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Original article

# Integrating soil physical and biological properties in contrasting tillage systems in organic and conventional farming

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ABSTRACT

Though soil physical and soil biological properties are intrinsically linked in the soil environment they are often studied separately. This work adds value to analyses of soil biophysical quality of tillage systems under organic and conventional farming systems by correlating physical and biological data otherwise left unexplored. Multivariate redundancy analysis was used to relate data on soil water, soil structure, soil carbon, crop yield, and earthworm species abundances (*Aporrectodea caliginosa*, *Aporrectodea rosea*, *Eiseniella tetraedra*, *Lumbricus rubellus*). Structural equation modelling was then used to infer causal relations amongst the variables. Effects of tillage system (i.e., mouldboard ploughing (MP) and non-inversion tillage (NIT)) on soil physical parameters and on the earthworm species *Lumbricus rubellus* were similar in organic and conventional farming. Despite sampling times in different seasons and different crops present at the time of sampling NIT correlated positively with *L. rubellus*, soil organic matter content, plant-available water content, soil aggregate stability, soil water content, and penetration resistance. Field-saturated hydraulic conductivity was negatively correlated with NIT and was negatively, or not correlated at all, with earthworm species abundances, possibly due to the absence of *Lumbricus terrestris* in these fields. In the comparison of organic fields, earthworms were positively correlated with the soil's ability to hold water but loosening by ploughing appears to have benefited the conduction of water through soil more than earthworms. Tillage systems and farming systems were found to have both direct and indirect influences on soil parameters. Organic farming increased soil organic matter content, soil water content, and both endogeic and epigeic earthworm species abundances. Non-inversion tillage increased crop yield, soil organic matter content, and soil penetration resistance. This study demonstrates that multivariate techniques can integrate and add value to data otherwise analysed separately.


## 1. Introduction

A reduction in soil tillage intensity by omitting ploughing is considered an option to improve soil water dynamics, soil structure, and ultimately crop yield [1,2]. In reduced tillage systems, it is assumed that soil biological activity, largely earthworms, will compensate for soil physical functions (i.e., porosity, root penetration, aeration) previously provided by ploughing [1,3].

Earthworms and soil physical properties have been studied simultaneously using various methodologies in-lab and in-field. For example, *Aporrectodea caliginosa* (endogeic) has been found to be positively related to infiltration rate and *Lumbricus rubellus* (epigeic) was positively related to soil water storage in a laboratory study with soil columns containing functionally distinct earthworm species [4]. *Lumbricus terrestris* burrows have been isolated in existing field experiments in order to ascertain their contribution to water infiltration [5,6]. Earthworm distribution in a field study was positively related to the amount and effectiveness of macropores using soil pits dug after rainfall experiments with brilliant blue dye, though there was high variability in patterns of infiltration [7]. Under controlled field conditions earthworm density and ecological type, infiltration capacity, plant species diversity, and plant functional group richness have been related using linear mixed-effect models and path analysis at the Jena site in Germany [8]. However, the electrical octet method used at the Jena site is known to poorly extract large *L. terrestris* individuals [9]. Plant functional groups effected earthworm biomass and in particular explained spatial and temporal variation in infiltration capacity. Field studies may also relate earthworm and soil physical properties after implementing tillage treatments. Tillage systems did not affect

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earthworm abundances or water infiltration but did change soil porosity in one study in France [10]. However an integrated analysis of all parameters was not done. Some studies have presented soil physical and soil biological data simultaneously, and attempted to correlate them using multivariate techniques. Multivariate analysis applied in a field study showed that reduced intensity tillage systems changed soil organic carbon distributions in topsoil and benefited earthworm species diversity, even though *Aporrectodea caliginosa* correlated positively to ploughing [11]. There have been recent efforts to simultaneously measure soil biological properties with soil physical functions in the field as well. Earthworms and water infiltration rates were measured simultaneously on the same pedon and it was concluded that doing so was feasible and that the data were realistic in scale [12].

The current work attempts to integrate soil biological, here meaning earthworm species abundance data, with soil physical data. Relations amongst earthworm species abundances and soil physical properties are explored and causal linkages proposed between tillage systems in conventional and organic farming.

## 2. Materials and methods

The current work is an exploration of soil biological (earthworm species abundances) and soil physical data taken from two separate data sets that were conducted at the same site [13,14].

### 2.1. Site description

The studies took place at the PPO Lelystad experimental farm of Applied Plant Research, Wageningen University and Research Centre, in The Netherlands (52° 31′N, 5° 29′E) [13,14]. Soil at the station is a calcareous marine clay loam (23% clay, 12% silt, 66% sand) with a pH of 7.9. Precipitation is 825 mm on average annually and the average annual temperature is 9.7 °C [15].

