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Article

Soil macrofauna and soil quality in agricultural and livestock agroecosystems of Campeche

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Abstract

Crops in the state of Campeche are intensifying, this causes transformations in the physicochemical and biological properties of the soil. The objective was to determine the effect of agroecosystems on soil macrofauna and soil properties. Ten sampling points per agroecosystem were taken, with three repetitions each. The sites were chosen according to the agricultural use (grassland, forest, intensive and traditional agricultural) and time of use (≥8 years). One kilogram from each sample was taken at a depth of 20 cm, then placed in polyethylene bags. The pH, electrical conductivity, organic matter, available phosphorus, total nitrogen and soil macrofauna were determined. With the data of each variable, an analysis of variance was performed and to determine the differences between land uses and sites, a mean test was carried out according to the Tukey statistic ($p \leq 0.05$), using the software Statistica version 7.1. The grassland agroecosystem of Palizada presented the best characteristics in the soils, with pH of 7.29, P, OM, N of 1.31 mg kg^{-1}, 5.05% and 0.31%, respectively and soil fauna with 66 individuals. The agroecosystem with the lowest soil quality was intensive crops of Hopelchén, with moderately acidic pHs (6.44), higher amount of P (33.42 mg kg^{-1}), lower OM (2.59%) and high N contents (0.23%) and without soil macrofauna. Soil management in agricultural agroecosystems does not favor the presence of soil macrofauna nor does it maintain the nutrients necessary for the proper functioning and quality of the soil.

Keywords: macroinvertebrates, production systems, soil quality.

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Introduction

Agroecosystems (AES) are anthropogenically modified ecological systems that use natural resources for agricultural production (Martínez-Castro *et al*., 2015), of which soil is the main component, because it offers the possibility of maintaining biological productivity and environmental quality, since it promotes health in crops, animals and humans (FAO, 2015). However, the productivity and functioning of AESs are affected by continuous changes in land use, inadequate land management, indiscriminate use of agricultural inputs and heavy agricultural machinery, which cause loss of soil quality (Cuadras-Berrelleza *et al*., 2021; Li *et al*., 2022), increased salinity (Mukhopadhyay *et al*., 2021), decreased soil fauna due to the intake of microplastics in agricultural systems (Zhang *et al*., 2022) and soil compaction that directly impacts crop yield due to increased nutrient leaching (Parvin *et al*., 2022).

In Campeche, Mexico, of the 5.79 million hectares of land it owns, 54.7% is secondary vegetation (forest), 15.9% rainforest (distributed between high, medium, low and fragmented rainforest), the latter affected by agricultural activities (SEMARNATCAM, 2009), through slash and burn, which have become land for traditional and intensive crops (Porter-Bolland *et al*., 2007; Bautista-Cruz *et al*., 2012) and for grasslands in livestock activities. Among the municipalities with the highest deforestation rates are Calakmul, going from 0.3% to 0.7% by 2005, and Hopelchén with 45 706 ha lost until 2015 (Ellis *et al*., 2017), this indicates that forest conversion is intensifying.

In addition to the above, it has been reported that most of the area of the state of Campeche has very stony soils with limited depth and of calcareous origin (Leptosols), not suitable for intensive agricultural use (Palma-López *et al*., 2017). Despite this situation, there are municipalities such as: Hopelchén, Escárcega, Candelaria and Palizada that allocate areas for agricultural crops of 91 109, 26 857.9, 23 360.5 and 10 848.3 ha, respectively, and in livestock farming 1 537 435 ha for grasslands in the state of Campeche (SIAP, 2017), where there were decreases in harvests in recent years.

Agricultural and livestock activities in inappropriate soils cause transformations in physical, chemical and biological properties (Torres-Torres and Rojas-Martínez, 2019), which have an impact on soil quality, mainly on its nutrients and functioning (Meza *et al*., 2017; Villanueva-López *et al*., 2019), such as degradation, compaction and erosion of grasslands due to overgrazing (FAO, 2015), interference in the composition and structure of the rhizosphere bacterial community (Qi *et al*., 2020), soil and aquifer contamination (Lorenzo-Flores *et al*., 2017), and modification of the habitat of microorganisms and macroinvertebrates (Giller *et al*., 1997). The latter caused by the indiscriminate use of organophosphate pesticides such as glyphosate (Rendón-von Osten and Dzul-Caamal, 2017), diazinon, dimethoate, methyl parathion, sulfotep and the use of degradable and biodegradable mulching (Qi *et al*., 2020).

