, as well as encouraging plant root development (Crossley et al. 1992; Rusek 1998; Behan-Pelletier 1999).

Conservation tillage is also quickly increasing in Brazil due to its advantages to the agroecosystem, such as reduction in soil erosion, fertilizer run-off, fuel and labour costs, and water conservation (Gebhardt et al. 1985; Quintela 2001). The practice has great impact on maize cultivation but the effects of such system have been explored mainly on insect-pests and their natural enemies (Guedes and Guedes 2001). Very little is known regarding the impact of no-tillage cultivation systems on the soil fauna and even less is known about springtails and soil mites (Wiktelius et al. 1999; Michereff-Filho et al. 2004). The few studies carried out on these taxa are restricted to general observations on changes in the overall abundance (Wiktelius et al. 1999).

The contrasting response of different arthropod species to no-tillage cultivation systems has diverse consequences for pest management, leading Tonhasca (1993) and Cárcamo et al. (1995) to suggest focusing only on more relevant species to improve the predictive capacity of impact studies in such systems. Mites, springtails and ants are some arthropods used to assess environmental impacts (Vadakepuram and Chakravorty 1991; Majer 1994; Peck et al. 1998). Studies on non-target impact of pesticides have been carried out with springtails (Frampton 1994, 1997) and ants (Samways 1981; Perfecto 1990; Michereff-Filho et al. 2004). Oribatida and Gamasida mites have been used to assess changes resulting from human activity (Moore et al. 1984; Norton and Sillman 1985; Minor et al. 2004).

No-tillage cultivation systems usually favour microarthropod populations, particularly those of mites and springtails (Stinner and House 1990; McLaughlin and Mineau 1995). Such cultivation systems also affect species of Coleoptera (Perner and Malt 2003; Araújo et al. 2004). Thus arthropods in no-tillage systems may be more susceptible to insecticides applied to the plant canopy than those in the conventional cultivation system (Edwards and Lofty 1978; Brust et al. 1985). In addition, as the no-tillage cultivation system commonly employed in Brazil includes a pre-sowing application of herbicides as desiccants (Fornasieri 1992; Guedes and Guedes 2001), the no-tillage impact on soil arthropods is likely to be further enhanced (Moore et al. 1984; Salminen et al. 1997). Curiously though, the impact of insecticides on arthropods associated with no-tillage cultivation systems has proved negligible in the few studies carried out so far in the tropics, in contrast to that which usually takes place in the temperate zone (Frampton 1997, 1999; Michereff-Filho et al. 2002a, 2004; Araújo et al. 2004; Badji et al. 2004). These findings in tropical areas suggest that no-tillage cultivation may buffer the insecticide impact under short-term exposure. However, the impact of insecticides on soil fauna under conventional and no-tillage cultivation systems has not yet been assessed. This is the aim of the current study.

Insecticides are used against maize pests in Brazil in both conventional and no-tillage cultivation, especially when the crop is late sown (Michereff-Filho et al. 2002a,b). The pyrethroid deltamethrin is one of the main insecticides used for controlling insect-pests of maize in both cultivation systems (Cruz 1997; Gallo et al. 2002). This insecticide is a broad-spectrum compound very toxic to arthropods, in general based on single species laboratory bioassays (Croft 1990; Gallo et al. 2002), but studies are still necessary to evaluate its impact on soil arthropods of tropical agroecosystems, where its degradation is probably faster reducing its environmental impact. The present study explores this deficiency assessing the potential buffering of no-tillage cultivation minimizing insecticide impact under conditions of short-term exposure in tropical fields.

## 2 Materials and Methods

### 2.1 Experimental area

The study was carried out at the UFV Field Experimental Station in Coimbra County, State of Minas Gerais, Brazil (20°51′24″S, 42°48′10″W), from January to June 2001. The soil type of the area resembles the paleudult of the American Classification, which is nutrient poor with moderate depth and low water permeability (USDA 1975; Resende et al. 1988). Three nearby fields spaced between 100 and 200 m and encompassing an overall area of 4.5 hectares of maize (hybrid AG 1051) were sown on 26 January using a $0.9 \times 0.2$ $m^2$ spacing (55 000 plants/ha). Each field had between 1.0 and 1.5 ha and they were split into four treatment plots arranged in a $2 \times 2$ factorial scheme (conventional and no-tillage, with or without deltamethrin spraying) with three random blocks (i.e. fields). Treatment plots within each field were $40 \times 15$ m and separated by a 5-m border. Cultural practices were carried out as commonly made in the region with mechanical removal of weeds and no post-emergence use of herbicides (Fancelli and Dourado Neto 1997). The herbicides glyphosate (1080 g a.i./ha) and 2,4-D (720 m a.i./ha) were used as desiccant 10 days before sowing in the no-tillage cultivation system and their effect was not separated from those of no-tillage. Weather data were collected at the site of the experimental fields and the soil content of organic matter was determined from soil samples drawn from the fields and subjected to routine determinations based on Tiurin's method as described by Dabin (1976).

