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CHANGES IN SOIL MACROFAUNA IN AGROECOSYSTEMS DERIVED FROM LOW DECIDUOUS TROPICAL FOREST ON LEPTOSOLS FROM KARSTIC ZONES

[CAMBIOS DE LA MACROFAUNA DEL SUELO EN AGROECOSISTEMAS DERIVADOS DE SELVA BAJA CADUCIFOLIA EN LEPTOSOLES DE ZONAS KÁRSTICAS]

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SUMMARY

In Yucatan Mexico the method of slash and burn is used for the establishment of pastures. Pastures are developed for 15 to 20 years, no more because weed control is too expensive. The impact of these practices on soil macrofauna had not been evaluated. Because of its wide distribution, diverse habits and high sensitivity to disturbance, soil macrofauna is considered a valuable indicator of soil health, allowing monitoring of soil sustainability. We studied soil macrofauna communities in low deciduous tropical forest and four livestock agroecosystems with increasing management-derived disturbance including a silvopastoral system, Taiwan grass (*Cynodon nlemfuensis*) and Star grass (*Pennisetum purpureum*) pastures in order to describe community structure across systems, and evaluate disturbance sensitivity of taxonomical groups to detect taxa with potential use as biological indicators of soil health or degradation. Pitfall traps were used at each of the systems to sample soil macrofauna. We estimate their taxonomical abundance, biomass, richness (order, morphospecies), diversity, dominance and response to disturbance on agroecosystems and the forest. We found 133 macrofauna morphospecies of 15 taxa. Groups with more individuals were: Hymenoptera (64.97%), Coleoptera (22.68%), and Orthoptera (3.91%). Agroecosystem of two-year old Taiwan-grass pasture (TP2) had the highest macrofauna abundances, biomass and richness, low diversity, and a non-homogeneous distribution of individuals among species; in contrast, silvopastoral system (SP), had low abundance and biomass, the lowest specific richness, high diversity and a homogeneous distribution of individuals among species. The discriminant analysis revealed that the agroecosystems and the forest serve to predict the macrofauna communities, since they have particular or typical soil macrofauna. The cases (sampled points) with a correct assignation by agroecosystems were: Forest (70%), Sivopastoral system (70%), Taiwan pasture of two year old (80%), Taiwan pasture of 12 years old (60%) and Star grass of 12 years old (60%). Hymenoptera (the most abundant taxa) and Orthoptera were the macrofauna groups that differ among agroecosystems. Response to disturbance by taxonomical groups showed that Hymenoptera had a temporal pattern, with peak dominance at systems with intermediate disturbance and decrease in dominance at SP; Coleoptera had an opportunistic behavior, becoming dominant as disturbance increased; Orthoptera and Arachnida showed susceptibility to disturbance.

Key words: Hymenoptera; Coleoptera; Orthoptera; Arachnida; Leptosol; Karst.

RESUMEN

En Yucatán, México se utiliza el método de roza, tumba y quema (rtq) para el establecimiento de pastizales. Los pastizales se usan no más de 15 a 20 años, debido al alto costo del control de las arvenses; posteriormente se dejan en barbecho (descanso) por 20 años luego de lo cual se preparan por rtq de nuevo. El impacto de estas prácticas sobre la macrofauna de suelo no ha sido evaluado hasta ahora. Debido a su amplia distribución, hábitos diversos y la alta sensibilidad frente a la perturbación, la macrofauna de suelo es considerada un indicador de la salud del mismo, con la que es posible monitorear la calidad de este. Se estudiaron las comunidades de macrofauna de suelo en una selva baja caducifolia y en cuatro agroecoecosistemas con diferente grado de perturbación incluyendo un sistema silvopastoril, pastizales de pasto Taiwán (*Cynodon nlemfuensis*) y de pasto Estrella (*Pennisetum purpureum*) para describir los cambios en la estructura de comunidad de macrofauna del suelo y evaluar la sensibilidad de los grupos taxonómicos al manejo agrícola y así detectar taxa con potencial uso de indicadores biológicos de la salud o degradación del suelo. Para el muestreo de la macrofauna del suelo se usaron trampas de caída libre en cada agroecosistema y en la selva. Se estimó la abundancia, biomasa, riqueza (orden y morfoespecie), diversidad, dominancia y respuesta al disturbio en los agroecosistemas y en la selva. Se encontraron 133 morfoespecies de 15 taxa. Los grupos con mayor número de individuos fueron Hymenoptera (64.97%), Coleoptera (22.68%), and Orthoptera (3.91%). El pastizal de Taiwán de dos años TP2 tuvo los mayores valores de abundancia, biomasa y riqueza de macroinvertebrados, además de una baja densidad y una distribución no homogénea de morfoespecies; por el contrario, el sistema silvopasatoril (SP) tuvo bajos valores de abundancia y biomasa, la más baja riqueza de especies, una alta diversidad y una distribución homogénea de individuos de las morfoespecies. El análisis discriminante reveló que los agroecosistemas y la selva sirven para predecir las comunidades de macrofauna; es decir, tienen una macrofauna particular o típica. De acuerdo con dicho análisis los casos (puntos de muestreo) correctamente asignados por agroecosistema fueron: Selva (70%), Sistema silvopastoril (70%), pastizal de Taiwán de dos años (80%), pastizal de Taiwán de 12 años (60%) y pastizal de Estrella de 12 años (60%). El sistema silvopastoril es un uso de suelo con una comunidad de macrofauna diferente de los otros agroecosistemas e incluso de la selva. Hymenoptera (el taxón más abundante) y Orthoptera fueron los grupos que ocasionaron las diferencias entre las comunidades de macrofauna del suelo de los agroecosistemas y la selva. La respuesta al disturbio, por grupos taxonómicos, muestra que Hymenoptera tuvo un patrón de comportamiento temporal, Coleoptera presentó una conducta oportunista que domina conforme el tiempo de disturbio se incrementa, mientras que Orthoptera y Arachnida fueron susceptibles al disturbio.

