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The effects of soil compaction mitigation on below-ground fauna: How earthworms respond to mechanical loosening and power harrow cultivation

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ABSTRACT

Soils are one of the most biologically diverse habitats within the terrestrial ecosystem. Although soils are vital to the provision of important ecosystem services, their direct protection and sustainable management are often lacking within conservation policy. Many grassland soils have undergone considerable management intensification and are subject to degradation pressures. Soil compaction is an important form of soil degradation that can reduce soil productivity and crop yields, although the impacts can be reversed through natural processes and mitigated through management interventions. While commonly used, substantial knowledge gaps exist regarding the impact of soil compaction mitigation techniques on key soil macrofauna; many of these organisms are essential to soil function. A complete split-plot design was used to investigate the impacts of mechanical loosening (subsurface soil disturbance using tines or radial blades without significant soil mixing or inversion) and power harrow cultivation (shearing and mixing of soil to prepare a seedbed for the establishment of a deep-rooting forb and legume mix) on the abundance and biomass of earthworms up to two years post-treatment. Mechanical loosening was undertaken at two depths, *c.* 20 cm and c. 35 cm as two separate treatments. There was a negative effect of mechanical loosening at both depths on the abundance and biomass of anecic earthworms, lasting up to two years post-treatment. There was no significant effect of power harrow cultivation on the abundance or biomass of earthworms. These negative effects are consistent with other studies that have shown mechanical loosening to be a source of earthworm mortality. Although these findings resulted from a single episode of power harrow cultivation and mechanical loosening at a single site, the results indicate that the mechanical loosening of grassland soil can have a negative impact on important soil macrofauna and should possibly only be undertaken when the soil is in the most severely degraded conditions. Further work is needed to determine whether the negative impact of mechanical loosening is common to multiple sites and soil types and to link the reduction in earthworm number and biomass to future soil function.

1. Introduction

The effects of soil management on soil biodiversity and function are not as well understood in grassland systems as they are in arable systems (Vickery et al., 2001). Grasslands provide multiple benefits to society, including food production, water regulation, carbon storage and the provision of important habitats for a wide range of taxa. These include invertebrates (Hendrickx et al., 2007), in particular lepidopterans (Bourn and Thomas, 2002); mammals (e.g. brown hare *Lepus europaeus* (Hutchings and Harris, 1996)); and birds (Vickery et al., 2001) (e.g. corncrake *Crex crex* (Green and Stowe, 1993)). Many of the species supported by grasslands are experiencing serious population declines due to a combination of factors including habitat loss, increases in stocking rates and

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intensification of management practices (Allan and Bossdorf, 2014). While the above-ground biodiversity of grasslands is of increasing conservation concern, soils are one of the most species-rich habitats within the terrestrial ecosystem (Bardgett, 2005; Heywood, 1995) and are often overlooked within conservation policy (Giller, 1996; Haygarth and Ritz, 2009). Soil biodiversity is likely to play an important role in the provision of important ecosystem services such as regulating water quality, maintaining food security and providing carbon storage (Millennium Ecosystem Assessment, 2005). Facilitative interactions between functionally diverse groups of soil organisms drive ecological processes, such as litter decomposition, nutrient cycling and bioturbation (Bradford et al., 2002; Heemsbergen et al., 2004).

Grasslands account for 40% of global land cover, excluding Greenland and Antarctica (White et al., 2000). UK grasslands contribute 5% of Europe's permanent grassland (Smit et al., 2008) and within the UK, permanent and temporary grasslands account for approximately 65% of agricultural land (DEFRA, 2014). However, intensification of management practices has led to 17% of vegetated lands experiencing human-induced soil degradation since 1945 (Bilotta et al., 2007; Oldeman, 1994). Compaction is an important form of physical soil degradation (DEFRA, 2009; European Parliament Council of the European Union, 2013 European Parliament Council of the European Union, 2013) that threatens soil function and agricultural productivity. While mitigation methods to alleviate compaction are a field of current interest, significant knowledge gaps exist as to how best to identify high risk areas due to data scarcity and the difficulty in interpreting the often complex interactions that drive soil processes (Troldborg et al., 2013). Soil compaction is a global problem, is widespread in Europe (Jones et al., 2003; Trautner et al., 2003) and is not as visually recognisable as other forms of soil degradation, such as erosion. Several assessment techniques exist to quantify soil condition (Mueller et al., 2009; Peerlkamp, 1967; Shepherd, 2000). Newell-Price et al. (2013) reported on the use of such visual evaluation techniques to assess soil structural condition in 300 grassland fields in England and Wales. They found that *c*. 10 % of grassland soils were in poor condition and *c*. 60% were in moderate condition.