### 2.2 Insecticide spraying

A single application of deltamethrin was carried out after leaf tube formation in maize plants, when the first stem node appeared above the surface (25 days after sowing) and the fall armyworm population reached its economic injury level (i.e. 20% plants attacked) (Cruz 1997; Gallo et al. 2002). Deltamethrin was applied at 5 g a.i./ha (Decis®25CE; emulsifiasble concentrate, Aventis Crop Science Brasil Ltda, São Paulo, Brazil) and at a rate of 150 l/ha using a tractor-drawn sprayer running at 6 km/h with a 3-bar pressure. The sprayer was equipped with a 10-nozzle bar equipped with conic nozzles (XR80015 Teejet; Teejet South America, São Paulo, Brazil). The jet was directed to the whorl during spraying.

### 2.3 Residue analysis

Three soil samples (100 g) were collected from each field plot (nine samples collected per treatment) early in the morning (around 8:00 AM) for residue analysis. The extraction methodology was carried out using 10 g of soil samples (sieved and dried) and 50 ml of the extraction solvent mixture (acetone, hexane, dichlorometane at 2.5:1.0:1.5) shaken for 1 h, which allowed a 95% recovery of deltamethrin. The supernatant was passed through filter paper with 20 g sodium sulfate (amhydrous), concentrated in a rotatory evaporator at 60°C and recovered in 10 ml hexane. The sample extract was analysed in a gas chromatograph (Shimadzu Model CG-17A; Kyoto, Japan) equipped with capillary column and electron capture detector. The column and injector temperature was maintained at 280°C throughout the analysis, while the detector temperature was held at 300°C. The flow of the carrier gas (N) was 1.3 ml/min, the split ratio was 1:5 and the injected volume was 1 $\mu$l. Each soil sample was subjected to triplicate determinations. Technical grade deltamethrin was purchased from ChemService (West Chester, PA, USA) and used as standard. The solvents used were all of analytical quality.

### 2.4 Arthropod sampling

Arthropod sampling was carried out following a before vs. after and control vs. impact design in the three fields, as advocated by Green (1993). Samples were taken 8 and 3 days before spraying and 1, 5, 17, 34, 54 and 74 days after deltamethrin spraying maintaining the traps active for two consecutive days at each sampling period. The epigeic arthropods were sampled using pitfall traps made of a plastic collector container (transparent, 12 cm high and 10 cm diameter) placed within a plastic cylinder previously inserted into the soil with a funnel on its top adjusted with the soil surface. The trap was covered with a plastic shade (20 cm diameter) supported by galvanized wire at 6 cm from the soil surface. Each collector container was filled with 200 ml of a solution of ethanol (80%), carbon tetrachloride and glycerine for sample preservation (Michereff-Filho et al. 2004). The traps were activated only a week after their placement to minimize eventual effects of soil disturbance caused by this placement (Digweed et al. 1995). Three traps were used in each experimental plot leading to the placement of nine traps per treatment and 36 traps in total (Frampton and Çilgi 1996).

The trapped insects were extracted by washing them through a set of sieves (nets of 1.0 and 0.044 mm) and subsequently transferring them to containers filled with a solution of ethanol (80%) and bidistilled glycerine. The mites collected were identified by Dr Aníbal R. Oliveira (Agricultural College 'Luiz de Queiroz' – ESALQ from the University of São Paulo, Piracicaba, SP, Brazil) and Dr Jeferson L. C. Mineiro (São Paulo State University at Jaboticabal, UNESP-Jaboticabal, SP, Brazil). The springtails were identified by Dr Elisiana Oliveira (National Research Institute of the Amazon – INPA, Manaus, AM, Brazil), the crickets by Dr Carlos F. Sperber (Federal University of Viçosa, Viçosa, MG, Brazil) and the ants by Dr Ivan C. Nascimento (National Centre of Cocoa Research – CEPLAC, Itabuna, BA, Brazil).

### 2.5 Statistical analyses

The impact of deltamethrin and the cultivation system in the arthropod assemblage sampled was assessed by comparing the arthropod abundance collected from the pitfall traps placed in each experimental unit. Only for ants the frequency of capture (number of times that a species was collected in the area, divided by the total number of samples and multiplied by 100) was used instead of abundance to prevent overestimation of the species with high worker recruiting capacity (Soares et al. 1998). All data were transformed to $\log_{10}(x + 1)$ before statistical analyses to meet the normality criteria and variance homogeneity (PROC UNIVARIATE; SAS Institute 2001). Mite data were grouped at the level of suborder, springtail data were grouped at the level of order and family and the remaining taxa were grouped at the family level (subfamily for ants). Only arthropods showing frequency of capture above 25% were included in the analysis, except ants in which all subfamilies were included.