Palabras clave: Hymenoptera; Coleoptera; Orthoptera; Arachnida; Leptosol; Karst.

INTRODUCTION

Soil macrofauna, invertebrates with a diameter larger than 2 mm, are diverse, abundant and multifunctional elements of most soils. They are considered useful indicators of soil health since they play diverse roles on the biological regulation system of soils, depending on their habits, distribution and abundance. Also because they are widely distributed, have diverse habits, are sensitive to disturbance, highly abundant and are easily captured and studied (Lavelle, 1984; Stork and Eggleton, 1992; Park and Cousins, 1995; Lavelle and Spain, 2001). Measurements of soil health by means of indicators allow us to understand how soil capacities and properties evolved under certain management systems either for food production or development of environmental functions in several time-space scales (Astier *et al.*, 2002). Within this context, it is important to choose the indicators that give complete information about its properties, biological productivity and quality of surrounding environment (Herrick, 2000).

Agricultural practices often deplete soil organic matter and alter composition and abundance of soil biota. Consequently, physical and chemical properties such as exchangeable cations, soil water retention capacity, contents of fundamental elements and pH, decrease also denoting a general decrease in soil function (Senapati *et al.*, 2002; Doran and Safley, 1997). A decrease in these parameters is often indicative of a soil disturbed by productive activities (Pankhurts *et al.*, 1997). However, field research on soil macrofauna community for identifying sensitive groups is scanty. This can be particularly noteworthy in field studies of macrofauna in Leptosol and in the subhumid tropics.

Soils in Yucatan, Mexico, as in many places of Latin America, have been historically devoted to the agricultural and livestock production sector. Currently, 20.1% of the surface of the state (1,798,692 ha) is used for livestock activity (Vester and Calmé, 2003) and most of these lands and those used for agriculture or forestry had been exploited without the previous analysis of soil properties, soil biota and its response to different management practices (Bautista and Jiménez, 2001). In Yucatan, the method of slash and burn is use for the establishment of pastures. Pastures are developed for 15 to 20 years, no more because weed control is too expensive. After that a fallow period of 20 years is necessary for soils to recover their fertility.

At present the silvopastoral systems (SP), based on the secondary vegetation, are promoted. The SP produce forage, his establishment is economic and it favors the biological conservation and diverse environmental services. The SP can coexist with the traditional cattle, though to promote them there is needed major technical knowledge of their functioning (Ku *et al.*, 1999; Sosa *et al.*, 2004).

In order to understand the degree of soil detriment caused by these activities in the state, it is essential to consider its effects in soil macrofauna communities. Despite in southeastern Mexico diverse studies on soil macrofauna communities had been carried out (Lavelle *et al.*, 1998; Brown *et al.*, 2001b; Fragoso, 2001), only two studies exist in Yucatan: One regarding community diversity of soil biota in fodder agroecosystems (Ciau *et al.*, 2003) and other focusing on the abundance of Oligochetae and Gasteropodae taxa in leguminous cultures (Bautista *et al.*, 2008). Neither study uses ecological estimates of soil macrofauna communities as predictors of disturbance due to soil management practices.

The aim of this study is to describe and compare the changes in soil macrofauna communities in dry lowland forest and four agroecosystems (Silvopastoral system, Taiwan grasslands of 2 years; Taiwan grasslands of 12 years and Star-grass of 12 years) of Yucatan in order to find sensitive biological groups.

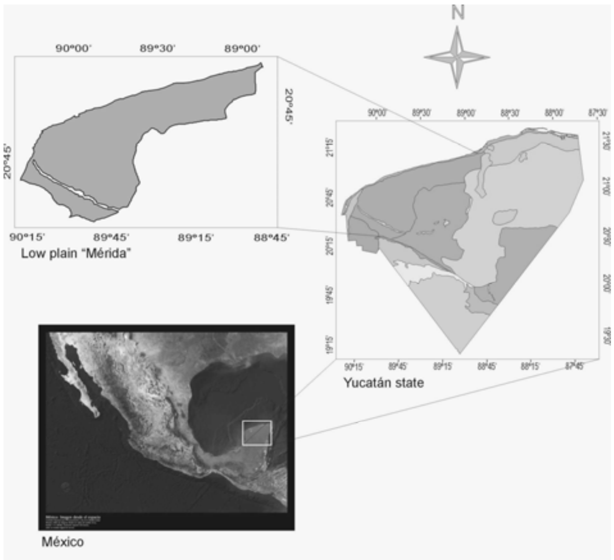

Figure 1. Localization of study area in Yucatan, Mexico.

MATERIALS AND METHODS

Study area

The study was carried out in Saramuyo and Kampepen ranches, located in kilometer 3 of Dzununcan–San Jose Tzal road in the municipality of Merida, in Yucatan state, Mexico (20°50´05´´N; 89°39´05´´W; elevation: 19 masl) (Figure 1). Vegetation is secondary, originated from low deciduous tropical forest (Flores and Espejel, 1994). Study sites are within a geomorphologic landscape called "karstic plain" that corresponds to a recent karst formation in Yucatan State Leptosol of deep to 20 cm over calcareous rocks are dominant. Climate is Ax'(wi)(i')gw (warm subhumid with summer rains) and drought the rest of the year; mean annual temperature is 26ºC, with an annual precipitation of 998 mm (Bautista *et al.*, 2003ab).

Study was conducted in secondary low deciduous tropical forest and four agroecosystems within the ovine ranches. These agroecosystems have different and contrasting disturbance degrees (type of activity and time since the last management practice), allowing to range them in the following gradient:

Silvopastoral system (SP). Ovine grazing system established two years before the sampling with the selective cut of trees, where *Leucaena leucocephala*, *Lysiloma latisiluquum* and *Piscidia piscipula*, are the standing vegetation elements annually pruned at the beginning of the rainy season. Previous to this land use, the system remained unmanaged (land rested) for four years, but before that it was a corn field growing on secondary vegetation (derived from an abandoned henequen culture).

