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Differences in soil enzyme activities, microbial community structure and short-term nitrogen mineralisation resulting from farm management history and organic matter amendments

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Abstract

Changes in soil microbial biomass, enzyme activities, microbial community structure and nitrogen (N) dynamics resulting from organic matter amendments were determined in soils with different management histories to gain better understanding of the effects of long- and short-term management practices on soil microbial properties and key soil processes. Two soils that had been under either long-term organic or conventional management and that varied in microbial biomass and enzyme activity levels but had similar fertility levels were amended with organic material (dried lupin residue, *Lupinus angustifolius* L.) at amounts equivalent to 0, 4 and 8 t dry matter lupin ha^{-1}. Microbial biomass C and N, arginine deaminase activity, fluorescein diacetate hydrolysis, dehydrogenase enzyme activity and gross N mineralisation were measured in intervals over an 81-day period. The community structure of eubacteria and actinomycetes was examined using PCR–DGGE of 16S rDNA fragments. Results suggested that no direct relationships existed between microbial community structure, enzyme activities and N mineralisation. Microbial biomass and activity changed as a result of lupin amendment whereas the microbial community structure was more strongly influenced by farm management history. The addition of 4 t ha^{-1} of lupin was sufficient to stimulate the microbial community in both soils, resulting in microbial biomass growth and increased enzyme activities and N mineralisation regardless of past management. Amendment with 8 t lupin ha^{-1} did not result in an increase proportional to the extra amount added; levels of soil microbial properties were only 1.1–1.7 times higher than in the 4 t ha^{-1} treatment. Microbial community structure differed significantly between the two soils, while no changes were detected in response to lupin amendment at either level during the short-term incubation. Correlation analyses for each treatment separately, however, revealed differences that were inconsistent with results obtained for soil biological properties suggesting that differences might exist in the structure or physiological properties of a microbial component that was not assessed in this study.

Keywords: Microbial community structure; DGGE; Microbial biomass; Nitrogen mineralisation; Enzyme activity; Green manure amendment; Lupin (*Lupinus angustifolius* L.); Organic and conventional farming practices

1. Introduction

Soil biota plays a vital role in the maintenance of soil fertility and productivity and soil microorganisms drive most soil processes, e.g. nutrient availability and retention, decomposition of organic materials, soil organic matter build-up and stabilisation of soil aggregates (Coleman et al., 2004). Interactions amongst soil organisms of

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different trophic levels can have an effect on crop quality, soil-borne plant diseases and beneficial organisms that are, for example, involved in nutrient cycling processes or antagonistic relationships with pest species. Consequently, soil biota and their interactions indirectly affect production levels and the sustainability of agroecosystems. Studying links between microbial community composition and key soil processes (e.g. N mineralisation) will enable us to better understand the role of soil biota, in general, and biodiversity and soil microbial community structure, in particular, in protecting soil ecosystems against disturbances. This, in turn, is essential to ensuring sustained productivity of agricultural production systems (Coleman et al., 2004; Brussaard et al., 2007). Although we are able to appreciate the significance of microorganisms in the soil, we have little information on the importance of microbial diversity in the functioning of soil systems, and most research suggests that the relationships are neither consistent nor direct (Nannipieri et al., 2003; Brussaard et al., 2004).

Microbial diversity in soils is influenced by different factors including anthropogenic activities, and microbial communities are known to respond to organic matter amendments with increased activity and growth, which affects soil processes, including nitrogen (N) mineralisation (e.g. Fauci and Dick, 1994). It is, hence, likely that farm management practices such as green manuring have a significant effect on the functioning of the soil microbial community, and that differences in nutrient cycling will be reflected in the structure of the soil microbial community (O'Donnell et al., 2001). Most research indicates that microbial community composition and associated processes in soils are less affected by land-use or production systems *per se* than by individual farming techniques (e.g. green manuring, use of catch crops, crop rotations, crop residue management) (Rovira, 1994). However, most nutrient retention-based management practices are more commonly used in organic farming systems. Biological properties of soils under long-term organic management should therefore be distinguishable from those in conventionally managed soils (Fraser et al., 1988; Fauci and Dick, 1994).

We aimed to determine the changes in biological properties (including microbial community structure, biomass size and activity) in arable soils in response to varying past and current management in New Zealand. In two experiments, contrasting microbial communities were exposed to different short-term management practices by amending soils from organic and conventional management with (i) equal amounts of nitrogen in organic and mineral form (Stark et al., 2007) and (ii) different quantities of organic material on a single occasion (results presented here). Including leguminous green manures in crop rotations is considered good management practice in any agricultural production system because of their many effects on soil fertility and quality (Watson et al., 2002). However, green manure crops are of particular importance in New Zealand, where organic cropping systems are solely dependent on biological processes to supply N to crops. The combination of prohibition of soluble N fertilisers and the unavailability of alternative organic N fertiliser materials, such as farmyard manure, results in a higher reliance on N-fixing legumes as green manure crops or pasture components. In this regard, New Zealand organic arable systems differ from many European production systems, where farmyard manure may be used to transfer nutrients directly from the livestock to the cropping phase to fertilise crops and maintain production. As year round grazing is almost exclusive practice in New Zealand, this option is not available to farmers (Condron et al., 2000). In order to simulate the incorporation of two different yields of green manure crops in the rotation (4 and 8 t ha^{-1}, respectively), we investigated the effects of addition of two quantities of dried lupin (*Lupinus angustifolius* L.) to the soils. Measurements of microbial biomass, enzyme activities, gross N mineralisation and community composition of eubacteria and actinomycetes were made at intervals over an 81-day incubation period.

2. Materials and methods

2.1. Experimental setup and site description

Topsoil samples (0–15 cm) were collected from two sites within the cropping farm at Lincoln University, Canterbury, New Zealand (43°38′S; 172°27′E) (approximately 2 km apart) that had the same soil type (Wakanui silt loam; mottled immature Pallic Soil, NZ classification; Udic Ustochrept, USDA) and similar chemical and physical soil properties (Table 1). The sites had been managed under contrasting organic and conventional management systems for at least 25 years. The organic site (ORG) was established in 1976, while the conventional site (CON) had been maintained under intensive mixed cropping for over 100 years (for a detailed site description refer to Stark et al. (2006)).

The soils were air dried and sieved (2 mm), and of each soil, 1.5 kg soil sample (dry weight equivalent) were placed in 21 plastic containers and the water content was adjusted

Table 1
Chemical and physical soil properties of ORG and CON topsoil samples (0–15 cm) taken before commencement of the lysimeter experiment

Soil property	ORG	CON
C (μg g^{-1})	27289	29121
N (μg g^{-1})	2403	2405
S (μg g^{-1})	260	300
pH	6.1	5.7
Total P (μg g^{-1})	813	771
CEC (cmol$_c$ kg^{-1})	14	14
Ca (cmol$_c$ kg^{-1})	7.3	7.0
Mg (cmol$_c$ kg^{-1})	0.79	0.56
K (cmol$_c$ kg^{-1})	0.76	0.39
Na (cmol$_c$ kg^{-1})	0.17	0.19
Water holding capacity (%, w/w)	27.2	31.6
Bulk density (g cm^{-3})	1.44	1.38