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Earthworm Diversity in Four Land Use Systems in the Regíon of Jaguapitã, Paraná State, Brazil

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ABSTRACT.-Little infonnation is available on earthwonn distribution and diversity in the State of Paraná, southern Brazil, Earthwonn abundanee and species diversity was evaluated in four land use systems near [aguapítã, (Paraná); where pastures are being eonverted to soybean and sugarcane. Samples were taken during the rainy and dry seasons of 2004 and 2005 in eight sites: two old degraded pastures, an old pasture being eonverted to row eropping, two grain erop fields, two sugareane fields and a native forest fragmento Twenty-five 25 x 25 em soil bloeks were taken at eaeh síte, 20 of them to 10 em and five to 30 em depth. Earthwonns were manually sorted from the soil and preserved in fonnaldehyde. Earthwonn species found were: the exotics *Pontoscolex corethrurus (Glossoscolecidae), Dichogaster affinis,* D. *bolaui* and D. *saliens* (Acanthodrí-Iidae), *Eukerria saltensis, E. eiseniana* and *Ocnerodrilus occidentalis* (Ocnerodrilídae), and *Amynthas* sp. (Megascolecidae): the native species *Glossoscolex* n. sp. and *Fimoscolex* n. sp. (Glossoscolecidae), *Belladrilus* n. sp.l and an unidentifiable Oenerodrilidae n, sp.l (probably *Belladrílus);* and two unidentified *Eukerria* spp. (of unknown origin) (Oenerodrilidae). Pasture eonversion to row erops had a negative effect on earth-wonn abundanee and diversity: fewer individuais and species were found in the eropping systems than the pastures. The forest was not a suitable referenee site, having low earthworm populations and diversity. Exotie species tended to predominate in the land use systems near [aguapítã, but native earthworm species still survived, even in degraded pastures and row erops, many years after deforestation.

KEYWORDs.-agroeeosyslems, pastures, Oligoehaela, biodiversity, native and exotic species

INTRODUCTION

Earthworms (Annelida: Oligochaeta) are important components of agroecosystem soils, since they contribute to soil physical-chemical properties and processes, and can substantially modify the biodiversity and function of soil communities (Lavelle 1988; [ones et al. 1994).

About 3500 earthworm species are known worldwide, and it is estimated that at least another 3000 species have yet to be discovered and described (Fragoso et al. 1997). In Brazíl, dose to 300 earthworm species have been recorded, of which 145 were described by Righi and his collaborators (James and Brown 2006). However, it has been estimated that at least another 1000 species might exist in the country (James and Brown 2006).

Over the last 100 years, the Northern portion of Paraná State in Southern Brazil was colonized primarily by immigrants coming from the neighboring state of São Paulo, and most of the native vegetation (Atlantic Forest) was converted to agricultura I land. In the region of [aguapítã, coffee, cotton and sugarcane were planted first, but these were transformed mostly to pastures in the 1980's due to soil degradation (Bousquet and Holveck 1999). Presently about 70% of the county' s area is used for extensive grazing, and the pastures are generally degraded and with low animal carrying capacity (Bousquet and Holveck 1999). Recently, however, increased national and global demand for sugar, alcohol and biodiesel has led to the expansion of soybean and sugarcane in Brazil, and many old pastures are being re-converted to crops.

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Land use change in the tropics, especially deforestation, is known to affect soil invertebrate communities dramatically; while row cropping generally decreases their populations the adoption of pastures often increases them (Lavelle et al. 1994). However, little is known of the effect of land use conversion on earthworm communities in Paraná, where more than 50 earthworm species (many of them new, undescribed species) have recently been found (Sauter et al. 2006). Therefore, as part of a project on the role of earthworms as bioindicators in the state of Paraná (Brown et al. 2004a), the present study was undertaken to evaluate earthworm populations (abundance and species diversity) in four land use systems: pastures, two cropping systems and a native forest near [aguapitã,

MATERIAL AND METHODS

The study was carried out in the vicinity of Jaguapitã, at 23°00'S and 51°30'W. This region is a transition zone between predominantly dayey and sandy textured soils, classified as Dark Red and Red LatossoIs (EMBRAPA 1999). All samples were taken in the same soil type.