Taiwan grasses pasture (TP2). A *Pennisetum purpureum* pastureland with two years since first established. It receives four prunes and ovine manure a year.

Forest (F). Secondary forest derived from dry lowland forest with no use or management for 15 years and the smallest disturbance regime. Dominant vegetation elements include *Gymnopodium floribundum*, *Neomilspaugia emarginata, Lysiloma latisiliquum, Dyospiros cuneata*, *Pithecellobium albicans*, *Mimosa bahamensis, Bursera simaruba, Bahuinia divaricata, Caesalpinia gaumeri, Piscidia piscipula, Chiococca alba* and *Bunchosia glandulosa*.

Taiwan grasses pasture (TP12). A *P. purpureum* pastureland, with twelve years since first established. It received an annual nitrogen supply for nine years, which was substituted by an annual supply of ovine manure for the last three years. Pruning occur each 2 or 3 months, depending on the season.

Star grasses pasture (SG12). A *Cynodon nlemfuensis* pastureland, with twelve years since first established (in 1991). Originally devoted to cattle raising (for seven years) it is currently used for ovine grazing with a rotation lapse among grazing periods of four weeks during the rainy season and seven weeks during the dry season. No manure or fertilizer is used in this land, but *Leucaena leucocephala* standing trees provide soil with nitrogen derived from liter decomposition. Comparative details on the biotic and management features of each agroecosystem are showed in Table 1.

Table 1. Characteristics and management practices of agroecosystems

Agroecosystems	Tree richness/ abundance/ dominance	Years since establishment / Derived from	Current management	Differential soil properties	Soil trampling	Maintenance
F	28/ 300/ 30.55	20 y / PF	No	CE^1, FC^1, PWP^1, Mg^5, P^5	No	No
SP	22/ 406/ 49.98	2 y / SF	(tfh) (ocg)	CE^2, FC^2, PWP^2, Mg^4, P^4	(O)	(p)
TP2	0	2 y / SV	(gh)	CE^3, FC^3, PWP^3, Mg^3, P^2	No	(m), (i)
TP12	0	12 y / SV	(gh)	CE^5, FC^5, PWP^5, Mg^2, P^1	No	(m), (i)
SG12	1 / NA/ NA	12 y / GP	(ocg)	CE^4, FC^4, PWP^4, Mg^1, P^3	(I)	(i)

Agroecosystems: F= forest, SP= Silvopastoral system, TP2= 2 year-old Taiwan grass pasture, TP12= 12 year-old Taiwan grass pasture, SG= 12 year-old star grass pasture; Tree abundance/dominance: NA=Not available; Derived from: PF=Primary forest, SF=Secondary forest, SV=Secondary vegetation (from abandoned henequen culture), GP=Grazing pasture; Current management: (tfh)= tree fodder harvest, (gh)= grass fodder harvest, (ocg)=ovine cattle grazing; Soil properties: CE=Cation exchange capacity, FC=Field capacity, PWP=Permanent wilting point, Mg=Magnesium, P=Phosphorus, superscript numbers indicate decreasing values (1=highest, 5=lowest) among agroecosystems; Soil trampling by cattle: (I)=Intensive, (O)=Occasional; Maintenance: (m)=manure, (i)=irrigation, (p)=pruning.

Sampling methods

The soil macrofauna was sampled using one transect with 10 sampling points at each agroecosystem (Anderson and Ingram, 1993). Pitfall traps were used at each of the systems to sample soil macrofauna. We excluded earthworms because (pitfall traps) is not appropriated sampling method for this macrofauna group. Sampling was carried out at the end of the rainy season in October 2003, when the highest diversity and population density of soil macrofauna is recorded (Brown *et al.*, 2001; Ciau *et al.*, 2003; Bautista *et al.*, 2008). A total of fifty sampling points (10 within each agroecosystem) were used for soil macrofauna within the Leptosol in each of the previously described agroecosystems inside the Saramuyo and Kampepen ranches. Because we carefully examined organisms and prepared a photographic catalogue, we considered the morphoespecies separation as considerably good approximations of species considered for further ecological analyses.

Ecological indexes

We estimated abundance and biomass of soil macrofauna in each system. The ecological characterization of macrofauna communities was based in species composition, richness, diversity, evenness, similarity and dominance. Given that species richness is based in the observation frequency of the rare species in a community, we used Jacknife (Magurran, 1989) equation for each agroecosystems, as follows:

$$S = s + k\,(n - 1)/n$$

Where S is the Jacknife richness estimator; s is the number of observed morphospecies; k is the number of unique or rare morphospecies, and n is the number of points sampled per agroecosystem.

Diversity of soil macrofauna morphospecies was calculated by the Shannon-Wiener diversity (H') and $(J' = H'/H'max)$ evenness indexes (Feinsinger, 2001) using BioDiversity Professional Beta (NHM & SAMS, 1997) statistical software. These indexes are useful to compare inter-habitat diversity considering that individuals are randomly sampled from an "infinitely large" population (Magurran, 1989). Values used to calculate these indexes were the log 10 (x+1) transformed abundance data.

Species richness, abundance, diversity and dominance were graphically represented with importance-value or dominance-diversity curves (also known as Whittaker curves) (Whittaker, 1972), which represent species in terms of their importance in the community (i.e. logarithmic or semilog values of abundance, productivity, etc.). To elaborate graphs in this study, we applied the following formula:

$$\text{Log } 10\ pi,$$

where *pi* is the proportion of individuals of species *i* in the community,

$$pi = ni / N$$

where: *ni* is the abundance of species *i* in the community and *N* is its total abundance at the site.

It worth notice that ecological estimates were used to compare macrofauna community structure and dominance among agroecosystems.

