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Short communication

Soil compaction by uniaxial loading and the survival of the earthworm *Aporrectodea caliginosa*

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ABSTRACT

Earthworms are the major component of the soil fauna in temperate agro-ecosystems. Land use and soil management are widely reported to influence earthworm populations. We report simple laboratory experiments in which earthworm survival was tested against uniaxial loads for a range of soil conditions. Across all the experimental conditions 86% of earthworms survived. While greater loads (up to 800 kPa) over longer exposure times (up to 60 s) decreased survival; even under the most severe test conditions 33% of earthworms survived. Our results suggest that decreased earthworm populations in compacted soil are not due to uniaxial loading alone, but may be the result of shearing the soil during loading or from changes to the soil properties.

1. Introduction

There have been numerous studies examining the relationship between earthworm populations and activities such as tillage (Boström, 1995; Chan, 2001), cropping regime (Hubbard et al., 1999; Radford et al., 2001), grazing management (Chan and Barchia, 2007), land management (Pizl, 1992; Hawkins et al., 2008; Smith et al., 2008) and pesticide use (Owen et al., 2008). For some of these, direct causal relationships are apparent. For example, Boström (1995) reported that rotary cultivation killed between 60 and 70% of earthworm biomass. Hawkins et al. (2008) proposed the inclusion of sand layers in trenches may deter earthworms because large sand particles are sufficiently coarse to wound burrowing earthworms. Owen et al. (2008) used molecular approaches to complement gross toxicity data and characterize transcriptome changes in earthworms exposed to cadmium, copper, the herbicide atrazine, and an organic pollutant. For other activities, including the relationship between soil compaction and earthworm populations, connections are less clear. This may be because the application of loads to soil used for crop production is often coupled with other agricultural activities, or because the act of soil compaction may both directly harm earthworm populations and adversely change soil properties.

Both the number of passes made by machinery across agricultural fields, and the mass of agricultural machinery are significantly increasing. Agricultural machines now exceed wheel loads of 10 Mg (Alakukku et al., 2003) and multiple repeated wheeling events during one crop rotation occur, especially in conventional soil management (Hamza and Anderson, 2005). The dynamic process of soil loading physically degrades soil by changing pore size distributions and causing associated decreases in hydraulic conductivity and air permeability and by increasing soil strength (Horn et al., 1995). Peak stresses under tyre lugs will depend on a range of soil factors including soil texture, structure and water content and machinery factors including axle loads, inflation pressures and lug design. Peak values have been reported (Burt et al., 1990) of up to 200 kPa for loose soil and almost 450 kPa for soil in firm condition. Arvidsson and Keller (2007) have reported even higher stresses under lugs, but these were determined on a hard surface rather than in soil.

Many common geophagous or endogeic species living in the surface soil have burrows that are aligned near to horizontal (McKenzie and Dexter, 1993). These burrows and earthworms in them will be more likely to be damaged by vertical stress than other species living in deep vertical burrows (Blackwell et al., 1990). McKenzie and Dexter (1988a,b) demonstrated the pressures generated by burrowing *Aporrectodea rosea* earthworms. Mean radial pressures generated by this species were around 200 kPa. This work has been extended to cover a wide range of species and ecotypes by Keudel and Schrader (1999) who reported pressures of similar magnitude.

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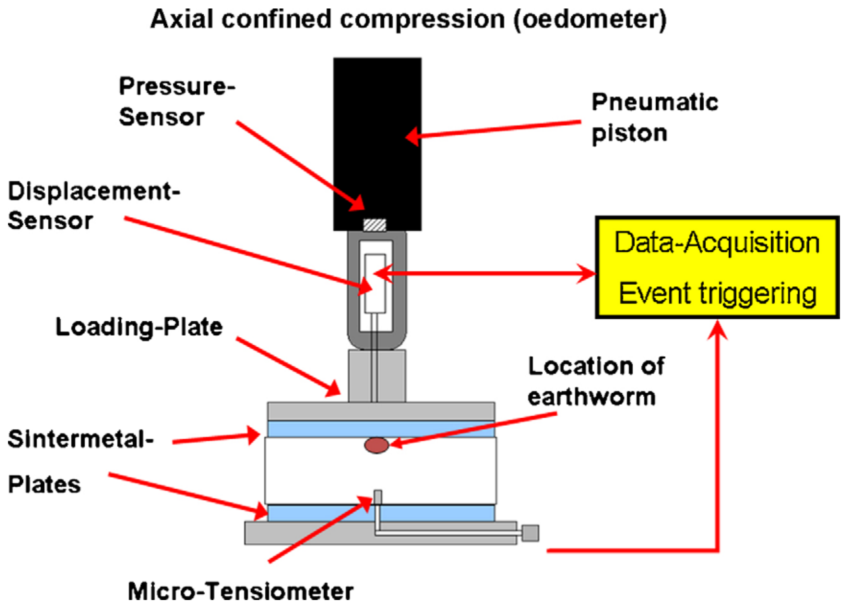

Fig. 1. Schematic of the oedometer used to apply uniaxial loads (after Peth, 2004) showing the experiment set up including the pneumatic piston, sensors and location of the earthworm.

