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HOW TO EVALUATE THE ROLE OF EARTHWORMS IN THE ELIMINATION OF HIGLY COMPACTED ZONES IN FIELD CONDITIONS

Y. Capowiez[1 (*)], S. Cadoux[2], P. Bouchant[2], H. Boizard[2], J. Roger-Estrade[3] and G. Richard[4]

[1]*UMR INRA / UAPV Laboratoire de Toxicologie Environnementale UAPV Site Agroparc F-84914 Avignon cedex 09*
[2]*INRA, Unité d'Agronomie de Laon-Péronne, F-80200 Estrées-Mons*
[3]*UMR INRA-INAPG, Laboratoire d'Agronomie, BP 01, F-78850 Thiverval-Grignon*
[4]*INRA, Unité de Science du Sol, Ardon, BP 20619, F-45166 OLIVET Cedex*

Abstract

Earthworms as ecosystem engineers influenced a great number of physical, chemical and biological processes in soil. It is often claimed that earthworms can have a great influence on the elimination of compacted zones in the soil. We wanted to put this assumption to the test. A field experiment was initiated in 1989 in northern France to evaluate the effects of cropping systems on the structure of the tilled layer in a loamy soil. Three levels of compaction were considered depending on the rotation and on the time of field operations because of high axle loads. Tillage (and no-tillage) was considered as a second factor. Earthworm populations were sampled in the different systems. If densities were high (between 100 and 400 ind./m2), only four earthworms species were found (*L. terrestris*, *N. giardi*, *A. rosea* and *A. caliginosa*). Tillage had a small negative effect on earthworm density (especially on N. giardi which seemed to be very sensitive). The cropping system (and level of compaction) had almost no effect on earthworm density but we observed that A. caliginosa was almost absent from cropping system II and III in reduced tillage. To determine if the remaining worms could decrease the importance of compacted zones, observations of macroporosity were made on horizontal planes at different depths. We observed that macroporosity was significantly higher in reduced tillage plots. To go further, a controlled compaction experiment was carried out in the field. Then, number of earthworms and macropores were counted regularly (every season) and compared between wheel and inter-wheel zones. We observed that if recolonization by earthworms is a rapid process, the related increase in macroporosity is much slower.

- ***Corresponding author. Tel + 33 4 32 72 26 16 ; Fax : + 33 4 32 72 26 02 ; Email :*** **capowiez@avignon.inra.fr**

Introduction

The structure of the tilled layer of cultivated fields changes with time because of human actions (tillage, compaction due to field traffic) and weathering, root growth and fauna activity (especially earthworms). Mechanised cultivation produces stresses within the soil which cause fragmentation, compaction and displacement of the soil. A long term field experiment was conducted in Northern France since 1989 to evaluate the cumulative effects of cropping systems on the structure of the ploughed layer in a plough tillage system and showed that the change in soil structure in a plough tillage system depend to a large extent on the scheduling of cultivation operations. Plots with late harvesting in autumn had the highest proportion of highly compacted zones which varied in the experiment from 20 and 70%. But the highly compacted zones could quickly disappear from the ploughed layer. The question arises whether earthworms are responsible for quick disappearance. Because (i) Northern France is an area of intensive agriculture with an oceanic climate and loess soils where compaction frequently occurs and (ii) increasing proportion of farmers abandons mouldboard plough tillage system, there is a need to better understanding change in soil structure with no-till or reduced tillage systems. The Estrées-Mons long term experiment was altered in 1999: ploughing was suppressed on half of the experimental plots, while it was continued on the other part. Tillage was reduced to 0-5 cm superficial cultivation in RT treatment when the same cultural operations were maintained in CT treatments.

If we want to clearly understand (and model) changes in soil structure, it is necessary to evaluate the role of earthworm in these processes. First of all, we studied which species or ecological types (anecic and endogeic) are present in function of different agricultural practices (tillage and cropping systems) and then we focused on the evolution of earthworm communities in a very compacted zones to gain insight into the dynamics of re-colonisation and their effects in term of macroporosity.

2. Materials and Methods

2.1 Site and soil

The field experiment began in 1989 in northern France at the INRA experimental centre of Estrees-Mons (Péronne, 50°N latitude, 3°E longitude, 85 m elevation). Three cropping systems were compared from 1990 to 2005 (Boizard et al., 2002).