Comparison of macrofauna communities between agroecosystems

We performed discriminant analysis (DA) (Statgraphics Plus version 4.1, Statistical Graphics Corp., 1999) to validate pertinence of our agroecosystem characterization according to the gradient of management disturbance (F>SP>TP2>TP12>SG12). Gradient of disturbance is based in the intensity of each management practice, the number of years with the current practice and on biotic and abiotic features of the systems (vegetation, original vegetation and soil properties) (see Table 1 for details).

DA was used to classify cases into the values (sampling points with macrofauna values) of a categorical dependent variable (agroecosystem), usually a dichotomy. If discriminant function analysis is effective for a set of data, the classification table of correct and incorrect estimates will yield a high percentage at correct assignation. DA was performed to evaluate if the macrofauna community at each sampling point is typical or characteristic of the agroecosystem. DA also assumes the agroecosystems (dependent variable) is a true dichotomy since data which are forced into dichotomous coding are truncated, attenuating correlation. Agroecosystems are predictors of macrofauna communities, in other words, they have macrofauna communities typical of that management system (Williams, 1983).

To analyze the response of each taxonomical group of soil macrofauna to disturbance, we estimated the disturbance response index (*DRI*) for the more dominant groups, that consider the less disturbed site as the comparison pattern, and which formula is:

$$DRI= -[1 - (T/S)]$$

where *DRI* is the disturbance response (+ / -); *T* is the abundance values of soil macrofauna groups in each system; and *S* is the abundance values of soil macrofauna groups in the “less disturbed” system (i.e. forest, in this study).

The DRI is a new method proposed to compare agroecosystems departing from the forest as base line; hereby it is possible to identify the management practices and intensities that affect positively and negatively the macrofauna groups in a particular agroecosystem. Values of DRI= 1 corresponding to 100% with respect to forest. Soil macrofauna taxa were classified according to the following patterns described by Brown et al. (2001): opportunistic (populations whose density is increased by disturbance), temporal (populations whose density is increased by recent disturbance and stabilize as time since disturbance increases), persistent (populations not affected by disturbance), resistant (populations slightly affected by disturbance), elastic (populations whose density fluctuate through disturbance), and susceptible (populations whose density is strongly affected by disturbance).

RESULTS AND DISCUSSION

Soil macrofauna community structure

We found 133 morphospecies of soil macrofauna belonging to 15 taxa, which we grouped in the following 7 taxonomical groups to facilitate analysis and comparisons: Isopoda, Arachnida, Orthoptera, Coleoptera, Hymenoptera, Diplopoda and Other macrofauna (Gasteropoda, Blattidae, Acarida, Homoptera, Hemiptera, Lepidoptera, Diptera, Chilopoda and Embioptera). The largest number of morphospecies was found at the agroecosystem TP2 (75), while the smallest numbers were found at SG12 (42) and SP (41).

Over ninety percent of macrofauna individuals were included within these taxonomical groups: Hymenoptera (64.97% of macrofauna individuals), Coleoptera (both, adult and larvae which correspond to 22.68% of macrofauna individuals), and Orthoptera (3.91%) (Figure 2). The other nine percent was approximately evenly distributed within the rest of taxonomical groups. The number of macrofauna individuals at TP2 (2588), threefold the abundance recorded for TP12 (the agroecosystem with the closest number of individuals) and is sixteen times larger than the abundance recorded by SP (the agroecosystem with the smallest number of individuals) (Figure 2). TP2 has 56.18% of total macrofauna abundance, TP12 has 16.34%, SG12 has 13.74%, F has 10.27% and SP has 3.47%.

Biomass records of macrofauna correspond almost completely to four taxonomical groups: Orthoptera, with 37.42% of total soil macrofauna biomass, Hymenoptera, with 20.76%, Coleoptera (both, adult and larvae) which correspond to 17.85% of biomass, and Arachnida, with 9.80%. The rest of taxonomical groups contribute similarly little to overall soil macrofauna biomass (Figure 3). TP2 contains 41.12% of soil macrofauna biomass (18.01 g), and, except for SP which have only 9.79% (four time less than TP2), the other agroecosystems contain similar intermediate macrofauna biomass percentages.

The differences in abundance and biomass of soil macrofauna among agroecosystems are presumably explained by management practices and effects of grazing. The SP had been used for low-intensity ovine grazing for two years, and before that it had no use or management for four years, being the least managed agroecosystem. This is consistent with the high diversity and evenness of soil macrofauna at this site. However, the low abundance and biomass values of SP, especially when compared with the TP2 suggest that absence of dominant taxa is probably due to more habitat complexity derived from plant strata of trees, shrubs and herbs. Bromham *et al.* (1999) found that grazed woodlands compared to those ungrazed maintained much more individuals, but a much less diverse soil macrofauna and suggest that changes in specific aspects of ground habitat of grazed woodlands (less habitat complexity, aeration and moisture versus higher insolation and compactation) may explained increased abundance and reduced biodiversity of grazed woodland and the under representation of many orders of macrofauna, particularly detritivores, and overrepresentation of abundant taxa such as Coleoptera, Hymenoptera and Aranae.

Richness, diversity and dominance

Ecological indexes of diversity and community structure of soil macrofauna showed different tendencies among agroecosystems. TP2 had high richness (Table 2), with low diversity and evenness, and at the importance-value curves (Figure 4) it shows a highly non-homogeneous distribution of individuals among species (as evidenced by the far-from-cero slope of the tendency line), indicating the presence of dominant species in the agroecosystem. SP had the lowest richness (Table 2) and high diversity and equity, with a homogeneous distribution of individuals among species (as evidenced by the close-to-cero slope of the tendency line, Figure 4), indicating the absence of dominant species in the agroecosystem. The F system had intermediate values of richness and diversity (Table 2), with low evenness and a non-homogeneous distribution of individuals among species (Figure 4). Soil macrofauna on SG12 had peculiar behavior, with the lowest richness (Table 2), intermediate diversity and evenness values, and a more homogeneous distribution of individuals among species (Figure 4), suggesting the absence of dominant species.

