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Short communication

Cover cropping with oilseed radish (*Raphanus sativus*) alone does not enhance deep burrowing earthworm (*Lumbricus terrestris*) midden counts

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ABSTRACT

Deep burrowing earthworms are important ecosystem service providers but their populations are reduced by arable cultivations. We need to both better understand the impact of changes in crop management on earthworms and implement practices to enhance their in-field populations. Two current trends in arable cropping are the increased use of non-inversion tillage and over winter cover crops. *Lumbricus terrestris* abundances were estimated using midden counting on two field trials comparing tillage and cover cropping management practices. The long running (8-year) field trial showed that shallow non-inversion tillage had significantly ($p < 0.01$) greater *L. terrestris* abundances at 4.3 middens per m^2, in comparison to deep (ca. 20 cm) non-inversion tillage (3 middens per m^2) and conventional ploughing (ca. 25 cm) (1.9 middens per m^2), indicating that it is inversion rather than the depth of soil disturbance that is detrimental to their abundance. All trials showed that cover cropping with oilseed radish had no significant ($p > 0.05$) effect on *L. terrestris* midden counts, either during winter cover cropping or within the arable rotation. Field observations identified that 93% of middens were associated with crop leaves (still attached to the stem) incorporated into the burrow which may be a novel route of agrochemical exposure and needs further investigation.

1. Introduction

Deep burrowing earthworms such as *Lumbricus terrestris* are beneficial to agricultural soils, for example, their burrowing activity delivers an important ecosystem service improving water infiltration and crop growth (Andriuzzi et al., 2015). These anecic worms are highly sensitive to soil disturbance, with inversion tillage (ploughing) significantly reducing their populations (Chan, 2001; van Capelle et al., 2012) and local extinctions occurring on intensively cultivated soils (Kladivko et al., 1997). Ploughing has dominated UK tillage regimes for the past 30 years, and still account for 60% of wheat cultivations (Knight et al., 2012). The common anecic earthworm *L. terrestris* have slow reproduction rates (Lowe and Butt, 2014) and are slow colonisers of agricultural fields from margins (Nuutinen et al., 2011). Whilst field margins have high *L. terrestris* densities, it is thought that these do not act as a source of earthworms for field recolonization and that their recovery relies on the residual, surviving in-field worm populations (Roarty and Schmidt, 2013). There is a need to find management practices that enhance their in-field populations. Two current trends in UK arable cropping are the increased use of non-inversion tillage to improve soil structure and reduce operational costs and the use of over winter cover crops; this has increased in parallel with more spring cropping, often to improve soil management. While these changes in management would be expected to be beneficial to earthworm populations, empirical data are lacking.

Reduced intensity tillage (depth and/or inversion) is associated with higher *L. terrestris* abundances (Joschko et al., 2009). To the authors knowledge there have been no studies at species level to determine the effects of non-inversion tillage depth (shallow or deep) on *L. terrestris* earthworm populations. Potentially deep (ca. 20 cm depth) non-inversion tillage may cause as much disturbance to *L. terrestris* as moldboard ploughing (ca. 25 cm depth), and needs investigation to best inform on tillage practices.

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The second most important factor to anecic earthworm abundance after tillage is organic matter (Simonsen et al., 2010). A potential source of organic matter is cover cropping, with *L. terrestris* known to prefer relatively fresh litter (Piearce, 1978). In terms of cover crops, *L. terrestris* has a feeding and habitat preference in the order of grasses < brassicas < oats cover crops (Valckx et al., 2011). None the less, cover crops such as oilseed radish, exude glucosinolates, allelochemicals that supress crop pests and soil-borne diseases and may cause avoidance behaviours by earthworms. Further, cover cropping is often destroyed using agrochemicals such as glyphosate, which is known to reduce *L. terrestris* reproduction rates (Gaupp-Berghausen et al., 2015). A better knowledge of cover cropping effects on deep burrowing earthworm populations from field studies is needed to inform the choice of cover crop species and method of destruction and incorporation of residues.

A sensitive technique to determine active anecic earthworm populations in field studies is midden counting. Middens are the surface accumulations of castings, leaves and other organic materials embedded into the burrow and surrounding area (Brown et al., 2000). The low numbers of middens in tilled organic farming systems precludes sampling (Moos et al., 2016), however, surveying 20% of the plot area on conventionally farmed fields was sufficient to determine treatment effects (Stroud et al., 2016a). Middens are formed by sub-adults and adult *L. terrestris*, and are surface features that are counted to provide a reliable estimate of their populations (Rossi and Nuutinen, 2004; Simonsen et al., 2010; Singh et al., 2015; Stroud et al., 2016a).

