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EFFECT OF SOIL CONSERVATION TILLAGE ON THE STRUCTURE OF EDAPHIC FAUNA COMMUNITIES

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ABSTRACT

Edaphic fauna is a determining factor for the maintenance of soil productivity. Other factors such as soil management can modify edaphic fauna communities and directly interfere with the ecosystem services they provide. The objective of this study was to evaluate the structure of edaphic faunal communities under different conservation tillage systems in Los Tuxtlas, Veracruz, Mexico. Six tillage systems were evaluated for soil conservation in maize plots, SL1: without soil removal and covered with *Mucuna* sp. residues; SL2: with soil removal and residue burning; SL3: with soil removal and residue incorporation; SL4: without soil inversion and covered with maize residue; SL5: with soil removal and no residue; SL6= without soil removal and maize residue. According to Jaccard's similarity coefficient, the most similar tillage systems in relation to the species present are the systems with soil removal and residue incorporation (SL3) and without soil removal and with maize residues (SL6) with a value of 0.83. The tillage systems with the greatest richness, diversity and equity of edaphic fauna were with soil removal and residue incorporation (SL3), without soil inversion and covered with maize residue (SL4) and without soil removal and with maize residue (SL6), mainly in the rainy season, which is the season that most affected the edaphic fauna communities.

Keywords: arthropod diversity, maize, residue cover, soil removal, *Mucuna* sp.

INTRODUCTION

Tillage, or mechanical soil manipulation, is a common practice in agriculture, which is performed to improve the decomposition of crop residues by incorporating them into the soil, which allows their physical decomposition (Busari *et al*., 2015). There are two main types of tillage systems, conventional and conservation tillage. Unlike conventional tillage, conservation tillage has several practices that conserve soil moisture and reduce soil erosion by maintaining a minimum of 30 % of the soil surface covered by residues after tillage (Garcia *et al*., 2018).

Crop residue retention protects the soil from the direct impact of raindrops and sunlight, while minimal soil modification improves biological activities in the soil,

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as well as air and water movement in the soil (Busari *et al*., 2015). If crop residues are removed by burning or ploughing, this can affect the biological properties of the soil, including edaphic fauna and microflora, affecting biological processes of some elements such as nitrogen, sulphur, and phosphorus. Soil organic matter content greatly influences the activities of edaphic organisms, and these in turn, soil organic carbon dynamics (Busari *et al*., 2015).

The retention of crop residues decreases soil temperature and thermal amplitude and favours water conservation in the soil. The degree of mechanical disturbance and the quantity, quality, and location of crop residues affect edaphic faunal communities in the soil differently (Botina *et al*., 2012).

The organisms that compose the edaphic fauna participate in the processes of organic matter decomposition, aeration, nutrient recycling and phosphorus and nitrogen mineralization. Edaphic fauna groups are regulators of the trophic chain in the soil and help in the formation of microstructure and are directly associated with the formation of channels, pores and aggregates in the soil that favour aeration and water infiltration (Bedano *et al*., 2016). Thus, soil fauna such as earthworms, termites and ants play a key role in creating habitats for other organisms and in controlling their activities through physical and biochemical processes, as the biogenic structures, organic and organo-mineral structures produced by these organisms accumulate in the soil to form three-dimensional mosaics of functional domains, inhabited by specific communities of smaller organisms such as microorganisms, microfauna and mesofauna that drive soil processes through specific pathways (Lavelle *et al*., 2016). However, edaphic fauna can be modified by several factors and thereby directly interfere with the ecosystem services they provide such as plant protection against pests and diseases, which is largely achieved through soil processes in the functioning of self-organized systems nested within each other (Lavelle *et al*., 2016).

Soil conditions can be modified by soil change or management, resulting in the displacement of edaphic species and edaphoclimatic alterations. The type of management, soil cover and agrochemicals have a direct influence on edaphic faunal communities and their ecology, as they can cause a decrease in biodiversity and species equity, or favour species dominance (Murillo *et al*., 2019). The groups that compose the edaphic fauna are sensitive to natural and anthropic disturbances of the environment, which is why the edaphic fauna is considered a biological indicator of soil conservation status (Cabrera-Mireles *et al*., 2019). The abundance, density, diversity, and equity of the groups that integrate the edaphic fauna are variables that help to evaluate the effect of different soil managements; as well as to consider in an integral way the functioning of an agroecosystem (Murillo-Cuevas *et al.*, 2019).

Maize (*Zea mays*) is one of the main crops grown in Mexico, as it is an important source of protein and energy in the diet. In Mexico, 1 209 277 ha are planted, and 8 262004 Megagrams (Mg) of maize are produced, of which the state of Veracruz contributes 469 540 Mg in an area of 194 268 ha and is fourth in production and second in planted area at the national scale (SIAP, 2020).