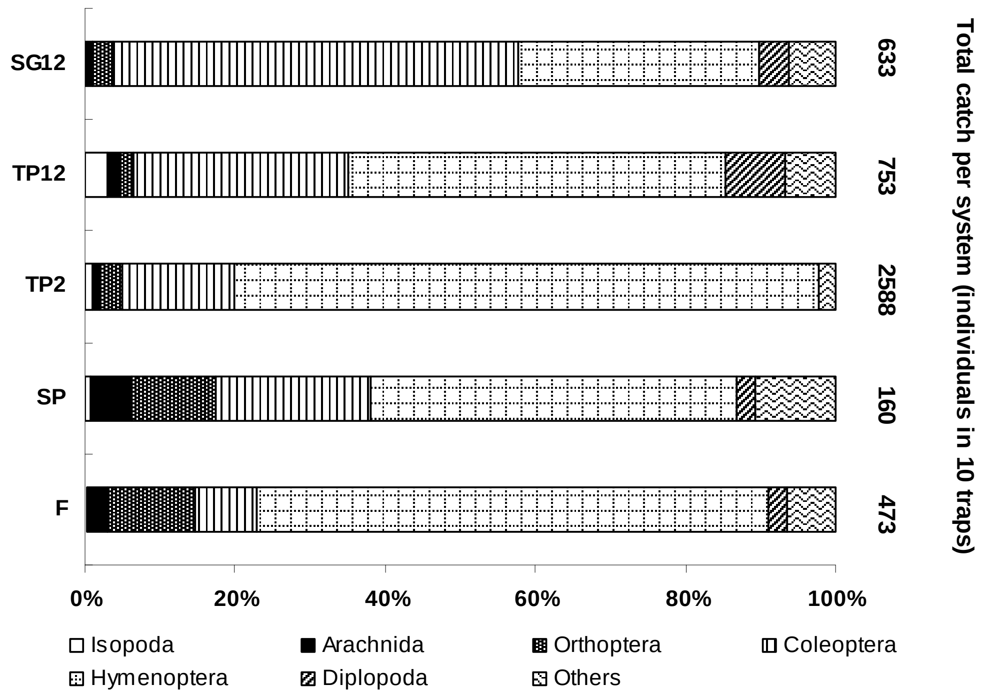

Figure 2. Abundance of soil macrofauna in agroecosystems and forest. F = Forest, SP = Silvopastoral system, TP2 = 2 year-old Taiwan pasture, TP12 = 12 year old Taiwan pasture, SG = 12 year old Star-grass pasture.

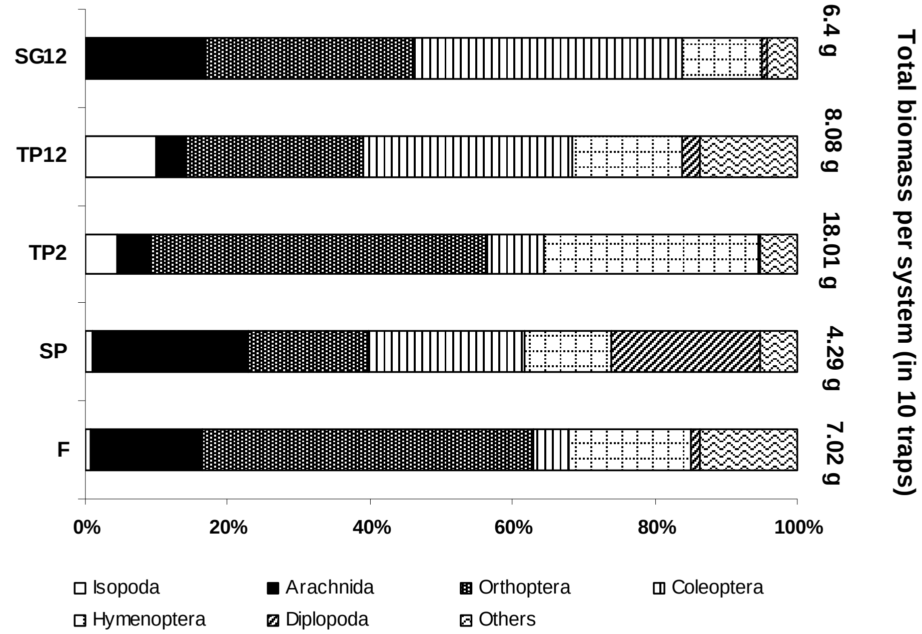

Figure 3. Biomass of soil macrofauna in agroecosystem and forest.

Table 2. Ecological indexes for macrofauna in agroecosystems

	F	SP	TP2	TP12	SG12
Richness	55	40	74	61	42
Diversity H’	1.96	2.48	1.46	2.39	1.92
Evenness J’	0.5	0.74	0.36	0.61	0.54

Macrofauna showed also specific dominance patterns in the dominance-diversity curve (Figure 4). An ant species recorded as Hymenoptera 9 (Subfamily Ecitoninae) was present and dominant in every agroecosystem, contrasting with the Ponerinae ant recorded as Hymenoptera sp. 4, also present in all systems but especially common at F and SP. Another ant species (Formicidae, Ecitoninae), recorded as Hymenoptera sp 1, although present everywhere was abundant only at TP2. Coleoptera was also a dominant group at the system. Coleoptera sp. 2 (Scarabeidae) was present in all systems but especially common at the most disturbed agroecosystems (TP12, SG12). Coleoptera sp. 1 (Lyctidae) was only common at the three pasturelands studied. Orthoptera sp. 3 was only present at the less disturbed sites, the forest and SP.

