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Assessing the impact of agricultural forage crops on soil biodiversity and abundance

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Maintaining soil biodiversity and function is key to maintaining soil health, nutrient cycling and decomposition. Different forage species have variable concentrations of essential nutrients and rooting patterns, potentially affecting soil biology and soil–plant–animal interactions. Our study compared the effect of growing different forage crops on soil faunal diversity and abundance. Plots of chicory (*Cichorium intybus*), red clover (*Trifolium pratense*), white clover (*Trifolium repens*) or perennial ryegrass (*Lolium perenne*) were established in 2009 and maintained over a four year period. Soil faunal samples were taken, including soil mesofauna, nematodes and earthworms, at the end of this period in autumn 2012 and spring 2013. Significant differences were found between the forages for a number of biological groups, as well as some seasonal differences; overall earthworm abundance and biomass was higher within the white clover treatment, specifically anecic earthworms. Nematode functional groups were found to differ, with greater numbers of fungal feeders in the clovers and chicory treatments, whilst the herbivores had the greatest abundances in the two ryegrass treatments. Overall the microarthropod order abundances did not differ, however two collembolan superfamilies did show differences between treatments with the detritivorous Poduromorpha having a higher abundance in the clovers and chicory treatment and the herbivorous Symphypleona had a higher abundance in the ryegrass treatment. Relatively little is known about the links between soil biology and the effects of plant type because of the complex nature of soil, however here we have begun to reveal some of these linkages. Overall, the findings indicate a relationship between ryegrass and herbivorous invertebrates, whilst the other forages have a stronger relationship with decomposer invertebrates; changing the dominance within the soil food web dependent on forage type.

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1. Introduction

There is increasing pressure from society for farming systems to deliver "ecosystem services" as well as feeding the world, and soil biology are vital in providing these services (Ferris and Tuomisto, 2015). The main ecosystem services a farming system provides are "provisioning" (food production), however other provided services that are considered include "regulating", "cultural" or "supporting" (Millennium Ecosystem Assessment, 2005). Agricultural production changes the abundance and diversity of soil biology, affecting the ecosystem services in both the short and long term. Soil fauna as a complete food web are important in the maintenance of plant production (Hunt and Wall, 2002). Maintaining a healthy soil will allow the soil biota to support nutrient cycling, decomposition and regulate the environment. Promoting the maintenance of a "healthy" soil could increase yields in the long term, with direct feedbacks between the above-ground and below-ground ecosystems (Wardle et al., 2004). Soil fauna could be a utilisable tool in sustainable agriculture (Paoletti, 1999), assessing abundance and diversity could be a proxy to monitor soil health, as there is often less diversity within agricultural soil due to management practices (Firbank et al., 2008). The soil fauna have a large amount of functional redundancy; however changes to soil health will occur if particularly influential species are lost (Nielsen et al., 2011).

Agricultural profitability and sustainability are crucial to farming successfully. Incorporating legumes into agricultural systems is thought to save farmers 137 € ha^{-1} across Europe through

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reduction in inorganic N use (Rochon et al., 2004). Forage legumes and chicory (*Cichorium intybus*) differ in their micronutrients concentrations (Marley et al., 2013a,b), increase the seasonal availability of high quality forage (Hare et al., 1987); and improve feed intake in livestock in comparison to feeding ryegrass (*Lolium perenne*) forage (Marley et al., 2007). The ability of legumes to fix atmospheric N has been demonstrated in numerous studies globally (Bullied et al., 2002; Evans et al., 2003; Marley et al., 2013c) and have also been found to have quantitatively more stable associations with mycorrhizal fungi than ryegrass (Zhu et al., 2000). Both red (*Trifolium pratense*) and white clover (*Trifolium repens*) have started to be used as a cover crop or living green manure as part of a crop rotation, reducing the risk of soil erosion and providing a residual N source for companion and future crops (Rasmussen et al., 2012) or soil fauna through root exudation. To enable the development of sustainable agriculture, there is a need now to understand how all crops affect belowground food webs.

Most of the biodiversity within agricultural systems resides in the soil (Brussaard et al., 2007), exceeding above-ground diversity by several orders of magnitude (Anderson, 2009). Agricultural grasslands support a relatively stable and numerous soil biota that contribute to soil functioning and fertility (Murray et al., 2012). Earthworms are ecosystem engineers (Jones et al., 1994), because of their large effect on the soil environment (Blouin et al., 2013). Microarthropods also have significant effects on belowground processes, contributing to the carbon/nitrogen cycles and litter decomposition (Osler and Sommerkorn, 2007) as well as improving soil aggregation (Siddiky et al., 2012), dispersing fungal spores (Dromph, 2001) and even affecting plant succession (Bonkowski and Roy, 2012). Maintaining an optimal environment suitable for these ecosystem engineers and key participants in nutrient cycling, should provide a cascade in benefits through the different functional groups within the soil and is key to good soil management and maintaining a healthy soil food web.