Samples were taken during the rainy (March 2004 and April 2005) and dry (August 2004 and September 2005) seasons of two successive years in the following land use systems: 1) an Atlantic Forest fragment (AFF) (sampled only in 2005); 2) two old pastures (OP1 and OP2), and an old pasture being converted to grain cropping (OP-GC); 3) two grain crop fields (GC1 and GC2) planted using conventional tillage, and in a rotation system including soybean, maize and oats; 4) two sugarcane (*Saccharum* sp.) fields planted using conventional tillage (SCl and SC2) (Table 1).

The old pastures (OP1 and OP2) were considered degraded, as they had a low productivity of both cattle and forage. OP1 had been in mato-grosso grass (*Paspalum notatum)* for 17 yrs, while OP2 was a 20 yr old, low-lying humid pasture with mato-grosso grass mixed with *[uncus* sp. (native species). OP-GC3 had been a mato-grosso pasture for 20 yrs when it was plowed in late 2004, and converted to annual crops (beginning with oats in the winter of 2005).

The annual crops GC1, GC2, SC1 and SC2 had previously been used as pastures with P. *notatum.* GC1 was converted from pastures in 1999 and GC2 in 2001; SCl and SC2 were converted to sugarcane in 2003. The soybean fields were limed (1,400 Kg/ha), and in all sites, whenever crops were planted, mechanical soil preparation (subsoiler, plowing and disking) was performed before planting.

The forest was a small fragment (about 2,500 m^2) of secondary vegetation in early secondary succession (Atlantic Forest), with few very tall trees. The area had been previously logged and disturbed by cattle.

Earthworms were collected using a

TABLE1. Land uses present at each site (Jaguapitã, PR), in the summer and winter of 2004 and 2005.

		Land uses and sampling dates			
Systems[1]	Age	Summer 2004	Winter 2004	Summer 2005	Winter 2005
OPl	17	Mato-grosso grass	Mato-grosso grass	Mato-grosso grass	Mato-grosso grass
OP2	20	n.s.[2]	*Paspa/um* + *[uncus* sp.	*Paspa/um* + *[uncus* sp.	*Paspa/um* + *[uncus* sp.
OP-GC	20	Mato-grosso grass	n.s,	Pallow"	Oats
GCl	5	Soybean	Oats	Maize	Fallow
GC2	3	Soybean	Fallow	Maize	Fallow
SCl	1	Sugarcane	Sugarcane	Sugarcane	Sugarcane
SC2	1	Sugarcane	Sugarcane	Sugarcane	Fallow
AFF		n.s.	n.s.	Secondary forest	Secondary forest

IOPl and OP2: old pastures; OP_GC: old pasture converted to grain cropping; and GC2: soybean and maize using conventional tillage; SCl and SC2: sugarcane planted with conventional tillage; AFF: Atlantic forest hagment subjected to disrurbance by cattle ~present) and \ogging ~past).

2n.s. = not sampled.

3Fallow = land being prepared for the following season's planting.

modified version of the TSBF (Tropical Soil Biology and Fertility) method (Anderson and Ingram 1993; modified by Benito 2005). It consisted in the removal of 25 soil blocks (25 x 25 em) over an area of 1,600 rrr', to a 10 em depth (Fig. 1). On the diagonal of the 5 x 5 sample matrix, earthworms were sampled to a 30 em depth (Fig. 1). Samples were taken in 10 m intervals. The soil blocks were placed in plastic bags, labeled and transported to the State University of Londrina (UEL), where the earthworms were manually removed from the soil, killed and placed in formaldehyde (4%), counted and identified to genera and species level, whenever possible.

