Effect of exclusion of the anecic earthworm *Martiodrilus carimaguensis* Jiménez and Moreno on soil properties and plant growth in grasslands of the eastern plains of Colombia

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Summary. The effects of a deep-burrowing earthworm species, *Martiodrilus carimaguensis*, on soil fertility and plant growth were assessed in two grasslands in the Eastern Plains of Colombia. This species aestivates deep in the soil during the dry season. Fibre glass netting was used to prevent colonisation of the top soil at the onset of the humid season. Effects of earthworm absence on soil properties and plant biomass were analysed with principal component analysis.

Experimental manipulation succeeded in preventing *M. carimaguensis* activity in the top soil. The larger part of the variance in our data (29.35%) was explained by the effect of pasture type and age on soil structure and organic matter. A lesser part (10.81%) was due to the effect of legumes on soil physical properties. The effect of earthworm absence on soil properties and plant growth explained 16.36% of the total variance. *M. carimaguensis* biomass was associated with low soil compaction, high C contents, low Al saturation, high herbaceous biomass and low weed biomass. These results support the general knowledge of how earthworms can affect soil fertility and plant growth.

Key words: Anecic earthworms, soil fertility, soil ecology, tropical grasslands, earthworm manipulations

Introduction

Most studies of the impact of earthworms on soil have been conducted in short-term pot experiments (e.g. Pashanasi et al. 1992; Spain et al. 1992; Derouard et al. 1997). Despite the significant advances this approach has made in the understanding of the role of earthworms in soil processes, there is still a lack of understanding of how these organisms may influence ecosystem processes in *in-situ* field conditions (Bohlen et al. 1995).

Our objective was to assess an innovative method (Baker 1998) to selectively exclude anecic earthworms (sensu Bouché 1977) from small experimental units. The efficiency of the method is discussed in relation to its ability to eliminate the large anecic earthworm *Martio-
odrilis carimaguensis Jiménez and Moreno from the top-soil of two grass-legume based pastures in the Eastern Plains of Colombia. At Carimagua, populations of this species are enhanced in intensive pastures and dramatically depleted in annual crops (Jiménez et al. 1998a). The effects of the disappearance of this species on soil properties and plant growth was assessed and compared with the effects of other environmental factors.

Materials and Methods

Study site

The study was carried out at the CIAT-CORPOICA research station of Carimagua, Eastern Plains, Meta, Colombia (4° 37’ N, 71° 19’W). The climate is humid tropical with an annual mean temperature and rainfall of 26°C and 2300 mm respectively (CIAT data). Native vegetation is a patchwork of open savannas and gallery forests. Soils are well aggregated Oxisols with high acidity and very low chemical fertility.

Experimental plots and design

This experiment was carried out in two pastures each grazed by cattle with 2.0 animal unit. ha⁻¹: (A) A 3 year-old pasture of Brachiaria humidicola, Arachis pintoi, Stylosanthes capitata and Centrosema acutifolium; (B) A one year-old pasture of Panicum maximum and Arachis pintoi.

The background ecology of the earthworm species of Carimaguas are available in Jiménez et al. (1998a, b). All species aestivate during the dry season. The anecic M. carimaguensis burrows deep into the soil profile (60–100 cm) and falls into diapause until the next wet season (Jiménez et al. 1998b). Our idea was to prevent individuals from returning to the top soil at the onset of the rains. As other species aestivate in superficial soil layers, we expected this experiment to have specific effects on M. carimaguensis.

Twelve small experimental units were established in each pasture at the end of the dry season (early March 1996) and submitted to grazing pressure. The protocol is synthesised in Fig. 1: (1) a 40 x 40 x 30 cm soil monolith was dug out with a spade; (2) the monolith sides (except the top side) were wrapped up in a fibre glass netting of 0.5 mm mesh; (3) the monolith was placed in a hole, and surface earthworm movements were avoided by surrounding the units with a buried metallic plate; (4) an area was delimited where individuals of M. carimaguensis (located by the presence of fresh casts, Jiménez et al. 1998b) were systematically controlled by injecting 0.01 g of active carbofuran in their burrow. Twelve plots were also established without fibre glass netting as controls. Plot location was randomly chosen in the field, avoiding the field edges.

Soil and vegetation were sampled before, 6 months and 18 months after the experiment was established (respectively October 1995, August 1996 and June 1997). At each date, four units were randomly chosen in each pasture. Samples aimed at characterising vegetation (shoot and root biomass), soil properties (bulk density, aggregate mean weight density, penetration resistance, sorptivity, infiltration, chemical properties) and earthworm (density and biomass), ant and termite populations (number of chambers). Methods were standardised methods recommended by the TSBF (Tropical Soil Biology and Fertility) program (Anderson & Ingram 1989). All samples were repeated 4 fold.

