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Exotic and Native Earthworms in Various Land Use Systems of Central, Southern and Eastern Uruguay

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ABSTRACT.—From 1995 to 2001 we conducted several surveys of earthworm populations in 7 land use systems, of varying intensity of disturbance, in Central, Southern and Eastern Uruguay. We evaluated the presence and density of various earthworm genera and species in selected land use systems. Most species found were exotic, belonging to the Lumbricidae (6 species) and Megascolecidae (1 species) families. We found only two native species, one ocnerodrilid and one acanthodrilid. Lumbricids were generally in disturbed agroecosystems, although native species were also found in some disturbed sites. *Eukerria* sp. had a mean density of 196 ind./m^2 in a rice field. The apple orchard, *Eucalyptus* sp. plantation and natural prairie showed maximum mean densities of 102 ind./m^2, 733 ind./m^2 and 317 ind./m^2, respectively. Our results show the great adaptability of lumbricids to various levels of disturbance and suggest the possibility of a large incidence of exotic worm species in Uruguayan soils.

KEYWORDS.—Lumbricidae, exotic species, land management, disturbance, agriculture, Uruguay

INTRODUCTION

Of the more than 3,500 known earthworm species, only 19 have been found in Uruguay (Grosso and Brown 2006). Of these, 12 are exotic and only seven are native species, grouped in ten genera and five families (Table 1). Most of them were identified and collected by Professor Ergasto Cordero (1890-1951), the first Uruguayan terrestrial Oligochaete researcher. He described several native genera and species, and also contributed to the fields of earthworm systematics, taxonomy and biogeography; especially to that of the Glossoscolecidae for which he established its distribution and phyletic relationships (Cordero 1931, 1943, 1945). Since Cordero's death, little additional work was done on earthworms in Uruguay until 1995 when we began our work and later Zerbino et al.'s (2005, 2006) work on the soil macrofauna populations in no-tillage systems at various INIA (National Agriculture Research Institute-Uruguay) stations.

The entire land surface of Uruguay (190,000 km^2 approx.) is located within the Temperate Climatic Region. It has a rainy, humid and relatively uniform climate (OEA-BID, 1992), and is covered by a diverse grass prairie intercepted by riparian and hillside (*quebradas*) forests. A wide variety of parent materials has created a diverse range of soil types, 40% of which can only be used as grazing land. The remaining 60%, predominantly composed of deep soils with medium and high levels of organic matter and nutrients, permits agricultural use. Agriculture in Uruguay involves mostly grain production (634,000 ha), especially wheat (213,538 ha) and rice plantations (174,728 ha), although forestry, with *Pinus* spp. and *Eucaliptus* spp. plantations have increased in importance and land area (from 660,667 ha in the year 2000, to more than 1,000,000 ha at present). Horticulture and fruit production are also important, especially in Southern and Northern Uruguay, along the Uruguay River watershed

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TABLE 1. Families, genera and species of earthworms present in Uruguay

Family	Genus	Species	Origin
Glossoscolecidae	*Glossoscolex*	*bonariensis, colonorum, rione, uruguayensis*	Natives
Ocnerodrilidae	*Eukerria*	*stagnalis*, sp. 1	Native
Acanthodrilidae	*Yagansia*	*epiphanica*	Native
	Microscolex	*dubius*	Native
Megascolecidae	*Amynthas*	*gracilis*	Exotic
Lumbricidae	*Eisenia*	*fetida*	Exotic
	Aporrectodea	*caliginosa, chlorotica, rosea, trapezoides*	Exotics
	Dendrodrilus	*rubidus*	Exotic
	Lumbricus	*friendi, terrestris*	Exotics
	Octolasion	*cyaneum, tyrtaeum*	Exotics

(Bella Unión and Salto) (Censo General Agropecuario 2000; OEA-BID 1992).

Soil degradation is widespread in the country. This degradation is primarily due to erosion in agricultural areas, overgrazing by cattle and sheep, and the careless or excessive use of agrochemicals. The main indicators of this degradation are decreasing productivity levels and the eutrophication of surface waters in areas of intensive agriculture.

