Applied Soil Ecology 73 (2014) 130–133

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Short communication

Slow recovery of earthworm populations after heavy traffic in two forest soils in northern France

N. Bottinelli[a,b,*], Y. Capowiez[c], J. Ranger[a]

[a] INRA, UR1138 INRA, Biogéochimie des Ecosystèmes Forestiers, F-54280 Champenoux, France
[b] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, CAS, Nanjing 210008, China
[c] INRA, UR 1115 Plantes et Systèmes Horticoles, Domaine Saint Paul, 84914 Avignon Cedex 09, France

ARTICLE INFO

Article history:
Received 9 April 2013
Received in revised form 26 August 2013
Accepted 30 August 2013

Keywords:
Soil compaction
Earthworms
Recolonisation

ABSTRACT

To determine the role of earthworms in regenerating compacted zones, it is essential to consider their capacity to colonise these zones. This study aimed to determine the short-term (3–4 years) response of earthworm populations to heavy traffic in two forest soils, at Azerailles (AZ) and Clermont-en-Argonne (CA) in north-eastern France. Earthworm populations were recorded immediately and for 3–4 years after heavy traffic by a 8-wheel drive forwarder with a load of about 23 Mg at AZ and 17 Mg at CA. To test the capacity of earthworms to recolonise traffic plot from the edges, an extra sampling was performed at the border of the traffic plots at AZ. Heavy traffic had a detrimental impact on the density and biomass of three earthworm functional groups. At AZ, earthworm populations, dominated by endogeic species, followed by anecic and epigeic species, had not fully recovered four years after compaction. The absence of statistically significant colonisation by the three functional groups from control to traffic plots indicated that the soil habitat was not yet favourable. At CA, earthworm populations, represented exclusively by epigeic species, had fully recovered three years after compaction, suggesting that the soil habitat was already suitable for them. This strong dependence on soil habitat quality is discussed and may be one reason for variation in the recovery rate of earthworms after compaction reported in the literature. In conclusion, this study did not support the hypothesis that earthworms play a role in regenerating soil structure the first few years following forest-soil compaction.

1. Introduction

The growing mechanisation of forest operations is increasing soil compaction, resulting in degradation of soil structure and soil functioning (Greacen and Sands, 1980; Horn et al., 2004). In forest ecosystems, the remediation of compaction by tillage is rarely used, being difficult to apply due to the presence of stumps and large roots. Therefore, compacted forest soils must recover their structure through natural processes (i.e., wetting–drying cycles, freeze–thaw cycles during winter or biological activity) (Greacen and Sands, 1980).

Among the main biological regulators of soil structure in temperate regions are earthworms, often called “soil engineers” due to the importance of their burrowing and casting activity to soil structure (Lee and Foster, 1991; Jouquet et al., 2006). It is generally claimed that earthworm activities contribute to the regeneration of compacted zones, and it is well-documented under controlled conditions where earthworms are forced to move through compacted zones (Langmaack et al., 1999; Larink et al., 2001; Capowiez et al., 2009; Jouquet et al., 2012; Müller-Inkmann et al., 2013). Few, however, have validated this role in the field (Capowiez et al., 2012). Because soil compaction is a physical disturbance that leads to a decrease in earthworm populations (Söchtig and Larink, 1992; Jordan et al., 1999; Althoff et al., 2009; Capowiez et al., 2012), the regeneration of soil structure by earthworms initially should depend on their capacity to colonise these zones. The colonisation of new environments by earthworms has been extensively studied (reviewed in Eijsackers, 2011). Even if in this review, soil bulk density was indicated as a limiting factor for colonisation, very few studies have investigated the natural recovery of earthworm populations after heavy traffic. Moreover they have produced inconsistent results, with full recovery of earthworm abundance varying from a few months to several years (Jordan et al., 1999; Althoff et al., 2009; Capowiez et al., 2012).