- cropping system **I**. The rotation was pea (*Pisum sativum L.*)/winter wheat (*Triticum aestivum*)/rape (*Brassica Napus L.*)/winter wheat. Rape was replaced by linen (*Linum usitatissimum*) in 1999. Sowing and harvesting were always carried out in summer or early autumn, i.e. during a dry period of the year. Pea and linen sowing were managed so as to avoid sowing and harvesting in wet conditions.

- cropping systems **II** and **III**. The rotation was sugar beet (*Beta vulgaris L.*)/winter wheat/maize (*Zea mays L.*)/winter wheat. Cropping system **II** was managed so as to avoid sowing and harvesting in wet conditions. Cropping system **III** was managed so as to maximise light interception by sugar beet and maize: sugar beet and maize were sown in early spring and harvested in late autumn, during wet periods of the year.

Each crop was grown every year, giving 12 treatments. The experimental design consisted of two blocks (total of 24 0.40 ha. plots) with a plough tillage system up to 1999. From 1999 the plough tillage system was continued in the first block and reduced tillage system was introduced in the second block. The plot size made it possible to reproduce the traffic patterns of machinery found in commercial farms.

The soil was classified as a silt loam (Luvisol Orthic, FAO classification). It contained an average of 190 g clay kg^{-1}, 738 g silt kg^{-1}, 50 g sand kg^{-1}, 17 g organic matter kg^{-1}, 5 g $CaCO_3$ kg^{-1} and had a pH of 7.6. Soil water contents at -10, -50, -100 and -1500 kPa were 0.252, 0.213, 0.164 and 0.083 g g^{-1} respectively.

The long-term average annual air temperature at the site is 9.6°C and the annual rainfall is 667 mm. The climate was much contrasted during the 2000-2005 years period with especially three dry years

in 2003, 2004 and 2005. The annual rainfall from 2000 to 2005 was 733, 802, 720, 414, 498 and 483 mm respectively and the autumn rainfall (September, October and December) was 262, 242, 201, 82, 101 and 99 mm.
For this experiment, only 6 plots were analysed. Observations (earthworms sampling and macroporosity estimations) were carried out at 4 dates (autumn 2003, spring and autun 2004 and spring 2005).
In one of the plot, we performed a controlled compaction experiment. Compacted was caused by a vehicle (weight = 8 t) in humid conditions. Four compacted zones (under the wheels) of 20 m length were obtained and were compared with uncompacted (between the wheels) zones.

2.2 Earthwormsand macroporositymeasurements
Earthworms were sampled using diluted mustard (15 g/l) as a repellent. After 30 mn, the soil was dug and carefully sorted to find earthworms that did not go to the surface (depth = 30 cm). In each plot at each date, 4 sampling zones (40 cm x 40 cm) were analysed near to the zone where observations of soil structure were carried out (Boizard et al 2006). Only 4 earthworms species were find in the plots, 2 anecic species (*Lumbricus terrestris* and *Nicrodrilus giardi*) and 2 endogeic one (*Aporrectodea caliginosa* and *Aporrectodea rosea*). It was difficult to discriminate very small juveniles (< 0.1 g) coming from the two endogeic species and therefore we classed into a “juvenile endogeic” category.
To estimate macroporosity related to earthworm activity, four horizontal planes (20 cm x 20 cm) were gently scratched with a knife and “cleaned” by an air-vacuum at four depths (-10, -20, -30 and -40 cm) in each plot. Photographs were then taken (at a distance of 40 cm). Images were analysed with the freeware NIH-Image and macropores were manually underlined (according to their shape) to estimate macropore number and area. Cracks were discarded.