Given the potentially negative impact of agriculture on soil life and the increased adoption of monocultures such as soybean, rice and *Eucalyptus* plantations, it is important to assess the impacts of these practices on soil organisms and their role in soils. In this context, the presence and populations of native and exotic earthworms can also be used as indicators of changes in soil processes and fertility, providing a rapid warning of ecosystem degradation or improvement (Paoletti 1999).

Therefore, we undertook this study to describe earthworm species diversity and populations in seven land use systems of varying intensity and disturbance levels (in increasing order of disturbance): a natural prairie (no tillage nor chemical input); two *Eucaliptus* spp. plantations (mechanical disturbance prior to seedling transplant); two urban gardens (manual tillage but no chemical inputs); a dairy farm with direct drilled pastures (with chemical inputs; i.e., fertilizers and herbicides); two apple orchards (with mechanical disturbance in between tree rows and chemical inputs in the tree rows); intensive horticulture (both tillage and chemical inputs); and a rice field (mechanical and chemical inputs: tillage, herbicides, fertilizers, fungicides and insecticides).

MATERIALS AND METHODS

We sampled from seven land use systems in five departments: Central (Tacuarembó), Southern (Canelones, Florida, and Montevideo) and Eastern (Treinta y Tres) Uruguay (Fig. 1). Surveys for earthworm

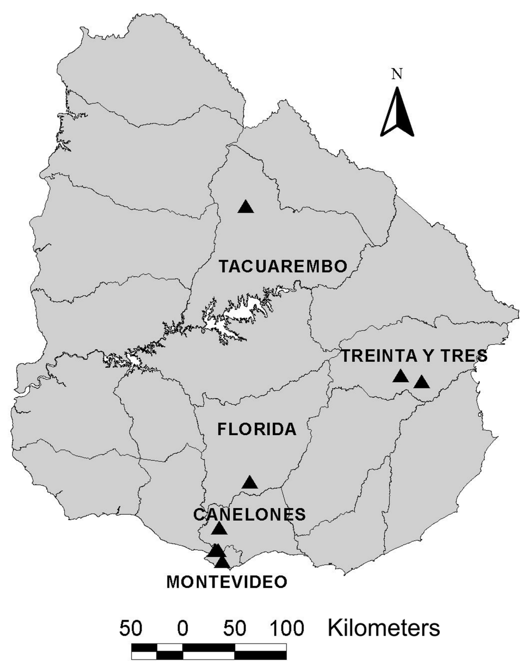

FIG. 1. Survey sites in the departments of Tacuarembó (site 2), Treinta y Tres (sites 5 and 10), Florida (site 6), Canelones (sites 1, 3 and 7) and Montevideo (sites 4, 8 and 9).

species diversity were carried in the following sites and land use systems in increasing order of disturbance: (1) Natural prairie (grassland) 1,500 m^2 patch within agroecosystems (sites 3 and 7), Joanicó, Canelones, km 42.5 Route 5; 34º34′S, 56º16′W; April, June, August and November 1996 and February and March 1997; (2) *Eucalyptus* sp. plantation (30-yr old), Los Molles, Tacuarembó; 31º46′S, 55º59′W; November 2001; (3) *Eucalyptus* sp. plantation (4-yr old), Joanicó, Canelones, km 42.5 Route 5; 34º34′S, 56º16′W; April, June, August and November 1996 and February and March 1997; (4) Urban garden (grass), La Teja, Montevideo; 34º51′S, 56º13′W; October 2005; (5) Urban garden (with grass, ferns and roses), Ciudad de Treinta y Tres, Treinta y Tres; 33º14′S, 54º23′W; September 2005; (6) Pastures in direct drilling at a dairy farm, Colonia "Treinta y Tres Orientales", Florida; 34º10′S, 55º57′W; May 1997; (7) Apple orchard (30-yr old), Joanicó, Canelones, km 42.5 Route 5; 34º34′S, 56º16′W; April, June, August and November 1996 and February and March 1997; (8) Apple orchard (12-yr old), Melilla, Montevideo; 34º45′S, 56º18′W; September 1995; (9) High-input horticulture (vegetables), Melilla, Montevideo; 34º45′S, 56º11′W; September 2001; (10) Irrigated low-land intensive rice field, INIA Treinta y Tres Experimental Research Station, Treinta y Tres; 33º17′S, 54º10′W; January and December 1999, January, February and March 2000.