To evaluate changes in soil properties affected by anthropic activities and therefore propose conservation strategies according to land use and physicochemical characteristics, physical, chemical, biological variables and their relationships, participation in production and stability of agroecosystems are analyzed (García *et al*., 2012). Among the indicators are land use, nitrogen mineralization, microbial biomass carbon, microbial C/N ratio, earthworm abundance (Krüger *et* *al*., 2018), soil fauna (Sofo *et al*., 2020), pH, electrical conductivity, total and organic carbon in particles, total nitrogen, hydraulic conductivity, texture and organic matter (Baridón and Casas, 2014). Therefore, the objective was to determine the soil macrofauna and soil quality in agricultural and livestock agroecosystems of Campeche.

Materials and methods

Study site

The work was carried out during the months from July to November 2020 in the municipalities of Candelaria, Palizada, Escárcega and Hopelchén of the state of Campeche. Candelaria is located at 17°49’ 00” and 18° 30’ 39” north latitude and 90° 14’ 00” and 91° 19’ 42” west longitude. It comprises a territorial extension of 5 574.8 km^2, at 46 masl, warm humid climate and warm subhumid tropical rainy climate, the average annual temperature of 26 ° C, the average annual rainfall is 1 700 mm (INEGI, 2009). Palizada is located at 17° 56’ and 18° 36’ north latitude and 91° 39’ and 92° 14’ west longitude, with an extension of 2 071.7 km^2, at 2 masl, with a humid climate with an average annual temperature of 27 °C and average annual rainfall of 1 750 mm (INEGI, 2009).

Escárcega is located at 18° 10’ and 19° 01” north latitude and 90° 03’ and 91° 02’ west longitude, at 60 masl, with warm subhumid climate, average annual temperature of 27 °C and average annual rainfall of 1 065 mm (INEGI, 2009). Hopelchén is located at 17° 48’ and 20° 11’ north latitude and 89° 06’ and 90° 09’ west longitude, the area of the municipality is 7 956.7 km^2, warm climate, at 89 masl, with average annual temperature of 26 °C and average annual rainfall of 105 mm (INEGI, 2009).

Soil selection and sampling

Three types of agroecosystems representative of the state of Campeche were differentiated, according to agricultural uses and time of use (≥8 years). Extensive livestock use (grassland), intensive agricultural use (corn and sorghum), traditional agricultural use (roselle and corn) and secondary vegetation as control (forest) (Figure 1) were systematically selected.

Figure 1. A) grassland; B) intensive crop; C) traditional crop; and D) forest.

In each AES, three sampling points (repetitions) were established with a separation of 500 m. A quadrant of 25 x 25 cm was placed to carry out soil sampling at a depth of 20 cm. Each of these contained an approximate weight of 1 kg. Then, they were placed in plastic bags and labeled with the name AES and repetition. Subsequently, they were transported to the water and soil laboratory of the Campeche Campus of the College of Postgraduates (Table 1).

Table 1. Number of total samples by agroecosystem in the municipalities of Candelaria, Palizada, Escárcega and Hopelchén.

Agroecosystem	No. of sites	Repetitions	Total samples
Grassland	10	3	30
Intensive agricultural	10	3	30
Traditional agricultural	10	3	30
Forest	10	3	30

Processing and analysis of soil samples

The soil samples were dried at room temperature, ground with a wooden hammer and sifted with a stainless-steel mesh with an opening of 2 mm in diameter. The texture determination (% silt, % clay and % sand) was performed using the Bouyoucos methodology. To measure the pH, the readings were taken with an Oaklon multiparameter PCSTestr35 previously calibrated with a buffer of pH 10, 7, 4.

Electrical conductivity (EC) was measured with a previously calibrated Oaklon multiparameter PCSTestr35. To obtain organic matter (OM), the methodology of Walkley and Black was followed. Available phosphorus (P) was quantified using the method proposed by Olsen (1980) and total nitrogen (N) was evaluated using the micro Kjeldahl methodology. The physicochemical determinations were carried out with the specifications of the Official Mexican Standard NOM-021-RECNAT-2000.

