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Potential effects of tillage and field borders on within-field spatial distribution patterns of earthworms

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ABSTRACT

Earthworms play a key role in regulating soil ecosystem functions and services. The small scale variability in earthworm abundance is often found to be very high, which is a problem for representative sampling of earthworm abundance at larger scales. In agricultural fields, soil tillage may influence both the average earthworm abundance as well as the spatial distribution of earthworms. Therefore we studied the abundance and spatial pattern of the different ecological earthworm types, i.e. endogeic, epigeic and anecic earthworms, in four agricultural fields differing in soil tillage (two fields with regular tillage and two fields with conservation tillage) and surrounding land use (other cropped fields or apple orchard and forest). To this aim we sampled earthworms on a total number of 430 plots ($50 \times 50\,\text{cm}^2$) using a combination of extraction with mustard solution and hand sorting. The results exhibit large differences in average earthworm abundance between the four fields. Only one of the two fields with conservation tillage had a comparatively very high overall abundance of earthworms. Furthermore, we found a high spatial variability of earthworms within the field scale often exhibiting a patchy distribution. We detected a trend of decreasing earthworm abundances from the field border into the field for different earthworm groups on each of the fields. In three fields with low total earthworm abundance (and only very few epigeic earthworms) there was a short scale autocorrelation with ranges varying strongly for the endogeic earthworms (37.9 m, 62.6 m, and 85.2 m) compared to anecic earthworms (19.8 m, 22.8 m, and 27.4 m). In the field with high abundance, after trend removal, the variogram models for anecic and endogeic earthworms were rejected based on their negative explained variances. On this field, we found only a short scale autocorrelation for the epigeic earthworms with a range of 143 m.

Based on these results it seems that ploughing alone cannot explain the differences in abundance and range of autocorrelation found on the four fields. The trend of strongly decreasing earthworm abundance from the field border into the field in the one field with high abundance does indicate that the field border or surrounding land use may also influence the recolonization of fields, but more research is required to provide further evidence for this hypothesis. Due to the very different patterns of earthworm distributions in the fields it remains difficult to recommend an optimal number and distance of samples to obtain a representative earthworm abundance for the field scale.

1. Introduction

Earthworms play a key role in regulating soil ecosystem function and services (Blouin et al., 2013). They are ecosystem engineers affecting soil structure (Lee and Foster, 1991), organic matter distribution and degradation (Alekseeva et al., 2006; Brown et al., 2000), soil aeration (Lee and Foster, 1991) and the storage and

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transport of water and solutes (Ernst et al., 2009; Klaus et al., 2014; Shipitalo and Butt, 1999; Shipitalo and Gibbs, 2000). While earthworms strongly influence soil characteristics and processes, at the same time their spatial distribution is determined by these characteristics and processes, meaning there is an important feedback loop (Schneider and Schröder, 2012). In order to understand the influence of earthworms on abiotic soil processes, it is necessary to quantify the spatial distribution of earthworms at different nested scales (Ettema and Wardle, 2002) and to relate earthworm abundance to the spatial distribution of macropores in the soil (van Schaik et al., 2014). The small scale variability in earthworm abundance is often found to be very high (Rossi, 2003b; Rossi and Nuutinen, 2004), posing a problem for representative sampling of earthworm abundance at the field scale. This leads to a large measurement-based model uncertainty in earthworm species distribution models for larger spatial scales (Palm et al., 2013).