Earthworms were identified by D. Nunes, using keys and descriptions available in the literature (mainly Righi 1990). S.W. [ames, C. Rodriguez and C. Mischis provided assistance for the identification of some species. The earthworms were deposited in the Entomology Laboratory of the State University of Londrina. Duplicates of the main species found will be deposited in the Museum of Zoology of the University of São Paulo.

Earthworm abundance (number of individuals per sample date and depth) and diversity (mean species richness per sample date) were compared between sites by ANOVA using the SAS® Statistical package.

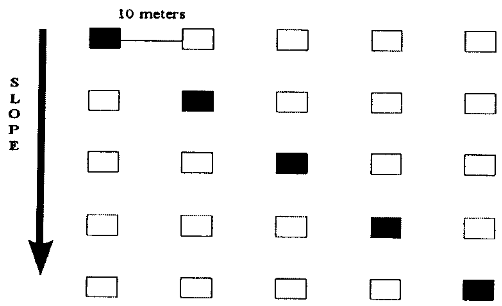

FIG. 1. Spatial distribution of the earthworm samples (25 x 25 em) taken in eaeh land use system in Jaguapitã, PRo Blaek squares represent samples taken to 30 em depth; white squares represent samples taken only to 10 em depth. Samples were taken in a straight angle according to the slope of each land use system.

RESULTS

Total density of earthworms in the [our land use systems

Earthworm density in Jaguapitã ranged from 3-739 individuals m^{-Z} in the pastures, 0-29 indiv. m^{-Z} in the cropping systems and 3-13 indiv. m^{-Z} in the forest (Table 2). Means tended to be higher when considering the deeper samples (0-30 em depth), particularly in the winter (except in the OP2 in 2005), when earthworms were found mostly below 10 em. This was especially evident in the W'inter of 2004.

OP2, in a low-lying area dose to a stream, appeared to be more favorable for earthworm populations as compared to the other sites as a significantly higher abundance at 0-10 em depth was found in this pasture than the other sites on every date it was sampled (Table 2). At 0-30 em depth, abundance was significantly higher than all sites only in the winter of both years. In the summer of 2004, OP1 and OP-GC (before it was converted to cropping) had significantly more earthworms than the remaining land use systems, During the winter (end of the dry season), when earthworm abundance was generally lower, differences with the other sites were not significanto Very few earthworms were recovered after the old pasture (OP-GC) was plowed and converted to annual cropping (even at 0-30 em depth). Conversion of pasture to grain cropping (OP-GC) and the use of row crops (soybean, maize and sugarcane) had, therefore, a negative effect on earthworm abundance, and this appeared to be related to soil disturbance.

Earthworm species diversity in Jaguapitã

Combining all the land use systems, fourteen earthworm species were found (Table 3). Of these, at least 8 species were exotic: *Pontoscolex corethrurus* (Clossoscolecidae), *Dichogaster offinis*, D. *bolaui*, D. *saliens* (Acanthodrilidae), *Eukerria eiseniana*, *E. saitensis*, *Ocnerodrilus occidentalis* (Ocnerodrilidae), and one ac1itellate *Amynthas* sp. (Megascolecidae). Of the total, at least 4

TABLE2. Earthworm abundanee (mean number of individuaIs per m^2, including adults, sub-adults, juveniles, eggs and head fragments), in the various land use systems studied in Iaguapítã, PR during two years (2004 and 2005). Values shown are means of the 25 samples taken to 10 em depth and in the five samples taken to 30 em depth. Values with similar letters within eaeh eoIumn are not signifieantly different, using Tukey's LSD test at $p < 0.05$. CV = Coefficient of Variability.

