

Composition and functional groups of epiedaphic ants (Hymenoptera: Formicidae) in irrigated agroecosystem and in nonagricultural areas

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Abstract – The objective of this work was to evaluate the species composition and functional groups of ants in nonagricultural (NA) and in irrigated areas (S, seasonal irrigation; P, irrigation with well water; W, irrigation with wastewater) in an arid agricultural region in central Mexico, throughout 2005 and 2006. A total of 52,358 ants belonging to 6 subfamilies, 21 genera and 39 species was collected using pitfall traps. The species best represented in all plots were: *Forelius pruinosus*, *Pheidole obtusospinosa*, *Monomorium minimum* and *Dorymyrmex* spp. NA plots recorded the highest density of ants. The highest values for diversity (H') and equitativity (J') were recorded in NA and P plots, while the lowest were recorded in W plots. Cluster analysis showed two different groups regarding species composition: NA-S and W-P. Functional groups recorded were: dominant Dolichoderinae, three species; subordinate Camponotini, five species; hot climate specialists, three species; tropical climate specialists, seven species; cold climate specialists, five species; cryptic species, one species; opportunists, six species; generalized Myrmicinae, nine species. Agricultural activity affects the structure of the ant community with epiedaphic forage, and the constant use of irrigation wastewater in conjunction with intense agricultural practices has negative effect upon species richness of epiedaphic ants.

Index terms: biodiversity, irrigated area, semiarid zone, wastewater.

Composição e grupos funcionais de formigas epiedáficas (Hymenoptera: Formicidae) em agroecossistema irrigado e em áreas não agrícolas

Resumo – O objetivo deste trabalho foi avaliar a composição de espécies e os grupos funcionais de formigas em áreas não agrícolas (NA) e em áreas irrigadas (S, irrigação sazonal; P, irrigação com águas de poço; W, irrigação com água residuária) em uma região agrícola de clima árido da região Central do México durante 2005 e 2006. Um total de 52.358 formigas pertencentes a 6 subfamílias, 21 gêneros e 39 espécies foi coletado por meio de armadilhas Pitfall. As espécies mais bem representadas em todas as parcelas foram: *Forelius pruinosus*, *Pheidole obtusospinosa*, *Monomorium minimum* e *Dorymyrmex* spp. As parcelas NA registraram a maior densidade de formigas. Os maiores valores de diversidade (H') e equitatividade (J') foram observados nas parcelas NA e P, e os menores, nas parcelas W. A análise de cluster mostrou grupos diferentes quanto à composição de espécies: NA-S e W-P. Os grupos funcionais registrados foram: Dolichoderinae dominantes, três espécies; Camponotini subordinadas, cinco espécies; especialistas de clima quente, três espécies; especialistas de clima tropical, sete espécies; especialistas de clima frio, cinco espécies; espécies crípticas, uma espécie; oportunistas, seis espécies; Myrmicinae generalizados, nove espécies. A atividade de agricultura afeta a estrutura das comunidades das formigas epiedáficas e a utilização constante de irrigação com água residuária, em conjunto com práticas agrícolas intensas tem um efeito negativo na riqueza de espécies de formigas epiedáficas.

Termos para indexação: biodiversidade, área irrigada, zona semiárida, água residuária.

Introduction

Environmental fragmentation due to human activity has contributed dramatically to modify the habitat of animals. Large natural ecosystems have recently been replaced by agricultural ecosystems. This generally causes a decrease in species richness and, consequently, impoverishes the natural landscape (Hole et al., 2005).

Major questions on the study of the role of diversity within agroecosystems are to quantitatively determine the effect of the transformation of ecosystems on regional biodiversity and to evaluate the extent to which such environments contribute to the contemporary landscapes regarding biodiversity (Hole et al., 2005; Sans, 2007).

It has been observed that ants may function as bioindicators, due to their complex ecological

interactions within their habitat, and to their sensitivity to disturbances (Read & Andersen, 2000). It is possible to analyze variations in the community of ants under the concept of functional groups, defined in accordance with their tolerance to disturbance and environmental stress, as well as with their ability for competitive interactions (Andersen, 1995).

Continuous irrigation within the investigational area has generated significant changes in the physical and chemical features of the soil (Siebe & Fisher, 1996), as well as high concentration of organic matter, which enhances the nutritional quality of the soil (Secretaría de Agricultura y Recursos Hidráulicos, 1994; Siebe & Cifuentes, 1995). This study tested the hypothesis that the structure of the community of epiedaphic ants related to agroecosystems is negatively affected by the intense use of agricultural areas and the frequent use of irrigation water.