Earthworms were collected by digging in several locations in each land use system (total area sampled variable). Sampled spots within each site were selected according to soil characteristics, where we thought it was more likely to find earthworms; i.e., humid conditions or presence of burrows and surface casts.

At four sites (1, 3, 7 and 10 from the list above), additional soil samples were taken to quantify earthworm populations. At sites 1, 3 and 7, three 40 m-transects were performed in each land use system, with five samples each, resulting in a total of fifteen samples per system. Earthworms collected from each land use system were counted, weighed and identified to species level, whenever possible.

At INIA Treinta y Tres (site 10), earthworms were hand sorted and washed out of 6-14 sample units (blocks of 0.25 m × 0.25 m × 0.25 m) in experimental rice plots, on five occasions (January and December 1999, January, February and March 2000). At Joanicó (Canelones), similar-sized samples were taken (but hand sorted only) in an apple orchard (site 7), a *Eucalyptus* spp. plantation (site 3), and a natural prairie (site 1) on six occasions (April, June, August and November 1996 and February and March 1997). An ANOVA was used to explore for differences among the sample dates in the rice field at Site 10 (Treinta y Tres) (Sokal and Rohlf 1995). To analyze the differences in earthworm density among Sites 1, 3 and 7 on different sampling dates, a two way ANOVA was used, with sampling dates and sites as factors (Sokal and Rohlf 1995). In both, single and two-way ANOVA, were used to analyze density of individuals. This variable, when square root transformed, did not present large deviations from Normality or variance of heterogeneity (Cochran $C > 0.05$).

RESULTS

We found nine earthworm species in the survey, belonging to the exotic Lumbricidae (6 spp.) and Megascolecidae (1 sp.) families and the native Ocnerodrilidae (1 sp.) and Acanthodrilidae (1 sp.) families (Table 2). Exotic species dominated practically all sites (9 out of 10), while native species were present at only two sites.

Lumbricids were found in agroecosystems with mechanical and chemical disturbance (apple orchard and high-input horticulture, direct drilled pastures) as well as in little or undisturbed systems (*Eucalyptus* plantation and natural grassland). One native species, *Eukerria* sp., was found exclusively in the rice field while *Eisenia fetida* was found only in the *Eucalyptus* forest litter (site 2) not far from a manure pile. *Amynthas* sp. was present only in the urban gardens (sites 4 and 5). We observed associations between species from different families in two sites: the urban garden in Montevideo (site 4), where both lumbricids

TABLE 2. Earthworm species found in the different survey sites in Central, Eastern and Southern Uruguay. Land management and disturbance factors abbreviated as follows: intensive irrigated (low-land) rice field (IR), high-input horticulture (HIH), apple orchard (AO), direct drilling pastures (DDP), urban garden (UG), *Eucalyptus* sp. plantation (EP), natural prairie (NP), mechanical disturbance (M), chemical inputs (Q), no- or little-disturbance (ND). Site number is given in parentheses.

Families	Species \ Management / Sites	M+Q	M+Q	M+Q	M+Q	Q	M	M	ND	ND	ND
		IR (10)	HIH (9)	AO (8)	AO (7)	DDP (6)	UG (5)	UG (4)	EP (3)	EP (2)	NP (1)
				Decreasing disturbance →							
Lumbricidae	*Aporrectodea caliginosa*		X	X	X	X			X		X
	A. chlorotica		X								X
	A. rosea		X						X		X
	Lumbricus terrestris		X	X				X			
	Eisenia fetida							X		X	
	Octolasion cyaneum		X								X
Megascolecidae	*Amynthas* sp.						X	X			
Acanthodrillidae	*Microscolex dubius*										X
Ocnerodrilidae	*Eukerria* spp.	X									
Total spp. site^{-1}		1	5	2	1	1	1	3	2	1	5

and *Amynthas* sp. species were found, and in the natural grassland (site 1), where lumbricids were found together with *M. dubius*.

Five sites had only one species present, and the average species number per site was 2.3. The highest diversity was in the high-input horticulture (5 lumbricids) and the natural prairie (4 lumbricids + *M. dubius*). The species most commonly encountered was *A. caliginosa* which appeared in six of the 10 sites studied.