The ecological indexes also showed that species composition and macrofauna community structure in each agroecosystem show contrasting patterns particularly between the SP and the TP2. The SP had high diversity and evenness values, the lowest specific richness and a homogeneous taxonomical distribution of individuals: this is a rich and environmentally heterogeneous agroecosystem that maintains a high proportion of forest elements (trees, shrubs and its influence in soil properties or available nutrients) and although they alternate with small grass patches, the system maintains a more similar vegetation structure to the original forest (Lavelle *et al.*, 1998). This has some advantages for soil conservation since macrofauna communities seem best conserved when the derived system has a structure similar to that of the original forest (Barros *et al.*, 2002). At the mosaic of soil microsites at SP in our study (which derives originally from forest), environmental conditions and nutrients could favor a diverse macrofauna assemblage with modest specific richness per group, preventing in turn, dominance of specific taxonomical groups. In contrast, the TP2 agroecosystem had high specific richness and low diversity and evenness values. This is the most recently disturbed agroecosystem and the pasture with the shortest lapse of management. DeAngelis (1995) states that recent disturbance favors specific groups or macrofauna taxa which are common in the community and become dominant when conditions are recently altered. These groups can show an opportunistic behavior, increasing their abundance and specific richness, reducing the abundance of less opportunistic groups (or displacing them).

Macrofauna at the forest showed intermediate richness and diversity values with low evenness and presence of dominant species. Similarly, high richness and diversity values, reflecting stable conditions were found at TP12 possible due to important income of organic matter due to cattle feces. Lavelle *et al.* (1997), states that the amount of organic matter and its quality favors succession of soil macrofauna communities, which tend to be richer with increased organic matter of quality. The TP12 agroecosystems could also show high richness and diversity because fodder for cattle is obtained by cut and carried to feeding sites, which releases the soil from intense trampling or stamping by animals. As Decaëns *et al.* (1994) suggest, low input or improved pastures does not transform the medium into "green deserts" but to the contrary increases the activity of local soil macrofauna communities.

The least favorable agroecosystem for soil macrofauna was SG12, which had low richness, low-intermediate diversity and evenness and a homogeneous distribution of individuals among taxonomical groups (no dominance of specific groups). This agroecosystem has been intensive managed with cattle rising and important disturbance by ground trampling by cattle, which diminish soil infiltration capacity and aeration, which in turn makes macrofauna subsistence much more difficult in these soils (Park and Cousins, 1995; Pankhurts, 2002). According to Bromham *et al.* (1999) intense grazing by cattle can reduce food and habitat resources for soil fauna (removal of vegetation and litter), alter soil microclimate, compact soil and simplify its structure. Similarly, Decaëns *et al.* (1994) suggest that overgrazing may not affect biomass or density of soil macrofauna communities, but necessarily reduces taxonomic richness. Those effects are consistent with the low macrofauna richness and diversity found in SG12 soils, while prolonged (12 years) systematic disturbance prevents taxa to become dominant. As noticed by Mathieu *et al.* (2004), managed grasslands and pastures have taxonomically homogeneous soil macrofauna communities relative to other land use systems (fallows, crops) and forests.

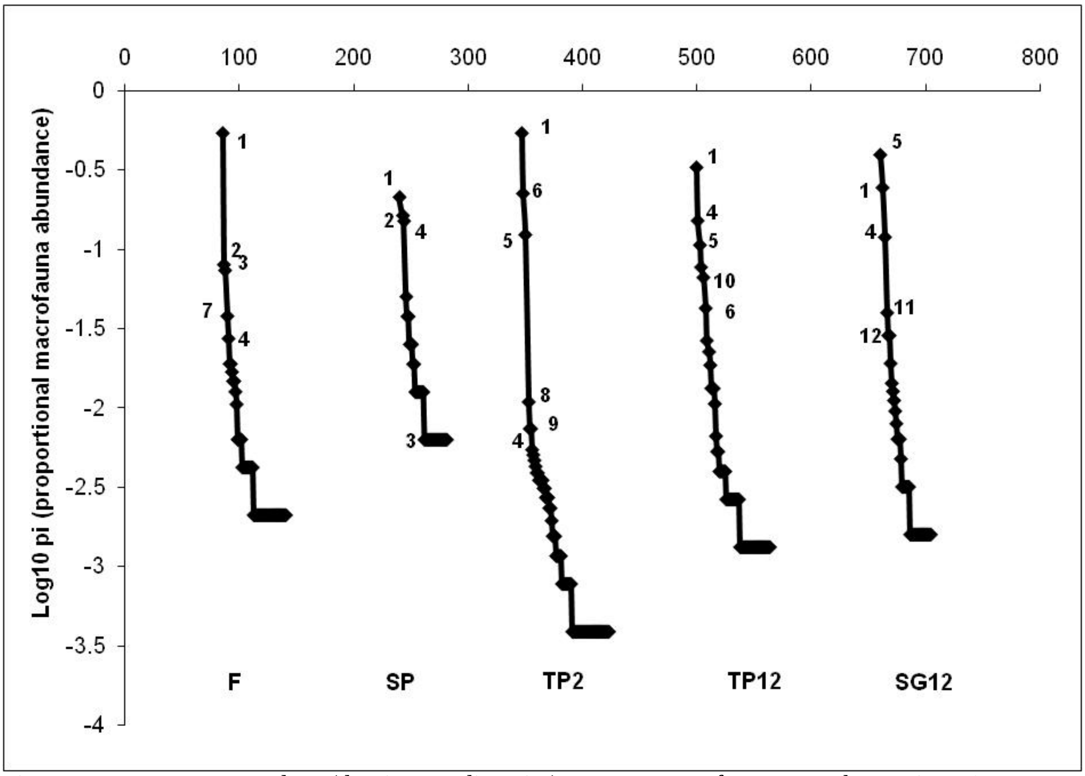

Figure 4. Importance value (dominance-diversity) curve macrofauna morphospecies: 1= Hymenoptera sp 9 (Formicidae, Ecitoninae); 2= Hymenoptera sp 4 (Formicidae, Ponerinae); 3= Orthoptera sp 3; 4= Coleoptera sp 2 (Scarabeidae); 5= Coleoptera sp 1 (Lyctidae); 6= Hymenoptera sp 1 (Formicidae, Ecitoninae); 7= Orthoptera sp 14; 8= Isopoda sp 1; 9= Coleoptera sp N5; 10= Hymenoptera sp 6 (Formicidae, Dolichoderinae); 11= Diptera sp 1; 12= Hymenoptera sp 16 (Formicidae, Ecitoninae).