The objective of this work was to evaluate the species composition and functional groups of ants in nonagricultural (NA) and in irrigated areas.

Materials and Methods

This study was carried out in Mezquital Valley, Hidalgo, Mexico, at a height between 1,700 and 2,100 m, in three places: Tezontepec de Aldama (2,100 m, 20°11'N, 99°16'W), Mixquiahuala de Juárez (2,050 m, 20°14'N, 99°12'W); and San Salvador (1,990 m, 20°16'N, 98°57'W) (Instituto Nacional de Estadística, Geografía y Informática, 1999).

This region is characterized by a semiarid climate, with summer rains (García, 1987). The annual mean temperature ranges between 12.2 and 23°C (Instituto Nacional de Estadística, Geografía y Informática, 1999). The Mezquital Valley shows shallow alluvial calcareous soils (Instituto Nacional de Estadística, Geografía y Informática, 1999). The vegetation in the region is represented by crasicaule scrub, with subinermis scrub and rosette scrub. Genera *Acacia* spp., *Mimosa* spp. and *Prosopis* spp. are the most prominent (Rzedowski, 1981). Due to the agricultural activity, the area has lost almost 50% of its natural vegetation.

In order to compare the structure of the ant community in various environments based on species richness, composition and functional groups, three places (Tezontepec, Mixquiahuala and San Salvador) were sampled in the dry and wet seasons using 39 plots with different irrigation methods: 6 agricultural areas irrigated

with well water (P); 15 agricultural areas irrigated with wastewater (W); 9 agricultural areas seasonally irrigated (S); and 9 plots located in nonagricultural areas (NA). Samples were taken throughout two years: NA, W and P plots in 2005, and S plots in 2006. P and W plots were more intensely used since they are artificially irrigated. Seasonal irrigation (S) requires irrigation with summer rainwater.

The following design was applied to two places (San Salvador and Tezontepec): four types of plots (P, W, NA and S) x two seasons x three plots per type. The design for Mixquiahuala was: three types of plots (W, NA and S) x two seasons, using three NA plots, three S plots and nine W plots. The sampling design was not balanced for the three sites since at Mixquiahuala there were no crops irrigated with well water, but there was a wide variety of plots with various periods of use being irrigated with wastewater, which generated lower numbers of samples from P plots and higher numbers of samples in W plots. Corn and alfalfa monocrops prevailed in agricultural plots, and polycrops (vegetables and ornamental plants) prevailed only in five plots (three of P and one of W).

In every plot, 12 pitfall traps were placed in transects (8x4), spaced by 7 m (Peck et al., 1998). Pitfall traps (75 mm diameter, 500 mL) contained car anti-freezing 15% solution (v/v) (Bardhal, Bardhal Manufacturing Corporation, USA) in 70% alcohol. All traps were placed and collected on the same weekday, after seven days in the field.

The use of pitfall traps allows to statistically compare diversity treatments and studies on forage ants in open areas and grasslands (Read & Andersen, 2000; Retana & Cerdá, 2000; Herrera et al., 2005; Phipps, 2006), as well as in disturbed areas (Ward et al., 2001; Graham et al., 2009); however, it implies certain limitations (Bestelmeyer et al., 2000; Delabie et al., 2000; Longino, 2000) that have to be taken into consideration in the collection technical plan (e.g. distance between barrels and lids, and trap diameter).

Shannon-Wiener diversity index (H'), equitativity Pielou index (J') and Simpson dominance index (λ) were calculated (Zar, 1999) taking absolute frequencies of species. Similarity indexes are given as IS (Sørensen, 1948). A dendrogram with relative frequency data was made with the Biodiversity Pro software, version 2 (McAleece, 1997) using the Bray-Curtis method to determine similarities in the composition of species in the various types of plots from traps percentage data of ants in each trap, in accordance with Longino (2000).

The effect of the type of plot upon ant density was assessed by means of a one-way variance analysis (ANOVA), while significant differences were determined based on a post hoc Tukey test (Zar, 1999). The classification of ants into functional groups in accordance with their response to stress and disturbance was based on Andersen (1995, 1997, 2000).

Results and Discussion

A total of 52,358 ants (17,832 in the dry season and 34,526 in the wet season) belonging to 39 species, 21 genera and 6 subfamilies were collected (Table 1). The NA plots had the highest species richness (35), while P and W plots had the lowest values (25 and 24 respectively).

