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The effect of tillage type and cropping system on earthworm communities, macroporosity and water infiltration

Yvan Capowiez [a,*], Stéphane Cadoux [b], Pierre Bouchant [b], Stéphane Ruy [c], Jean Roger-Estrade [d], Guy Richard [e], Hubert Boizard [b]

[a] INRA, UR 1115 Plantes et Systèmes Horticoles, Domaine Saint Paul, 84914 Avignon Cedex 09, France
[b] INRA, US 1158 Agro-Impact, 2 Chaussée Brunehaut, Estrées-Mons, BP 50136, 80203 Péronne Cedex, France
[c] INRA, UMR Climat-Sol-Environnement, Domaine Saint Paul, 84914 Avignon Cedex 09, France
[d] AgriParisTech, département SIAFEE, Bâtiment EGER, BP 01, 78850 Thiverval-Grignon, France
[e] INRA, UR 0272 Science du Sol, 45166 Olivet, France

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ABSTRACT

To test the assumption that changes to earthworm communities subsequently affect macroporosity and then soil water infiltration, we carried out a 3 year study of the earthworm communities in a experimental site having six experimental treatments: 2 tillage management systems and 3 cropping systems. The tillage management was either conventional (CT; annual mouldboard ploughing up to −30 cm depth) or reduced (RT; rotary harrow up to −7 cm depth). The 3 cropping systems were established to obtain a wide range of soil compaction intensities depending on the crop rotations and the rules of decision making. In the spring of 2005, the impact of these different treatments on earthworm induced macroporosity and water infiltration was studied. During the 3 years of observation, tillage management had a significant effect on bulk density (1.27 in CT and 1.49 mg m^{-3} in RT) whereas cropping system had a significant effect on bulk density in RT plots only. Tillage management did not significantly affect earthworm abundance but significantly influenced the ecological type of earthworms found in each plot (anecic were more abundant in RT). On the contrary cropping system did have a significant negative effect on earthworm abundance (104 and 129 ind. m^{-2} in the less and most compacted plots, respectively). Significantly higher numbers of *Aporrectodea giardi* and lower numbers of *Aporrectodea caliginosa* were found in the most compacted plots. CT affected all classes of porosity leading to a significant decrease in the number of pores and their continuity. Only larger pores, with a diameter superior to 6 mm, however, were adversely affected by soil compaction. Tillage management did not change water infiltration, probably because the increase in macroporosity in RT plots was offset by a significant increase in soil bulk density. However, cropping system had a significant effect on water infiltration (119 vs 79 mm h^{-1} in the less and most compacted plots, respectively). In RT plots, a significant correlation was observed between larger macropores (diameter > 6 mm) and water infiltration illustrating the potential positive effect of earthworms in these plots.

1. Introduction

With the intensification of arable land use over the last four decades, deterioration of soil fertility has emerged as a major issue. There is therefore a need for sustainable farming systems with practices that exploit the natural biotic mechanisms to maintain soil structure, fertility and drainage (Pfiffner and Luka, 2007). Presently there is an increasing interest in new soil conservation management practices such as minimum or zero-tillage or control traffic farming. There is some evidence that these practices can lead to increased earthworm populations because earthworms are substantially influenced by changes in their habitat (mainly soil structure and soil organic matter content). In particular, it is well known that tillage (type and intensity) and soil compaction have a large impact on soil structure and subsequently affect earthworm communities.

The effect of tillage on earthworm communities was previously documented in a large number of studies and most of these reported (i) changes in earthworm diversity and (ii) higher earthworm numbers under no or reduced tillage compared to conventional tillage systems (see the review of Chan, 2001). However, as stated by Chan in this review, "(the) ecological and agronomic significance of such increases is not clear". The effect of tillage on macroporosity and subsequently water infiltration was also studied by many authors who described a decreasing number

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* Corresponding author. Tel.: +33 4 32 72 24 38; fax: +33 4 32 72 22 82.
E-mail address: capowiez@avignon.inra.fr (Y. Capowiez).

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of macropores and decreased water infiltration in Conventional Tillage (CT) compared to Reduced Tillage (RT) or conservation tillage systems (Ehlers, 1975; Edwards et al., 1990; Shipitalo et al., 1990; Chan, 2004). Most of these studies focused on burrows made by anecic species (*L. terrestris* for Edwards et al., 1990 and *Spencerellia hamiltoni* for Chan, 2004, for instance) since these earthworms make large and vertical burrows often open to the surface. However this ecological type of earthworm is rarely dominant in abundance in arable lands (Lee, 1985). The role of endogeic earthworm burrows in water infiltration has been studied less (Zachmann et al., 1987; Trojan and Linden, 1992).

With regards to soil compaction, a large number of studies reported that increases in soil bulk density caused a decrease in earthworm abundance in arable lands (Söchtig and Larink, 1992; Hansen and Engelstad, 1999; Radford et al., 2001), forests (Jordan et al., 2000), orchards (Pizl, 1992), pastures (Chan and Barchia, 2007) and urban parks (Smetak et al., 2007). These negative effects depend on the ecological type (epigeic species are more sensitive), species and age/size of earthworms under consideration (Pizl, 1992; Cluzeau et al., 1992; Jordan et al., 2000). Thus, soil compaction decreases earthworm quantities directly (crushing) and indirectly (habitat modification). The same is true for macroporosity, which is also affected directly (macropore destruction) or indirectly (limitation of earthworm burrowing activity (Rushton, 1986; Joschko et al., 1989; Stovold et al., 2004)). In the first case, the effect of soil compaction depends on macropore diameter and orientation (Blackwell et al., 1990; Pagliai et al., 2000). Soil compaction was also reported to have adverse effects on water infiltration (Servadio et al., 2001).