The municipality of San Andres Tuxtla ranks third in maize planted area in the state of Veracruz, with 120 611 Mg in an area of 30 221 ha (SIAP, 2020). However, the intensive use of the soil, poor soil management practices in maize production, in addition to the hillside lands where a large part of the production is grown, intense rainfall and steep slopes, have generated thin soils with low fertility and little residual moisture retention capacity, which over time has caused soil loss due to erosion (Francisco-Nicolás, *et al*., 2006).

In hillside soils, it is necessary to use agricultural practices focused on soil conservation (such as conservation tillage), and to understand how different soil management practices can reduce or eliminate populations of soil fauna susceptible to physical, chemical, and biological soil management. Different conservation tillage systems can have different impacts on the structure of edaphic fauna communities, with some systems standing out in the conservation of the richness and diversity of edaphic fauna. The objective of this study was to evaluate the structure of edaphic faunal communities under different conservation tillage systems in Los Tuxtlas, Veracruz, Mexico.

MATERIALS AND METHODS

Study area

The study was conducted in two common lands in the municipality of San Andres Tuxtla, Veracruz, México. This municipality is located in the southern zone of the state of Veracruz, in the Sierra de San Martin, at coordinates 18° 27” N and 95° 13” W, at an altitude of 300 m. It borders to the north with the Gulf of Mexico; to the east with Catemaco; to the south with Hueyapan de Ocampo; to the west with Santiago Tuxtla and Angel R. Cabada. This region is characterized by the diverse use of tillage methods ranging from traditional tillage to the adoption of new strategies, due to the need to reduce soil loss, which is a limiting factor in this region.

The climate at the municipality is warm-subtropical Aw1, as classified by Köppen and modified by García (1981) with an average temperature of 23.8 °C; its average annual rainfall is 1800 mm. Soils varied within the acrisol and lithosol, characterized by the accumulation of clay, poor in nutrients and susceptible to erosion. The common lands used for this study were Chuniapan de Arriba and Tilapan, where the temperature varies regularly from 20 to 28 °C on average, with the lowest temperature of 20 °C being recorded from November to January, and the highest temperatures of 30 to 35 °C in April and May.

Sample collection

Six tillage systems were evaluated for soil conservation in maize plots (*Zea maiz* L.) (Table 1). In each tillage system, two fall traps for terrestrial arthropods were randomly placed with coverage of 36 m^2 per trap, made with four PVC tubes of 2 inches diameter and 3 m length, slotted at 2 cm longitudinally, buried at ground level and inserted into a 20 L bucket buried with the slot exposed at ground level and with a lid, the

Table 1. Tillage systems for soil conservation evaluated in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andres Tuxtla, Veracruz, Mexico.

Systems	Description
SL1	Without soil removal and covered with *Mucun*a sp. residues
SL2	With soil removal and burning of residues
SL3	With soil removal and residue incorporation
SL4	Without soil inversion and covered with corn residues
SL5	With soil removal and without residues
SL6	Without soil removal and with corn residues

PVC tubes were plugged from the end out of the bucket and uncovered from the end remaining inside the bucket (Figure 1), based on the method used by Gist and Crossley (1973).

A 4 L bucket with moistened sand was placed inside the 20 L bucket into which the organisms inside the PVC tubes were trapped (Figure 1). The 4 L buckets from each of the traps were removed and the sand containing the live organisms was emptied into plastic bags labelled with the sample data and subsequently the 4 L buckets were placed back into the traps. During a 24-week period, the organisms were surveyed on a weekly basis. The study was carried out during two periods of the year, during the