### 2.2. Experimental design and farming practices

Data were combined from two immediately adjacent sets of fields separated by 120 m (Fig. 1). One set of fields was managed using conventional agricultural practices and the other with organic farming management. Crop rotations were also unique to each set of fields, and the rotations were not synchronised between fields within management type. Tillage systems were the same for conventional and organic farming and were arranged in randomised complete block designs within each field (Fig. 1). Data from two fields under organic farming (Org A and Org B) and one under conventional farming (Conv A) were used in the current work.

Organically managed fields received annual animal manure applications of 20–40 Mg ha$^{-1}$ yr$^{-1}$, though no manure was applied to Org A in autumn 2011 since the following leguminous crop (wheat/faba) did not require additional nitrogen. Conventional fields received yearly synthetic fertiliser applications to satisfy crop requirements and during the growing season were treated biweekly with herbicides, whereas organic fields had not received synthetic fertilisers or herbicides since 2002. Organic certification was awarded in 2004. Tillage systems were established in 2008 in all experimental fields. Tillage systems were mouldboard ploughing (MP) to 23–25 cm in autumn and cultivation to 8 cm for seedbed preparation and non-inversion tillage (NIT) with yearly sub-soiling using a Kongskilde Paragrubber to 18–23 cm in autumn and cultivation to 8 cm for seedbed preparation. Tillage treatments within each farming system received equal amounts of fertilisers or animal manures. For plot plans and detailed crop rotation information see Refs. [13] and [14]. Crop rotations included mainly root and cereal crops, with the addition of grass and cabbage in organic farming. Cover crops were seeded after main crop harvest when possible.

### 2.3. Field sampling and laboratory analyses

Earthworms were sampled by handsorting through 20 cm$^3$ soil monoliths and applying a formalin solution to the bottom of the empty pit to extract anecic earthworm species [16]. A total of three subsamples per plot were taken in Org A (before harvest and ploughing) in 2011, and in Org B and Conv A in spring 2012 (post plant emergence). These data are from the 'medium-term' data presented in previous work [13]. Earthworms were identified to species level following [17] and [18].

Field-saturated hydraulic conductivity was estimated using a falling-head double ring infiltromoter method [14]. Soil aggregate stability was measured by removing intact 10 cm$^3$ soil blocks at 0–10 cm and 10–20 cm depths then wet sieving [19] and

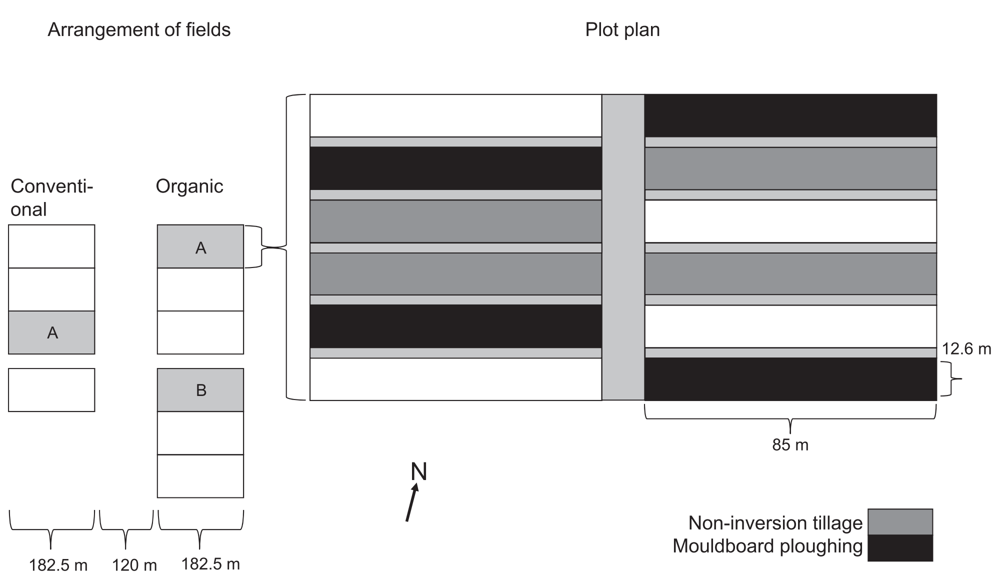


**Fig. 1.** Arrangement of conventional and organic fields, and example distribution of plots within one field.