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No-tillage greatly increases earthworm populations in Paraná state, Brazil

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Summary

No-tillage (NT) agroecosystems now occupy >18 million ha in Brazil, of which 5 million are in the state of Paraná, where NT began in the early 1970's. The first NT farmers created an association to promote their practices, the 'Clube da Minhoca' (Earthworm Club), thus named because of the observed increase in earthworm numbers in their fields after adopting NT. However, little data were available on the topic until 1996, when more intensive studies began near Londrina, in N Paraná. Earthworms were sampled by hand-sorting soil monoliths (25 × 25 cm square, 30–40 cm depth) at 8 sites, comprising various natural and agricultural land-use and management systems. Data from the literature were collected from a further 6 sites for comparative purposes. The results for N Paraná confirm the presence of higher earthworm populations under NT (46–116 indiv., 0.49-1.06 g f.wt. m^{-2}; mean values in dry-wet seasons, respectively), minimum tillage (42–179 indiv., 0.68–1.05 g f.wt. m^{-2}), pastures (48–182 indiv. m^{-2}) and native forests (16–42 indiv., 1.56–0.83 g f.wt. m^{-2}) than under conventional tillage (13–22 indiv. and 0.13–0.02 g f.wt. m^{-2}). Soil disturbance thus had a negative impact on earthworm populations, and significant positive relationships were observed between earthworm abundance and age of NT systems, as well as with soil % C. In the Londrina area, some species present in the primary forests were absent in NT, where most earthworms were small-sized endogeic or epi-endogeic species. These results contrasted greatly with those from the cooler region in E Paraná, where the exotic epi-endogeic *Amynthas* spp. dominated, reaching high densities (up to >100 indiv. m^{-2}) and biomass (up to >30 g f.wt. m^{-2}), especially under NT. Given the high abundance of worms under NT, further work should focus on estimating their potential contributions to soil processes, fertility and plant production in these systems.

Key words: Earthworm populations, no tillage, conventional tillage, soil management, Paraná

Introduction

Many publications have addressed the effects of different tillage practices on earthworms (review in Chan 2001), although very few papers deal with tropical environments (e.g., Reddy & Reddy 1990; Reddy et al. 1995, 1997; Robertson 1989; Robertson et al. 1994). In general, soil disturbance has a negative effect on earth-

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worm populations due to direct damage by the equipment and predation by birds of the earthworms exposed at the soil surface, and indirectly through modifications in the soil environment, including loss of organic matter (OM), destruction of burrows and changes in soil strucuture (Lee 1985; Edwards & Bohlen 1996). On the other hand, a reduction in tillage and, especially, the adoption of no-tillage practices (NT), has been shown on many occasions to be highly beneficial to earthworm populations (Chan 2001).

No-tillage agriculture began in Brazil in the early 1970's, mainly as an effort to control soil erosion caused by conventional tillage (CT) practices. In 2002, 30 yr later, more than 50 % of the nation's cultivated area is in NT (>18 million ha). The first farmers to adopt NT were located near Londrina, N Paraná state, in the South of Brazil. These were closely followed by others, mostly near Ponta Grossa, in the Eastern part of the state (Derpsch 1999). Currently, about 5 million ha in Paraná (25 % of the state's surface area) are in NT.

The first NT farmer's association was called the "Clube da Minhoca" (Earthworm Club) due to empirical observations of greater earthworm populations under NT. However, even with the rapid advancement of NT, up until 1996 few data and publications were available dealing specifically with earthworm populations in NT. From 1996–2002, several studies were undertaken to assess earthworm populations in various ecosystems of the Londrina region, focusing on the abundance, biomass and community composition according to various tillage and rotation practices. The hypotheses tested in these studies were: a) earthworms can be used as sensitive bioindicators of soil disturbance; b) lesser soil disturbance increases earthworm populations;
c) older NT systems have greater earthworm populations; d) crop rotations vs. traditional double-cropping increase earthworm populations.