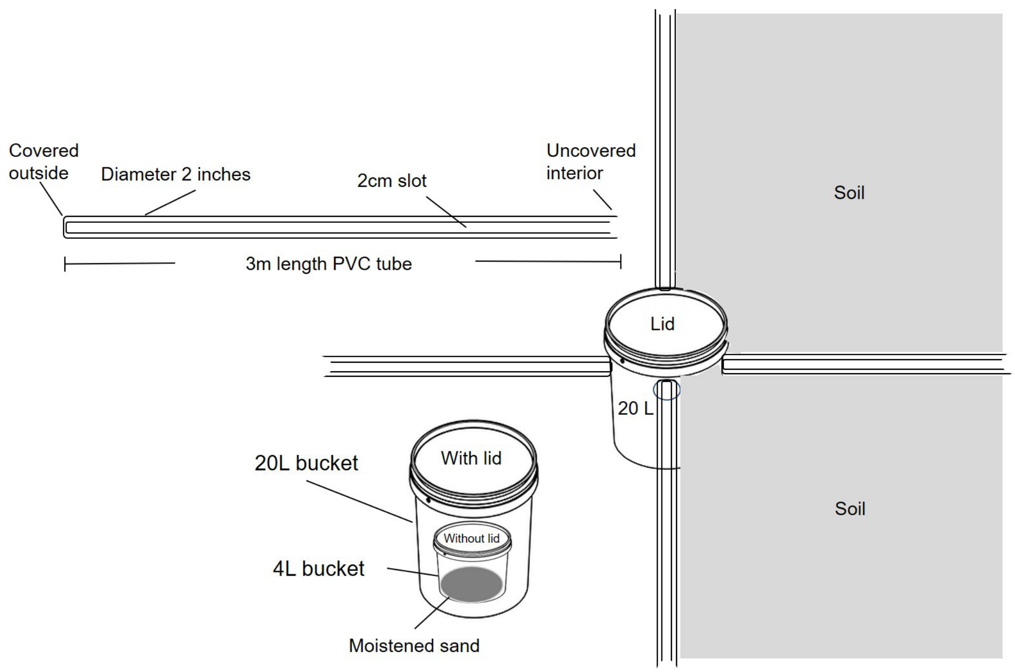

Figure 1. Diagram of the fall traps used to capture edaphic fauna in the different conservation tillage systems established in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andres Tuxtla, Veracruz, Mexico.

dry season (March-May) and the rainy season (July-September). Two replications per tillage system (treatments) were used for 24 weeks, resulting in a total of 48 replications over time.

Sample processing

Samples were processed in the Entomology Laboratory of the Experimental Field "Cotaxtla" of INIFAP, for which the samples contained in the plastic bags were emptied into plastic trays for the search and extraction of the edaphic fauna with the support of magnifying lenses and external light. All arthropods and molluscs present in the sample were considered as edaphic fauna. A Carl Zeiss® Stemi VD4 VD4 stereo microscope was used to separate and identify the organisms.

The edaphic fauna was identified at the family level and the main trophic level of each organism was determined using the keys of Triplehorn and Johnson (2005). Organisms were counted at the morphospecies branch (morphologically identical organisms) for abundance, richness, diversity, and equity calculations. The organisms were preserved in flasks with 70 % alcohol.

Statistical analysis

The structure of the edaphic fauna communities was determined through abundance considering the number of organisms of each morphospecies, to calculate the richness the number of morphospecies was considered, regarding diversity, this was determined through the Shannon-Weaver index (H'), which expresses the uniformity of the importance values through all the species of the sample (Moreno, 2001). It was calculated with the following formula:

$$H' = -\Sigma p_i \ln p_i$$

where p_i= proportional abundance of species *i*, this is, the number of individuals of species *i* divided by the total number of individuals in the sample.

Equity was calculated using the Pielou index (J'), which measures the ratio of observed diversity to the maximum expected diversity. Its value ranges from 0 to 0.1, so that 0.1 corresponds to situations where all species are equally abundant (Moreno, 2001). The following formula was used:

$$J' = H'/H'_{max}$$

where H'_{max}= ln (S) y S= Total number of species.

To determine if the tillage systems studied are similar according to the species found in them, the Jaccard similarity coefficient (I_J) was calculated (Moreno, 2001), with the following formula:

$I_J = c/a+b-c$

where a= number of species present at site A, b= number of species present at site B and c= number of species present at both sites A and B.

A Kolmogorov-Smirnov goodness-of-fit test was performed, which determined that the data did not have a normal distribution, so nonparametric tests were performed. First, the Wilcoxon test was performed for independent samples to compare the seasons of the year in relation to the structure of the edaphic fauna communities. The Kruskal-Wallis' test was then used to detect significant differences ($p \leq 0.05$) between conservation tillage systems and a comparison was made between means of the ranges of abundance, richness, diversity, and equity of edaphic fauna between conservation tillage systems.

The procedure used to judge the significance of multiple comparisons and postulated contrasts is the one described in Conover (1999). Statistical analyses were performed in InfoStat® version 2020 (Di Rienzo, 2020). Descriptive statistics were performed with averages ± standard error of the abundance of organisms according to their trophic level by tillage system.

RESULTS AND DISCUSSION

A total of 40 taxa were identified, corresponding to edaphic fauna of arthropods (insects, mites, spiders, scorpions, millipedes, and ground sowbugs) and molluscs (snails and slugs). The most abundant taxa were phytophagous taxa of the families Gryllidae 24 % (crickets), Cydnidae 2 % (bedbugs), and Elateridae 2 % (beetles); predators of the families Formicidae 18 % (ants), Carabidae 9 % (beetles), Reduviidae 4 % (bedbugs), Gelastocoridae 3 % (bugs), and Araneae 1 % (spiders); saprophytes of the families Gastropoda 15 % (snails), Acari 4 % (mites), Diplopoda 3 % (millipedes), Scarabaeidae 2 % (beetles), Veronicellidae 1 % (slugs), and Isopoda 2 % (ground sowbugs); saproxylophagous of the family Passalidae 2 % (beetles); scavengers of the family Staphylinidae 1 % (beetle); and omnivores of the family Blattidae 1 % (cockroaches) were also found (Table 2).