Two experimental sites were set up in two temperate forests in north-eastern France to monitor changes and recovery in physical, chemical and biological properties following traffic by a full-loaded forwarder (Goutal et al., 2012a,b; Goutal et al., 2013). In the initial

* Corresponding author at: Agriculture, Institute of Soil Science, Chinese Academy of Sciences, 71 East Beijing Road, Nanjing 210008, China. Tel.: +86 25 8688 1198; fax: +86 25 8688 1000.
E-mail address: nicobottinelli86@hotmail.com (N. Bottinelli).

0929-1393/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.apsoil.2013.08.017

study, Goutal et al. (2012a) reported that soil specific volume to a depth of 10 cm had been completely restored on one site three years after traffic, whereas recovery was not achieved (1.01 vs. 0.95 $cm^3 g^{-1}$ in control and traffic plots, respectively) fourth year of monitoring at a second site. This study raised the question of which natural processes contributed to such a difference in recovery rate between the two sites.

In this study, we hypothesised that the different recovery rates of specific soil volume at these sites could be explained by differing recovery rates of earthworm populations. The objective of this study was, therefore, to determine the short-term response of earthworm populations (abundance, biomass and diversity) to heavy traffic in two temperate-forest soils. Earthworm populations were recorded immediately and for 3–4 years after heavy traffic at two sites.

2. Materials and methods

2.1. Study sites

The two study sites are located in two state-owned forests in north-eastern France: near Azerailles (AZ) (48°29′19″ N, 6°41′43″ E) and near Clermont-en-Argonne (CA) (49°06′23″ N, 5° 04′18″ E). As described by Goutal et al. (2012a), the two sites had similar soil morphology, classified as Luvisol (ruptic) (FAO/WRB). Yet, differences occurred in soil organic carbon (SOC) content, pH and mull types, which are known to influence earthworm populations. Down to 30 cm, the soil at AZ had a SOC content of 11–27 g kg^1 and a pH water of 4.6–4.8, while that at CA had a SOC content of 5–26 g kg^{-1} and a pH water of 4.4–4.5 (Goutal et al., 2012a). The humus forms varied from Mull mesomull at AZ to Mull dysmull and Moder at CA.

The two forest stands dominated by beech (*Fagus sylvatica* L.) and oak (*Quercus petraea* L.) were clear-cut over a 5-ha area. Each site was divided into three blocks. In each block, the same fully-loaded 8-wheel drive forwarder (1996 Valmet 840) drove on land strips for an equivalent of two passes (one forward and one rearward pass) in May 2007 and March 2008 at AZ and CA, respectively. The tires of the forwarder were 60 cm wide, had a diameter of 133 cm (600/55 × 26.5) and were inflated to a pressure of 360 kPa for both sites. The empty forwarder weighed 11.4 Mg, the four front wheels supporting 6.9 Mg and the four rear wheels supporting 4.5 Mg. In AZ, the wood-loaded forwarder weighed 23.3 Mg, the four front and the four rear wheels supporting 7.56 Mg (i.e. the empty weight on the four front wheels + 5% of the load) and 15.76 Mg (i.e. the unloaded weight on the four rear wheels + 95% of the load), respectively. In CA, we only weighed the wood load and deduced the total weight of the loaded forwarder (16.7 Mg), the loaded weight on the four front wheels (7.17 Mg) and rear wheels (9.57 Mg) according to the measurements taken in AZ. The soil at CA was wetter (0.49 g g^{-1} at 5 cm depth) at the time of traffic than at AZ (0.34 g g^{-1} at 5 cm depth). Each plot measured 50 m × 50 m, with two undisturbed control 10 m × 50 m strips of land on each side of the 30 m × 50 m traffic area. In autumn 2007 (AZ) and 2008 (CA) the entire surface of each site was planted with sessile oak (*Quercus petraea L.*) at a density of 1600 seedlings ha^{-1}.