Land use systems sampled	Earthworm abundanee							
	0-10 em depth (n = 25)				0-30 em depth (n = 5)			
	2004		2005		2004		2005	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
AFF			3b	4b			7b	13b
OP1	40 a	3b	17b	30b	52 a	36 b	68 ab	90b
OP2		282 a	161 a	739 a		544 a	359 a	596 a
OP-CC	64a		Ob	2b	96 a		10 b	7b
CC-SB1	7b	Ob	Ob	20b	13a	4b	7b	16 b
CC-SB2	4b	Ob	Ob	lOb	13a	4b	29ab	29b
SC1	1b	Ob	2b	llb	20 a	13b	13b	13b
SC2	Ob	5b	Ob	Ob	Oa	10 b	4b	4b
CV(%)	60.45	67.06	88.11	62.06	59.58	34.83	91.09	65.51

TABLE3. Earthworm diversity (% of total and total number of individuaIs found including ali samples and sample dates) in the pastures, eropping systems and forest in the vicinity of Jaguapitã, in the years 2004 and 2005.

Earthworm species	Origín	Sites (land use systems)							
		OP1	OP2	OP-CC	CCl	*CC2*	SC1	SC2	AFF
Fimoscolex n. sp.'	Native	7.2[6]	0.1		2.5			27.3	
Oenerodrilidae n. sp. 1[2]	Native		0.1		12.5				
Glossoscolex n. Sp.3	Native	2.0		1.8					
Belladrilus n. sp.l '	Native	3.3		1.8		32.4	7.4		
Eukerria eiseniana'	Exotie		1.4						
Pontoscolex coreihrurus'	Exotie	28.9	76.1	64.0			33.3	9.1	7.7
Dichogaster affinis'	Exotie	4.6		0.9		2.7	22.2	27.3	23.1
Dichogaster bolaui'	Exotie	1.3	0.1						
Dichogaster saliens:	Exotie	15.1	0.8	3.6	20.0			9.1	
Dichogaster spp."	Exotic	4.6		1.8	2.5	10.8	18.5	18.2	
Ocnerodrilus occidcntalis'	Exotic				7.5				
Eukerria ealtensis'	Exotie		0.1						
Eukerria spp.'	?		0.7						
Amynthas sp."	Exotie		0.1						
Unidentified juveniles		32.9	20.6		55.0	54.1	18.5	9.1	69.2
Total N° individuaIs		152[7]	1011	111	40	37	27	11	13
Total species riehness		8	9	6	5	3	4	5	2
Mean species riehness"		4.0ab	5.7 a	2.7 ab	1.8b	1.0 b	1.8b	1.5b	1.0 b

'Adulrs: 2sub-adults and adults; 3juveniles and sub-adults; 4juveniles, sub-adults and adults; ssub-adult; "Data for speeies indieates total pereentage of individuaIs per site in 0-30 em depth (sum of 4 seasons: n = 50-100); 7Total number of earthworms sampled per site (from ali samples); "Mean number of earthworm species collected at eaeh sample date in each site. Values labeled with the same letter do not differ in mean species ríchness: Tukey test ($p < 0.01$; n = 4).

species were native *Glossoscolex* n. Sp., *Fimoscolex* n. sp. (Clossoscolecídae), Ocnerodrilidae n. sp.l, *Belladrilus* n. sp.l (Ocnerodrilidae), and two unidentifieable ocnerodrilid species of unknown origin *(Eukerria* spp.), were also found.

The three pastures sampled (OPl, OP2 and *OP-CC* before conversion) had the highest total specific richness (6-9 species) and mean number of species (2.7-5.7 spp.) per sample date (Table 3). However, mean species richness was only significantly higher in OP2 (5.7 species on average and 9 species total), compared to the other systems. The cropping systems and the forest had less than 5 species total and fewer than 2 species per sampling date.

Under forest, very few earthworms were encountered, representing an extremely low sample density on both sample dates, and most of the individuals recovered were exotics *(D. saliens)* (Table 3 and Fig. 2).