Crickets were the most numerous organisms in SL5 (513) and SL1 (449) tillage systems. Ants were abundant in the SL2 system (475) and were less abundant in SL3 (68). Snails and carabids were more abundant in the SL2 (276) and SL6 (380) systems. Passalid beetles and mealybugs were more abundant in the SL4 system (103 and 96 organisms, respectively); in addition, bedbugs of the family Reduviidae, millipedes, scarabaeids and spiders were more abundant in the SL3 and SL4 systems (Table 2).

In regard to the trophic levels of the soil fauna found in the conservation tillage systems, the system without soil removal and covered with *Mucuna* sp. residues (SL1) recorded the highest average of phytophagous (18.0), scavengers (10.8) and predators (6.4) and was significantly different from the other tillage systems, it also recorded the highest significant difference between phytophages and predators within the system (11.6), being more abundant on average the phytophages than the predators (Figure 2).

Table 2. Abundance of edaphic fauna taxa in each of the soil conservation tillage systems established in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andrés Tuxtla, Veracruz, Mexico.

Taxa	SL1	SL2	SL3	SL4	SL5	SL6	ATP
Gryllidae	449	173	45	89	513	192	Phytophage
Formicidae	155	475	68	116	75	220	Predator
Gastropoda	107	276	38	75	37	380	Saprophaga
Carabidae	193	85	42	54	17	175	Predator
Passalidae	0	0	13	103	5	14	Saproxylophagous
Isopoda	5	0	14	96	15	17	Saprophaga
Gelastocoridae	84	21	30	3	0	27	Predator
Acari	57	67	33	33	12	57	Saprophaga
Reduviidae	37	13	52	65	16	57	Predator
Diplopoda	26	12	28	73	0	30	Saprophaga
Scarabaeidae	19	6	20	44	17	15	Saprophaga
Araneae	5	3	11	34	6	18	Predator
Cydnidae	10	4	25	63	0	19	Phytophage
Elateridae	17	11	24	31	16	21	Phytophage
Veronicellidae	7	3	10	5	5	11	Saprophaga
Staphylinidae	4	3	13	16	7	15	Scavenger
Scorpionidae	4	3	2	14	3	17	Predator
Blattidae	3	32	12	12	9	16	Omnivore
Phoridae	3	0	2	9	1	6	Omnivore
Lepidoptera larvae	3	2	3	2	2	4	Phytophage
Cicadellidae	3	0	0	1	0	2	Phytophage
Pompilidae	3	1	4	1	3	4	Parasitoid
Cicindelidae	2	4	5	19	5	9	Predator
Mutillidae	2	0	0	15	7	6	Parasitoid
Dermaptera	2	3	1	0	0	5	Predator
Lathridiidae	2	0	2	0	4	4	Phytophage
Curculionidae	0	1	0	8	2	4	Phytophage
Apidae	0	0	3	4	0	6	Phytophage
Myrmeleontidae	0	0	3	4	1	1	Predator
Gryllacrididae	0	0	0	2	5	2	Phytophage
Bostrichidae	0	0	0	1	0	0	Phytophage
Cucujidae	0	0	0	1	0	0	Saprophaga
Diptera Larvae	0	1	1	1	0	3	Phytophage
Pentatomidae	0	0	3	1	0	2	Phytophage
Anthicidae	0	0	0	0	1	0	Saprophaga
Chrysomelidae	0	1	0	0	0	1	Predator
Chrysopidae	0	0	1	0	0	3	Predator
Evaniidae	0	0	3	0	0	2	Parasitoid
Gryllotalpidae	0	0	2	0	0	4	Phytophage
Nabidae	0	0	0	0	3	5	Predator

SL1: without soil removal and covered with mucuna residues; SL2: with soil removal and burning residues; SL3: with soil removal and residue incorporation; SL4: without soil inversion and covered with corn residues; SL5: with soil removal and without residues; SL6: without soil removal and with corn residues; ATP= Predominant Trophic Activity.