Data were subjected to principal component analysis (PCA) using the software Canoco 3.1 (Ter Braak and Smilauer 1998). Euclidean distances (i.e. inter-sample distances) were used for scaling on PCA with the data centred and standardized by taxa abundance (springtails, mites and beetles) or relative frequency (ants). The influence of environmental conditions (i.e. rainfall, temperature, relative humidity and organic matter content of the soil) were also included as co-variables in the analysis. The weather variables were recorded *in situ* at each sampling period using a mini weather station $\mu$METOS® SMR 300 (Pessl Instruments, Werksweg, Austria). Ordination diagrams were interpreted following the usual rules (Jongman et al. 1995). The main arthropod taxa contributing for the treatment separation and with capture frequency over 25% were also subjected to repeated-measures analysis of variance (PROC ANOVA with the PROFILE statement; SAS Institute 2001). These analyses were carried out to recognize the differential abundance of each taxa in each treatment using the subsequent sampling dates as repeated measures of the same experimental unit avoiding problems of pseudo-replication in time (Green 1993; Paine 1996).

## 3 Results

### 3.1 Taxonomic composition and residue levels

Three suborders of mites (Acarina) were collected throughout the study: Oribatida (families Scheloribatidae, Nothridae, Eremulidae, Xylobatidae, Galumnidae, Haplozetidae, Euphthiracaridae and Oppiidae), Gamasida (families Laelapidae, Parasitidae and Ascidae) and Acaridida (a single genus, *Tyrophagus* spp.). Among Collembola, three orders were collected: Symphypleona (families Dicyrtomidae, Arrhopalitidae and Sminthuridae), Entomobryomorpha (families Entomobryidae, Isotomidae and Paronellidae), and Podumorpha (families Hypogastruridae and Brachystomellidae). Besides these taxa, 11 families of Coleoptera were also collected, along with crickets (Gryllidae), earwigs (Forficulidae) and ants (Formicidae) belonging to the subfamilies Dolichoderinae, Myrmicinae, Formicinae, Ecitoninae and Ponerinae (table 1).

Residue levels of deltamethrin were not detectable 24 h after application (data not presented). Complementary assays using fortified doses of deltamethrin (2.5-fold higher than the recommended dose for field use) also did not provide detectable levels of this insecticide 24 h after application. These findings suggest a fast degradation of this compound under the field conditions of use in tropical areas.

### 3.2 General arthropod response

The overall arthropod response to the treatments was recognized by PCA using environmental co-variables to explain their effect on each taxa. The first axes generated by PCA represented 28.7% and 13.8% of the total variance explained (42.5%) using the data for the taxa listed in table 1. Temperature and relative humidity were the main environmental factors significantly explaining the variance observed in the treatments, recognized by the long arrows in the plot (fig. 1a). They have an opposing effect with their arrows extending towards opposite direction and quadrants. The only treatment significantly different in its arthropod assemblage was the conventional cultivation without insecticide spraying, recognized by its long arrow in the plot and in a direction opposite to the other treatments, which resemble one another. As the plotted arrow is representative of the conventional cultivation without insecticide, it follows the direction and mirrors the magnitude of the arrow representing the effect of relative humidity; this was the main co-variable discriminating and explaining the variance observed in this particular treatment. In contrast, other treatments were mainly affected by temperature.

***Table 1.*** *Overall abundance and frequency (%) (± standard error) of arthropods collected in 96 pitfall traps placed in conventional and no-tillage maize fields subjected or not to deltamethrin spraying*

