Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252024v3712340rc

Scientific Article

Influence of pesticide use on soil macrofauna in a fruit growing area

Influência do uso de pesticidas sobre a macrofauna do solo em área frutífera

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ABSTRACT - The action of pest insects directly affects agricultural productivity, thus requiring a large number of insecticide applications for their control. The main products used come from the organophosphate, pyrethroid and spinosyn groups, but indiscriminate use of these products can cause negative effects, especially on soil organisms. Thus, the objective of this study was to evaluate changes in soil macrofauna caused by the application of insecticides in a fruit production area. The insecticides malathion, deltamethrin and spinetoram were applied at the maximum dose indicated by the manufacturer, using twice the volume of solution for terrestrial applications. The experimental design was randomized blocks, consisting of four treatments with five replicates each, distributed in five blocks. After application, soil macrofauna was evaluated according to the Tropical Soil Biology and Fertility (TSBF) method. Individuals were quantified and identified by taxonomic groups for further determination of density, richness, Shannon-Weaver diversity index (H') and Pielou evenness index (*J'*). Malathion, deltamethrin and spinetoram did not affect the total density, as well as the density per taxonomic group, except for the Coleoptera group, which had lower density of individuals per m^2 in soil treated with malathion and deltamethrin, differing from the soils treated with spinetoram and from the control treatment. Therefore, it is found that deltamethrin applications reduce the density of Coleoptera in the soil under the conditions tested.

Keywords: Malathion. Deltamethrin. Spinetoram. Soil macrofauna.

RESUMO - A ação de insetos-praga afeta diretamente a produtividade agrícola, demandando assim grande quantidade de aplicações de inseticidas para o controle dos mesmos. Os principais produtos utilizados são advindos dos grupos organofosforados, piretróides e espinosinas, no entanto, o uso indiscriminado desses produtos pode gerar efeitos negativos, principalmente aos organismos do solo. Com isso, objetivou-se neste estudo avaliar as alterações sofridas pela macrofauna do solo provocada pela aplicação de inseticidas em área de produção frutífera. Os inseticidas malationa, deltametrina e espinetoram, foram aplicados na dosagem máxima indicada pelo fabricante, utilizando-se o dobro do volume de calda para aplicações terrestres. O delineamento experimental ocorreu em blocos ao acaso, constituído por quatro tratamentos com cinco repetições cada, distribuídas em cinco blocos. Após a aplicação, a macrofauna do solo foi avaliada de acordo com o método *Tropical Soil Biology and Fertility* (TSBF). Foi realizada a quantificação e identificação dos indivíduos por grupos taxonômicos, para posterior determinação da densidade, riqueza, índices de diversidade de Shannon-Weaver (H') e equabilidade de Pielou (*J'*). Constatou-se que malationa, deltametrina e espinetoram não afetaram a densidade total, assim como a densidade por grupo grupos taxonômicos, exceto o grupo Coleoptera que apresentou menor densidade de indivíduos por m^2 em solo tratado com malationa e deltametrina, diferindo dos solos tratados com o inseticida espinetoram e ao tratamento controle. Portanto, constata-se que aplicações de deltametrina reduzem a densidade de Coleoptera do solo, sob as condições testadas.

Palavras-chave: Malationa. Deltametrina. Espinetoram. Macrofauna do solo.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: November 2, 2023.
Accepted in: February 2, 2024.

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INTRODUCTION

Intensification of agriculture combined with the action of pest insects requires large number of insecticide applications (NIVA et al., 2016), especially in the fruit growing sector, which is very susceptible to the incidence of pests, such as those of the order Diptera and family Tephritidae, known as fruit flies. Among these, the species *Ceratitis capitata* (Wiedemann) stands out as one of the most relevant and harmful (BARONIO et al., 2019).

Polyphagous insect with a cosmopolitan habit (BARONIO et al., 2019), *C. capitata* is responsible for causing damage to the epidermis of fruits during oviposition and later with larval development inside, making them unsuitable for marketing. In addition to the aforementioned damage, the embargo on fruit exports to countries free of the occurrence of the pest becomes a limiting factor for the fruit growing economy (GROVÉ; DE JAGER; THELEDI, 2019). Thus, extensive use of foliar sprays of insecticides, especially those that make up the organophosphate, pyrethroid, and spinosyn chemical groups, is required (MORAIS et al., 2021).