Exotic specíes dominated in most sites, although even in cropping systems with frequent disturbance, such as in GC2 and SC2 (where soil was mixed to a depth of 40 em). native species were present (Fig. 2, Table 3). In GC2, *Belladrilus* n. sp.l was the most abundant species; this was the only site where native species appeared to dominate (Fig. 2). Nevertheless, the sites GCl, GC2 and the forest had the greatest proportion of unidentified juvenile earthworms (>54%) of all the sample sites (Table 3), indicating that these results must be taken with caution, since the unidentified juveniles could shift the proportion of native/ exotic species either positively or negatively.

Of a11 earthworms encountered, the exotic species P. *corethrurus* was the most common (especia11y in the pastures), reaching as much as 76% of the total number of individuals in OP2 and 64% in OP-GC (Table 3, Fig. 2). The species was, however, absent in the grain crop fields and the forest samples, In terms of total number, the other species most commonly encountered were the exotic *Dichogaster* spp., that represented the majority of the earthworms sampled in the sugar cane fields (54% in SC2 and 41% in SCl) and over 20% of the individuals in GCl and OPl (Table 3).

DISCUSSION

Annual cropping in Jaguapitã is performed using conventional tillage practices (subsoiling, plowing and disking). These rnethods of seedbed preparation generally reduce earthworm populations (Edwards and Bohlen 1996), and were probably responsible for the lower earthworm abundance found in the cropping systems, The machinery may cause direct damage to the earthworms or (in the case of plowing) expose thern to predation by birds and other natural enemies, as we11 as create conditions that inhibit earthworm growth, development and reproduction (Nuutinen 1992; PaoIetti 1999), including reduction of soil organic matter and soil water storage capacity, and higher soil temperatures (Sá 1993).

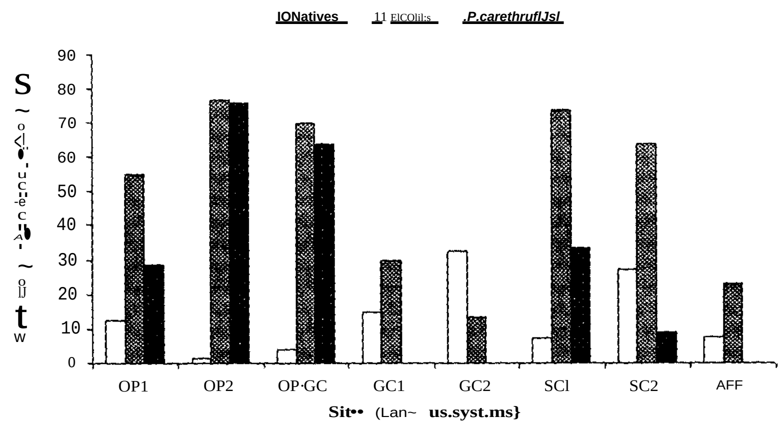

FIG. 2. Proportion of native and exotic earthworm species (total), and of the exotic P. *corethrurus* (%) in each site and land use system in the region of Iaguapítã, during the years 2004 and 2005. Values do not add up to 100% because unidentified juveniles were excIuded.

The present results agree with those published earlier on earthworms from the region (Brown et al. 2003, 2004a), that showed pastures (and no-tillage systems) sustained relatively high earthworm populations compared with conventionally tilled cropping systems. Other studies in tropical and subtropical regions have aIso shown that pastures can maintain higher earthworm populations (and diversity) than cropping systems (e.g., Decãens et al. 2004; Lavelle and Pashanasi 1989). This is probably due to the lack of soil disturbance, the higher soil organic matter content and the abundance organic resources deposited by grass roots in pasture soils. For instance, in South Africa, earthworm density was greater under 50 yr old permanent (>230 índs.m ") and annual pastures (163 inds.m") than in maize or sugar cane cropping systems «60 inds.m F) (Haynes et al. 2003).