We hypothesised that a radish cover cropping would be associated with higher abundances of *L. terrestris* middens in comparison to non-cover cropping management practices, and that the differences would be greater as tillage intensity is reduced because it provides more surface residues and less soil disturbance. Further, that long-term arable management practices that include cover cropping would significantly enhance *L. terrestris* midden counts in-field during the arable rotation series.

2. Materials and methods

2.1. Field experiments

The long-term field experiments conducted at NIAB as part of the New Farming Systems (NFS) programme, Morley, Norfolk, UK, which has a sandy loam soil (Ashley series) with sand 69%, silt 18%, clay 13% and organic matter content 2%. The experiments are arable rotation trials that have been running since 2008 and have been described elsewhere (Stobart and Morris, 2014). The cultivations trial is a factorial randomised block experiment, with the earthworm survey sub plot unit size 12 m × 12 m. The trial compares conventional moldboard ploughing (ca. 25 cm), deep non-inversion (20 cm using a combination of surface cultivation and deeper legs), and shallow non-inversion (just working the soil surface to no greater than 10 cm) and is managed with or without oilseed radish cover cropping at a seed rate of 10 kg ha^{-1}. Wider research examining soil physical conditions and other production characteristics are being assessed under contrasting tillage regimes (Stobart et al., 2014) has identified some changes in soil structure and stability; however, yield differences due to tillage regime in winter wheat were generally small. The fertility building trial is a randomized block design experiment, with earthworm survey sub plot size of 12 m × 12 m. The trial is managed using shallow non-inversion tillage and the treatments studied were those managed at the 100% N-fertilisation dose (RB209) with or without oilseed radish cover cropping.

A conventionally managed cover cropping field trial was conducted at the Rothamsted Experimental Farm, Harpenden, (51.80°N, −0.36°W, 128 m altitude), which has a flinty silty clay loam soil (Batcombe series) with sand 28%, silt 52% and clay 20%, and organic matter content of 2%. The experiment was started in Autumn 2015, and is a complete randomized block design with four replicate plots per treatment, each plot with an area of 9 m × 6 m^2. The plot treatments studied included (a) control (ploughed), (b) shallow non-inversion tillage, (c) shallow non-inversion tillage and cover cropping, (d) direct drilling, and (e) direct drilling and cover cropping following a winter wheat crop. In terms of tillage, a plough was used to ca. 25 cm depth for conventional stubble management, shallow non-inversion tillage was performed using a Lemken Karat stubble cultivator consisting of tines, discs and a crumbler roll to a depth of ca. 10 cm. Direct drilling was performed using a Moore uni-drill. The winter cover crop, oilseed radish (150 seeds m^2) was established in September 2015.

2.2. L. Terrestris *population estimates using midden counting*

Field descriptions of midden characteristics were recorded (size, organic debris). Midden counting and verification was performed as previously described (Stroud et al., 2016a). Briefly, a 1 m^2 quadrat was used to survey 6 m^2 per plot; 20 plots were surveyed at Rothamsted (120 m^2) and 24 plots were surveyed at the cultivations trial at Morley (144 m^2) and 8 plots were surveyed on the fertility building trial at Morley (48 m^2). Following Singh et al. (2015), these counts were verified by using a vermifuge (mustard solution, 10 g Colmans® mustard powder added to 1 litre of water) on 10 × 0.25 m^2 areas representing midden densities across the field. Earthworms were collected, rinsed, identified and biomass (field weight, returned to the field after measurement) was recorded. Spearman's rank correlation co-efficient was used to assess the correlation to midden counts (n = 15, correlation = 0.6, $p < 0.01$).

2.2.1. Midden counting within the arable rotation series with and without cover cropping

Midden counting was performed on both Morley field trials in Spring (May) 2015, when earthworms are most active and when the trials were under winter wheat (cv. Relay). This was to study the effects of long term rotation management that includes cover cropping.

2.2.2. Middens associated with and without the cover crop

Midden counting was performed on the Morley cultivations field trial and Rothamsted cover cropping trial in Winter (January) 2016, when the trial was sown with an oilseed radish to determine *L. terrestris* midden counts associated with this winter cover crop.

2.3. Statistical analyses

The midden abundance data were tested for normality (and if appropriate, log transformed) then analysis of variance was carried out to assess the statistical significance of midden abundance between the tillage and cover cropping treatments (Genstat, 2012, 14th addition, VSN International Ltd., UK).

3. Results

3.1. Midden description

Middens found on both these arable field trials were identified as a pile (minimum 2 cm high and 5 cm in diameter), composed of casts, small (<3 cm) stones and straw and/or wheat leaves underlain by a burrow (diameter ca. >5 mm) lined (up to 6 cm depth) by leaves. The species recovered from the midden