Counting and identification of soil macrofauna

To collect the soil macrofauna, the monolith method, proposed by the Institute of Biology and Fertility of Tropical Soils (TSBF), was used. The collected macrofauna was deposited in bottles with 70% alcohol for conservation and subsequent identification (Decaëns *et al*., 1994) at the order level.

Statistical analysis

To evaluate the effect of agroecosystems (grassland, traditional crop, intensive crop and forest) on the dependent variables (pH, EC, P, OM, N, texture and abundance of soil fauna), a completely randomized analysis of variance with a linear model was used, and to determine the differences between land uses and sites, a Tukey mean test ($p\leq 0.05$) was performed with the software Statistica version 7.1.

Results and discussion

Physicochemical analysis of the soil

When comparing the physicochemical parameters of the soil by agroecosystem, it was observed that the EC was higher in the traditional crop with 0.25 dS m^{-1} ($p\leq 0.05$) and lower in the intensive crop with 0.1 dS m^{-1}, both remained in non-saline (NOM-021-RECNAT-2000). In this sense, FAO

(2017) mentions that as electrical conductivity decreases (≤1), plants become stressed, affecting biomass production; this phenomenon has been observed in crops of *Origanum vulgare* ssp. *hirtum*, where treatment with 25% nutrient solution and EC less than 1 dS m^{-1} obtained the lowest production of total fresh and dry matter (Juárez-Rosete *et al*., 2019).

The pH of the soils of the forest, traditional crop and grassland are moderately alkaline ($p\leq 0.05$), while the soils of the intensive crop are moderately acidic (NOM-021-RECNAT-2000) Table 2. In agricultural soils of Jalisco, 61.1 and 38.9% of the sampled agricultural area had strongly acidic and moderately acidic pH, respectively, because the agricultural activity is intensive and the chemical inputs they apply cause acidity (Ibarra-Castillo *et al*., 2009). The phosphorus content showed statistical differences ($p\leq 0.05$), according to the classification of Olsen (1980), the soil of the grassland and forest are low with <12, while traditional and intensive crops presented medium and optimal values with ranges within 12-24 and 24-36, respectively (NOM-021-RECNAT-2000).

Nitrogen was found in very low amounts for forest and grassland with less than 0.02%, for the traditional crop it was medium with 0.13% and high for the intensive crop with 0.23% (NOM-021-RECNAT-2000) (Table 2), this is due to the application of synthetic NPK-based fertilizers to crops (Medina *et al*., 2018). However, the excessive use of these fertilizers (Montejo-Martínez *et al*., 2018), from agricultural and livestock agroecosystems causes contamination to the aquifer, reaching rivers, such as the Usumacinta (Ferat *et al*., 2020).

With regard to organic matter, the highest contents were found in the traditional crop, followed by forest and grassland with 9.66, 7 and 6.19% respectively, and the lowest was observed for intensive crops with 2.59% (NOM-021-RECNAT-2000) (Table 2), which clearly indicates that they are systems that tend to stabilize the OM content in the soil by providing litter residues (Palma-López *et al*., 2015). Traditional management and systems with different strata or inclusion of legumes increase the amount of OM and fertility (Arteaga *et al*., 2016).

Table 2. Physicochemical composition of the soil of agroecosystems of Campeche.

Variables	Grassland	Agroecosystem Intensive crop	Traditional crop	Forest
PH	7.63 a	6.44 b	7.71 a	7.42 ab
EC (dS m^{-1})	0.21 ab	0.1 b	0.25 a	0.21 ab
P (mg kg^{-1})	2.49 b	33.42 a	19.39 ab	3.1 b
OM (%)	6.19 b	2.59 c	9.66 a	7 ab
N (%)	0.01 a	0.23 a	0.13 a	0.02 a
Clay (%)	58.92 a	63.32 a	54.32 a	61.04 a
Silt (%)	23 a	16 a	15.36 a	13.53 a
Sand (%)	18.08 a	20.68 a	30.32 a	25.42 a

a, b, c= different literals in the same column indicate significant differences $p\leq 0.05$.

Unlike intensive crops, which, like the conventional management of the monoculture *Solanum tuberosum* L. and the meadow of *Pennisetum clandestinum* have lower percentages of OM, total N and exchangeable bases (Arteaga *et al*., 2016), due to the removal of native vegetation and the use of plough for crop establishment, the infiltration capacity, amount of organic matter and nutrients from the soil decrease (Sosa-Quintero and Godínez-Álvarez, 2019). Therefore, they are usually deficient in more than one micronutrient, resulting in low concentration in plant tissues, which does not allow them optimal growth (Noval-Artiles *et al*., 2014).