| | Abundance (mean ± SEM) (no. individuals/plot) | | | | |
|---|---|---|---|---|---|
| | Conventional cultivation | | No-tillage cultivation | | |
| Taxa | Without insecticide | With insecticide | Without insecticide | With insecticide | Frequency (%) |
| Arachnida | | | | | |
| Acarina | | | | | |
| Oribatida | 2280.00 ± 7.57 | 2163.10 ± 4.75 | 888.00 ± 1.45 | 390.00 ± 1.02 | 82.64 |
| Gamasida | 1241.33 ± 2.60 | 1580.00 ± 3.22 | 681.20 ± 1.22 | 617.67 ± 1.30 | 80.90 |
| Acaridida | 1455.00 ± 5.60 | 1825.20 ± 7.54 | 1660.00 ± 6.13 | 1496.20 ± 5.79 | 61.00 |
| Collembola | | | | | |
| Symphypleona | | | | | |
| Dicyrtomidae/Arrhopalitidae/ Sminthuridae | 303.20 ± 1.92 | 314.67 ± 1.32 | 113.67 ± 0.36 | 138.67 ± 0.41 | 40.00 |
| Entomobryomorpha | | | | | |
| Entomobryidae/Paronellidae | 1180.00 ± 1.98 | 1489.33 ± 3.22 | 1088.67 ± 1.51 | 783.00 ± 1.41 | 81.30 |
| Isotomidae | 1014.00 ± 2.53 | 2538.00 ± 6.31 | 1889.67 ± 3.70 | 2822.67 ± 8.62 | 82.30 |
| Podumorpha | | | | | |
| Hypogastruridae/Brachystomellidae | 948.00 ± 3.27 | 2963.67 ± 13.60 | 2424.00 ± 7.62 | 3437.67 ± 9.40 | 76.89 |
| Insecta | | | | | |
| Orthoptera | | | | | |
| Gryllidae [*Gryllus assimilis* (Fabr.)] | 63.20 ± 0.14 | 56.67 ± 0.14 | 54.00 ± 0.12 | 34.33 ± 0.09 | 42.67 |
| Dermaptera | | | | | |
| Forficulidae [*Doru luteipes* (Scudder)] | 30.00 ± 0.13 | 31.33 ± 0.09 | 29.33 ± 0.11 | 32.67 ± 0.10 | 25.00 |
| Coleoptera | | | | | |
| Scolytidae (*Xyleborus* sp.) | 194.20 ± 0.41 | 182.33 ± 0.39 | 135.33 ± 0.27 | 125.00 ± 0.28 | 63.20 |
| Nitidulidae (sp. 1) | 258.67 ± 0.14 | 208.33 ± 0.40 | 20.67 ± 0.16 | 54.20 ± 0.16 | 53.67 |
| Nitidulidae (sp. 2) | 55.33 ± 0.13 | 60.20 ± 0.20 | 15.67 ± 0.06 | 19.33 ± 0.06 | 29.50 |
| Nitidulidae (sp. 3) | 8.33 ± 0.05 | 1.20 ± 0.01 | 1.67 ± 0.01 | 0.00 ± 0.00 | 1.04 |
| Nitidulidae (sp. 4) | 4.20 ± 0.04 | 0.00 ± 0.00 | 0.00 ± 0.00 | 1.33 ± 0.01 | 1.74 |
| Nitidulidae (sp. 5) | 12.00 ± 0.09 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 1.74 |
| Nitidulidae (sp. 6) | 17.67 ± 0.12 | 7.33 ± 0.04 | 0.00 ± 0.00 | 1.20 ± 0.01 | 4.51 |
| Cucujidae | 21.00 ± 0.08 | 22.00 ± 0.10 | 3.20 ± 0.02 | 2.00 ± 0.03 | 11.11 |
| Bruchidae | 2.00 ± 0.02 | 2.00 ± 0.02 | 0.00 ± 0.00 | 1.00 ± 0.01 | 1.74 |
| Tenebrionidae | 17.00 ± 0.08 | 11.33 ± 0.06 | 0.00 ± 0.00 | 3.33 ± 0.02 | 7.30 |
| Cicindelidae | 6.00 ± 0.05 | 1.20 ± 0.01 | 2.33 ± 0.02 | 0.00 ± 0.00 | 2.10 |
| Scarabaeidae (sp. 1) | 0.00 ± 0.00 | 7.00 ± 0.06 | 2.00 ± 0.02 | 0.00 ± 0.00 | 2.40 |
| Scarabaeidae (sp. 2) | 6.33 ± 0.05 | 10.20 ± 0.06 | 0.00 ± 0.00 | 5.67 ± 0.03 | 4.51 |
| Carabidae (sp. 1) | 1.00 ± 0.01 | 0.00 ± 0.00 | 2.00 ± 0.02 | 0.00 ± 0.00 | 1.04 |
| Carabidae (sp. 2) | 2.00 ± 0.02 | 0.00 ± 0.00 | 2.67 ± 0.03 | 0.00 ± 0.00 | 1.04 |
| Lagriidae | 1.00 ± 0.01 | 1.00 ± 0.01 | 1.00 ± 0.01 | 0.00 ± 0.00 | 1.04 |
| Chrysomelidae | 0.00 ± 0.00 | 0.00 ± 0.00 | 1.00 ± 0.00 | 1.00 ± 0.00 | 0.70 |
| Staphylinidae | 4.33 ± 0.04 | 0.00 ± 0.00 | 1.67 ± 0.01 | 0.00 ± 0.00 | 1.04 |
| Hymenoptera | | | | | |
| Myrmicinae | – | – | – | – | 67.36 |
| Formicinae | – | – | – | – | 34.03 |
| Ecitoninae | – | – | – | – | 5.21 |
| Dolichoderinae | – | – | – | – | 4.16 |
| Ponerinae | – | – | – | – | 17.36 |