As the use of these products increases, there is also a growing concern about environmental contamination, considering that spraying is not limited only to the pest-affected areas, dissipating throughout the field, mainly through spray drift (CECH et al., 2023). According to Kafaei et al. (2020), among the various environments in which insecticide residues can be found after application, the most common is the soil, which is directly reached by about 30% of the product used in foliar applications (CONTIERO; BIFFE; CATAPAN., 2018).

Soil is a living system that has a complex variety of members responsible for several key functions in the ecosystem, which can be impaired due to contamination of this environment (ROCHA et al., 2020). According to Gunstone et al. (2021), several soil invertebrate taxa are negatively affected by the use of insecticides, and those intended for the control of pest insects are the most harmful. The impacts generated are directly seen when they affect the gene expression, behavior, reproduction or life cycle of non-target organisms and indirectly seen when they affect trophic interactions (RÖMBKE; SCHMELZ; PELOSI, 2017), problems that can only be observed by studying these organisms.

The detection of problems generated in the soil community can be evaluated according to the abundance and diversity of organisms existing in that habitat. Representatives of macrofauna, for example, are classified as excellent quality bioindicators, as they are highly sensitive to environmental changes and have a rapid response to impacts on the ecosystem (CHAMORRO-MARTÍNEZ et al., 2022). This group includes organisms with size between 2 mm and 20 mm, such as isopods, myriapods, collembolans, and insects such as ants, beetles, termites, among others, individuals that have high ecological importance and easy identification (SOFO; ALBA; RICCIUTI, 2020).

Several ecotoxicity studies have been carried out in the laboratory to evaluate the effect of insecticides on soil organisms (KAFAEI et al., 2020; CARNIEL et al., 2019). However, under controlled conditions it is not possible to estimate the effect of the exposure of organisms in the field, where there is a wide diversity of ecosystem interactions and environmental factors that can affect the effect of these products.

Thus, field experiments aimed at evaluating the effect of insecticides on soil organisms are necessary to confirm laboratory tests. This study will contribute to the adoption of sustainable agricultural practices, such as the choice of active ingredients that are less harmful to the environment. Thus, this study aimed to evaluate changes in soil macrofauna caused by the application of insecticides in a fruit production area.

MATERIAL AND METHODS

The study was conducted in soil of an experimental orchard, with area of 220 m^2, belonging to the Center for Agrarian Sciences (CCA) of the Federal University of Paraíba (UFPB), Campus II, located in the city of Areia, state of Paraíba, Northeast Brazil. The area is used for the cultivation of several varieties of West Indian cherry for experimental purposes. It is managed only with the weeding of spontaneous plants and is free of previous applications of insecticides.

The soil was classified with a sandy loam texture with 82.8% sand, 12.3% clay, 4.9% silt, 2.36% organic matter and pH 6.3%, analyzed by the Soil Laboratory of CCA-UFPB following the methodology of Teixeira (2017). According to Köppen's classification, the climate of the region is AS, which corresponds to a hot and humid climate, with a rainy season encompassing January, February and September, with an average annual rainfall of 1,400 mm. The average annual temperature varies between 22 and 26 °C (JACOMINE et al., 1972).

The study was conducted from November 2021 to January 2022, under the weather conditions presented in Table 1, provided by the Weather Station located in Areia. Soil moisture content and temperature were also evaluated using an Electronic Soil Moisture Meter (*HidroFarm* - HFM2010 / HFM2030) and a digital thermometer (Top 101), as shown in Table 1.

Table 1. Precipitation (mm), average temperature (ºC), relative humidity – RH (%), wind speed (m/s), soil moisture content and soil temperature recorded monthly from November 2021 to January 2022, in Areia, PB, Brazil.

Parameters	Month/Year		
	November 2021	December 2021	January 2022
Precipitation (mm)	0.1	3.6	2.3
Average temperature (ºC)	26.7	25.7	25.2
Relative humidity (%)	67.0	78.0	81.0
Wind speed (m/s)	3.1	3.2	3.3
Soil temperature (ºC)	36.4	32.3	29.3
Soil moisture content (%)	3.1	6.1	6.2

The products used are commercial formulations of pesticides with the following active ingredients: malathion 1,000.0 g/L (T1), deltamethrin 25 g/L (T2) and spinetoram 250.00 g/kg (T3), registered with the Ministry of Agriculture, Livestock and Food Supply (MAPA), for the control of *C. capitata* in citrus (T1 and T2) and guava (T3). All of them were applied at the maximum dose allowed (200 and 50 mL c.p./100 L water for T1 and T2, respectively, and 120g c.p./ha for T3), using twice the volume of solution indicated on the labels of each product for terrestrial applications (4,000, 5,500 and 1,000 L/ha respectively); for the control treatment (T4), only distilled water was used. The number of applications followed the recommendations contained in the product labels for the cycle of each crop (T1: three applications, the initial one and others at 15 and 30 days after the first application; T2: single application; T3: two applications, the initial one and the other at 15 days after the first application; and T4: maximum number of applications between the products). The samples were collected according to the safety interval for each product: T1 - seven days, T2 - 21 days, T3 - three days after the last application of the product, and the control treatment followed the same interval as T2.