3. Results

3.1 Effects of tillage and cropping system on earthworm communities and macroporosity

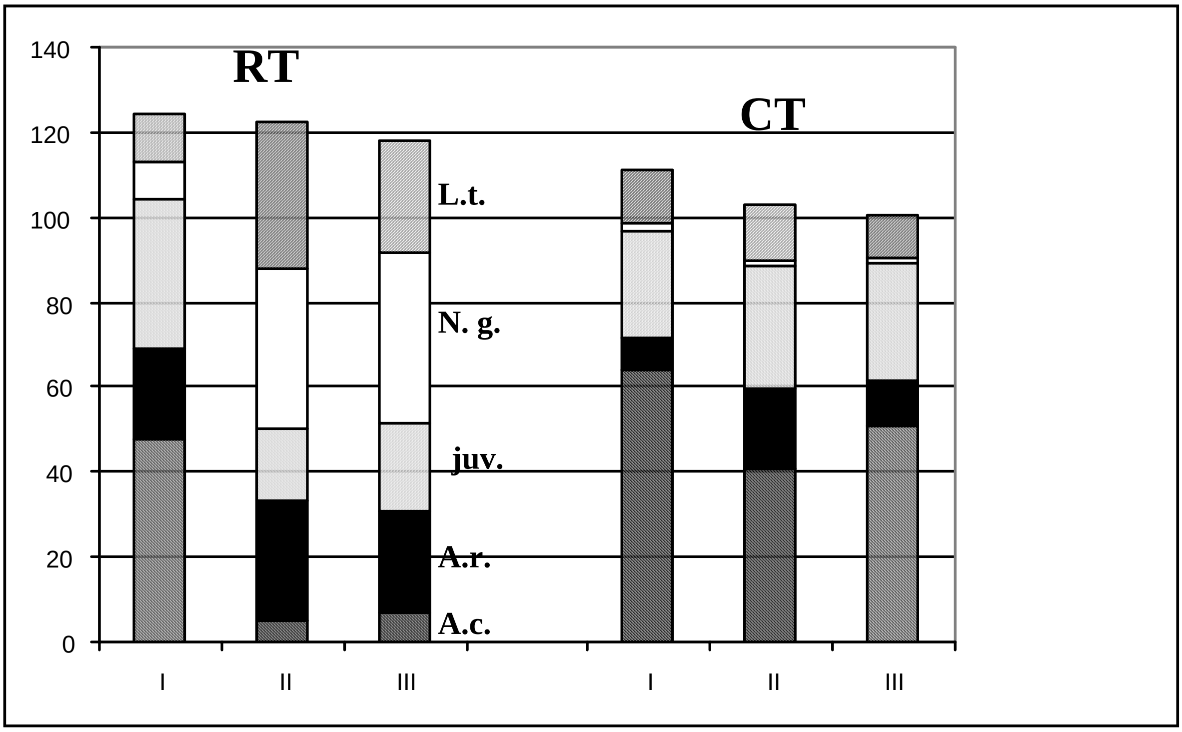

Figure1. Mean earthworm densities (m^{-2}) in conventional (CT) or reduced timlmage (RT) and the 3 different cropping systems (I,II and III) (right dashed = *L. terrestris* ; white = *N. giardi* ; dotted = juvenile endogeic ; black = *A. rosea* and left dashed = *A. caliginosa*).

Cropping systems has consequences on soil compaction (see Boizard et al 2006): cropping system II and III has statistically more compacted (delta) zones. As far as total earthworm abundance is concerned, tillage and cropping systems have very limited effects (Figure 1). However some earthworm species were more or less sensitive to tillage and cropping systems. Anecic species were less present in conventional tillage plots (as described by Chan 2001) even if *L. terrestris* seems to be less sensitive than *N. giardi*. Cropping system has not clear effect in conventional tillage but we observed in reduced tillage that *A. caliginosa* populations were greatly decreased in cropping system II and III contrarily to the two anecic species and especially *N. giardi* whose populations increased in these cropping systems.