Nonagricultural plots had higher density of ants than the remaining plots. Likewise, agricultural seasonally irrigated plots (S) recorded higher density than the plots irrigated with wastewater (W) and well water (P) (Table 1).

The highest values for H' , J' and λ indexes were recorded in NA (H' , 2.64; J' , 0.74) and P plots (H' , 2.63; J' , 0.82), and the lowest values for such parameters were recorded in W plots (H' , 2.13; J' , 0.67), where dominance (λ , 0.33) reached the highest value (Table 1).

The highest similarity among communities was recorded between the W and P plots, which shared 21 species (IS, 85.7%), and between the NA and S plots (26 species; IS, 81.3%). The lowest similarity values were recorded between the NA and W plots (22 species; IS, 74.6%). The Cluster analysis showed two groups in accordance with species composition: one including the NA and S plots and another including the W and P plots (Figure 1).

A significant effect of the plot type on the ant density (individuals per trap) was recorded (Table 1). The NA plots recorded the highest ant density, while the S plots recorded an ant density significantly higher than the W and P plots, which were similar in this parameter.

From 39 species, 13 were the most frequent and abundant in four types of plots. The lowest values, in general, were recorded for the P and W plots. The predominant species in all types of plots were: *Forelius pruinosus*, *Pheidole obtusospinosa*, *Monomorium minimum* and *Dorymyrmex* spp. In plots that were not irrigated (NA and S), *Myrmecocystus melliger*, *Pogonomyrmex barbatus* and *Pheidole calens* were better represented, while in plots

continually irrigated (P and W), *Tapinoma sessile* and *Pheidole coracina* were more frequent. *Temnothorax* sp. 2 and *Odontomachus clarus* were more frequently recorded only for NA plots.

Taking into account the model of functional groups of ants, in accordance with the response to stress and disturbance proposed by Andersen (1995, 1997, 2000), eight functional groups were recorded in the Mezquital Valley: three species of dominant Dolichoderinae (DD); five species of subordinate Camponotini (SC); three species of hot climate specialists (HCS); seven species of tropical climate specialists (TCS); five species of cold climate specialists (CCS); one species of cryptic species (C); six species of opportunists (O); and nine species of generalized Myrmicinae (GM) (Table 1). Classification of material in functional groups was revised by A.N. Andersen. Within the complex of four *Dorymyrmex* species (*D. insanus*, *D. bureni*, *D. smithi*, and *D. paiute*), *D. insanus* is predominant regarding abundance and frequency. This study was conservatively determined to include every specimens of this genus within the functional group of opportunists (O), but not all the specimens of the group could be differentiated at the species level.

Taking into account relative frequencies of species, different patterns in ant communities were observed regarding the various uses of soil in Valley of Mezquital (Figure 2). From all functional groups, GM represented the highest relative frequency, with W plots being the highest and NA plots being the lowest. The second most important group was O, with P plots having the highest percentage. For NA plots, the second most important group was HCS. The third most important groups were: HCS for S and P; O for NA, and DD for W. In the fourth place, the most important were: DD for NA, S and P; and HCS for W.

The richness of genera found in the study is higher (21 with 39 species) than the richness recorded in other studies carried out in natural arid areas in central Mexico (14 genera with 28 species; Ríos-Casanova et al., 2004), and in a previous study carried out in the same area (16 genera with 21 species; Hernández-Ruiz & Castaño-Meneses, 2006), both with a lower collection effort.

From the higher species richness and average density of NA, it may be inferred that the community of ants benefits from having more stable places, with more diverse local resources (Phipps, 2006). Seasonal

irrigation (S) plots, which represent an intermediate degree of use of soil in the study, showed the highest richness and density of species in agricultural areas but, when compared to NA, their values were lower, apparently due to the higher disturbance. This caused

a negative impact on diversity (in comparison to NA), but not necessarily on ant density, when compared to P and W (Bardgett & Cook, 1998).

Seasonal irrigation areas (S), unlike the plots irrigated throughout the year (W and P), were less

Table 1. Relative frequency (% of traps) and density (number of individuals per trap; between parentheses) of ant species in nonagricultural and in agricultural areas of Mezquital Valley, Hidalgo, Mexico⁽¹⁾.