Materials and Methods

From 1979–2002, earthworms were sampled in at least 14 sites with various crop and soil management (tillage) systems and natural vegetation in Paraná, most of them in the region surrounding Londrina (including Cambé and Rolândia), and the remaining in several locations close to Carambeí and Arapoti. Londrina is located just above the tropic of Capricorn (23°20'S, 51°11'W), at an approximate altitude of 590 m, and with annual precipitation of about 1620 mm. The climate is subtropical humid mesothermic, with hot summers (Dec–Mar) and infrequent winter frosts in the winter (Jun–Sept), which tends to be drier (lower rainfall) than summer (Cfa, Köppen). Carambeí (24°57'S, 50°00'W) and Arapoti (24°09'S, 49°49'W) are located at 900–1100 m altitude, with similar annual precipitations (around 1600 mm), but a cooler climate than Londrina, with cool summers, frequent and severe frosts in winter and no distinct dry season (Cfb, Köppen). The soils at the sample sites were predominantly Alfisols (Paleudalf) and Oxisols (Haplorthox), with very high clay content (>65 %), acid pH ($CaCl_2 < 6$), relatively high base saturation and C contents between 1.6 and 1.9 % (Derpsch et al. 1991). The soils were all highly porous and flocculated, with a very low bulk density (0.9–1.1 g cm^3), due to abundant Fe and Al hydroxides. However, they were also very sticky (adherent) due to the predominance of kaolinitic clays.

The region near Londrina was converted from native Atlantic Forest to agricultural uses after around 1940, while the native vegetation around Arapoti and Carambeí (native grasslands on the highlands and gallery forests dominated by the subtropical *Araucaria angustifolia* in the valleys), was transformed to agricultural uses a few earlier decades.

Earthworms were sampled using mostly the Tropical Soil Biology and Fertility Programme (TSBF) Handbook method (Anderson & Ingram 1993), involving hand-sorting of 25 × 25 cm square soil monoliths, divided into several layers of 10 cm, to a total depth of 30–40 cm, although in some cases they were previously extracted from the soil using a dilute formalin solution (sites in E Paraná) poured over a 50 × 50 cm area.

The following classification scheme was used: CT for sites with the greatest amount of soil disturbance using the conventional disk plow (mixes the soil to depth of approx. 25 cm); MT (minimum tillage) for sites with intermediate soil disturbance using the field cultivator (breaks through the soil to depth of approx. 25 cm) every year or periodically (e.g., every 3 yrs); NT for sites with minimum soil disturbance, in no-tillage.

A total of 14 sites were sampled: 1) Embrapa Soybean Research Station (near Londrina), with NT (8, 13, 20, 21 yr), CT (>22, >23 yr) and MT (13, 20 yr); 2) Private Farm with a native Atlantic forest reserve near Embrapa Soybean; 3) Godoy State Forest (near Londrina), with primary Atlantic forest; 4) State University of Londrina (UEL, in Londrina) Research Farm, with a tillage experiment on a 4 yr old NT field; 5) São Manuel Farm (near Cambé), with areas in long term NT (20–23 yr), a one-time tilled area (MT, 3 months) after long-term (20 yr) NT, immediately reconverted to NT (1 yr, after d = disk, or fc = field cultivation), and a slightly disturbed Atlantic forest; 6) Private Farm (next to São Manuel Farm), with MT (3, 4 yr) after 24 yr of CT; 7) Private Farm (next to São Manuel Farm), with a

12 yr *Brachiaria decumbens* pasture; 8) Renânia Farm (near Rolândia), with a 10 yr *Brachiaria* sp. pasture, *Eucalyptus* forest with mixed native brush undergrowth and NT (24 yr) with or without grazing of crop residues; 9) IAPAR (Paraná Agronomic Institute in Londrina) Research Station, with NT (6 yr), CT and MT (5 yr) and permanent cover crops; 10) Fazenda Marta (near Rolândia), with NT (3.5 yr), CT and MT (1.5 yr); 11) Private Farm (near Carambeí), with NT (4 yr) and CT (>4 yr); 12) Frank'Ana Farm (near Carambeí), with NT (18 yr), CT (>18 yr), and a small remnant of subtropical native Atlantic forest dominated by *Araucaria angustifolia*; 13) Private Farm (next to Frank'Ana Farm), with native grassland; 14) Decolores Farm (near Arapotí), with NT (6.5, 7.5 yr).