The second PCA plot shows the species divergence (fig. 1b) and its overlap with the first PCA plot indicates the species composition of each treatment (fig. 1). The arthropod taxa with the highest scores (i.e. longest arrows) on the PCA species plot (fig. 1b) contributed the most for the sample and consequently the treatment divergence observed and represented in fig. 1a. Acaridida mites (*Tyrophagus* spp.) and Ecitoninae ants were the most abundant taxa collected in the conventional cultivation system without insecticide spraying with a higher influence of relative humidity in their occurrence (fig. 1). In contrast, springtails (Podumorpha and Symphypleona), Oribatida and Gamasida mites, Gryllidae and two species of Coleoptera (Nitidulidae sp. 1 and the scolytid *Xyloborus* sp.) were the most abundant taxa collected in other treatments, which were more strongly influenced by temperature (fig. 1). The arthropod assemblage showed significant species fluctuation during the crop cycle with more drastic changes in species composition taking place 54 and mainly 74 days after deltamethrin spraying, whose samples concentrated on the left quadrants of the bottom (for 54 days after spraying) and the top (for 74 days after spraying) of the species plot (data not presented).

### 3.3 Response of individual taxa

Springtails and mites were the most abundant arthropods collected with Symphypleona and Entomobryidae/Paronellidae springtails prevailing under the conventional cultivation system, as was Oribatida

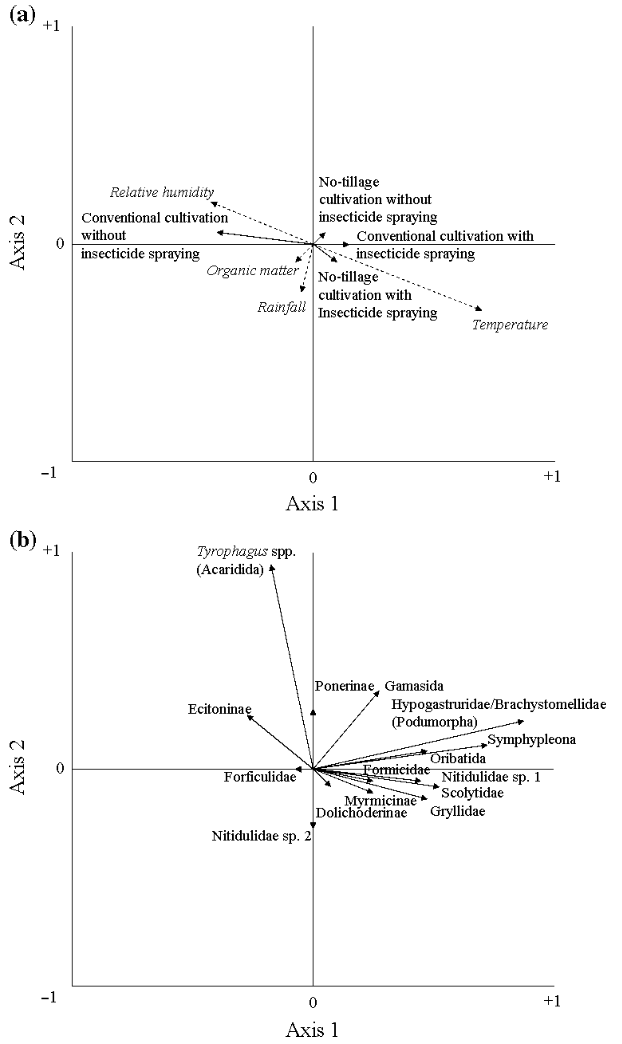

***Fig. 1.*** *Ordination diagrams of principal component analysis (PCA) based on the abundance of arthropod taxa from the soil surface of tropical maize fields (a) PCA treatment plot showing the discrimination between fields under conventional and no-tillage cultivation and subjected or not to deltamethrin spraying. Environmental variables were also plotted (b) PCA species site plot where only the most important species for axis separation were represented. Arrow length is proportional to the variable score value. Arrows projected in the same direction indicate positive correlation of taxa abundance, while projections in opposite directions indicate negative correlations. Perpendicular arrows indicate absence of correlation. Orthogonal projection of the treatment over an arrow in the species plot indicates their taxon composition*

and Gamasida mites (table 1). The same trend was observed for the beetle Nitidulidae sp. 1 (table 1). Deltamethrin spraying seems to favour the overall abundance of Isotomidae and Podumorpha springtails (table 1), while the other main taxa as recognized by the PCA (i.e. Acaridida mites, crickets, the scolytid *Xyloborus* sp. and Ecitoninae ants) did not show any apparent trend based on their overall abundance (table 1). These taxa were also subjected to individual repeated-measures ANOVA allowing the interpretation of the within-subject factor (time and its interactions) for each one of them. All interactions between treatments [a $2 \times 2$ factorial combination (cultivation system × insecticide use)] and time (days before and after insecticide spraying) were tested. Again there was no significant difference between treatments for Acarididae mites, crickets, the scolytid *Xyloborus* sp. and Ecitoninae ants ($P > 0.05$; data of abundance through time not presented).