Ant species	FG ⁽²⁾	Nonagricultural	Agricultural ⁽³⁾		
			S	W	P
Dolichoderinae					
<i>Dorymyrmex</i> spp.	O	58.0(36.4)	66.2(6.5)	9.0(0.7)	28.2(1.4)
<i>Forelius pruinosus</i>	DD	62.4(9.2)	24.5(15.3)	8.7(0.5)	13.0(0.8)
<i>Linepithema dispertitum</i>	DD	0	0.5(0.01)	0.4(0.01)	0
<i>Liometopum apiculatum</i>	DD	0.5(0.005)	0	0	0
<i>Tapinoma sessile</i>	O	0.23(0.002)	1.9(0.04)	17.7(0.5)	18.7(0.5)
Ecitoninae					
<i>Neivamyrmex harrisii</i>	TCS	0.7(0.01)	0	0	0
<i>Neivamyrmex melanocephalus</i>	TCS	0.2(0.002)	0	0	0.4(0.004)
<i>Neivamyrmex swainsonii</i>	TCS	0	0.5(0.06)	0	0
<i>Neivamyrmex texanus</i>	TCS	0.2(0.01)	2.5(0.2)	0.3(0.01)	1.4(0.02)
Formicinae					
<i>Camponotus atriceps</i>	SC	0.2(0.002)	0	0	0
<i>Camponotus festinatus</i>	SC	6.8(0.1)	0.5(0.005)	0	0.7(0.01)
<i>Camponotus</i> sp. 3	SC	2.8(0.04)	0.2(0.002)	0	0
<i>Camponotus</i> sp. 4	SC	3.3(0.1)	0.2(0.002)	0	0
<i>Camponotus</i> sp. 6	SC	0.7(0.01)	0.2(0.002)	0.3(0.003)	1.1(0.01)
<i>Myrmecocystus melliger</i>	HCS	29.1(1.3)	26.4(0.7)	0.6(0.01)	2.5(0.03)
<i>Paratrechina bourbonica</i>	O	2.6(0.04)	7.2(0.1)	2.1(0.03)	8.8(0.1)
<i>Paratrechina terricola</i>	O	6.1(0.2)	2.5(0.03)	0.7(0.01)	2.1(0.02)
Myrmicinae					
<i>Atta mexicana</i>	TCS	1.6(0.06)	3.7(0.1)	0	0
<i>Cardiocondyla emeryi</i>	O	2.1(0.1)	0.2(0.002)	0	3.9(0.06)
<i>Crematogaster opaca</i>	GM	0.2(0.002)	2.8(0.04)	0.1(0.001)	0
<i>Monomorium minimum</i>	GM	25.1(1.1)	33.6(1.8)	24.8(2.06)	22.9(0.7)
<i>Pheidole calens</i>	GM	18.8(0.9)	56.9(3.5)	2.7(0.1)	5.3(0.2)
<i>Pheidole coracina</i>	GM	8.5(0.3)	3(0.1)	13(0.7)	13.4(0.7)
<i>Pheidole laevivertex</i>	GM	7.5(0.3)	0	1(0.01)	15.8(0.9)
<i>Pheidole obtusospinosa</i>	GM	31.7(10.9)	49.3(4.7)	42.9(4.5)	25.7(1.1)
<i>Pheidole</i> sp. 1	GM	2.1(0.03)	15(0.5)	3.1(0.2)	6.7(0.1)
<i>Pheidole</i> sp. 3	GM	0.2(0.002)	0	0.3(0.004)	0
<i>Pheidole</i> sp. 4	GM	0	0.2(0.03)	0	0
<i>Pogonomyrmex barbatus</i>	HCS	42.7(3.5)	18.5(1.9)	1.6(0.03)	1.8(0.1)
<i>Solenopsis xyloni</i>	HCS	12.4(0.4)	9.5(0.5)	3.3(0.2)	18.3(0.6)
<i>Temnothorax pergandei</i>	CCS	1.4(0.03)	0	0	0
<i>Temnothorax</i> sp. 1	CCS	1.9(0.02)	0.5(0.005)	0.1(0.001)	1.8(0.02)
<i>Temnothorax</i> sp. 2	CCS	10.88(0.2)	5.1(0.06)	0.3(0.003)	2.5(0.03)
<i>Temnothorax</i> sp. 3	CCS	2.8(0.06)	5.8(0.1)	0.6(0.006)	0.7(0.03)
<i>Temnothorax</i> sp. 4	CCS	1.2(0.02)	0	0	0
<i>Trachymyrmex</i> sp.	TCS	0.2(0.002)	0	0	0
Ponerinae					
<i>Hypoponera</i> sp.	C	0	0	0.1(0.001)	0.4(0.004)
<i>Odontomachus clarus</i>	O	8.2(0.1)	1.9(0.03)	0.6(0.006)	0.4(0.004)
Pseudomyrmecinae					
<i>Pseudomyrmex pallidus</i>	TCS	0.5(0.005)	0.5(0.005)	0	0.4(0.004)
Number of ants		27,838	15,743	6,688	2,089
Species richness		35	29	24	25
Number of traps		426	432	702	284
Average density±EE		65.4±9.4a	36.4±6.8b	9.5±1.4c	7.3±0.8c
Shannon-Wiener diversity		2.638	2.456	2.128	2.626
Pielou equitativity		0.742	0.729	0.669	0.816
Simpson dominance		0.258	0.271	0.33	0.184