Comparison of communities of macrofauna between agroecosystems

Percent similarity values among agroecosystems ranged from 42.3 (between SP and TP2) to 57.3 (between SG12 and TP12). Pasturelands shared the highest number of macrofauna morphospecies (49% or more), and this is especially true for the pastures that had been exploited for a longer period of time (TP12 and SG12). Forest similarities to agroecosystems were: 52.2% (TP12), 49.5% (SP), 46.2% (TP2) and 45.1% (SG12), while similarities of SP were: 49.5% (F), 47.9% (SG12), 45.5% (TP12) and 42.3% (TP2).

Discriminant analysis using management practice as the discriminating variable, gave a 68% correct assignation of soil macrofauna to agroecosystems and explained 66% of total variance in the classification (Wilk´s lambda = 0.0756, $P<0.001$), resulting thus in a correct validation of agroecosystems. In other words, the studied agroecosystems possess a typical community of macrofauna, mainly in F, SP and TP2 for these high percentages of cases correctly classified (Table 3).

In this study, the comparison between agroecosystems and forest using discriminant analysis prove to be a useful method for comparing each sample of soil macrofauna community among agroecosystems and forest, with quite acceptable percentages of correct classification of soil macrofauna. However discriminant analysis is infrequently used in soil macrofauna studies (Mathieu *et al.*, 2005), especially when compared to other ordination or classification multivariate techniques. Using this tool we could identify the taxa that define the resulting agroecosystem classifications, given their abundance and biomass contributions to soil macrofauna: Hymenoptera, followed by Orthoptera who had differential dominances at the agroecosystems.

Table 3. Numerical classification based in dominance values of macrofauna morphospecies, using management practice as the discriminant variable.

System	CC (%)	F*	SP[1]	TP2 [1]	TP12[2]	SG12[2]
F	70	7	0	3	0	0
SP	70	7	0	0	0	3
TP2	80	2	0	8	0	0
TP12	60	0	3	0	6	1
SG12	60	1	2	0	1	6

CC = correct classification
System of comparison; [1] = More distant systems; [2] = More similar systems; F = Forest, SP = Silvopastoral system, TP2 = 2 year-old Taiwan pasture, TP12 = 12 year old Taiwan pasture, SG = 12 year old Star-grass pasture**.**

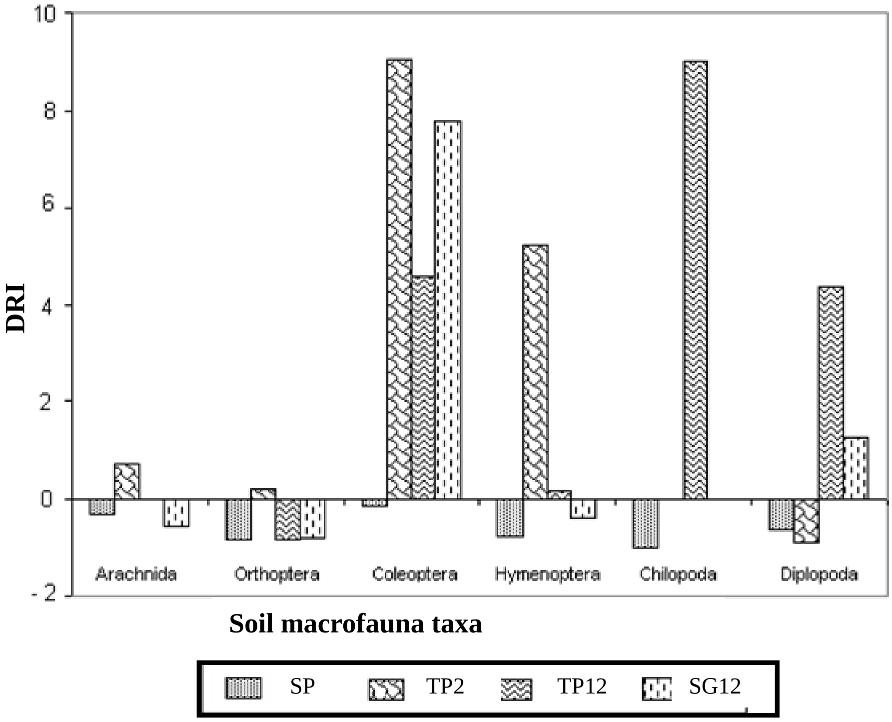

Figure 5. Macrofauna response to disturbance based in the disturbance response index.

Coleoptera showed a positive and high response to disturbance (Figure 5), with a remarkable increase in every agroecosystem (pastures) except for SP (negative 0.15 DRI, disturbance response index). Orthoptera respond negatively to disturbance, with a less than 1.0 decrease in DRI in 12 year-old pastures. DIR's values can be given also as percentages because values of 1 correspond to 100% of change with respect to forest. Hymenoptera respond importantly in a positive way at TP2 and Chilopoda and Diplopoda respond importantly in a positive way at TP12.

The disturbance response index show that as Hymenoptera and Diplopoda have both negative and positive responses to disturbance (given their dominance fluctuations), only Orthoptera is considered useful indicators of healthy soils while Coleoptera is a useful indicator of soil degradation by productive activities at the studied systems, in accordance to Decaëns *et al.*, (1994), who found that Coleoptera is more abundant at the most highly grazed plots.

