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Understanding the legacy effect of previous forage crop and tillage management on soil biology, after conversion to an arable crop rotation

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ABSTRACT

The soil ecosystem provides a habitat for numerous and diverse fauna which hold a pivotal role driving decomposition and nutrient cycling. However, changing land use or management can alter population dynamics, changing soil biology within the system. The implementation of different field management can improve soil fertility, whilst natural variations in plant species growth and root system may create changes to soil structure and properties. All plant species create a legacy effect within the soil to some extent; changing the environment either physically or through remaining plant residues. An experiment investigated the hypothesis that previous forage cropping and tillage management would alter the diversity and abundance of soil fauna, after changing from a stable soil environment for three years to an annual arable crop rotation to complete a five-year rotation cycle. Four replicate plots (crop 1) of either perennial ryegrass (*Lolium perenne*), red clover (*Trifolium pratense*), white clover (*Trifolium* repens) or chicory (*Cichorium intybus*) were grown in a randomised block design (2009–2013) as the first crop, before conversion to an arable crop rotation. Spring wheat (*Triticum aestivum*) was established in 2013, either by conventional ploughing (CP) or direct drilling (DD); and winter barley (*Hordeum vulgare*) established using the same methodology the following autumn 2013 and harvested in 2014. Soil fauna abundance was sampled each year after the cereal crop was harvested, and included microfauna (nematodes), mesofauna (mites) and macrofauna (earthworms). Nematodes were found in greatest abundance in the previously ryegrass treatments, with greater numbers of bacterial feeders and herbivores (in 2013). Mesostigmata and oribatid mites had larger abundances in the ryegrass treatments, although Prostigmata were found in numbers five times higher after red clover in DD plots (in 2013); earthworms were found in significantly greater numbers in the previously white clover plots, across both cereal crops. These legacy effects began to diminish by the end of the second cereal crop in the rotation (in 2014). Tillage management also affected abundance, although these were fauna dependent, with earthworm numbers being detrimentally affected by ploughing whilst nematode abundances increased with ploughing. The combination of legacy and tillage elucidated interactions with the different groups of fauna, for example, epigeic earthworms, wireworms, and prostigmatid mites showed changes in abundance dependent on the combined effect of forage and tillage. Overall, legacy effects were found across three organism scales, highlighting the impact agricultural cultivations have across the whole soil food web.

1. Introduction

Demand for food production is increasing globally and the need for it to be a sustainable intensification of agriculture (Garnett et al., 2013) is also increasing. Understanding how to increase yields with minimum degradation to soil structure and function is key to agriculture in the long term. The global need to provide increased crop yields with minimal environmental impact (Ball et al., 2005)

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has led to our investigation of arable crop rotation after forage leys, as a potential soil improving cropping system to promote soil health and consequently soil biodiversity. Soil invertebrates are one of the best indicators of soil quality as changes in soil properties affect both composition and abundance (Lavelle et al., 2006). Agricultural grasslands (permanent pasture) support a relatively stable and numerous soil biota that contribute to soil functioning and fertility (Murray et al., 2012). However, arable crops are not considered to be a stable environment, as plant species change from a perennial to an annual, eliminating soil fauna that are susceptible to damage, desiccation and destruction of microhabitats (Behan Pelletier, 2003).

Soil fauna are classified across a range of scales within the soil food web that span three orders of magnitude (Swift et al., 1979). Nematodes (microfauna) are extremely diverse in both species and function, (feeding on bacteria, fungi, plants, as well as being omnivorous and predatory) (Yeates et al., 1993); they also play a large role in nutrient cycling and microbial turnover (Neher, 2001; Bonkowski, 2004). Mesofauna are key mediators of soil function, including the comminution and incorporation of litter, as well as regulating microbial communities (Lavelle et al., 2006). Earthworms have the largest effect as they are ecosystem engineers (Jones et al., 1994) changing both the physical structure of the soil habitat as well as altering its chemical composition (Blouin et al., 2013). However, when agricultural grassland becomes part of an arable crop rotation, the intensity of land use alters the stability of the environment and loss of biodiversity, and reductions in abundance have been shown to occur (Firbank et al., 2008). Soil fauna have been found to be negatively affected by the intensity of agriculture (fertiliser inputs/crop rotation) (Ponge et al., 2013); with, high inputs of inorganic fertiliser and increased tillage promoting bacterial feeding organisms, whilst low inputs and minimum tillage, promotes fungal feeding organisms (De Vries et al., 2012). However, considering the changes in agriculture as part of an arable crop rotation, negative effects may be buffered by the legacy of the previous cropping system (Detheridge et al., 2016).