⁽¹⁾ Means followed by equal letters in the line do not differ by Tukey's post hoc test, at 5% probability. ⁽²⁾ Functional group: DD, dominant Dolichoderinae; SC, subordinate Camponotini; H/C/TCS, hot/cold/tropical climate specialists; C, cryptic species; O, opportunists; GM, generalized Myrmicinae (Andersen, 1995, 1997, 2000). ⁽³⁾ S, seasonal irrigation; W, wastewater irrigation; P, well water irrigation.

affected, maybe due to a lower intensity of use of the soil (Bardgett & Cook, 1998), since the plot was prepared for a single crop every year. Besides, this area was not subject to continual irrigation, which may constitute an important disturbance for ants. On the other hand, it is possible that constant irrigation limited the nesting of rare species in the region and the foraging of individuals nesting in nearby areas.

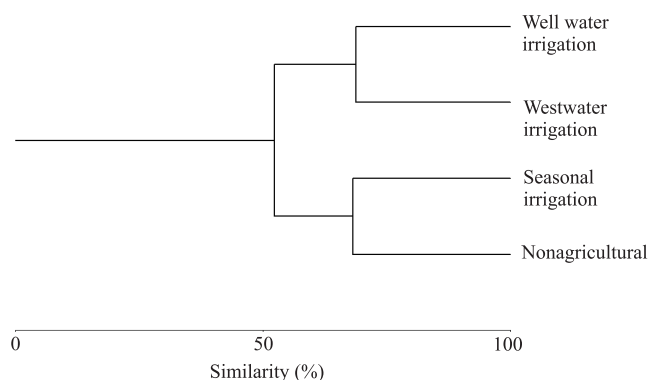


Figure 1. Dendrogram of Bray-Curtis Cluster analysis for agricultural and nonagricultural plots in Mezquital Valley, Hidalgo, Mexico.

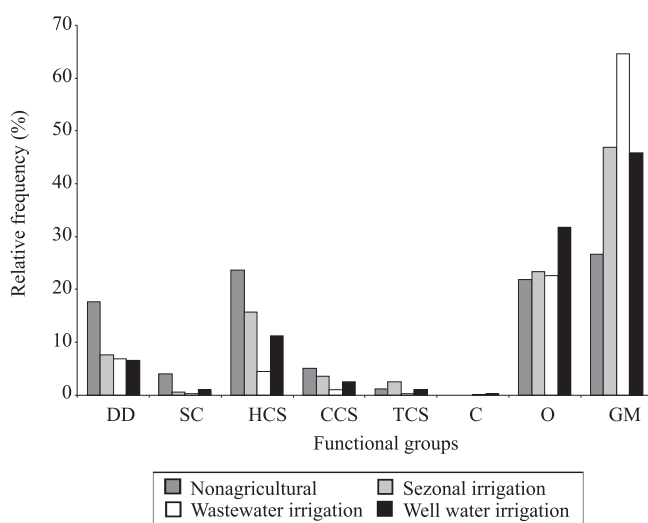


Figure 2. Relative frequency, in percentages of ants from different functional groups (sensu Andersen, 1995, 1997, 2000), in four plots in Valley of Mezquital, Hidalgo, Mexico: NA, nonagricultural; P, irrigated with well water; W, irrigated with wastewater; S, seasonally irrigated. Functional groups: DD, dominant Dolichoderinae; SC, subordinate Camponotini; H/C/TCS, hot/cold/tropical climate specialists; C, cryptic species; O, opportunists; GM, generalized Myrmicinae.