DRI is an important method for compare each agroecosystem with the forest. DRI allow identifying the positive or negative responses to disturbance and the magnitude of the change.

Macrofauna taxa

Hymenoptera (which in our study are mainly ants) had by far the highest abundances and biomass in most systems compared to the other dominant taxa, except for the SG12. Ant foraging activity is highly limited by high temperature and low humidity (Rojas, 2001; Cerdá *et al.*, 1998), conditions which are exacerbated at this highly disturbed agroecosystem in our study. Overall, ants and termites are resilient groups that tend to recover after human disturbance ceases: Mathieu *et al.* (2005) found that populations of ants and termites were highly diminished by forest clearance and transformation into a rice field, but when succession and vegetation recovery advanced, these taxa recover greatly in fallows. Similarly, Barros *et al.*, (2002) found high numbers of termites and ants in fallows and agroforestry systems relative to other agroecosystems. As explained by Andersen, (2000), ants as modular organisms are only affected by disturbance if too many “modules” are lost; this meaning that habitat disturbance causes widespread destruction of colonies, which happens only with severe habitat transformation. In our study, ants were the most dominant group at the TP2 agroecosystem. Most of the individuals belong to subfamilies Ecitoninae and Ponerinae, which are considered “specialist predators” (*sensu* Andersen, 2000), and often forage in dense groups (i.e. army ants) on many arthropods, including other ants. It is no surprising that the abundance and biomass of ants found in our study is large at TP2, where high soil macrofauna biomass and abundance is available as potential food for predatory ants. The same elevated ant abundance at managed pastures was found by Bromham *et al.*, (1999) who report ants as the dominant group at soils of three management systems, whose abundances were higher at grazed pastures (a disturbed agroecosystem), intermediate at grazed woodlands and lowest at ungrazed woodlands. Our findings suggest however, that prolonged or extreme disturbance at a particular management system notoriously decreases ant abundances or dominance (i.e. SG12).

In contrast, Coleoptera were particularly dominant in the most disturbed system SG12, where they displaced ants as dominant taxa. Beetles were also a highly abundant group at pasturelands, as reported by Lavelle *et al.*, (1998). Most of Coleoptera individuals found in our study, belong to subfamilies Scarabaeidae and Lyctidae, the former being mainly coprophagues and the later feeding on dead plant material (dead roots, dry wood). It is well known that pasture systems have high densities of Coleoptera relative to other systems such as forests, and that these populations are mainly rhizophagous (i.e. larvae feed on roots), what could explain the correlation between high root density and production in pastures and high beetle density (Fragoso *et al.*, 1997; Barros *et al.*, 2002). Given the nature of disturbance in the agroecosystems we studied, where either dung availability or grass root biomass increases with management or time since activity was established, Coleoptera clearly show an opportunistic behavior to disturbance.

Orthoptera is also clearly a taxa susceptible to disturbance. Abundances and biomass are higher at TP2 and forest, followed by the other pastures and SP. While Orthoptera were not the dominant group at TP2 because ants occupied this position, they were an important (subdominant group) both at TP2 and forest.

Crickets and grasshoppers as generalist herbivores depend greatly on plant food availability and predator abundance. In our study forest offers abundant plant food resources (especially for folivorous species) and TP2 agroecosystem also offers food resources (especially for rhizophagus species) and the lowest levels of potential predators (i.e. Arachnida) (Sunderland and Samu, 2000; Bell *et al.*, 2001). Escape from predation is also congruent with the fact that at SP agroecosystem, Orthoptera show the lowest abundances, biomass and dominance, while Arachnida (potential predators) show the highest records: the result is an opposite pattern of dominance of both groups among agroecosystems. Other biological explanation for susceptibility of Orthoptera to disturbance lies in their physiology: Bieringer and Zulka, (2003) report a larger number of acridid species at grassland proximities that edges of pine plantations, and state that this was related to irradiance and soil temperature: acridid species (in contrast to tettigonidae species) need sufficient warmth to complete their annual life cycle (embryonic development proceeds faster under warmer conditions).

Overall, the soil macrofauna communities we evaluated in dry lowland forest and derived livestock agroecosystem on Leptosol showed a wide array of sensitivity to disturbance owe to management practices. Understanding community composition, structure and dominance patterns of soil macrofauna in response to agroecosystems, allowed us to identify taxa of soil health indicators in previously non-biologically characterized soils of Yucatan. Although we made a good characterization of management-derived disturbance in the agroecosystems studied, macrofauna data should be enriched considering earthworms and a finer taxonomical study (species level) of the other macrofauna groups; also the physical and chemical properties of soils and litter in the state should be analyzed within a seasonal variation context in order to provide a more complete diagnostic tool that improves management practices in the context of sustainable development and environmental services.

CONCLUSIONS

Ecological indexes and discriminant analysis revealed that macrofauna soil communities in agroecosystems and low deciduous tropical forest in Leptosols differ from each other. The practices of managing of the agroecosystems cause changes in the macrofauna communities and therefore it is possible to predict the structure of the community of macrofauna soil based in the management of the studied agroecosystems, if we focus on the response of specific macroinvertebrate taxa to soil disturbance. Hymenoptera and Orthoptera are the main groups that define the macrofauna soil communities.

As it was expected from management intensity and periodicity, the least favorable agroecosystem for soil macrofauna was 12 year old Star-grass pasture, which showed low richness, low-intermediate diversity and evenness and a homogeneous distribution of individuals among taxonomical groups of macrofauna. Silvopastoral system was the agroecosystem that less change (compared to the deciduous forest) produces in macrofauna soil communities.

Orthoptera can be considered as indicators of healthy soils. In contrast, Coleoptera can be considering as indicator of soil degradation in grass agroecosystems in Leptosols from Karstic zones.

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