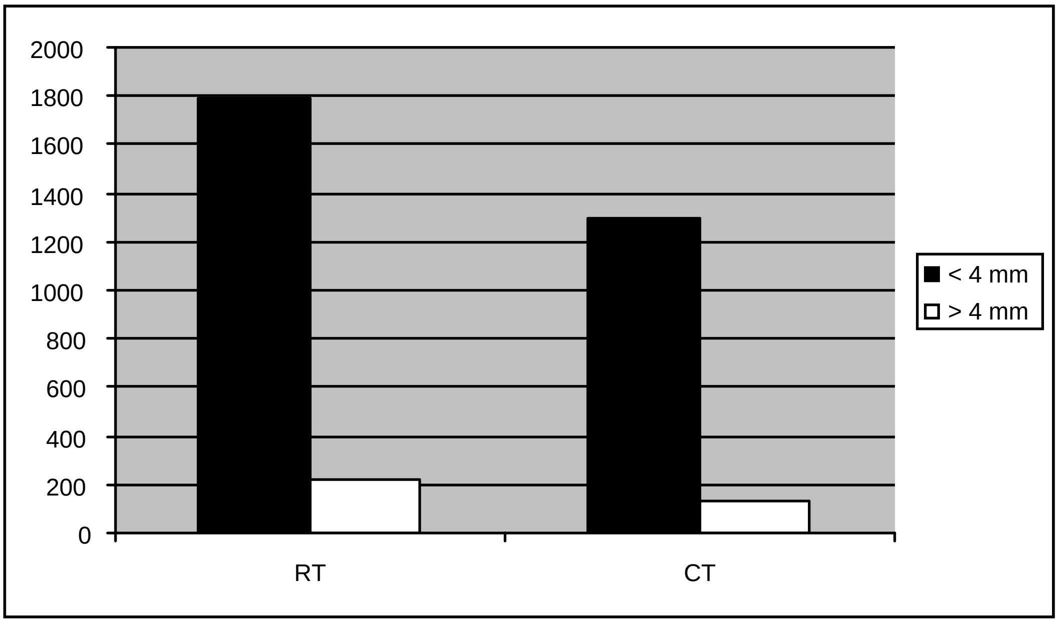

Figure 2. Mean number of macropore (m-2) in reduced (RT) or convetional tillage (CT). Two classes of equivalent pore diameter are considered.

Regarding macroporosity, macropores between 2 mm (limit for visual detection in the images) and 4 mm are far more numerous that bigger pores (Figure 2). No significant difference was observed for cropping system (results not shown). Tillage has a significant effect for both size classes: the number of macropores was decreased in CT. This effect is not only due to difference in earthworm abundances but was related to the fact that tillage has as well a direct effect by destroying macropores.

3.1 Effects of tillage and cropping system on earthworm communities and macroporosity

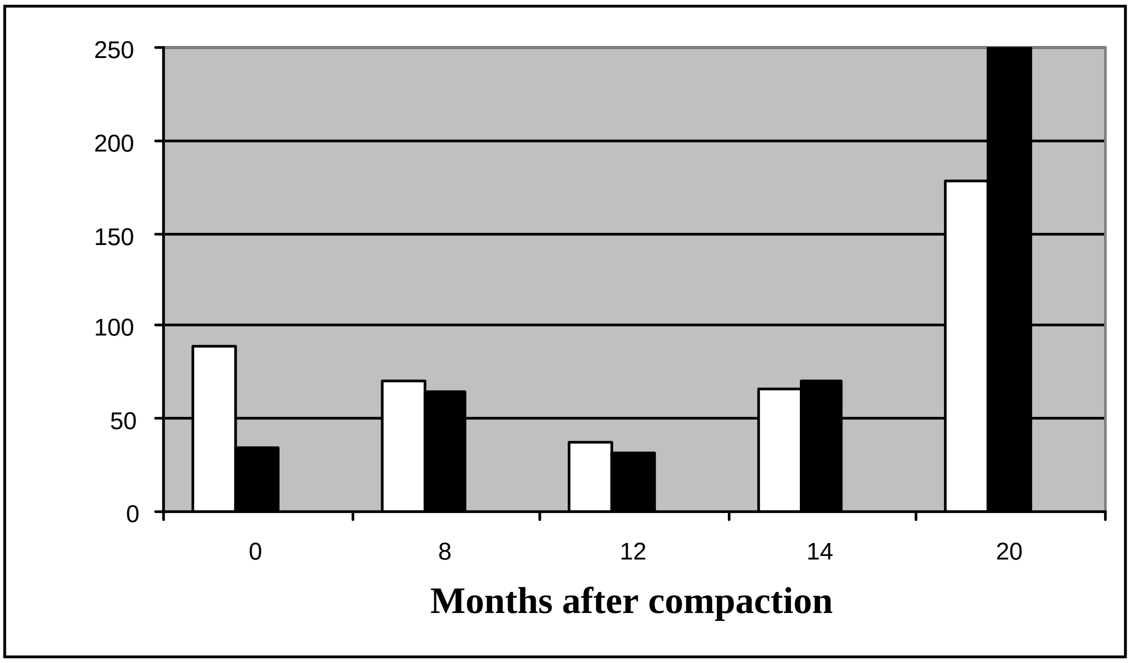

Figure 3. Mean earthworm densities (m^{-2}) in compacted (black) and uncompacted (white) zones with time.