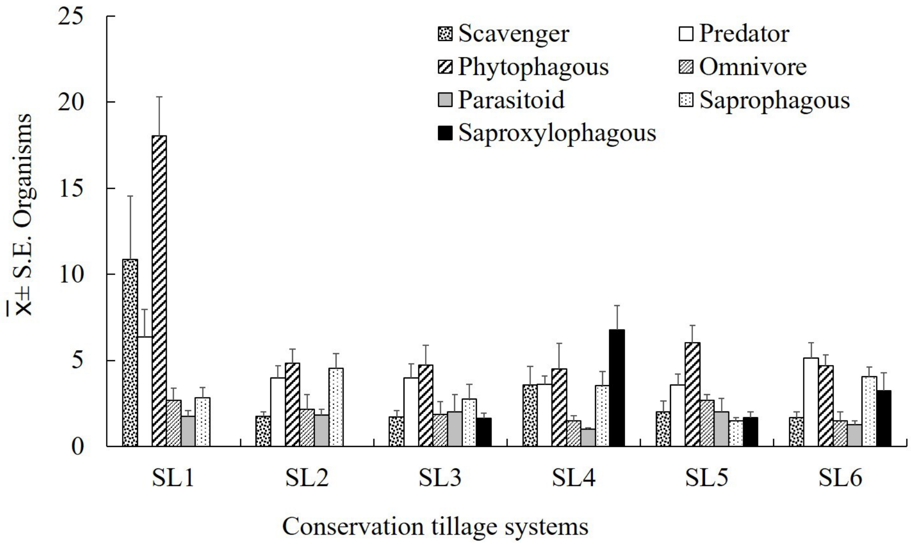

Figure 2. Average number of organisms represented by their predominant trophic activities in conservation tillage systems established in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andrés Tuxtla, Veracruz, Mexico. SL1: without soil removal and covered with *Mucuna* sp. residues; SL2: with soil removal and residue burning; SL3: with soil removal and residue incorporation; SL4: without soil inversion and covered with maize residue; SL5: with soil removal and without residue; SL6: without soil removal and with maize residue.

Systems SL2, SL3, SL4 and SL6 had phytophages and predators equally represented, unlike the system with soil removal and no residues (SL5) in which phytophages significantly predominated (6.0). The system without soil inversion and covered with maize residue (SL4) presented on average a significant abundance of scavenger (3.5) and saproxylophagous (3.5) organisms in contrast to the other systems (Figure 2).

The total number of individuals by taxa and predominant trophic activity of edaphic fauna varied between tillage systems. The phytophagous Gryllidae, the predators Formicidae and Carabidae, and the saprophagous Gastropoda were the predominant organisms with variations in their abundances according to the conservation tillage system.

Regarding the morphospecies Gryllidae (*Gryllus* sp.), commonly known as field crickets, adults, and nymphs of this insect burrow in moist soil to hide under leaf litter during the day, are active and feed on the soil surface at night, large nymphs and adults cut stems, eat foliage and roots of young plants and seedlings. They are not major pests but may occur as minor or secondary pests in crops such as cabbage ((*Brassica oleracea* var. *capitata*), pineapple (*Ananas comosus*), cushaw pumpkin (*Cucurbita argyrosperma*), common bean (*Phaseolus vulgaris*), onion (*Allium cepa*), maize, rice (*Oryza sativa*), tomato (*Solanum lycopersisum*), tobacco (*Nicotiana tabacum*), watermelon (*Citrullus lanatus*), cucumber (*Cucumis sativus*), soybean (*Glycine max*), cotton (*Gossypium hirsutum*), and potato (*Solanum tuberosum*) (Santiago, 2019).

Although this cricket family has phytophagous and burrowing habits, both in the adult stage and in nymphs, it was affected by the system with soil removal and residue incorporation (SL3), which drastically reduced abundance. This is because soil removal exposes crickets to predation and desiccation, and residue incorporation helps to increase predation of crickets by other organisms such as assassin bedbugs of the family Reduviidae, or spiders, which are abundant in this tillage system. This situation has been reported for other phytophages such as slugs in cereals, where conventional tillage by the mechanical action of implements reduces phytophage populations as opposed to minimum tillage (Kennedy *et al*., 2013).

Members of the family Formicidae were the second most abundant group, especially in two of the tillage systems SL2 (475) and SL6 (220). This result corroborates those of Privado *et al.* (2018), who indicate that differences in these edaphic faunal communities are influenced by soil management, even differences are observed at a high taxonomic indication level such as family to genus-species branches. One of the tillage systems in which the abundance of Formicidae was particularly high was that without soil removal and maize residues (SL6), which is due to the application of biomass on the soil surface, as this favours the presence of some functional groups of soil fauna such as ants (Moura *et al*., 2015). On the other hand, ants were also abundant in the tillage system with soil removal and residue burning, which was to be expected since ants are among the most tolerant organisms to the effects of burning in different terrestrial ecosystems (Cabrera-Mireles *et al*., 2019).