Repeated-measures ANOVA indicated a significant interaction between cultivation system and sampling date for the springtails Entomobryidae/Paronellidae ($F = 7.13$, $P < 0.0001$), Symphypleona ($F = 3.19$, $P = 0.01$) and Isotomidae ($F = 4.50$, $P = 0.002$) (fig. 2). These results indicate a significant effect of the cultivation system through time with Entomobryidae/Paronellidae and Symphypleona showing a decrease in abundance in the conventional cultivation system to similar or even lower levels than in the no-tillage cultivation system (fig. 2a,b). Isotomidae also showed a decline in abundance with the 15 initial days of crop development with a subsequent increase in abundance in the no-tillage system that lasted for about 20 days (fig. 2d).

There was a significant effect of the cultivation system for Podumorpha springtails (Hypogastruridae/Brachystomelidae) ($F = 18.85$; $P = 0.012$) (fig. 2c), Oribatida ($F = 8.03$, $P = 0.04$) and Gamasida mites ($F = 44.09$, $P = 0.002$), and a single beetle species of Nitidulidae (sp. 1) ($F = 32.71$, $P = 0.0012$). This effect was regardless of time and Podumorpha showed higher abundance in the no-tillage system (table 1, fig. 2c), while the opposite was observed for Oribatida and Gamasida mites (table 1, fig. 3a,b) and Nitidulidae sp. 1 (table 1, fig. 4), which showed higher abundance in the conventional cultivation.

A significant effect of deltamethrin spraying was observed only for Nitidulidae sp. 1 ($F = 11.05$, $P = 0.01$). This Nitidulidae species (sp. 1), which was favoured by the conventional cultivation system was significantly suppressed by deltamethrin spraying (fig. 4). Such effects were particularly strong until about 15 days of sowing.

## 4 Discussion

Assessment of the non-targeted assemblage of soil arthropods associated with maize fields (under conventional and no-tillage cultivation) subjected to deltamethrin spraying was the main objective of the present investigation. Such assessment was carried out on late sown maize fields in a tropical area when exposed to deltamethrin, a broad-spectrum pyrethroid insecticide commonly used for controlling maize pest insects (Cruz 1997; Gallo et al. 2002). The cultivation system was expected to mitigate the impact of insecticides based on a previous investigation carried out to assess the arthropod fauna associated with the maize canopy (Badji et al. 2004). Besides, the epigeic fauna associated with the maize agroecosystem is poorly known in tropical areas.

The overall trend was a distinction between the conventionally cultivated maize without insecticide