Soil compaction arises through repeated compressive forces from heavy farm vehicles (Defossez and Richard, 2002; Håkansson et al., 1988) or from livestock trampling that can be exacerbated by high stocking densities or extended grazing periods (Mulholland and Fullen, 1991; Warren et al., 1986). However, the potential risk of compaction can depend as much on the water content and structural strength of the soil as it does on the magnitude of the applied force (Batey, 2009), with compaction a greater risk in soils with higher moisture contents (MAFF, 1970). This change in the spatial arrangement of soil aggregates reduces soil permeability and macroporosity, leading to a reduction in overall soil function. Severe soil compaction can lead to a reduction in soil productivity and ultimately crop yields (Whalley et al., 1995); degraded soils are less able to provide essential ecosystem services (Matson et al., 1997) and maintain soil diversity.

Although there are several soil compaction mitigation techniques that can improve the structure of compacted soils, sustainable soil management should aim to avoid compaction through good practice. Methods such as mechanical loosening (subsurface soil disturbance using tines or radial blades without significant soil mixing or inversion) often cannot fully compensate for the impacts of soil structural degradation and the treated soils can be susceptible to recompaction (Spoor et al., 2003). The three main types of equipment used to mitigate soil compaction in grassland soils vary in terms of their mode of action and the depth of effective operation: aerators can loosen soil to *c*. 10 cm depth; sward-lifters to *c*. 35 cm depth; and subsoilers *c*. 45 cm depth. Aerators or slitters consist of a series of radial blades or spikes, on a horizontal transverse non-powered rotor, that cut through the grass sward into the upper horizon of the topsoil. The nature and angle of the blades (or tines) will affect the degree of disturbance caused by the machine, as does forward speed, soil type and soil moisture level at the time of operation. By contrast, sward lifters and subsoilers work by lifting or fracturing the soil to alleviate the compacted area. Biological approaches to soil compaction mitigation also exist. For example, deep-rooted herb and legume species can have an observable effect on soil compaction by improving soil structure and macroporosity (Głąb, 2008; Latif et al., 1992; Lesturgez et al., 2004).

Any soil disturbance event, such as power harrow cultivation (shearing and mixing of soil to prepare a seedbed) or mechanical loosening, will alter not only the soil structure, but also the physical environment for soil organisms. Earthworms are an important group within soil macrofauna. They create burrows while mixing, ingesting and excreting soil material, thereby modifying the physical structure and availability of soil resources, and fulfilling the role of 'ecosystem engineers' (Lavelle, 2012; Lavelle et al., 1997; Pulleman et al., 2012). Earthworms are grouped into three ecological groups or ecotypes that exhibit different behaviours and provide different functions: anecics, endogeics, and epigeics. Anecic species, such as *Lumbricus terrestris,* create large vertical or subvertical permanent burrows from the surface down into the soil, a process that aids litter decomposition and nutrient cycling by pulling leaf-litter down into the soil. These burrows also increase water infiltration rates and root development by creating macropores that improve soil structure and porosity. Endogeic species feed on mineral soil enriched with organic matter and also improve soil structure by creating a netlike system of smaller subsurface burrows. Epigeic species are found in the humus layer and feed on plant litter.

This paper investigates the null hypothesis that mechanical loosening, power harrow cultivation, or the addition of deep-rooted forbs, have no effect on the abundance and biomass of earthworms. Although other studies (Emmerling, 2001; Ernst and Emmerling, 2009; Wyss and Glasstetter, 1992) have investigated the impacts of different tillage systems, and land use type and intensity (Boag et al., 1997; Smith et al., 2008) on the taxonomic diversity of earthworms in arable systems, the effect of mechanical loosening on earthworm ecotypes in grassland has not been studied. The experimental results from this study provide an indication of the extent to which mechanical loosening of degraded grassland soils can improve soil function and health.

2. Methods

We tested two methods known to alleviate soil compaction: mechanical loosening, and power harrow (PH) cultivation with the establishment of deep rooting forbs, including legumes. We investigated the effect these treatments had on the abundance and biomass of earthworms up to two years post-treatment. A collective analysis was firstly performed on all earthworm data, before separately analysing how anecic earthworms responded to treatments. Endogeic earthworms were not analysed separately due to the low numbers observed. Only adult earthworms were identified to species level due to uncertainty in the species identification of juveniles.

2.1. Study site and data collection

Field experiments were carried out at Nafferton Farm, northern England (54°98′57 N, 001°90′04 W). The soil was a sandy clay loam and was historically in a grassland-arable rotation; seven years grassland, followed by four years arable production. Arable