Natural ecosystems usually have greater species diversity when compared to pastures and cultivated systems (Fragoso et al, 1999). However, the forest chosen for the present study was not a good reference point. The small earthworm number and diversity encountered is likely due to the degraded state of the forest, and the strong impact of past (removal of large trees for wood) and present disturbances (cattle trampling). Further sampling efforts in other forest fragments in the region may reveal some of the same native species found in the pastures studied here, although earthworm abundance in forests of northern Paraná tends to be low, and dominated by small-bodied species (small glossoscolecids and ocnerodrilids) (james and Brown 2006; Brown et al. 2004a).

Surprisingly, earthworm diversity was highest in the old pastures that also had more native species than the cropping systems with frequent disturbance. In fact, native earthworms were found in all of the sample sites at [aguapitã, even in highly disturbed cropping systems. In CC2, the dominant species (native) *Belladrilus* n. sp.l, was probably more abundant due to the lower intensity of land use and the fewer years in cropping compared with CCl. These results agree with those of Fragoso et al. (1997, 1999), who found that native species could survive in disturbed ecosystems in various tropical countries, particularly pastures but also cropping systems. However, Fragoso et al. (1997) also showed that as the time and amount of disturbance increased, native species tended to disappear.

In fact, most native species tend to disappear from cropping systems over time, especially as agricultura 1 intensification at a local and regional scale increases the frequency of (soil and environmental) disturbance and the loss of native vegetation fragments that are usually sources of native earthworms (Fragoso et aI. 1997, 1999). Nonetheless, earthworm species differ in their susceptibility to agricultural practices: some are negatively affected, while others adapt and survive well in agriculturalland-scapes. This is due to differences in the ecology, feeding habits and physiological characteristics of each species (Nahmani et al. 2003). For instance, conventional tillage, such as that used in CC and SC, can also influence the sexual maturity of earthworms, due to the changes in soil microclímate (Hauser 1993). Therefore, in the sites at [aguapitã, the differences observed in terms of earthworm diversity, abundance and species composition may be related not only to the environmental conditions therein, but also to differences in the life cycles of the different earthworm species and populations found in each system.

Of the exotic species encountered at [aguapítã, P. *corethrurus* was the most common and abundant. This species often becomes dominant in pastures, but does not appear to survive as well in annual cropping systems (Lavelle et al. 1994; Brown et al. 2004a), especially those involving frequent tillage and no cover crops, like CC1 and CC2. On the other hand, *Dichogaster* spp. appeared to be more resistant to tillage, such as that used in sugar cane croppingo Both *Dichogaster* spp. and P. *coreihrurus* are widespread throughout the tropics and Brazil, and have adapted to a wide range of habitat conditions including pastures and less intensive row crop agroecosystems (Fragoso et al. 1999; [ames and Brown 2006), where they commonly become dominant components of the population. These species can, in fact, be used as indicators of disturbance in natural and anthropogenic land use systems, and their dominance in practically all of the land use systems in the present study indicates the high level of perturbation that they have been subjected.

Considering the present results therefore, pastures had, in general, greater earthworm populations and diversity than the annual crops and the forest, confirming previous results (e.g., Mexican pastures; Fragoso et al, 1999). Exotic species dominated over natives, probably because the introduced pastures and crop systems all involved exotic plant species, not native to Brazil. This contrasts with results of communities in native pastures in Mexico, where native earthworm species were more prevalent (Brown et al. 2004b).

Nevertheless, given the continued presence and survival of native earthworms, even in the most highly disturbed agroecosystems in Jaguapitã (GC and SC), it would be interesting to follow these systems over time, to assess their ability to preserve or not indefinitely, native earthworm species and populations. The conditions that limit the colonization and invasion of exotic species and simultaneously promote the conservation, maintenance and or increase of native earthworm species also require further research. These conditions should help conserve biodiversity, reduce possible negative effects of exotic earthworm invasions (Bohlen et al. 2004), and generate various ecosystem services important to human well being (Decãens et al. 2006).

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