The physicochemical variables by municipality show that Hopelchén is the only area that is found with moderately acidic soils with pH= 6.48, with lower EC (0.16 dS m^{-1}), available phosphorus in the medium range with 20.55 mg kg^{-1}, lower percentage of organic matter (0.06%) and higher total nitrogen content (1.51%) (Table 3). It should be noted that samples of intensive crops, where mechanized agriculture is practiced (Ellis *et al*., 2017), use genetically improved seeds and chemicals for the production of corn, soybeans and sorghum, in order to obtain productive efficiency (Vargas and García, 2018).

Table 3. Physicochemical composition of the soil of four municipalities of Campeche.

Characteristics	Candelaria	Palizada	Escárcega	Hopelchén
PH	7.68 a	7.29 ab	7.33 ab	6.48 b
EC (dS m^{-1})	0.19 a	0.25 a	0.23 a	0.16 a
P (mg kg^{-1})	1.93 b	1.31 b	4.95 ab	20.55 a
OM (%)	7.12 a	5.05 b	8.23 a	4.06 c
N (%)	0.46 b	0.31 b	0.54 b	1.51 a
Clay (%)	57.44 b	61.57 ab	72.42 a	57.43 b
Silt (%)	20.09 ab	28.9 a	10.42 b	15.63 b
Sand (%)	26.93 a	9.52 b	17.14 ab	22.47 ab

a, b, c= different literals in the same column indicate significant differences $p \leq 0.05$.

Soil macroinvertebrates

A total of 123 individuals belonging to the following five orders were recorded; Haplotaxida, Scolopendromorpha, Coleoptera, Dermaptera and Hymenoptera. The order Haplotaxida (earthworm) was the most abundant ($p \leq 0.05$), followed by orders; Scolopendromorpha, Coleoptera, Dermaptera and Hymenoptera, with 54, 36, 24, 6 and 3 individuals, respectively (Figure 2A). The soil macrofauna presents alterations in their composition and biodiversity, this depends on the disturbance of the soil caused by its modification, considering these species as bioindicators of the environmental alteration (Cabrera, 2012). Likewise, Mesa-Pérez *et al*. (2016) mention that the sampling of Diplopoda, Coleoptera, Hymenoptera and earthworm is sufficient to determine the state of soil health.

The richness found in the soils was higher in the grasslands that registered five orders ($p \leq 0.05$), followed by forest with three orders (Haplotaxida, Scolopendromorpha and Dermaptera), traditional crop with one order (Coleoptera) and absence of these organisms in intensive crops (Figure 2B). The presence of earthworm (Haplotaxida) as an index of soil conservation indicates that the least disturbed are the forest and grassland soils. The orders of arthropods are similar to those found by Rosa and Negrete-Yankelevich (2012), where the presence of Hymenoptera and Coleoptera was 38 and 16.4% in reedbeds and in secondary vegetation it was 22.7 and 23.5%, respectively.