Samples 1–8 were taken by the authors, while 9–14 were taken by others and published elsewhere (see sources in Table 1). Samples were taken in the summer (wet) season, from Nov–Apr and the winter (dry) season, from Jun–Oct, generally in soybean or maize (summer) and wheat or black oats (winter). Further details are given in Table 1.

Only sites 1–7 (all near Londrina) had data available for individual samples, so statistical tests were performed using only these data. For the remaining sites (except 12 and 13), only mean values were available. Means for earthworm biomass and abundance were compared using ANOVA, to evaluate the significance ($P < 0.05$) of treatment (tillage and land use systems) effects, using the statistical packages SAS© and Statistica©. The age of NT and CT systems and soil % C of sites for which these data were available, were regressed against earthworm biomass and density and the correlation coefficients calculated and tested using Statistica©.

Results

Earthworm abundance and biomass at the sites near Londrina (1–10) ranged from a minimum of 0 (Site 1, 5) up to a maximum of 407 individuals (Site 6) and 2 g m^{-2} (Site 3; Table 1). Mean abundance and biomass (for Sites 1–7) in each tillage and land-use system in the summer (rainy season) and the winter (dry season), revealed significantly higher values in NT (46–116 indiv., 0.49–1.06 g f. wt. m^{-2}; dry-wet season means, respectively) and MT (42–179 indiv., 0.68-1.05 g f. wt. m^{-2}) than under CT (13–22 indiv. and 0.13–0.02 g m^{-2}) in the summer, but not the winter (Table 2). Populations in pastures (48–182 indiv. m^{-2}) and native forests (16–42 indiv., 1.56–0.83 g f. wt. m^{-2}) were slightly larger but not significantly different than those in CT (Table 2). Combining all sites, abundance was significantly higher (more than 2-times) in the summer than the winter, although the effect of seasons on earthworm biomass was not significant. In both CT and the forest, mean biomass tended to be higher (but not significantly different) in the dry than the wet season, as the earthworms found had higher overall individual biomass (Table 2). No difference was found in populations under rotations compared with traditional double cropping, when combining all treatments.

A significant positive relationship of NT age with earthworm abundance in the wet season ($R^2 = 0.46$, $P < 0.05$) was observed when all data (means at each sample site) were combined from both E and N Paraná regions (Fig. 1). When this relationship was combined with the age of CT (considered as negative years of NT; Fig. 1), the correlation coefficient ($R^2 = 0.49$) was also significant ($P < 0.01$). However, when these relationships were explored with data from the dry season, the results were not significant. When earthworm biomass values for both wet and dry seasons in sites in N Paraná were regressed against age of NT ($R^2 = 0.33$, $P < 0.05$), and age of NT combined with age of CT ($R^2 = 0.46$, $P < 0.01$), significant relationships were observed. When topsoil % C (0–10 cm depth) was related to earthworm abundance in crop fields at Embrapa Soybean (local level, $n = 11$ samples), the correlation coefficient was also significant ($R^2 = 0.45$, $P < 0.05$). Using data for crop fields of both N and E Paraná regions (regional level, $n = 26$ samples), a smaller, but still significant, correlation coefficient was observed ($R^2 = 0.24$, $P<0.05$).

In N Paraná, native earthworms were found mostly in the well-preserved primary Atlantic forests. However, only in the undisturbed forests were relatively large (about 5 cm long) native (greenish-colored) earthworms found (species not yet identified). These were absent in the disturbed forests, indicating the susceptibility of this epi-endogeic earthworm to disturbance. Earthworms in the disturbed forests and the agroecosystems were mainly of the Octochaetidae (Dichogastrini) and Glossoscolecidae families. *Pontoscolex corethrurus* was found only rarely, and most earthworms sampled were small (< 2 cm length) and immature, and unidentifiable by the authors.

Earthworm abundance and biomass in the E Paraná region (Sites 11–14) ranged from 0–168 individuals and up to 38.5 g m^{-2}. Abundance values in NT systems near Carambeí (Sites 11–13) were much greater than in CT, and earthworms were more abundant in *Araucaria* forests than the native grasslands (Table 1). Density values were fairly similar to those in N Paraná, but clearly the biomass was much greater in E than N Paraná, due to the presence of dominant exotic (invasive) *Amynthas* spp. earthworms, that had a much higher individual biomass than the small earthworms found in the Londrina region.