Soil density in the compacted zone (1.61) was significantly higher than in uncompacted zones (1.49). A few days after compaction, we observed a significant decrease in earthworm numbers in compacted zones (-60%). This difference completely disappeared 8 months after compaction (Figure 3). The compacted zones (width = 30 cm) were rapidly re-colonized by earthworms.

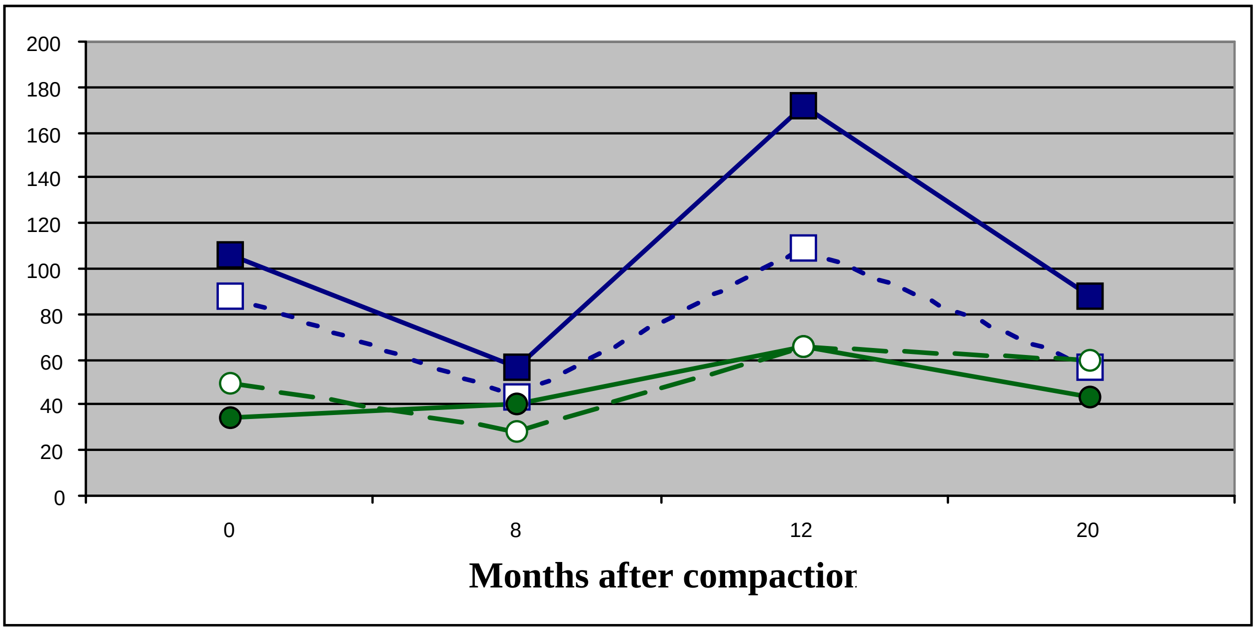

Figure 4. Mean number of macropore (m^{-2}) at –10 cm (plain) and – 20 cm depth (dashed lines) in uncompacted (squares) and compacted (circles) zones.

It was surprising to observe a seasonality in number of earthworm macropores in uncompacted zones (Figure 4). There was a decrease in macropore number between spring and autumn. Comparing macropores number in compacted and uncompacted zones revealed that the number of macropores remained higher in uncompacted zones during 20 months for the horizontal planes at –

10 cm depth. For the deeper horizontal plane, we observed that the numbers of macropores became very similar only 20 months after compaction.

Conclusions

Tillage and cropping systems had limited effect on earthworm abundances but different effects can be observed for different earthworm species. However it should be noted that the system effect reported here is not only linked to soil compaction. There are other differences between cropping system I on one hand and cropping systems II and III on the other hand: crops and therefore pesticides could also have an effect on earthworm communities and activities.

Regarding the controlled compaction experiment in the field, we concluded that even if re-colonisation by earthworms can be rapid in field conditions, the retrieval of macroporosity is a much slower process. This means that estimating earthworm communities only is not sufficient to fully understand the processes that earthworm can influence and their dynamics.

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