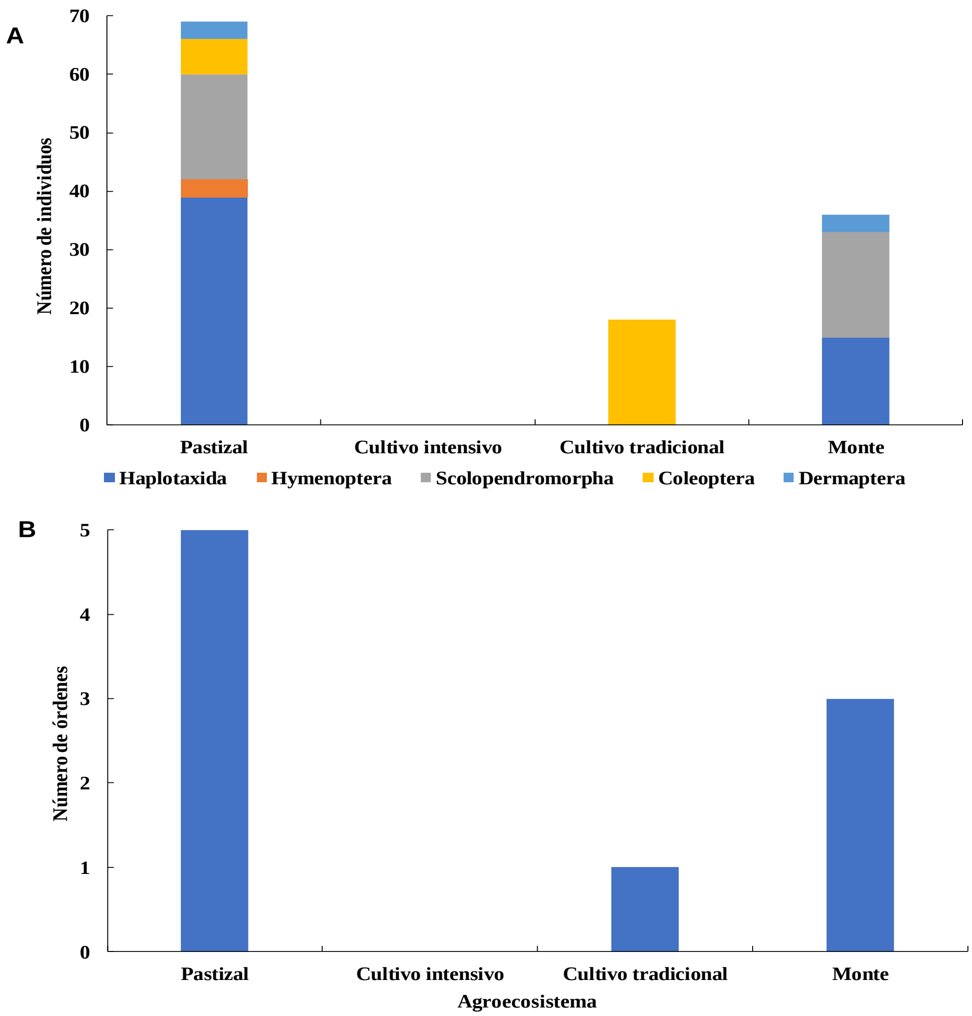

Figure 2. A) number of individuals; and B) orders of soil macrofauna in four agroecosystems of Campeche.

Like Chi *et al*. (2020) who registered 38% of Hymenoptera in sugarcane fields, 16.4% of Coleoptera, 11.7% of Blattodea, 9.7% of Chilopoda and 8.8% of Araneae and in the secondary forest, Coleoptera showed a greater abundance with 23.5%, Hymenoptera obtained 22.7%, Isoptera 12.1%, Gastropoda 9.1% and Aranea 6.8%.

The municipality of Palizada had the highest number of worms, with 39 individuals ($p \leq 0.05$), followed by Candelaria, Escárcega and Hopelchén with 12, 3 and 0 individuals, respectively, Figure 3A. This indicates that the extensive grasslands of these sites are less disturbed, explaining the relevance of the grassland agroecosystem of the municipality of Palizada, since it promotes adequate habitat, such as vegetation cover that provides aerial and root biomass of plants. The greatest richness was recorded in the municipality of Palizada with four orders (haplotoxida, scolopendromorpha, coleoptera and dermaptera), followed by Candelaria with three orders (scolopendromorpha, haplotoxida and hymenoptera), Escárcega with two orders (haplotoxida and dermaptera) and Hopelchén with the presence of an order (coleoptera) belonging to the traditional crop (Figure 3B).