Besides, it is possible that with less agricultural impact, during the following dry season a higher richness of species became apparent. This is due to the diversification of microhabitats, a result from the presence of annual scrubs, favoring stability in the agroecosystem (Bardgett & Cook, 1998). In this way, seasonal plots may be functioning in a similar way to abandoned areas and that such are functioning as biodiversity refuges (Richter et al., 2007), since ants are less active during the hottest and driest season of the year (Rico-Gray et al., 1998).

The fact that the NA and irrigated with well water (P) plots showed the highest diversity, equitativity and, consequently, the lowest Simpson dominance index, reveals that there is a higher balance in frequency, despite the fact that in P exists an agricultural use.

The difference in specific richness among NA and P might be due to the fact that there are less species in flooded places (Bihna et al., 2008), but the equality of diversity could be evidencing that the sampling places in NA showed another type of disturbance equivalent to the one caused by the agricultural impact of P plots. However, the highest value of J' in P is an evidency of a more balanced environment than in NA. Therefore, in the studied plots it is not sufficient to take into account the value of diversity, but the equitativity, in order to visualize differences in the community (Graham et al., 2009). In other words, P agricultural plots show a higher environmental stability when compared to the rest of the areas of study, and NA plots show another type of disturbance.

The difference between the values of H' , J' and λ among P and W agricultural plots shows that well water had a less negative effect on the physical and chemical features of the soil due to the quality of this type of water. Water causing a higher fraction of polycrops provides more microenvironments and resources (Herrera et al., 2005; Graham et al., 2009).

The similarity in the composition of the community of ants between S and NA plots as well as between P and W plots (Figure 1) could be reflecting similar environments available for ants with epiedaphic forage in semiarid altered environments. Two communities were clearly distinguishable, although the similarity ranges were very close: one typical of nonirrigated areas (with low or no use of soil) and a second one typical of irrigated areas (with high frequency of disturbance related to frequent fallow and use of fertilizers and pesticides). In fact, a gradient in the decrease of species

richness in the community of ants was observed as the intensity of disturbance increased (NA>S>P and W) (Perfecto et al., 2003; McNeely, 2004).

Clearly in this work, the TCS functional group (Figure 2) decrease significantly in sites, such as: S (2.5%)>NA (1.2%)>P (1.0%) and W (0.2%). Probably, the highest richness found in temporary irrigated plots, where low disturbance is present, allowed the succession of species when compared to nonagricultural areas, where established ant communities do not allowed invasion by other species.

On the other hand, NA plots were characterized by the presence of SC and HCS, which are common in preserved areas and natural arid areas respectively. Groups shown a nonagricultural area where the native fauna of the region might be appearing. Besides the fact of being represented in the four types of plots, the three species recorded in HCS (Table 1) might be showing that certain native fauna has been able to adapt itself to agricultural disturbance in the region. The presence of *Tapinoma sessile* (O), which is characteristic in rural environments in P and W plots, shows a high ecological tolerance.

There are several species which were inefficient as indicators, since they were only recorded for a single type of use of soil due to their low frequency and abundance, such as: *Liometopum apiculatum* (DD), *Camponotus atriceps* (SC), *Neivamyrmex harrisii*, *N. swainsonii* and *Trachymyrmex* sp. (from TCS), *Temnothorax pergandei* (CCS) *Hypoponera* sp. (C) and *Pheidole* sp. 4 (GM).

The sampling technique with pitfall traps, widely used for environments with disturbance (Graham et al., 2009) and open areas (Retana & Cerdá, 2000), benefits this project; however, certain species might be lowered in the collection due to specific features of every species, such as movement and number of individuals per colony (Hölldobler & Wilson, 1990; Longino, 2000).

The high abundance of GM and O (characterized by their wide geographical distribution due to their higher resistance to environments with and without disturbance and to their dominance if DD are not present or are present in lower numbers) in every environment, as well as the absence, in this study, of specialist predators (recorded only for natural environments), and the high overall resemblance in species composition and similarity suggest that there are habitats with certain degrees of disturbance throughout the whole area (Andersen, 1995, 1997).

Conclusions

1. The predominant ant species in every environment are *Forelius pruinosus*, *Pheidole obtusospinosa*, *Monomorium minimum* and *Dorymyrmex* spp.

2. The group of tropical climate specialists (TCS) provides the highest specific variation, which helps characterize the types of plots in the Mezquital Valley.

3. Agricultural activity affects the structure of the ant community with epiedaphic forage, and the constant use of irrigation wastewater in conjunction with intense agricultural practices has a negative effect upon species richness of epiedaphic ants.

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