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Impacts of farming practice within organic farming systems on below-ground ecology and ecosystem function

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Summary

Maintaining ecosystem function is a key issue for sustainable farming systems which contribute broadly to global ecosystem health. A focus simply on the diversity of below-ground organisms is not sufficient and there is a need to consider the contribution of below-ground biological processes to the maintenance and enhancement of soil function and ecosystem services. A critical literature review on the impacts of land management practices on below-ground ecology and function shows that farm management practices can have a major impact. A particular challenge for organic farming systems is to explore to what extent reduced tillage can be adopted to the benefit of below-ground ecology without critically upsetting the whole farm management balance.

Key words: Below-ground ecology; biodiversity; soil function; soil management; tillage; arbuscular mycorrhizal fungi

Introduction

Many essential goods and services are provided as a result of processes within natural and managed ecosystems; the value of these environmental services to humans has been estimated to be worth more than the world total gross national product (Costanza *et al*., 1997). Biological processes and cycles mediated by soil organisms are critical to the delivery of ecosystem services (Murphy *et al*., 2003). Consequently it can be argued that good soil health is fundamental if we are interested in plant, animal or human health; a principle held by Lady Eve Balfour, pioneer of organic farming in the UK: "*My subject is food, which concerns everyone; it is health, which concerns everyone; it is the soil, which concerns everyone — though they may not realize it*".

It has been established that organic farming systems increase above–ground species abundance and/or richness (Bengtsson *et al*., 2005; Hole *et al*., 2005). Hole *et al*. (2005) identified that some management practices typical of organic farming systems were particularly beneficial for wildlife: reduced use of fertilisers and pesticides; sympathetic management of non-cropped habitats, use of mixed farming systems. However, less is known about the impact of farming practice on below-ground ecology and ecosystem function. This paper therefore reports some of the key findings from a recent critical review (Stockdale *et al*., 2006) and draws out implications for organic farming systems.

Links between below-ground ecology and soil function

The protection of soil is now an important policy aim with a focus on the maintenance and enhancement of soil function (e.g. Defra, 2004). The definition of soil functions is anthropocentric, recognising the importance of soil in delivering ecosystem services. For England and Wales, six key functions have been defined: food and fibre production; environmental interaction (between soil, air and water); support of ecological habitats and biodiversity; protection of cultural heritage; providing a platform for construction, providing raw materials (Defra, 2004). Soil functions are the result of the interaction and/or integration of a number of soil processes; in many cases the same processes may be linked to a number of functions. Alongside these concepts must be included consideration of the resistance of soil function and its potential resilience when disturbed (Griffiths *et al*., 2001).

While the precise role of many organisms in relation to soil processes is not fully known, allocation of below-ground species to functional groups, which contain a variable number of species (Brussaard, 1998), provides a useful frame to describe and make links between below-ground populations and soil function. Decomposition is a central process (Fig. 1) which drives the delivery of most ecosystem services, together with the formation and stabilisation of soil structure. The soil food web is therefore critical in controlling the soil processes which drive soil function. However, for many processes there are also additional “keystone” below-ground organisms that perform a fundamental functional role in the processes e.g. N-fixing organisms, arbuscular mycorrhizal fungi (AMF), methanogens.

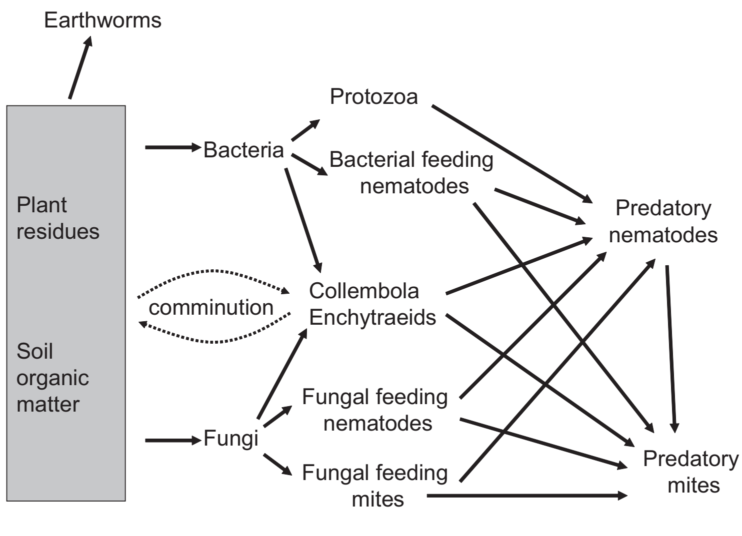

Fig. 1. Decomposition of organic matter is the result of the intermeshing vital processes of many soil organisms and is shown here in relation to the functional groups within the soil food web. Returns to the pool of organic matter in excreta and/or on the death of organisms are not shown. Figure taken from Stockdale *et al*. (2006).