In the case of predatory carabids, the systems of tillage without soil removal and covered with *Mucuna* sp. residues (SL1) and SL6 were those that most favoured their abundance. For the SL1 system, the abundance of carabids is related to the presence of the legume *Mucuna* sp., since a large part of its waste is used by other organisms that act on soil structure and nutrient availability. Phytophagous, scavengers and predators presented higher abundance averages in the SL1 system, than in any other tillage system (Figure 2) which allows greater stability in the system, since where there is a large population of organisms with different trophic activities, there is a greater functional performance in ecosystem engineering by organisms, which directly or indirectly modulate the availability of resources for other species, by causing changes in the physical state of biotic and abiotic materials (Lavelle *et al*., 2016). These results match those of Privado *et al.* (2018) in which ants dominated the *Leucaena leucocephala* biomass treatment.

Ants are predators that directly or indirectly modulate the availability of resources for other species by causing changes in the physical state of the soil by building earth mounds, tunnels, and subway chambers where they concentrate organic matter. In the case of the SL6 system, conservation tillage and no soil removal support more arthropod communities including carabid beetles (Menalled *et al*., 2007). However, ploughing has also been shown to affect the survival of many carabid species (Holland and Reynolds, 2003). Reducing the population of carabids can increase the number of phytophagous organisms, which in some cases can cause imbalance in trophic webs and interactions between organisms, affecting the production of signalling molecules that act as ecological mediators of biological engineering processes, a process that helps protect plants against pests and diseases.

For the case of snails of the family Gastropoda and slugs of the family Veronicellidae, it has been reported that reduced or conservation tillage systems increase their populations (Kennedy *et al*., 2013), which was observed in the snails of systems SL1, SL2 and SL6, where these were more abundant. Snails and slugs contribute to soil nutrition, as their movement allows soil aeration, formation, and fertilization. However, slugs can become an important pest for the bean crop, which is commonly grown alongside or intercropped with maize in many regions, so high slug populations can severely affect the development of plants that serve a purpose in the agroecosystem. Non-inversion tillage methods generally have less effect on snail and slug populations than ploughing combined with subsequent cultivation (Glen and Symondson, 2003). The greater and more intensive the crop management, the more likely it is that slug numbers will be substantially reduced, with non-inversion tillage generally being less effective in reducing slug numbers than conventional tillage (Glen and Symondson, 2003).

In relation to the structure of edaphic fauna communities, the highest abundance (1374 organisms) and taxa richness (37) was recorded in the system without soil removal and with maize residues (SL6), the highest diversity (2.92) and equity (0.85) in the systems with soil removal and residue incorporation (SL3) and without soil inversion and covered with maize residue (SL4) (2.85 and 0.82) (Table 3). In terms of maximum diversity that can be found in the system, the SL3 system had 0.85 or 85 % and SL4 had 0.82 or 82 % of the total diversity that can be found in each of these systems, in contrast to the SL2 and SL5 systems that did not even reach 0.6 or 60 % of the total diversity that can be found in each of these systems (Table 3).

According to Jaccard's similarity coefficient (Table 4), the tillage systems with the highest similarity in relation to the species present are the systems with soil removal

Table 3. Ecological indicators of edaphic fauna communities in six soil conservation tillage systems established in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andres Tuxtla, Veracruz, Mexico.

Ecological indicators	Tillage systems					
	SL1	SL2	SL3	SL4	SL5	SL6
Abundance	1207	1200	513	995	787	1374
Richness	25	23	31	32	26	37
Diversity H	2.06	1.81	2.92	2.85	1.56	2.44
Diversity $H_{máx}$	3.22	3.14	3.43	3.47	3.26	3.61
Equity	0.64	0.58	0.85	0.82	0.48	0.68

SL1: without soil removal and covered with *Mucuna* sp. residues; SL2: with soil removal and residue burning; SL3: with soil removal and residue incorporation; SL4: without soil inversion and covered with corn residue; SL5: with soil removal and without residue; SL6: without soil removal and with corn residue; Abundance= #organisms, Richness= #morphospecies.

Table 4. Jaccard's similarity coefficient (Ij) to compare tillage systems in relation to the degree to which two systems are similar for the species present in them, in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andrés Tuxtla, Veracruz, Mexico.

	Tillage systems					
	SL1	SL2	SL3	SL4	SL5	SL6
SL1	1	0.69	0.70	0.68	0.65	0.68
SL2		1	0.66	0.64	0.55	0.64
SL3			1	0.69	0.57	0.83
SL4				1	0.65	0.76
SL5					1	0.65
SL6						1

SL1: without soil removal and covered with *Mucuna* sp. residues; SL2: with soil removal and residue burning; SL3: with soil removal and residue incorporation; SL4: without soil inversion and covered with maize residue; SL5: with soil removal and without residue; SL6: without soil removal and with maize residue.

and residue incorporation (SL3) and without soil removal and with maize residues (SL6) with a value of 0.83, followed by SL4 and SL6 with 0.76 and SL1and SL3 with 0.70, this indicates that the tillage systems shared characteristics that benefit the same edaphic fauna species.