Forage crops may buffer the impacts of grassland conversion into arable crops by altering the overall resilience of the soil in relation to change. For example, to obtain maximum yields from ryegrass swards, inorganic fertilisers are applied regularly whilst legumes fix atmospheric N (Carlsson and Huss-Danell, 2012) reducing the intensity of management. The addition of inorganic fertiliser will leave a different legacy to the leguminous forages which are known to leave residual N for future crop uptake (Kirkegaard and Ryan, 2014). Different grassland species have variable concentrations of essential nutrients and different rooting patterns, all potentially affecting the soil environment. Chicory, for example, has a deep tap rooting system that has been found to mine micronutrients from the soil, changing the location of nutrients within the soil profile (Belesky et al., 2001). Variability among rooting systems and plant cover between species leads to differences in productivity, the stability of soil, changing microbial processes (White et al., 2013) and affects the soil food web itself.

Our previous work has shown that earthworm abundance was higher in white clover than other forages as well as increasing herbivore abundance of invertebrates within ryegrass compared to chicory and clovers (Crotty et al., 2015). However, we do not understand the legacy effects of the previous forage crops on the succeeding crop within a rotation in relation to soil biology. Legacy effects, or ecological inheritances (Han et al., 2014), are the impact of historical management or perturbation that continues to affect ecosystem structure and function. Crop rotation alters the soil ecosystem, either directly through the cultivation of the soil or, indirectly, via the replacement of perennial plants with annual crops (DuPont et al., 2010). Agricultural grassland is commonly changed to become part of an arable crop rotation, with wheat often followed by barley in rotation (BIO Intelligence Service, 2010). Different tillage regimes can also be used to effectively prepare the seedbed and sow the following crop. Tillage (ploughing) is known to be detrimental to soil fauna, particularly earthworms (Bertrand et al., 2015); Collembola (Bedano et al. (2006); Acari (Behan Pelletier, 2003) and to a lesser extent Nematodes (Fiscus and Neher, 2002). It is also unknown whether there will be an interaction between the legacy effect of a previous forage crop and the method of establishment used e.g. tillage or direct drill.

This study examined the legacy effects from four preceding forage crops, (perennial ryegrass (*Lolium perenne*) low N fertiliser or 200 kg N fertiliser per annum, red clover (*Trifolium pratense*), white clover (*Trifolium repens*) or chicory (*Cichorium intybus*)), on soil fauna after spring wheat (*Triticum aestivum*) established either by conventional mould-board ploughing (CP) or by direct drilling (DD) inverted T, coulter drill; and, followed by winter barley (*Hordeum vulgare*) established by the same methods. Will legacy effects be found to affect soil fauna abundance after the first cereal crop, will they remain and differ between the different tillage managements after a second cereal rotation? Will the tillage management (ploughing or direct drill) affect all soil fauna in similar ways independent of forage legacy effects?

2. Materials and methods

2.1. Experimental site, plot establishment and maintenance

2.1.1. Crop 1: original pure sward forages

A full description of the experimental methods regarding the previous forage crops was presented in Crotty et al. (2015). In brief, the experimental area was set up at Institute of Biological, Environmental and Rural Sciences (IBERS), Aberystwyth University, Wales (52°25′ 59″N, 4°1′ 26″W) in 2009; plots were uniformly ploughed to the same depth (175 mm) and standardised in accordance with UK farming guidelines (RB209; DEFRA, 2010). Replicated plots (7.5 m × 12 m) of five forage treatments were set up on an area of stony, well-drained loam of the Rheidol soil series in a randomised block design ($n = 4$). Perennial ryegrass (*Lolium perenne*) (cv. Premium) with minimal input of inorganic N ha^{-1} (80 kg N ha^{-1} only, applied in three years) (PRG Low N), perennial ryegrass plus 200 kg inorganic N ha^{-1} $annum^{-1}$ (PRG 200N), chicory (*Cichorium intybus*) (cv. Puna II) (CH), white clover (*Trifolium repens*) (cv. AberDai) (WC) and red clover (*Trifolium pratense*) (cv. Merviot) (RC). All crops were mechanically harvested regularly to simulate a silage cutting system, experimental maintenance and forage sampling was as described in Marley et al. (2013).

2.1.2. Crop 2: spring wheat (*Triticum aestivum*)

In February 2013, 360 g l^{-1} glyphosate at 4 l ha^{-1} (Gallup 360 herbicide, Barclay Ltd, Dublin, Ireland) was applied to all plots. Each plot was split (3.75 m × 12 m) into two sub-plots and allocated at random to two tillage treatments (either conventional ploughed (CP) or no-till direct drilled (DD)). Sub-plots CP were mould board ploughed to a depth of 175 mm and power-harrowed, whilst those DD were undisturbed prior to sowing. Spring wheat (cv Tybalt) was sown using a Duncan Ecoseeder (Duncan Ag, Timaru, NZ) at a rate of 253 kg ha^{-1}, on all plots on the 5th of April, and flat rolled. This Ecoseeder has an inverted T type coulter drill forming a slot to sow the seed creating minimal soil disturbance. Spring wheat was harvested on 29th August 2013, using a Sampo harvester and the grain and straw removed.

2.1.3. Crop 3: winter barley (*Hordeum vulgare*)

Following the harvest of spring wheat, all plots were treated