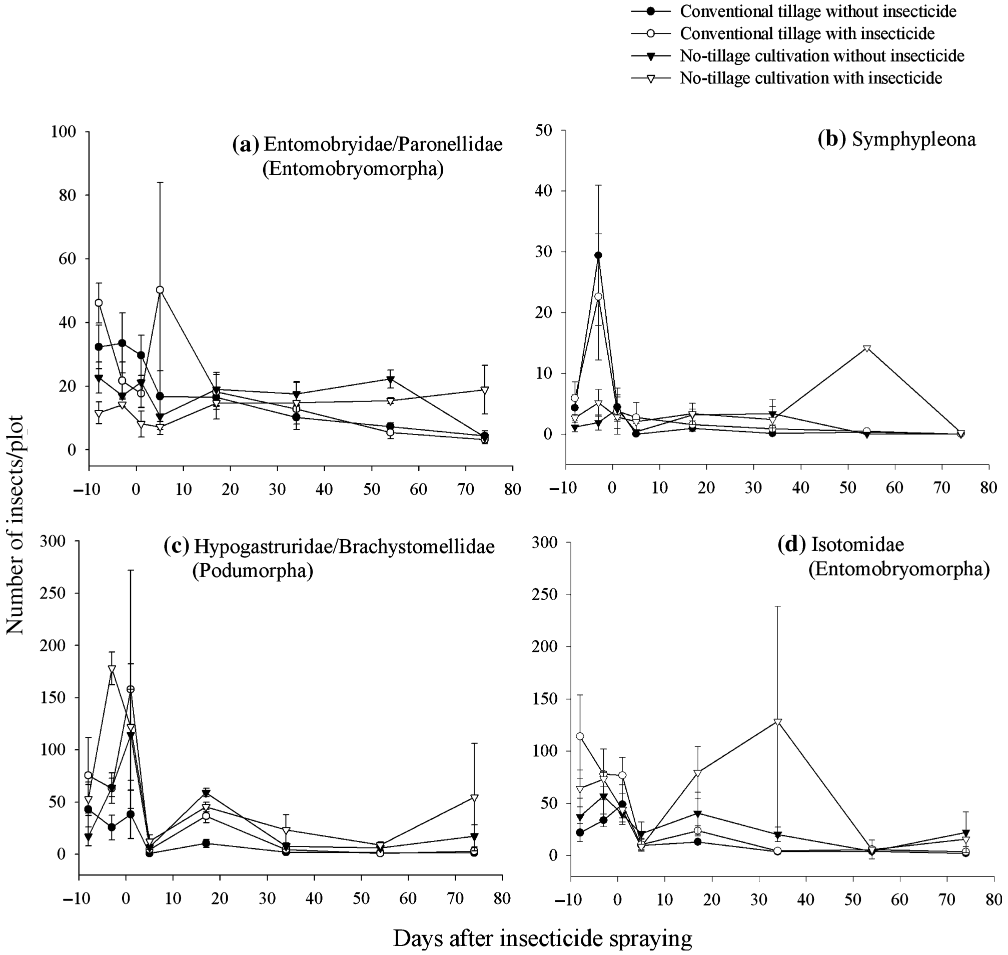

*Fig. 2. Variation in abundance (mean ± standard error) of springtails (Collembola) associated with maize fields cultivated under conventional (circle) and no-tillage (triangle) systems and subjected (open symbols) or not (filled symbols) to deltamethrin spraying. Insecticide spraying took place 25 days after sowing and after two samplings (8 and 3 days before spraying)*

spraying and the other systems. Deltamethrin spraying was clearly not a direct determinant of this outcome. The non-detectable residue levels of the insecticide after only 24 h of spraying provides support for this finding, which was also observed for the organophosphate insecticide chlorpyrifos in tropical areas (Michereff-Filho et al. 2002a,b 2004). Insecticide impact in temperate areas is usually higher (Wiles and Frampton 1996; Frampton 1997, 1999), a likely reflex of their lower rate of degradation in such conditions compared with tropical areas (International Programme on Chemical Safety 1990; Naumann 1990; Racke 1993).

Despite the lack of an overall trend regarding the impact of deltamethrin on soil arthropod assemblage, such effects on individual species may exist, resembling that reported in other studies from tropical areas (Marquini et al. 2002; Araújo et al. 2004). Epigeic springtails were significantly affected by the cultivation system, but not by the insecticide. Deltamethrin probably did not reach the soil in concentrations high enough to impact the springtails and its fast degradation prevented an extended exposure which may have impacted the assemblage.

The effect of the cultivation system is long lasting though and the springtails responded to it as earlier predicted by Stinner et al. (1986). The conventional cultivation system favoured higher abundance of Symphypleona and Entomobryidae/Paronellidae springtails, that was unexpected based on earlier general predictions (Petersen and Luxton 1982; Stinner and House 1990; Paoletti and Bressan 1996; Neave and Fox 1998). In contrast, Isotomidae and Podumorpha springtails were favoured by no-tillage cultivation, as expected for such detritivorous species (Stinner and House 1990; Paoletti and Bressan 1996; Neave and Fox 1998; Marquini et al. 2002). The unexpected higher abundance of Symphypleona and Entomobryidae/Paronellidae springtails under the conventional cultivation system may be due to the likely impact of the herbicides used as desiccants in the no-tillage cultivation system, which probably did not impact the other springtail taxa due to susceptibility differences among them (Frampton 1994, 1997). Differences in springtail species composition between temperate and tropical areas may also account for the differences observed on Symphypleona and Entomobryidae/Paronellidae reported here.

Oribatida and Gamasida mites were significantly affected by the cultivation system, not by insecticide application. Oribatida mites are regarded as tolerant to some insecticides (Cockfield and Potter 1983;