The products were selected according to the following criteria: being registered in MAPA for the control of *C. capitata*; being part of different chemical groups; being classified between categories IV and V of the toxicological classification, considered to be a product that is not very toxic or unlikely to cause acute harm; and being easy to acquire and cost-effective.

The experimental design was in randomized blocks, consisting of four treatments with five replicates each, totaling 20 plots. The products were applied in the afternoon between 4 p.m. and 5 p.m. with a manual sprayer, being sprayed directly on the ground in an area of 25 x 25 cm, marked with stakes and isolation tape, with five replicates.

Macroorganisms were evaluated according to a methodology based on the Tropical Soil Biology and Fertility (TSBF) method, described by Anderson and Ingram (1994). The five application points of the treatments were randomly distributed for each treatment, represented by stakes and area isolation tape, forming squares (sampling area where the insecticides were applied), measuring about 25 x 25 cm.

Samples were collected at 7, 21 and 3 days after the last application of malathion, deltamethrin and spinetoram, respectively, between 7 and 11 a.m. For each collection point, samples were taken from the first 10 cm of soil in each plot. Then, the samples were packed in plastic bags labeled with information about the area, collection point number, collection date, and sample. Once packaged, the samples were taken to the laboratory, where they were homogenized for the screening of individuals visible to the naked eye, with the aid of a 1-mm-mesh metal sieve (25 cm in diameter x 10 cm in height). After screening, the specimens found were stored in 70% alcohol for later identification in taxonomic groups.

Identification of individuals was performed using a stereoscopic microscope and based on specific literature (CIVIDANES, 2021). After identifying the individuals, the density (individuals per m²) of the groups was determined from the total sample area (25 x 25 x10 cm), dividing it by 1 m^2, and the value obtained was multiplied by the mean number of individuals found. Richness, by the number of taxonomic groups, the Shannon-Weaver diversity index (H') and the Pielou evenness index (*J'*) were also estimated.

The data were evaluated using the Bootstrap test, estimating the confidence intervals with 95% probability level, generated with a non-parametric technique of bootstrap sampling and resampling, with 10,000 pseudo-replicates, and each parameter was resampled in each treatment with the "boot" package of R software (ANGELO; BRIAN, 2021). The analyses were performed using R software (R CORE TEAM, 2022).

RESULTS AND DISCUSSION

When analyzing the macrofauna of the soil treated with malathion, deltamethrin and spinetoram, no statistically significant difference was observed between the insecticides and the control treatment for total density, as well as for the taxonomic groups individually, except for Coleoptera. The insecticides tested caused significant changes in Coleoptera, with a lower density of individuals per m^2 in soil treated with malathion and deltamethrin, differing from soil treated with the insecticide spinetoram, which was equal to the control treatment (Table 2).

Table 2. Means (95% CI) for total density (ind. m^2) of the taxonomic groups of soil macrofauna, sampled by the TSBF collection method in an area treated with insecticides.

Taxonomic group	Malathion	Deltamethrin	Spinetoram	Control
Coleoptera	0.87 (0.00-2.64)b	0.87 (0.00-2.64)b	8.80 (8.16-11.44)a	6.15 (2.64-11.44)a
Hemiptera	0.88 (0.00-2.64) a	1.76 (0.00-5.28) a	0.0 (0.00-0.00)a	0.0 (0.00-0.00)a
Hymenoptera	13.20 (3.52-23.76)a	20.22 (3.52-45.76)a	25.27 (13.20-38.50)a	24.61(11.44-38.72)a
Blattodea	0.88 (0.00-2.64) a	1.76 (0.00-5.28)a	0.0 (0.00-0.00)a	0.0(0.00-0.00) a
Araneae	4.37 (0.00-10.56)a	0.0 (0.00-0.00)a	9.93(0.00-23.10)a	1.75(0.00-3.52)a
Total Density	20.24 (13.20-26.40)a	24.59 (7.92-46.64)a	36.97 (23.76-49.28)a	32.55 (21.12-44.88)a

Means followed by the same letter in the rows do not differ from each other by the 95% confidence intervals.