Table 1. Earthworm populations in different soil management and land-use systems, at various sample locations in Paraná state (nd = not determined; *n* = Nº samples; SE = Standard Error; ? = unknown; CT = conventional tillage; NT = no tillage; MT = minimum tillage)

Sample site **Soil management & Land use (crops + year experiment began)**	***n***	**Summer season (Nov–Apr)** **Density ± SE¹ (Nº m⁻²)**	**Summer season (Nov–Apr)** **Biomass ± SE² (g m⁻²)**	**Winter season (Jun–Oct)** **Density ± SE¹ (Nº m⁻²)**	**Winter season (Jun–Oct)** **Biomass ± SE² (g m⁻²)**	**Source**
AUTHOR'S DATA						
1. Embrapa Soybean (near Londrina)						Brown et al. (2002)
CT >22 yr (soybean/wheat >1993)	4	nd	nd	24 ± 19 cde	0.21 ± 0.18	
CT >22 yr (rotation >1988)	4	8 ± 5 cde	0.03 ± 0.02	nd	nd	
CT >22 yr (soybean/wheat >1988)	4	0 e	0	nd	nd	
CT >22 yr (soybean/wheat >1981)	4	nd	nd	0 e	0	
CT >23 yr (soybean/wheat >1981)	4	nd	nd	16 ± 11 cde	0.19 ± 0.18	
MT 20 yr (soybean/wheat >1981)	4	nd	nd	8 ± 8 de	1.02 ± 1.02	
MT 13 yr (rotation >1988)	4	80 ± 31 cde	0.28 ± 0.15	nd	nd	
MT 13 yr (soybean/wheat >1988)	4	64 ± 54 cde	1.60 ± 1.55	nd	nd	
NT 8 yr (rotation >1993)	4	nd	nd	40 ± 19 cde	0.37 ± 0.13	
NT 13 yr (rotation >1988)	4	100 ± 18 abcde	0.75 ± 0.29	nd	nd	
NT 13 yr (soybean/wheat >1988)	4	76 ± 34 bcde	0.69 ± 0.30	nd	nd	
NT 20 yr (soybean/wheat >1981)	6	nd	nd	69 ± 17 bcde	0.54 ± 0.15	
NT 21 yr (soybean/wheat >1981)	6	nd	nd	85 ± 25 bcde	0.61 ± 0.22	
2. Private Farm (near Embrapa)						Brown et al. (2002)
Native Atlantic forest	7	nd	nd	18 ± 2 cde	1.98 ± 1.27	
3. Godoy State Park (near Londrina)						Brown et al. (2002)
Native Atlantic forest	7	50 ± 16 bcde	1.24 ± 0.66	nd	nd	
4. University Research Farm (Londrina)						Benito et al. (2002)
CT 3 months (soybean/wheat)	6	45 ± 22 cde	nd	nd	nd	
NT 4 yr (soybean/wheat)	6	34 ± 12 cde	nd	nd	nd	
5. São Manuel Farm (near Cambé)						Benito (2002); Benito et al. (unpublished)
MT 3 months (maize/soybean/wheat)	5	122 ± 8 abcd	1.69 ± 0.66	nd	nd	
NTfc 1 yr (maize/soybean/wheat)	5	nd	nd	45 ± 14 cde	0.13 ± 0.04	
NTd 1 yr (maize/soybean/wheat)	5	nd	nd	0 e	0	
NT 20 yr (maize/soybean/wheat)	5	83 ± 32 bcde	1.12 ± 0.7	nd	nd	
NT 21 yr (maize/soybean/wheat)	5	nd	nd	10 ± 10 de	0.21 ± 0.21	
NT 22 yr (maize/soybean/wheat)	5	291 ± 92 ab	1.53 ± 0.45	80 ± 45 bcde	1.53 ± 1.36	
NT 23 yr (maize/soybean/wheat)	5	nd	nd	22 ± 4 cde	nd	
Slightly disturbed forest (yr 1)	5	51 ± 27 cde	0.44 ± 0.32	13 ± 6 cde	0.66 ± 0.42	
Slightly disturbed forest (yr 2)	5	22 ± 16 cde	0.66 ± 0.45	nd	nd	
6. Private Farm (next to site 5)						Benito et al. (unpublished)
MT 3 yr (maize/soybean/wheat)	5	407 ± 154 a	nd	86 ± 39 bcde	0.40 ± 0.23	
MT 4 yr (maize/soybean/wheat)	5	nd	nd	26 ± 18 cde	nd	