In the present study, we aimed to examine and compare the effect of a wide range of soil compaction and fragmentation intensity on earthworm communities in arable land and then demonstrate the possible outcome of changes in these communities on macroporosity and water infiltration. For this, we followed the approach outlined by Davidson and Grieve (2006) and investigated the relationships between earthworm communities and soil structure and functions. To reach this objective, we first thoroughly characterised the consequences of these agricultural practices on soil structure. Moreover, in order to avoid transient effects resulting from only recent modifications (Johnson-Maynard et al., 2007), the INRA long-term experimental field site at Estrées-Mons (Boizard et al., 2002) with a long history of consistent management was chosen.

2. Materials and methods

2.1. Site and experimental design

The field trial comprising 24 plots of 0.4 ha each (80 m × 48 m) was initiated in 1989 in northern France (Estrées-Mons, 50°N latitude, 3°E longitude, 85 m elevation) and modified in 1999 to include RT (on half of the experimental site). The soil is a silt loam (Orthic Luvisol following FAO classification with 19% clay, 76% silt, 5% sand and 1.7% organic C) and has a pH of 7.6. Soil water contents at −10, −32, −50, −100 and −1500 kPa were 0.253, 0.229, 0.208, 0.175 and 0.084 $g\,g^{-1}$, respectively. Water content at field capacity, measured during winter in field 2–3 days after excess water has drained away, was 0.24 $g\,g^{-1}$ (Hillel, 1971). The average air temperature is 9.6 °C and the annual rainfall is 667 mm. The climate was very dry from 2003 to 2006 with annual rainfall of 414, 499, 483 and 614 mm, respectively. Two tillage types were compared: a CT system with annual mouldboard ploughing and a RT system with only superficial tillage. In CT system, each plot underwent mouldboard ploughing every year at 30 cm depth and seed bed preparation was made with a rotary or a combined harrow at 7 cm maximum depth. In RT system, seed bed preparation was made using a rotary or disc harrow at 7 cm maximal depth. Additionally, one or two additional pass of disc was made for weed control or stubble mixing between two crops. Three cropping systems (systems I, II and III) were established to obtain a wide range of soil compaction intensities depending on the crops rotation and the rules of decision making. The rules for decision making in each cropping system were built to combine crop physiology requirements and soil workability. The rules concerning soil workability were based on soil water content at the time of cultural operation were built from references obtained during preliminary experiments (Boizard et al., 2002). The crop rotation in cropping system I was pea (*Pisum sativum*)/winter wheat (*Triticum aestivum*)/linen (*Linum usitatissimum*)/winter wheat. Harvesting and sowing were mainly carried out in summer or early autumn, i.e. during the dry period of the year, except for pea and linen sowings. Pea and linen sowings were made when soil water content was lower than 0.22 $g\,g^{-1}$ (water suction of 35 kPa) in the 0–20 cm layer to limit soil compaction. The rotation in cropping systems II and III was sugar beet/winter wheat/maize/winter wheat. Cropping system II was managed to avoid wet conditions as much as possible during sowing and harvesting. Sowing were made when soil water content was lower than 0.22 $g\,g^{-1}$ in the 0–20 cm layer and sugar beet and maize harvesting were made in early autumn. In contrast, cropping system III was managed so as to maximise light interception by the sugar beet and maize canopies by sowing in early spring and harvesting in late autumn, without taking into account the possible severe compaction caused by machinery traffic during these wet periods of the year, which are generally wet in this region. Thus, winter wheat sowing dates were later in cropping system III than in cropping systems I and II. The effect of the crop rotation and the rules for decisions making on the compaction intensity under wheel tracks was evaluated in CT from 1990 to 1999 (Boizard et al., 2002). Annual compaction intensity depended to a large extent on the cropping system with increasing compaction intensity from cropping system I to III. Maximum compaction occurred during harvesting in wet conditions because of high axle loads but the inter-annual variation of compaction was high due to variation in weather conditions and then soil water contents.

Each crop of each cropping system was grown every year leading to 12 plots for each tillage management. Among these, 6 plots (2 tillage managements × 3 cropping systems) were used for this study with tillage management as main plots and cropping system as sub-plots. Wheel traffic was not confined and the location of wheel tracks was recorded after each operation. The soil water content of each plot was measured before each tillage and harvest operation. A description of the decision rules and the main characteristics of the machinery used in each cropping system can be found in Boizard et al. (2002; Tables 1 and 2). Because, the crops are not the same in the rotation and because sowing dates can vary, pesticides application is different between the three cropping systems (but is identical for RT and CT). None of the pesticide used was classified as to be toxic or very toxic to earthworms (Edwards and Bohlen, 1996 and internet databases). Regarding fertilisation, the same quantity of P_2O_5 was applied in all plots whereas quantities of K_2O and NO_3 were adapted to the needs of each crop.

2.2. Characterisation of soil structure

We measured the soil bulk density after each sowing outside wheel tracks at seedbed preparation and sowing, using a transmission gamma ray probe (10 replicates) at three depths (0.125, 0.175 and 0.225 m). We directly observed the soil macrostructure from a soil pit with 3-m wide and 0.8-m depth. The pit was dug perpendicularly to the traffic and tillage direction. This observation was carried out on each plot, each year after