Spatial variation exists at different spatial scales driven by environmental variables as well as population processes (Borcard and Legendre, 2002). At macro-ecological level, the spatial distribution of earthworms is mainly driven by climate (Lavelle and Spain, 2001). At a regional (landscape) scale, composition of earthworm communities and earthworm abundance was found to mainly depend on land use: in general, significantly higher earthworm abundance and species diversity were found in grasslands than in forests or agricultural fields (Fragoso et al., 1997; Hendrix et al., 1992; Whalen, 2004). In grasslands or forests, soil characteristics such as pH (Baker and Whitby, 2003), soil organic matter content (Jiménez et al., 2011; Lowe and Butt, 2002), pollutant content (Spurgeon and Hopkin, 1999), soil texture (Baker et al., 1998) as well as soil moisture and temperature regime (Perreault and Whalen, 2006) have repeatedly been shown to influence the distribution and population dynamics of individual earthworm species and determine the composition of earthworm communities. In agricultural fields, soil management (Crittenden et al., 2014; Palm et al., 2013), i.e. soil tillage (Chan, 2001; Pelosi et al., 2013), fertiliser application (Sharpley et al., 2011; van Eekeren et al., 2009) and pesticide use (Pelosi et al., 2014) have a strong impact on the abundance and composition of earthworm communities additionally to the aforementioned factors. The spatial distribution and autocorrelation of earthworms at very small scales, i.e. within-field scales, has been studied for different earthworm species in differing climates and regions all over the world (e.g. Colombia (Jiménez et al., 2001), Germany (Poier and Richter, 1992), Ivory Coast (Rossi, 2003a,b)) and differing land use within one region (Whalen, 2004), and was summarized by Valckx et al. (2011). At such short distances, i.e. within-field scale, the spatial distribution of earthworms is generally found to be patchy, with a high semi-variance at the closest sampling distance (Rossi, 2003a), i.e. up to 5 m. This patchiness can be the result of patchiness in the controlling environmental factors and/or population processes (Borcard and Legendre, 2002; Rossi et al., 1997). The spatial correlation lengths are found to depend on the:

- earthworm species studied (Valckx et al., 2009),
- species' life-stage: juvenile *Lumbricus terrestris* and *Aporrectodea longa* have a larger range than adults, though for the endogeic earthworms *Aporrectodea caliginosa* and *Aporrectodea rosea* the range is similar for juveniles and adults (Valckx et al., 2009). Poier and Richter (1992), however, found a larger range for juveniles than for the adults of both *L. terrestris* and *A. caliginosa*,
- season (Hernandez et al., 2007), with larger patches in fall than in spring.

The small scale spatial patterns of earthworms were found to correlate spatially with organic carbon (Poier and Richter, 1992), soil hydromorphy (Cannavacciuolo et al., 1998), and aggregate density (Poier and Richter, 1992; Rossi, 2003c). Decaens and Rossi (2001) found a positive correlation between spatial patterns of small earthworms and bulk density as well as between larger earthworm species and root biomass and total carbon levels. They conclude, however, that it is impossible to say whether the soil factors determine the earthworm abundance or the earthworms influence the soil properties, which is typical for ecosystem engineers. In some cases, negative correlations of different earthworm species' distributions on each other are found (Jiménez et al., 2011; Palm et al., 2013; Rossi, 2003c). Additionally a negative correlation between different life stages was found, for instance an inverse patchy distribution for the distribution of juveniles and adults of the endogeic earthworm *Polypheretima elongata* (Rossi et al., 1997).

Most of the studies on autocorrelation and spatial distribution of earthworms at the small scale were carried out in natural systems or by comparing land uses, without taking into account the influence disturbance through soil tillage may have on the abundance and spatial distribution of earthworms. Ernst and Emmerling (2009), Yahyaabadi and Asadi (2010), Palm et al. (2013) as well as Pelosi et al. (2013) showed that the abundance of anecic earthworms decreased and that the abundance of endogeic earthworms increased in deeply ploughed soils. This effect was attributed to the disturbance or destruction of earthworm burrows, removal of litter from the soil surface and distribution of organic matter through the top soil layer instead of accumulation on the surface. Therefore, we hypothesize that in agricultural fields ploughing influences both the abundance as well as the patchiness of earthworms. To test this hypothesis, we studied the abundance and spatial pattern of the different ecological earthworm types, i.e. endogeic, epigeic and anecic earthworms according to Bouché (1977), in four agricultural fields differing in soil tillage (two regular vs. two conservation tillage), with a total number of 430 sampling plots. Additionally, we analysed the correlations between the ecological earthworm types and between the earthworm abundance and different soil properties, such as soil moisture content, temperature, organic matter and pH at 10 cm depth at a subset of sampling plots, in order to investigate the spatial relationship between earthworm group abundances and soil properties.

Table 1
Characteristics of the four experimental fields.

Field	Field size (m^2)	Number of plots	Management	Surrounding land use	Crop
CONS1	46437	115	No ploughing for at least 15 years	Fields, one row of trees at north-east border	Mustard
CONS2	14934	75	No ploughing for at least 15 years	Small forest patch (E), apple orchard (S), field (N), road (W)	Mustard (taller plants)
REG1	31124	90	Last ploughing 2 years before measurements	Fields, row of tall shrubs on the field	Mustard and peas
REG2	39111	150	Regular ploughing	Meadow (E), road (N), field (W), field (S)	Mustard (very small plants)