Sample site **Soil management & Land use**	***n***	**Summer season (Nov–Apr)** **Density ± SE[1] (N° m^{-2})**	 **Biomass ± SE[2] (g m^{-2})**	**Winter season (Jun–Oct)** **Density ± SE[1] (N° m^{-2})**	 **Biomass ± SE[2] (g m^{-2})**	**Source**
7. Private Farm (next to site 5)						Benito (2002)
Pasture 12 yr (*Brachiaria* sp.)	5	48 ± 36.5 cde	0.82 ± 0.46	182 ± 66 abc	nd	
8. Renânia Farm (near Rolândia)						Guimarães et al. (2002)
NT 24 yr (with residues grazed)	5	nd	nd	3.2	0.63	
NT 24 yr (no grazing of residues)	5	nd	nd	13.4	0.47	
Pasture 10 yr (*Brachiaria brizantha*)	5	nd	nd	2.4	0.40	
Eucalyptus sp. dominated Forest	5	nd	nd	12.2	0.67	
OTHER (PREVIOUS) WORK						
9. IAPAR Research Station (Londrina)						Derpsch et al. (1984, 1991);
CT 5 yr (various rotations)	12	3	nd	nd	nd	Voss (1986)
MT 5 yr (various rotations)	12	5	nd	nd	nd	
NT 6 yr (various rotations)	12	28	nd	nd	nd	
Permanent cover crops	4	56	nd	nd	nd	
10. Marta Farm (near Rolândia)						Derpsch et al. (1991)
CT 1.5 yr (various rotations)	36	6	nd	nd	nd	
MT 1.5 yr (various rotations)	36	8	nd	nd	nd	
NT 3.5 yr (various rotations)	36	13	nd	nd	nd	
11. Private Farm (near Carambeí)						Voss (1986)
CT>4 yr (soybean/wheat)	?	nd	nd	0	nd	
CT>4 yr (wheat/maize)	?	nd	nd	0	nd	
NT 4 yr (soybean/wheat)	?	nd	nd	117	nd	
NT 4 yr (wheat/maize)	?	nd	nd	44	nd	
12. Frank'Ana Farm (near Carambeí)						Tanck et al. (2000)
CT>18 yr (maize/triticale/soybean)	5*	2 ± 1	0.1 ± 0.06	2 ± 1	0.19 ± 0.14	
NT 18 yr (maize/triticale/soybean)	5*	118 ± 20	31.1 ± 5.2	100 ± 19	26.2 ± 7.3	
Araucaria angustifolia native forest	5*	63 ± 8	38.5 ± 5.5	65 ± 15	34.5 ± 7.8	
13. Private Farm (next to site 12)						Tanck et al. (2000)
Native grassland	5*	0	0	0	0	
14. Decolores Farm (near Arapotí)						Peixoto & Marochi (1996)
NT 6.5 yr (rotation)	12	72	nd	nd	nd	
NT 7.5 yr (rotation)	12	168	nd	nd	nd	

[1] Values with different letters are significantly different (Tukey test, $P < 0.05$); [2] No significant differences; * Values are means of samples taken monthly from Feb–Apr 1993 (summer) & Jun–Sep 1993 (winter)

Table 2. Mean earthworm density (N° indiv. m-2) and biomass (g m-2) in the winter (dry) and summer (wet) seasons, in different tillage and land-use systems near Londrina (means of each land use system in samples from Sites 1–7), N Paraná