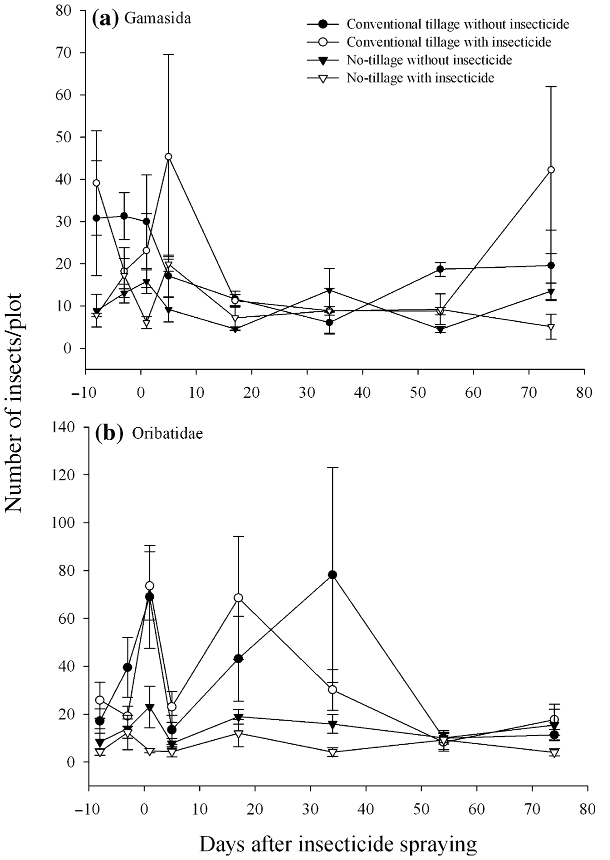

*Fig. 3. Variation in abundance (mean ± standard error) of soil mites (Acarina) associated with maize fields cultivated under conventional (circle) and no-tillage (triangle) systems and subjected (open symbols) or not (filled symbols) to deltamethrin spraying. Insecticide spraying took place 25 days after sowing and after two samplings (8 and 3 days before spraying)*

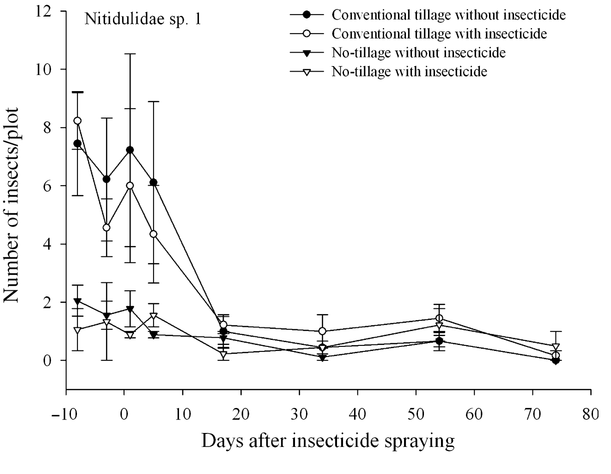

*Fig. 4. Variation in abundance (mean ± standard error) of a beetle species of Nitidulidae (sp. 1) associated with maize fields cultivated under conventional (circle) and no-tillage (triangle) systems and subjected (open symbols) or not (filled symbols) to deltamethrin spraying. Insecticide spraying took place 25 days after sowing and after two samplings (8 and 3 days before spraying)*

Stark 1992; Michereff-Filho et al. 2004), a feature also found in relation to deltamethrin. Oribatida mites are mycophagous and saprophagous, and are likely to be affected by the cultivation system (Stinner et al. 1986; Minor et al. 2004). A greater abundance of Oribatida mites was observed in the conventional cultivation system, as reported by Stinner et al. (1986). However, Minor et al. (2004) and Gormsen et al. (2006) observed higher abundance of Oribatida mites in less disturbed soil conditions, but they focused on far more complex plant communities and long-term modifications, unlike the present investigation.

Gamasida mites, which are predators, are usually regarded as more susceptible to environmental changes than Oribatida mites and therefore with higher potential as bioindicators of environmental stress (e.g. Minor et al. 2003; Gormsen et al. 2006). Gamasida followed the same trend of Oribatida in the present study – higher abundance with conventional tillage. The initial expectation was of lower abundance of Gamasida mites on maize fields under conventional tillage based on studies of long-term soil disturbance, but we are unaware of investigations on tropical areas. Therefore, species differences between temperate and tropical areas may account for the unexpected abundance of Gamasida mites on maize under conventional cultivation, but herbicide applications carried out at the no-tillage cultivation may have drastically impacted the Oribatida and Gamasida mite assemblage (Moore et al. 1984; Salminen et al. 1997).

Nitidulidae (sp. 1) was significantly affected by deltamethrin spraying and cultivation system. This species was suppressed by deltamethrin application, but was favoured by the conventional cultivation. This group of beetles is mainly detritivorous and their suppression is likely to affect soil structure and fertility (Crossley et al. 1992). Their suppression by the broad-spectrum deltamethrin indicates their high susceptibility to this insecticide, but their lower abundance under no-tillage cultivation is likely to be a consequence of herbicide application in this system, which deserves future attention.

The results reported here suggest that the impact of deltamethrin on soil arthropods from tropical maize fields varies among species and is lower than expected. The cultivation system imposes more drastic effects on arthropod soil assemblage and these effects might be a consequence of herbicide use under the no-tillage cultivation system or might be due to species differences between temperate and tropical areas. Springtails, soil mites and a species of Nitidulidae showed potential as biological indicators of soil disturbances, but their responses to deltamethrin and no-tillage cultivation differed from those of the majority of the taxa sampled.

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