Statistics

The effect of the experimental manipulation on both earthworm biomass and the abundance of ant and termite chambers was tested using the Fisher PLSD test. Asymmetry of data frequency distribution was reduced by Box-Cox transformation (Sokal & Rohlf 1995) with the software Vernorn (Legendre & Vaudor 1991). The Bonferroni procedure for nested tests was used and the adjusted 0.05, 0.01 and 0.001 significance levels were respectively: 0.008, 0.002 and 0.0002.

A Principal Component Analysis (PCA) was performed with ADE software (Thioulouse et al. 1997) to extract the principal source of variance in the environmental data sets. We used a matrix of 40 lines (samples) x 23 columns (soil and vegetation variables). The biomass of each earthworm species and the abundance of ant and termite chambers were projected on the PCA axes as additional columns. Simple linear regressions were used to test the correlations between faunal parameters and PCA axes.
Results

Only one individual of *M. carinaguensis* was found in the experimental units at the end of the study. Due to the large size of *M. carinaguensis*, slight decreases in the density of this species resulted in sharp decreases in overall earthworm biomass (from -89% to -100%, p < 0.01) (Fig. 2a, 2b). Differences observed for other earthworm species (Fig. 2a, 2b) and social arthropods (not shown) were not significant.

Axis 1 of the PCA accounted for 29.33% of the total inertia (Table 1). The correlation ratio associated with the variables showed negative relationships between (i) high gramineous, herbaceous and root biomass, high bulk density in the 5–10 cm layer, high penetration resistance, high pH and available nutrient content, and (ii) high aluminium saturation (Fig. 3a, Table 1).

Ordination of the sample scores showed a separation between (i) samples taken in the first two dates and those taken later (Fig. 3b), and (ii) samples taken in the pasture A and in the pasture B (Fig. 3c). This axis was interpreted as the effect of pasture characteristics and age on soil physical and chemical properties.

Axis 2 accounted for 16.52% of the total inertia (Table 1). It opposed (i) high weed biomass, high bulk density, high penetration resistance, high total N content and high aluminium saturation to (ii) high herbaceous (legume and gramineous) and root biomass, high total C content and high mean diameter of soil aggregates (Fig. 3a, Table 1). It clearly segregated samples taken inside the exclusion units with those taken in the control units (Fig. 3d), and was defined as the effect of the exclusion of *M. carinaguensis* on soil fertility and plant growth.

Axis 3 accounted for 10.81% of the total inertia. It was driven by the abundance of legumes in the plant cover and the soil hydraulic properties (sorptivity and infiltration) (Table 1).
Fig. 2. Density (a) and biomass (b) of each earthworm species in the experimental units with (+) and without (−) netting, at each sampling date and in the two pastures (N = 8 for 0 m and 4 for the other sampling dates; ind. = individuals; fm = fresh matter; 0 m = before; 6 m = 6 months; 18 m = 18 months)

Table 1. Relative inertia for each of the three first axes (in brackets) and correlation ratios associated with the variables included in the principal correspondence analysis (PCA)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Code</th>
<th>Axis 1 (29.33%)</th>
<th>Axis 2 (16.52%)</th>
<th>Axis 3 (10.81%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graminina biomass</td>
<td>GB</td>
<td>−0.751</td>
<td>−0.447</td>
<td>−0.039</td>
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<tr>
<td>Legume biomass</td>
<td>LB</td>
<td>−0.173</td>
<td>−0.402</td>
<td>−0.709</td>
</tr>
<tr>
<td>Weed biomass</td>
<td>WB</td>
<td>−0.086</td>
<td>0.402</td>
<td>0.044</td>
</tr>
<tr>
<td>% of legumes</td>
<td>%L</td>
<td>0.080</td>
<td>−0.101</td>
<td>−0.796</td>
</tr>
<tr>
<td>Herbaceous biomass</td>
<td>HB</td>
<td>−0.748</td>
<td>−0.464</td>
<td>−0.191</td>
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<tr>
<td>Root biomass</td>
<td>RB</td>
<td>−0.707</td>
<td>−0.500</td>
<td>−0.245</td>
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<tr>
<td>Soil chemical properties (0–5 cm)</td>
<td></td>
<td></td>
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<tr>
<td>pH</td>
<td></td>
<td>−0.786</td>
<td>0.159</td>
<td>0.114</td>
</tr>
<tr>
<td>Total C content</td>
<td>C%</td>
<td>−0.168</td>
<td>−0.359</td>
<td>0.018</td>
</tr>
<tr>
<td>Total N content</td>
<td>N%</td>
<td>−0.188</td>
<td>0.532</td>
<td>−0.089</td>
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<tr>
<td>Total P content</td>
<td>TP</td>
<td>−0.738</td>
<td>0.190</td>
<td>0.030</td>
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<tr>
<td>Al saturation</td>
<td>Al</td>
<td>0.025</td>
<td>0.493</td>
<td>−0.360</td>
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<tr>
<td>Ca content</td>
<td>Ca</td>
<td>−0.817</td>
<td>−0.332</td>
<td>0.217</td>
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<tr>
<td>Mg content</td>
<td>Mg</td>
<td>−0.803</td>
<td>−0.347</td>
<td>0.262</td>
</tr>
<tr>
<td>K content</td>
<td>K</td>
<td>−0.336</td>
<td>−0.182</td>
<td>0.251</td>
</tr>
<tr>
<td>Soil physical properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk density (0–5 cm)</td>
<td>BD0</td>
<td>−0.281</td>
<td>0.518</td>
<td>−0.131</td>
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<tr>
<td>Bulk density (5–10 cm)</td>
<td>BDC</td>
<td>−0.612</td>
<td>0.515</td>
<td>−0.091</td>
</tr>
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<td>Mean weight diameter of aggr. (0–10 cm)</td>
<td>MWD</td>
<td>−0.054</td>
<td>0.377</td>
<td>0.167</td>
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<tr>
<td>Penetration resistance (0–15 cm)</td>
<td>PRO1</td>
<td>−0.623</td>
<td>0.538</td>
<td>0.205</td>
</tr>
<tr>
<td>Penetration resistance (15–30 cm)</td>
<td>PRO5</td>
<td>−0.651</td>
<td>0.499</td>
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<td>Penetration resistance (30–60 cm)</td>
<td>PRO30</td>
<td>−0.464</td>
<td>0.400</td>
<td>−0.198</td>
</tr>
<tr>
<td>Penetration resistance (0–60 cm)</td>
<td>PRO6</td>
<td>−0.703</td>
<td>0.579</td>
<td>−0.021</td>
</tr>
<tr>
<td>Sorpitivity</td>
<td>S</td>
<td>−0.164</td>
<td>−0.171</td>
<td>−0.645</td>
</tr>
<tr>
<td>Infiltration constant</td>
<td>A</td>
<td>−0.174</td>
<td>0.030</td>
<td>−0.579</td>
</tr>
</tbody>
</table>