When comparing the seasons of the year in relation to the structure of the edaphic fauna communities, it was found that the environmental conditions of the rainy season in the study region negatively affected the abundance, richness and diversity of the edaphic fauna, obtaining the lowest values compared to the dry season (Table 5).

The structure of the edaphic fauna communities changed according to the time of the year and conservation tillage systems. The rainy season had a more marked effect on the abundance, richness, diversity and equity of edaphic fauna, which was resisted only by some tillage systems (Figure 3). In the dry season, the system without soil removal and covered with *Mucuna* sp. residues (SL1) maintained the highest average

Table 5. Wilcoxon test for independent samples in the comparison of the seasons of the year in six soil conservation tillage systems established in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andres Tuxtla, Veracruz, Mexico.

Variables	Dry	Rain	W	*P*
Abundance	21.11 (27.19†)	5.76 (7.50†)	17894.50	0.0001
Richness	3.98 (2.77)	2.22 (1.38)	19400.00	0.0001
Diversity	0.86 (0.50)	0.54 (0.50)	21209.50	0.0001
Equity	0.65 (0.33)	0.52 (0.45)	25973.50	0.2611

†Standard Deviation, W: Wilcoxon value, *P*= probability.

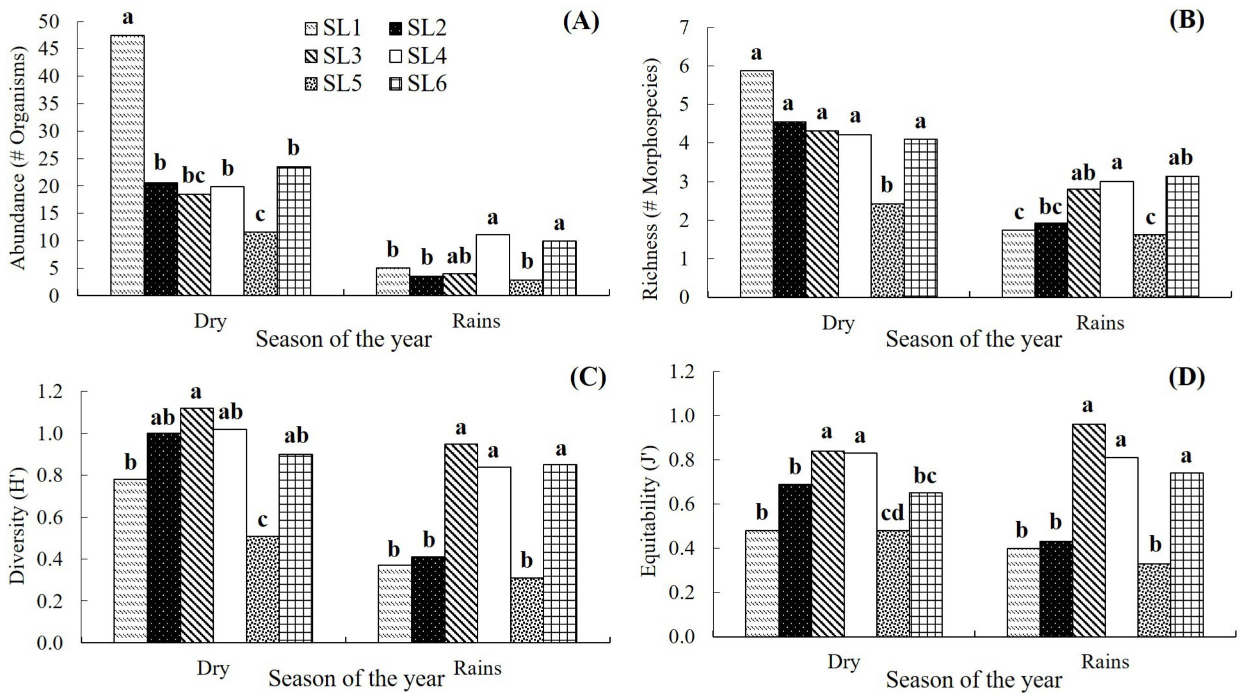

Figure 3. Abundance (A), richness (B), diversity (c) and equity (D) of edaphic fauna as a function of conservation tillage systems and seasons of the year in maize (*Zea mays*) plots in the common lands of Chuniapan de Arriba and Tilapan in the municipality of San Andrés Tuxtla, Veracruz, Mexico. SL1: without soil removal and covered with *Mucuna* sp. residues; SL2: with soil removal and burning residues; SL3: with soil removal and residue incorporation; SL4: without soil inversion and covered with maize residues; SL5: with soil removal and without residues; SL6: without soil removal and with maize residues.

abundance of edaphic fauna (47.4) and was significantly different from the other systems (p=0.0001), the system without soil removal and with maize residues (SL6) had the lowest abundance (11.5), while the other systems maintained an abundance without significant differences above 18.0 organisms on average. In the rainy season the systems without soil inversion and with maize residue cover SL4 and SL6 were the ones that maintained on average the highest abundance of organisms (11.1 and 10.0 respectively), being significantly different (p=0.0001) to the other tillage systems (Figure 3A).