2.2. Earthworm sampling and identification

Earthworms were sampled during three sampling dates in the centre of traffic (10–15 m from control plots) and control plots, corresponding to June 2007, November 2008 and April 2011 (i.e., one month, one year and four years after heavy traffic) for AZ and to April 2008, November 2009 and April 2011 (i.e., one month, one year and three years after heavy traffic) for CA. To test the capacity of earthworms to recolonise traffic-plot edges, extra sampling was performed at the border of the traffic plots (e.g. less than 2 m from control plots) in April 2011 at AZ. In total, 117 sampling points were analysed (i.e., three dates × two sites × two locations: the centre of control and traffic plots x three blocks × three sampling points + one location: traffic-plot edges × three blocks x three sampling points). Earthworms were collected by hand sorting within 0.09 m^2 (i.e., 0.3 m × 0.3 m) to a depth of 25 cm, and species were identified using Bouché's (1972) key in the laboratory. Earthworm density and biomass were quantified (m^{-2}) and species were classified into epigeic, anecic and endogeic functional groups.

2.3. Statistical analysis

One-way ANOVA models were used to test the effect of treatment (e.g. the centre and border of the traffic plots and the centre of the control plots) on earthworm density and biomass for each sampling date and study site. Treatment was the main fixed effect, and blocks were the random effect. Analyses were performed with a balanced mixed-effects model (aov) using R software. When effects were found to be significant at $p < 0.05$, means were compared using the Tukey test.

3. Results and discussion

3.1. Earthworm abundance and diversity

Earthworm density ranged from 69 to 177 and 0 to 91 individuals m^{-2} in control plots at AZ and CA, respectively (Fig. 1), while earthworm biomass ranged from 21 to 67 and 0 to 31 g m^2 in control plots at AZ and CA, respectively (Fig. 2). The number of species found in control plots in 2011 was higher at AZ than at CA (5 vs. 2, respectively), as was the number of functional groups (3 vs. 1, respective). At AZ, the endogeic species *Aporrectodea caliginosa* (30%) and *Aporrectodea rosea* (34%) dominated, followed by the anecic species *Lumbricus terrestris* (26%). The anecic species *Aporrectodea giardi* and the epigeic species *Lumbricus castaneus* were uncommon, together representing only 10%. At CA, the community was dominated by the epigeic *L. castaneus* (71%) followed by the epigeic species *Lumbricus rubellus* (29%). The difference in earthworm populations may be attributed partly to the lower pH found at CA (4.4–4.5 in the upper 30 cm) than at AZ (4.6–4.8 in the upper 30 cm). The abundance, biomass and diversity of earthworms found in our study are consistent with previous studies regarding pH values and humus forms (e.g. Mull vs. Moder) (Deleporte et al., 1997; Muys and Granval, 1997; Potthoff et al., 2008).

3.2. Initial effect of heavy traffic on earthworms

Our results showed that epigeic species found in both sites were missing at T_0 (Fig. 1), indicating that deforestation, including vegetation destruction, litter removal, and changes in soil moisture and temperature regime, impacted them more than anecic and endogeic species. Because epigeic species use the litter layer both as habitat and as food source (Bouché, 1977), this result is expected. The passage of the heavy forwarder decreased the specific soil volume by 17 and 21% at CA and AZ, respectively (Goutal et al., 2012a). Moreover, it is thought that soil compaction can displace topsoil along with accompanying soil organic matter, decrease structural porosity and increase water stagnation (Greacen and Sands, 1980; Horn et al., 2004). All of these effects may have contributed to the significant decrease in the density (by 97%, $p < 0.001$) and biomass (by 94%, $p < 0.001$) of earthworms measured at AZ, which agrees with previous studies carried out in forest (Jordan et al., 1999), prairie (Althoff et al., 2009) and agricultural systems (Söchtig and Larink, 1992; Capowiez et al., 2012). When the effect is analysed by functional group, endogeic species seemed less sensitive than