838 Pedobiologia 43 (1999) 6
This axis was interpreted as the effect of legumes on soil physical properties. Samples were not ordinated along this axis according to a logical scheme as was the case for the first two axes (not shown).

When projected on the plane defined by the axes 1 and 2 of the PCA (insert in the fig. 3a) the biomass of *M. carinaguensis* was negatively correlated with axis 2 (Fig. 3a). This negative relationship was confirmed by the regression coefficients ($r = 0.63; p < 0.01$). The biomass of other earth worm species and the abundance of social insect chambers were located near the axes intersections, showing that these variables were not correlated with any of them (Fig. 3a). No significant correlations were found between faunal biomass and the third PCA axis.
Discussion

Field experiments are pertinent for evaluating earthworm effects on soil parameters and plant growth. This may be very useful in assessing the role of earthworms on primary production in both natural and managed ecosystems (Bohlen et al. 1995). In our study, preventing vertical movements of earthworms at an appropriate time and depth was an efficient method to eliminate a targeted anecic species.

The main factors influencing soil properties were pasture type and age. This may be due to plant specific effects, soil protection by the plant cover, litter quality and production, and the cumulative effects of animal trampling that may be different according to the history and the nature of pastures (Sánchez et al. 1991; Gijsman 1996; Gijsman & Thomas 1996). The effect of legumes on soil physical properties was of third importance. This may be explained by the effect of root channels that increase soil macroporosity and permeability (Mytton et al. 1993).

Disappearance of M. carinaguensis resulted in significant changes in soil properties and plant biomass, although this impact was of secondary importance when compared with pasture effect. The decrease in earthworm biomass was associated with soil degradation (increased soil compaction and aluminium saturation, decreased carbon content) and herbaceous biomass. Decrease of plant biomass, in turn, favoured opportunistic weed species. These results are consistent with the general knowledge of how earthworms can influence soil properties and plant growth (see reviews by Lee 1983; Lal 1988; Edwards & Bohlen 1996; Lalvelle 1997). It demonstrates that the loss of one species in an earthworm community, when it is associated with an important decrease in biomass, may result in significant losses in ecosystem function. The rapidity and intensity of the effects observed in our study, however, may have been accentuated by intensive animal trampling. In natural undisturbed conditions, earthworm impacts on soil processes are known to be persistent on a longer time scale (i.e. several months to years) (Blanchart 1992).

Earthworm populations are highly sensitive to land use practices (see, e.g. Lavelle & Pas- hanski 1989; Reddy et al. 1995). At Carimaguá, native species biomass is greatly increased in man-made pasture or, in contrast, dramatically decreased in annual crops (Decaëns et al. 1994; Jiménez et al. 1998a). Such impacts may have determinant consequences on soil function and primary production (Lavelle 1996; Lalvelle 1997). Attention should now be paid to managing earthworm populations in tropical agroecosystems in order to profit from their impacts on soil fertility and enhance the sustainability of agricultural production.

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References