Season Land use System	**N° locations** (*n*)	**Density ± SE**[1] (N° m-2)	**N° locations** (*n*)	**Biomass ± SE**[2] (g m-2)
Winter (dry)				
NT	8 (41)	46 ± 8 bc	7 (36)	0.49 ± 0.20
MT	3 (14)	42 ± 17 bc	2 (9)	0.68 ± 0.45
CT	3 (12)	13 ± 7 c	3 (12)	0.13 ± 0.08
Forests	2 (12)	16 ± 3 c	2 (11)	1.56 ± 0.82
Pasture	1 (5)	182 ± 66	0	nd
Summer (wet)				
NT	5 (24)	116 ± 27 ab	4 (18)	1.06 ± 0.24
MT	4 (18)	179 ± 54 a	4 (18)	1.05 ± 0.38
CT	3 (14)	22 ± 11 c	2 (8)	0.02 ± 0.01
Forests	3 (17)	42 ± 11 bc	3 (17)	0.83 ± 0.31
Pasture	1 (5)	48 ± 36	1 (5)	0.82 ± 0.47

[1] Values with different letters differ significantly at P<0.05 (Tukey Test). Pastures were excluded from the analysis.
[2] Biomass values were not significantly different

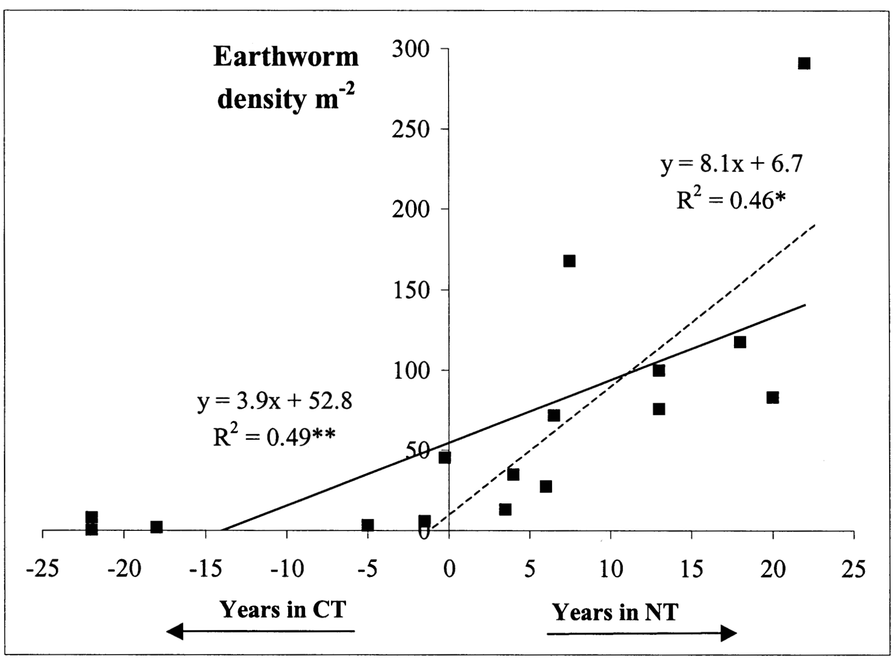

Fig. 1. Relationship between age (in yr) of NT alone (dotted line) or combined with age of CT (solid line; represented as negative numbers) and the abundance of earthworms in the wet season at various sites in E and N Paraná State (n = 16 total; n = 10 for NT). *P < 0.05, **P<0.01

Comparing the results for the sites that were field cultivated (MT) vs. disk (CT) plowed, it can be seen that the field cultivator used in MT (every yr or every 3 yr) is much less damaging than the disk plow, which seems to eradicate or greatly reduce earthworm populations. At Site 5, the one-time use of a field cultivator (fc) preserved earthworms, while the disk plow (d) eliminated their populations (NTfc vs. NTd). At Site 11, no worms were found in CT, while in NT, up to >100 m-2 were recovered, after only 4 yr of NT. The presence of more permanent vegetation cover showed a trend for positive effects on earthworm abundance, compared to areas with sparser cover or annual cropping (e.g., no grazing of residues at Site 8 and permanent cover crops at Site 9). Small differences in the cropping systems adopted (e.g., more complex rotations vs. double crops), appeared to have an effect in isolated cases, but the low number of replicates did not permit adequate detection of significant differences. These were further complicated by the year-to-year sampling variation in abundance, observed at several locations (Sites 1, 5, 6, 14).