Our aim was to isolate the direct effects of uniaxially compacting soil on the survival of earthworms from the effects of shear stresses, and from the possibly detrimental effects that the resultant soil physical conditions may have on earthworm survival. This was done in laboratory experiments using a dose response approach varying initial soil density, load intensity and duration.

2. Materials and methods

Surface soil was collected from Christian-Albrechts-University experiment farm at Hohenschulen (54°19′N, 9°58′E). The soil was a Stagnic Luvisol derived from glacial till. The soil from the top 30 cm was composed of sand 59%, silt 29% and clay 12%, contained 1.5% organic carbon and had no carbonate present. Collected soil was air-dried, sieved to less than 2 mm and packed into cores (diameter 100 mm, height 30 mm) to achieve bulk densities of 1.4, 1.5 and 1.6 g cm^{-3}. The cores were then saturated for 24 h then equilibrated to a matric potential of −5 kPa on ceramic plates. This potential was in the range for which earthworm activity typically occurs (Lee, 1985). A channel was made by removing soil across the diameter of the core. This was done by scraping away soil with a spatula to produce a hemispherical, horizontal channel, with a depth of 2 mm, and a cross-sectional area of approximately 6.3 mm^2. This is typical of the cross-sectional area of the burrows produced by geophagous earthworms (Rogaar and Boswinkel, 1978; McKenzie and Dexter, 1993).

Earthworms were collected from the same site as the soil. Mature adult or sub-adult earthworms (*Aporrectodea caliginosa*) were selected for the experiments. Identification was with the key of Sims and Gerard (1985) to *A. caliginosa* and the morph described as *trapezoides*. This species is now common in agricultural soils across the globe and is geophagous. Individuals are found in the upper 10 cm of the profile where they have temporary horizontal or near horizontal burrows (Sims and Gerard, 1985) but detailed excavations of burrows have shown that most have a section that is nearer to vertical and extends to deeper than 10 cm (McKenzie and Dexter, 1993).

Immediately prior to loading the soil an earthworm was placed into the horizontal channel and a stress transmitting plate placed on top. This plate prevented the earthworm from leaving the soil core. A randomized trial was conducted to investigate the effect of load (200, 400 and 800 kPa), time of exposure to load (5, 15, and 60 s) and initial density of the soil (1.4, 1.5 and 1.6 g cm^{-3}) on the survival of individual earthworms. Stresses were applied to the soil core containing the earthworm in the surface channel. Stresses were applied with a pneumatic piston in a standard oedometer device (Fig. 1). During the loading process measurement of vertical displacement (strain) was recorded by a potentiometric displacement transducer and the matric potential recorded by a micro-tensiometer.

When the load was removed, the core was taken from the oedometer and the stress transmitting plate removed. The earthworm was removed from the soil core and placed into a beaker containing approximately 100 g of moist soil. After 24 h the survival of the earthworm was recorded. As the results of each experiment were survival or non-survival, data were binomially distributed.

2.1. Statistical analysis

A total of 81 cores were tested (3 initial bulk densities × 3 loads × 3 times × 3 replications). The effects of these factors, as categorical variables, on strain and earthworm survival were analysed using ANOVA and a generalized linear model (GLM) with binomial errors and logit link function respectively. The relationship between strain and earthworm survival was also analysed using a GLM. To determine whether weight of the earthworm influenced survival, weight was included in the regression, but was not significant. Weight was thus removed from all subsequent analysis. Statistical analysis was performed in Genstat (VSN International, Herts, U.K.).

3. Results and discussion

The stresses used here (200, 400 and 800 kPa) are of similar magnitude, to those found in many agricultural situations, and are also of similar magnitude to the radial pressures generated by earthworms. Greenwood and McKenzie (2001) reviewed loads reported under a range of grazing animals and found that sheep typically applied less than 100 kPa and cattle less than 200 kPa. In experiments to study compaction induced changes to soil structure Schaffer et al. (2006) reported mean static ground