In the rice field, *Eukerria* sp. had a mean density of 7.84 individuals (S.D. 5.03) per sample unit; i.e., a mean density of 196 earthworms/m^2, reaching a maximum of 425 individuals/m^2 in the samples. However, no significant differences in densities were detected among the different months ($F(3, 27) = 2.75$; $p = 0.064$) at the same site.

The apple orchard, the *Eucalyptus* sp. plantation and the natural prairie showed maximum mean densities of 102 ind./m^2, 733 ind./m^2 and 317 ind./m^2, respectively. Significant effects of site, time and the interaction between site and time were detected in these sites in Joanicó, Canelones (Fig. 2). In the apple orchard, the densities of worms at the first three sample dates remained constant and significantly lower from those in the *Eucalyptus* sp. plantation and in the natural prairie. However, at the following two sampling dates no earthworms were encountered. Before this period, the natural prairie held an intermediate density of earthworms (higher than those of the apple orchard), but after this there was no significant difference in the worm abundance between these two sites. In August 1996 and March 1997, the *Eucalyptus* sp. plantation had significantly higher earthworm density; in addition, shortly after the sample dates with no earthworms this system showed a relatively high resilience, with rapid recovery of the population to previous abundance values.

DISCUSSION

Exotic earthworms, particularly of the Lumbricidae family, are frequently dominant in agroecosystems and disturbed land use systems of Europe and North America (Bohlen et al. 2004). For instance, Callaham and Blair (1999) found that their distribution in North American tall grass prairie could be attributed to land management practices and that they were apparently displacing native species. Herein, lumbricids were also the most commonly found earthworms, although their presence was not directly related to the level of ecosystem disturbance. Nonetheless, size and closeness of the undisturbed natural prairie

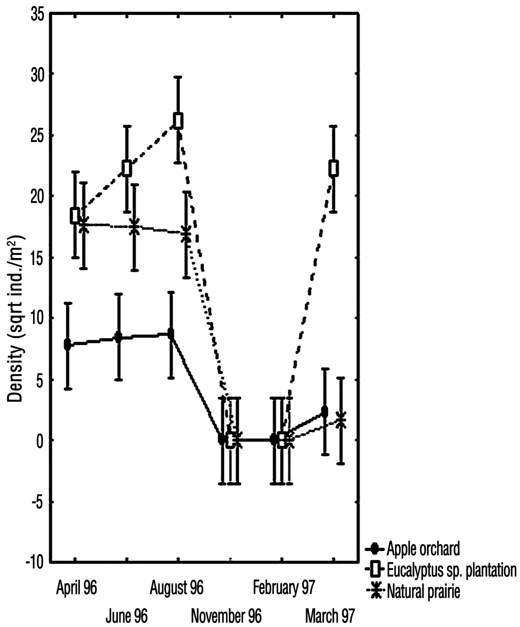

FIG. 2. Earthworm abundance in three sites (Apple orchard, *Eucalyptus* sp. plantation, Natural Prairie) in Joanicó, Canelones. The axis of density expresses the square root of numbers of ind./m^2. Vertical bars denote 0.95 confidence intervals.

patch to agroecosystems such as the apple orchard should be considered when analyzing the results. The passive introduction of lumbricids to Uruguay may have been due to importation of many exotic plants and soil containing these worms by the Europeans that settled in the area. The similarity of Uruguay's climate with that of the temperate climatic region of the Northern hemisphere, where lumbricids are natives, could explain the dispersion success of these earthworms in Uruguay.

Alternatively, the presence of native species is generally associated with well preserved natural ecosystems. In the present case, the native species *M. dubius* was found in a natural grassland. The other native species (*Eukerria* sp.), however, was found in an intensively disturbed rice plantation, associated with the rice root zone, where it may play an important role in the fertility and productivity of these systems. The presence of this species in rice fields may be related to their presence in the native inundated grasslands of Eastern Uruguay and Southern Brazil (da Silva et al. 2006), and to the relative similarity of the native vegetation to the irrigated rice fields. Furthermore, their small size and location in the soil may help protect them from the intensive disturbance associated with rice cultivation.