The richness of edaphic fauna showed greater similarity between the tillage systems in the dry season than in the rainy season, being the system with soil removal and without residues (SL5) the one that registered significant differences (p=0.0001) with the lowest richness on average in the dry season (2.4 morphospecies). The systems with no soil removal and covered with *Mucuna* sp. residues (SL1), with soil removal and residue burning (SL2) and SL5 had the lowest edaphic fauna richness on average in the rainy season (1.7, 1.9 and 1.6 morphospecies, respectively) and were significantly different (p=0.0001) from the system without soil inversion and covered with maize residue (Figure 3B). Regarding the diversity and equity of edaphic fauna, the tillage systems with soil removal and residue incorporation (SL3), without soil inversion and with maize residue cover (SL4) and without soil removal and with maize residue (SL6) were those that maintained the highest values in the two seasons of the year, being significantly different (p=0.0001) from the systems without soil removal and covered with *Mucuna* sp. residues (SL1) and with soil removal and without residue (SL5) (Figure 3C and 3D). (SL1) and with soil removal and without residues (SL5) (Figure 3C and 3D).

The results showed that the rainy season affects the structure of edaphic fauna communities and that tillage practices exerted a great influence on the activity of the studied arthropod and mollusk fauna groups, which corroborates the fact that the abundance, richness, diversity and equity of edaphic fauna is affected by climate and soil management, which are not independently responsible, but have a cumulative effect, as indicated by Sharma and Parwez (2018). The tillage systems that favored edaphic fauna were the systems with soil removal and residue incorporation (SL3), without soil inversion and covered with maize residue (SL4), and without soil removal and with maize residue (SL6), which was mainly reflected in the rainy season. These systems had the greatest richness, diversity and equity of edaphic fauna, which could be due to the shared characteristics of little or no soil removal and incorporation of vegetation cover, which could favor edaphic fauna. These systems also shared greater similarity in terms of the species they share, indicating that these tillage systems present similar characteristics, such as the incorporation of organic matter into the soil and minimal or no soil removal that benefit the same edaphic fauna species, such as phytophagous, predators, scavengers, saprophytes and saproxylophagous. These results suggest that when cultivation is carried out with tillage practices that do little damage to the soil and that also incorporate organic matter, proportional relationships between groups of edaphic fauna can be maintained. The advantages of conservation tillage practices over conventional systems is that they promote system stability (Bedano *et al*., 2016), through functional domains, inhabited by specific communities of organisms that drive soil processes through different pathways. On the contrary, when agroecosystems are altered by conventional practices, the balance between the different functional groups is affected, reducing the richness, diversity and equity of the edaphic fauna and, consequently, its functions in the soil.

Tillage involving soil removal and organic matter altered by burning practices negatively affects arthropod community structure and activity (Brennan *et al*., 2006). Also, abundance, richness and diversity of macrofauna are significantly lower in no-tillage than in natural pastures, due to a greater contribution and incorporation of organic matter to the soil in pastures (Domínguez *et al.* 2010). In fact, abundance and diversity of edaphic fauna are favored by reduced tillage (Marasas *et al*., 2001), due to minimal or no physical soil disturbance. Our results show greater diversity and equity of edaphic fauna in the tillage systems with soil removal and residue incorporation (SL3), without soil inversion and covered with maize residue (SL4) and without soil removal and with maize residue (SL6), which allow greater incorporation of organic matter and less physical alteration in the soil.

CONCLUSIONS

Conservation tillage systems maintained a similar representation among the different trophic groups, with an equal representation between phytophagous and predators. The exception was the tillage system without soil removal and covered with *Mucuna* sp. residues (SL1). (SL1), in which phytophages, mainly *Gryllus* sp. predominated, increasing the abundance of organisms in this tillage system.

Under the climatic conditions of the study, the most favorable conservation tillage systems for the structure of edaphic fauna communities were the tillage systems with soil removal and residue incorporation (SL3), without soil inversion and with maize residue cover (SL4) and without soil removal and with maize residue (SL6), which promoted a greater richness, diversity and equity of edaphic fauna, mainly in the rainy season, which was the most unfavorable season for edaphic fauna communities.

This study confirms that different conservation tillage systems have different effects on soil fauna. Some conservation tillage systems were more similar among themselves than others, and significant differences in ecological indicators were observed among some of the different conservation tillage systems, which indicates that these systems act differently on soil fauna, since their components or mechanisms affect the soil in different ways; some tillage systems protect and promote the structure of soil fauna communities and others do not.

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