Impacts of farming practice

Soil (and consequently ecosystem) function is dependent on the interaction of below-ground populations and their associated habitats within the soil. Abiotic factors, such as climate and soil texture, are also major determinants of ecosystem function – however, the relative importance of these factors in driving soil processes at a range of scales is not well understood (Bardgett, 2002). Seasonal changes in soil populations and processes may also be larger than average impacts of management *per se*. Nonetheless, increased mechanistic understanding of ecological interactions is needed if the effects of human management (intentional and unintentional) are to be evaluated and remedied. Farming practice may influence below-ground ecology both directly (though physiological effects on organisms) and indirectly through impacts on the soil habitat and/or other organisms. There have been a large number of studies which consider the impact of individual management practices on functional groups and/or species in soil. However, it is rare for management practices to be fully resolved to distinguish their direct and indirect impacts on the interactions between soil populations and their habitats. For any management practice e.g. tillage, a table showing the impact of the practice on a range of organisms can be drawn out from the literature (Table 1).

Table 1. *Summary of tillage impacts on below-ground organisms*

Species/group	Average impact of tillage or increased tillage intensity	Key references
Bacteria and archaea	Mild inhibition	Wardle, 1995
Rhizobia	No evidence found	
Nitrifiers	Little evidence, stimulation of group 3 *Nitrosospira* by cultivation	Mendum & Hirsch, 2002
Fungi	Mild inhibition	Wardle, 1995
AMF	Inhibition of AM colonisation of roots and spore numbers	Gosling *et al.,* 2006
Protozoa	Little evidence, minor impact	Foissner, 1997
Nematodes	Little effect; mild stimulation of bacterial feeders, mild inhibition of fungal feeders	Wardle, 1995
Collembola, Mites	Moderate to mild inhibition, some studies show stimulation	Wardle, 1995
Enchytraeids	Little effect, as often stimulated as inhibited.	Wardle, 1995
Earthworms, insects	Moderate to extreme inhibition	Wardle, 1995

It is also possible to draw out the effects of a range of management practices on a functional group and/or species. Taking AMF as an example, reduced plant species diversity (and modern cultivars), the use of non-mycorrhizal crops, fallow and excessive tillage are all likely to give a negative impact on mycorrhizal species diversity and infectivity (Harrier and Watson, 2003; Gosling *et al*., 2006). Rotational cropping using a range of appropriate hosts with reduced tillage intensity and regular inputs of organic matter is likely to be generally positive for AMF.

Despite this wealth of studies, scientists have been wary of drawing general principles that can be used practically to guide management; they usually conclude that more work is needed. However, the detailed increased understanding of physiology and function that is felt necessary is unlikely ever to be achieved. Interactions between practices are also rarely studied. It is therefore unclear to what extent, e.g. tillage intensity needs to be reduced to mitigate its effects, nor to what extent other factors e.g. organic matter inputs may moderate the impacts of tillage and hence how these practices could be optimised simultaneously. Nonetheless interactions between practices are often the focus of farm management decisions. The critical review of the literature confirms that farm management practices do alter below-ground ecology and ecosystem function. However, it is much less clear what steps could or should be taken to mitigate these effects. Mulder *et al*. (2003) conclude that increased intensity of management practices act on most taxa to reduce diversity within functional groups, and hence also possibly to reduce the resilience of these managed ecosystems. There is also sufficient data to indicate that reducing the intensity of use of mechanical and manufactured inputs and (re)-discovering cost-effective ways to integrate biological inputs, will benefit below–ground biodiversity, particularly in lowland grassland and cropping systems. A particular challenge for organic farming systems is to explore to what extent reduced tillage can be adopted to the benefit of below-ground ecology without unbalancing other management aspects, such as weed control.

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