Various species of *Eukerria* have been reported as potential rice pests: harmful effects have been reported in rice fields in the Philippines, China and Japan (Otanes and Sison 1947; Chen and Liu 1963; Inoue and Kondo 1962; cited in Edwards and Bohlen 1996). Harm may be caused by high worm densities, which create water turbidity, impeding light from reaching the growing plants. The worms may also cause physical damage to the plants due to bioturbation in the root zone, which favors the entrance of pathogenic organisms into the rice plant. In an experimental study with potted plants, Stevens and Warren (2000) found that densities of 2500 to 5000 individuals/m^2 of *E. saltensis* could have harmful effects on the rice plants due to higher water turbidity. In our study, the observed densities did not surpass 425 individuals/m^2 and no harmful effect was evident on the plants. Further studies are necessary to assess the potential benefits or harm of large populations of *Eukerria* spp. in rice fields of Uruguay and Southern Brazil (da Silva et al. 2006). The fact that this species dwells in totally inundated grasslands, and that the rice plant completely covers the surface when it grows, makes their habitat relatively stable and less exposed to weather changes. This could explain why no significant differences in densities were found among months.

Aporrectodea caliginosa was the exotic species registered in the greatest number of sites (in six of 10). Its presence in both disturbed and undisturbed sites reveals its great adaptability to different environments and to soil disturbance. Similarly, *L. terrestris, A. rosea* and *O. cyaneum* were also present in sites subject to mechanical and chemical disturbance and in undisturbed sites, indicating their ecological plasticity.

Eisenia fetida is present all over the country as it has been used for vermicomposting for more than 20 years. Its presence is generally associated with high accumulation of organic matter in soils, and animal presence or plant wastes in early stages of decomposition. In our study this species was found with *L. terrestris* and *Amynthas* sp. in the urban garden where household refuse is regularly incorporated into the soil; and alone under *Eucalyptus* litter at Tacuarembó. It probably migrated from nearby manure stockpiles. *Amynthas* spp. have been found in urban and rural areas throughout Latin America (Fragoso et al. 1999a, b) and are aggressive exotic colonizers, generally associated with human dispersal activities. In Uruguay, this genus has been recorded only in urban gardens, close to human habitations.

In the area of Joanicó, the severe drought that took place between October 1996 and February 1997 may have had a strong impact on earthworm populations as no earthworm was found in the samples of this period (dug to a depth of 20 cm).

Although the levels of precipitation did not increase from February (73.4 mm) to March (75.3 mm), with the beginning of autumn in March there was a considerable decrease in evapotranspiration (from 132.34 mm to 114.24 mm). We noticed this in the field by a reduction in the difficulty to dig; in February it was practically impossible to penetrate the earth with the spade. However, this change in the hydrologic budget was only reflected in one of the sites studied. In March the populations in the natural prairie and the apple orchard remained close to zero, probably because of a high level of mortality, while the *Eucalyptus* sp. plantation showed a number of individuals similar to that of August 1996. Considering that the three sites are located at the same latitude and that all have the same soil type (Brunozem), the fact that *Eucalyptus* sp. plantation presents higher resilience after the drought may be due to the canopy protection and improved microclimatic conditions. Very likely, the earthworms migrated deeper into the soil during the drought, below the 20 cm sample depth (all the earthworms found in the sites were endogeic), and once humidity levels were restored, their presence in the upper horizon was rapidly re-established. This, however, did not occur in the other sites without the canopy protection.

Conclusions

The present study and previous ones suggest the possibility of a large incidence of exotic worm species in Uruguayan soils; a point which should be further analyzed in future studies. Our results also show the great adaptability of lumbricids to the various land use systems of Central, Eastern and Southern Uruguay. These species were found in native vegetation and also survived in intensively managed sites. Interestingly, native earthworms can also thrive under intensive management, as was observed for *Eukerria* sp. in an inundated rice field. Nevertheless, these preliminary surveys highlight the need to determine the factors associated with the invasion and colonization of exotic earthworms in Uruguay, as well as the factors that permit the maintenance of native earthworm assemblages. No native Glossoscolecids were encountered in these studies, and further sampling, particularly in the northern and western part of the country should be undertaken to ascertain their continued presence and diversity in Uruguay. Future studies could focus particularly on the impact of native and exotic earthworm communities on soil processes (stability and erosion), plant productivity, and the conservation/protection of native worm populations.

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