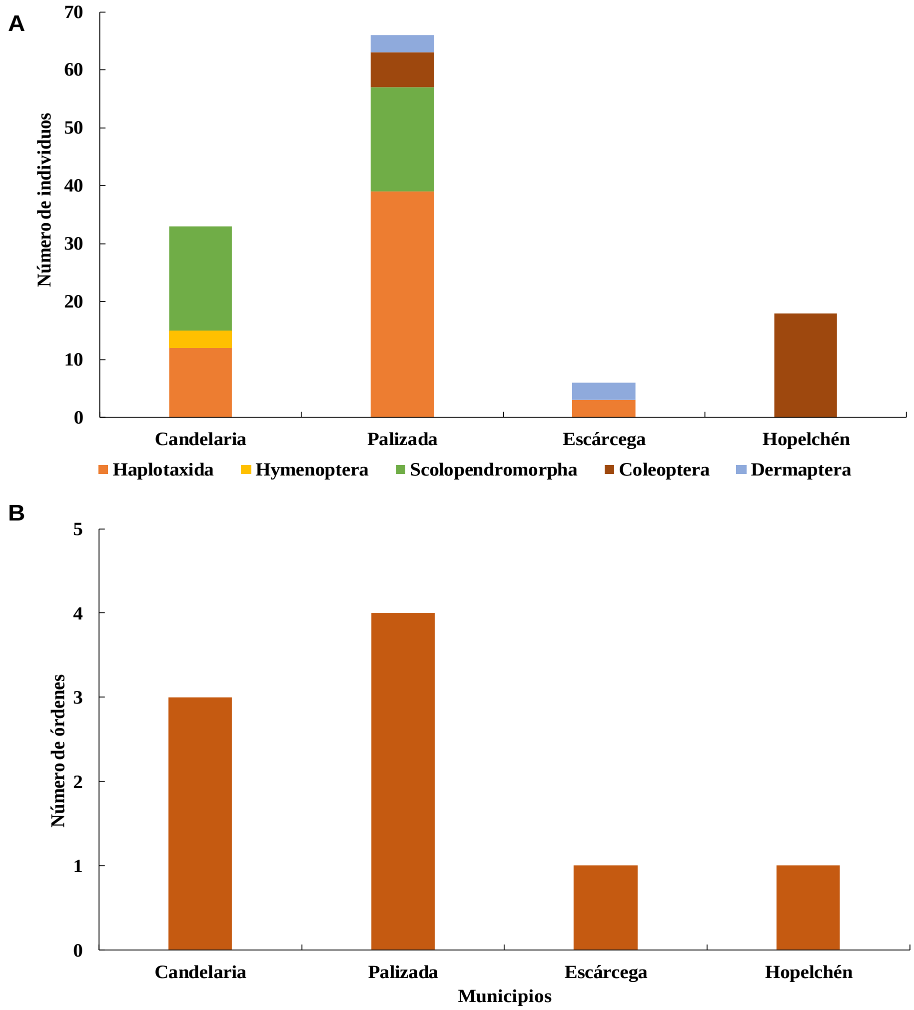

Figure 3. A) abundance; and B) richness of soil macrofauna by municipality of the state of Campeche.

In the intensive crops of Hopelchén, which presented less forest cover and high-intensity practices, no soil fauna was recorded. This is due to the fact that some taxonomic groups are more sensitive to changes, when there is conversion of an area of natural vegetation for agricultural activities (Rosa and Negrete-Yankelevich, 2012). This decrease in soil fauna for agricultural systems with intensive management has been observed in soybean crops of Hopelchén, Campeche, on the decrease of bees (Vides-Borrell *et al*., 2019), in sugarcane in Veracruz, with lower abundance of springtails and ants compared to systems with traditional management (Cabrera-Mireles *et al*., 2019) and in monocultures of Persian lime (*Citrus latifolia*), negative impact was found on the soil fauna, compared to polycultures of Persian lime, banana (*Musa* spp.) and cacao (*Theobroma cacao*) (Murillo-Cuevas *et al*., 2020).

Conclusions

The extensive grassland agroecosystem of the municipality of Palizada presents the best characteristics in the soils, with pH of 7.29, levels of phosphorus, organic matter and nitrogen of 1.31 mg kg^{-1}, 5.05% and 0.31%, respectively, which affect the quality of the soil and favor the presence of soil macrofauna, specifically of the orders Haplotaxida (earthworm), Scolopendromorpha (millipede), Coleoptera (white grub) and Dermaptera (earwigs). The agroecosystem that presented the soils with the lowest quality was that of intensive crops of the municipality of Hopelchén, with moderately acidic soils (6.44), greater amount of phosphorus 33.42 mg kg^{-1}, lower amount of organic matter (2.59%) and high nitrogen contents (0.23%), which affect the populations of beneficial soil macrofauna, since no individual was collected.

Therefore, in the systems of intensive agricultural crops, it is recommended to decrease the use of pesticides, harrowing with machinery and burning of vegetable residues. As well as incorporating harvest residues and planting some nitrogen-fixing plant species, to favor the presence of soil macrofauna and reconvert soils.

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