Variability among rooting systems and sward cover of plant species, leads to differences in their effects on overall productivity, stability of soil, microbial processes (White et al., 2013) and the soil food web itself. For example, perennial ryegrass has a shallow but extensive rooting system that is highly branched and produces fine adventitious roots, whereas chicory and (to a lesser extent) red clover produce deep tap roots that have the potential to 'mine' deep soil resources that are inaccessible to other shallower rooting plants (Belesky et al., 2001). Whilst white clover after initially producing a short tap root spreads through the production of stolons at root nodules (Marriott and Haystead, 1992). Pores created by chicory's taproot, have been found to provide better access for the next crop to the nutrients located within deeper soil (Perkons et al., 2014), increased porosity has also been found to increase earthworm abundance (Kautz et al., 2014). These differences in root architecture affect the soil ecosystem, changing the soil faunal assemblage to those best adapted to the environment they are residing in (Bonkowski, 2004).

Studies have focused on whether the soil food web is driven from litter or root inputs, utilising stable isotopes (Pollierer et al., 2007), or whether the soil food web drives plant species diversity (Bennett, 2010), however few look at the effects of specific plant species on the food web itself. To further our understanding of the effect of different forages on soil fauna, an experiment was set up to test the hypothesis that alternative forages to ryegrass, such as forbs/legumes, would alter the soil habitat. The hypothesis we investigated, was that a change in soil habitat (plant type) will influence the environment and should be reflected in the faunal biodiversity residing there; these differences will potentially be linked to the specific attributes of the different forages, e.g. tap roots, nitrogen fixation, or mycorrhizal association, and be visible through differences in abundance and diversity of the soil fauna. Specifically we hypothesise that the differences in forage rooting system (fine/extensive for ryegrass, tap roots/stolons for chicory and clovers) will favour different functional groups of soil fauna to a lesser or greater extent. Also those forages that are more strongly mycorrhizal will favour soil faunal functional groups linked to fungivory.

2. Material and methods

2.1. Experimental site, plot characteristics and maintenance

Twenty plots (7.5 m × 12 m) were set up at the Institute of Biological, Environmental and Rural Sciences (IBERS), University of Aberystwyth, Wales (52° 25′ 59″ N, 4° 1′ 26″ W) in June 2009. Plots were set up on an area of stony, well-drained loam of the Rheidol soil series (see Table 1 for site characteristics). Soil temperatures are typical of a temperate European climate in this area of the UK with the 50 year average ranging from 3.8 °C in winter to 16.8 °C in summer. The experimental area was ploughed to a uniform depth and soil nutrient status was standardised, the area received ground dolomitic limestone (magnesium lime) at 5 t ha^{-1} to achieve a soil pH of 6.0–6.5 (pre-cultivation pH = 5.75; Mg = 65.5 mg L^{-1}; Ca 1279.5 mg L^{-1}). Soil P and K were amended using a muriate of potash applied at the rate of 60 kg K_2CO_3 and triple super phosphate at the rate of 60 kg P_2O_5 ha^{-1} (pre-cultivation P = 33.5 mg L^{-1} and K = 125.1 mg L^{-1}). Initial soil analysis was performed prior to setting up the experimental plots as in Crotty et al. (2014); mineral soil analysis (Table 1) (0–7.5 cm cores) was determined for ammonium-N (NH_4-N), nitrate (NO_3-N), phosphorus, potassium, calcium, and magnesium. Soil minerals were extracted using acetic acid and measured by inductively coupled plasma optical emission spectroscopy (ICP–OES). Soil pH was determined as 1:1 (soil:water) mixture, shaken for 30 min prior to pH measure. Field plots of the five treatments were established in a randomised block design ($n = 4$). Perennial ryegrass (*L. perenne*) (cv. Premium) with minimal input of inorganic N ha^{-1} (80 kg N ha^{-1} applied during the three years prior to the experiment) (Low N), perennial ryegrass plus 200 kg N ha^{-1} $annum^{-1}$ (200 N), chicory (*C. intybus*; cv. Puna II) plus 200 kg N ha^{-1} $annum^{-1}$, white clover (*T. repens*; cv. AberDai) and red clover (*T. pratense*; cv. Merviot) were established using seed rates of 33, 33, 6, 6 and 16 kg ha^{-1}, respectively.

During 2010–2012, fertiliser was applied as ammonium nitrate (Yara Ltd, Grimsby, UK) mid-March, and then immediately after the 1st, 2nd and 3rd harvesting cuts at a rate of 80, 60, 30 and 30 kg N,

Table 1
Site characteristics, previous cropping, soil analysis and meteorological data (mean ± standard error). Met Office weather station data located at Gogerddan.

Location characteristics	
UK Ordinance Survey Grid ref	52° 25′ 59″ N, 4° 1′ 26″ W
Altitude (a.s.l.)	30 m
Soil series	Rheidol
Soil type	Stony, loam
Drainage status	Well-drained
Site history	Grass
Soil temperature (at 10 cm) (°C) 50 year average	9.7 (±1.41)
Soil analysis (autumn 2012)	
pH (H_2O)	6.2 (±0.03)
Ammonium-N (mg kg^{-1} DM)	6.25 (±0.374)
Nitrate N (mg kg^{-1} DM)	7.15 (±0.235)
Organic C (g/kg^{-1})	29.26 (±0.581)
Phosphorus (ppm)	22.0 (±0.64)
Potassium (mg kg^{-1})	90.6 (±4.25)
Calcium (mg kg^{-1})	1064.4 (±27.99)
Magnesium (mg kg^{-1})	189.2 (±4.46)

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