Discussion

Increased earthworm populations due to adoption of reduced (minimum) or NT practices have frequently been observed throughout the world (Chan 2001). The present study confirms this trend for the E and N region of Paraná state, under subtropical climate conditions. This region has the oldest NT farms in Latin America (up to 30 yr old), and the age of NT practices was positively related with earthworm abundance.

The adoption of NT gradually increases earthworm populations, as the naturally occurring individuals grow and reproduce under the more favorable soil environmental conditions found in NT, including greater moisture retention, surface litter protection, greater food resources and lack of disturbance (House & Parmelee 1985). NT systems lead to increases in soil C in the topmost layers in both E and N Paraná regions (Sá 1993), and this may be an important factor positively influencing populations under NT compared with CT systems which, over the long-term, decrease soil C stocks (Hendrix et al. 1992). The present data confirm a positive relationship between soil % C at 0–10 cm and earthworm populations in Paraná state, especially at the local level, where samples were taken in the same soil and climate types. Combining samples from different sites tends to dilute this relationship, as they often include different climatic conditions, earthworm species and/or soil types (Zou & González 2001). This may be the reason for the lower coefficient observed when data from both N and E Paraná regions were combined. The measurement of C in different particle size fractions might help clarify this relationship, since earthworms show preference for specific size fractions of C (Barois et al. 1999) that can be preferentially altered in NT systems (Sá et al. 2001).

The exotic widespread anthropochorous Asiatic *Amynthas* spp. (*A. hawayanus* and *A. difringens*) worms, widely sold as fish bait to clients of the many fish farms around Londrina (and all over Paraná), can be found in disturbed secondary forests and many city/house gardens (G. Brown, personal observation), where OM contents and protection (from sunlight and disturbance) are higher. However, the hotter climate around Londrina, with higher mean annual temperatures and a small dry season in the winter, tend to reduce the amounts of OM left on the soil surface in NT (Sá 1993), creating conditions which probably limit *Amynthas* spp. colonization and survival in the region. These species predominated in both NT and forests in the E region with a cooler climate. No native earthworms were reported at the sites sampled in E Paraná, although they have been found in recent sampling efforts (G. Brown, personal observation). Under NT management, *Amynthas* spp. populations reached 44–168 indiv. m^{-2} and up to >30 g m^{-2} (summer season means).

Since *Amynthas* spp. earthworms have been shown to have a moderate potential to increase plant production (Brown et al. 1999), and mean annual biomass of these earthworms was often high under NT in E Paraná, it is likely that these earthworms have important effects on grain yields in these systems. This was confirmed by Peixoto & Marochi (1996), where soil conditions and yields of several plants were compared in two areas under NT with or without invading *Amynthas* spp. (Site 14). These authors found that where earthworms had invaded, soybean yields were 51, 47 and 22 % higher over a 3-year consecutive period, than where they were absent. Biomass of black oats and wheat, grown in the winter was also significantly higher in the presence of earthworms. Soil aggregation, infiltration and soil fertility were also higher in the areas with earthworms, where practically the whole top 10 cm of the soil consisted of earthworm casts.

To the authors' knowledge, this is the only such study involving earthworms in a large-scale commercial NT system in the tropics. Given the recent boost towards wide-spread adoption of NT practices both in Latin America and Africa, and the consequent increase in earthworm populations in these systems, further work on their potential beneficial effects to soil properties and processes and plant growth is warranted. Furthermore, means should be sought to enhance populations of naturally-occurring earthworms (especially native spp.), which could prevent invasion of the exotic *Amynthas* where they are not desired (e.g., areas with predominance of native species that might be negatively affected by invasion of exotics). Where desired, *Amynthas* could be either vermicultured or collected *en-masse* and inoculated into the field to promote decomposition and incorporation of surface OM and crop residues in NT systems, enhancing soil fertility and crop yields. In N Paraná, introduction of *Amynthas* worms must be accompanied by cropping practices that enhance soil cover and surface OM levels, so that the introduced individuals find a suitable environment for feeding, growth and reproduction.

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