The reduction in the density (ind. m^2) of Coleoptera observed in soils with deltamethrin is worrisome, since individuals of this group act in the ecological regulation and management of pest insects, especially in fruit orchards. For example, coleopterans of the family Carabidae have confirmed predation on immature phases of *C. capitata* (NOURMOHAMMADPOUR-AMIRI; SHAYANMEHR; AMIRI-BESHELI, 2022), aphids, lepidopteran larvae, and slugs (CIVIDANES, 2021). In addition to being predators of pests, this group assists in the decomposition of organic matter, responsible for providing nutrients that will improve soil quality and consequently plant performance.

Adverse effects caused by deltamethrin on insects of the order Coleoptera have been reported in the literature, as highlighted by Garzón et al. (2015), who studied deltamethrin and other insecticides with the same mode of action and observed that deltamethrin caused greater toxicity in *Adalia bipunctata* (L.) (Coleoptera: Coccinellidae). Effect of deltamethrin on the Coccinellidae family has also been reported by Skouras et al. (2021), and this insecticide was responsible for reducing the population growth of *Ceratomegilla undecimnotata* (Schneider).

Negative effects of deltamethrin have also been observed in other non-target arthropods and natural enemies, such as the reduction of parasitism and emergence rate of *Palmistichus elaeisis* (Hymenoptera: Eulophidae) (COSTA et al., 2020). It also influenced by reducing maternal brood defense, feeding, and the expression of self-grooming in females of *Forficula auricularia* (Dermaptera: Forficulidae) (MAUDUIT LÉCUREUIL; MEUNIER, 2021). In addition, Souza et al. (2012) observed that the use of deltamethrin was responsible for the exclusion of phytophagous, predators and detritivorous arthropods.

Regarding macrofauna attributes, there was no statistically significant difference between the treatments for richness. Shannon-Weaver and Pielou indices showed difference only between deltamethrin and malathion, with lower values for deltamethrin (Table 3).

Table 3. Means (95% CI) for richness, Shannon-Weaver diversity index (*H*') and Pielou evenness index (*J*') of the taxonomic groups of soil macrofauna, sampled by the TSBF collection method in an area treated with insecticides.

Macrofauna attribute	Malathion	Deltamethrin	Spinetoram	Control
Richness	2.60 (1.60-3.60) a	1.79 (1.20-2.40)a	2.39(2.00-2.80) a	2.19 (2.00-2.60)a
Shannon-Weaver (*H*')	0.96 (0.73-1.23) a	0.36(0.08-0.65) b	0.67 (0.48-0.83)ab	0.82 (0.70-0.95)a
Pielou (*J*')	0.88 (0.80-0.96) a	0.42(0.12-0.74) b	0.67(0.53-0.82) ab	0.76(0.62-0.90) ab

Means followed by the same letter in the rows do not differ from each other by the 95% confidence intervals.

The soil macrofauna showed greater sensitivity to deltamethrin, since there was lower diversity of individuals (Shannon-Weaver index) and lower evenness (Pielou index). These indices have been studied to assess the equilibrium status of ecosystems (GARCÍA-SEGURA et al., 2018; SILVA; SIQUEIRA, 2020).

According to Vasconcelos et al. (2020), the lower values of the diversity indices indicate a lower uniformity among the diversity of taxonomic groups, which represents lower structural integrity of the community. It also indicates that the area must be experiencing disturbances and that these can be caused by predatory action between individuals, as predators become more numerous due to the development of the feeding process (CARVALHO, 2014).

In addition to biotic factors, abiotic factors, such as seasonality between the dry and rainy seasons, influence the diversity of species of soil arthropods, with greater diversity during the rainy season due to higher relative humidity and consequently greater food availability (MARTINS et al., 2023). However, little variability between climatic conditions throughout the experimental cycle was observed in the present study. Thus, the relationship between the disturbance of the area and the food chain is a point that deserves to be highlighted in this study, as the taxonomic groups Hymenoptera, Araneae and Coleoptera (considered natural predators) were more numerous than the others.

Knowledge about the effect of exposure of non-target organisms present in the soil to the main insecticides of fruit growing areas contributes to the ecological conservation of these environments. Thus, field studies contribute to a more realistic understanding, enabling the correct choice of products compatible with integrated pest management, which aims to effectively control pests in an economically viable and ecologically compatible manner.

CONCLUSION

Use of deltamethrin in fruit growing areas reduces the diversity of macrofauna and the density of coleopterans in the soil under the conditions tested.

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