Effects of past and current crop management on leaching losses, soil microbial community composition and activity

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Abstract

A lysimeter experiment was conducted to investigate differences in soil biological properties and leaching losses caused by past and present management practices. Intact monolith lysimeters were taken from sites of the same soil type that had either been under long-term organic or conventional crop management and were then managed according to organic and conventional practices and subjected to the same crop rotation for a period of 30 months. Soil samples were taken at the start and the end of the experiment and analysed for biological soil properties, including microbial diversity. Leachate was analysed for mineral N losses. Results indicated that over the trial period, leaching losses were similar for all treatments and that current management practices, e.g. crop rotation and green manuring, were the main influences on microbial biomass composition and size resulting in microbial communities of similar size and structure for all treatments. Enzyme activities showed significant differences that were equally caused by past and present management practices.

Introduction

Soil biota play a vital role in the maintenance of soil fertility and productivity; however, we know little about the role of microbial community structure and function in sustaining soil ecosystems (Ritz *et al.* 1994; Insam & Rangger 1997). Microbial diversity in soils is influenced by many factors, including soil properties, environmental conditions, and anthropogenic activities, including land management techniques like organic production systems. Therefore, changing management practices could have significant effects on the soil microbial community and associated soil processes (Shepherd *et al.* 2000; Waldrop *et al.* 2000; O'Donnell *et al.* 2001; Girvan *et al.* 2003). Intact monolith lysimeters (0.2 m^2 surface area) are a suitable way to investigate microbial diversity (community composition, activity and function) and its relationship to nutrient cycling and the associated environmental impacts (e.g. Di *et al.* 1998). They provide the benefits of a pot trial with the ability to subject soils to various management practices and measure leaching losses. The objectives of this study were to evaluate the influence of organic and conventional farm management practices on the soil microbial community and mineral N leaching losses, and to compare impacts of soil history and current management on selected soil properties, including microbial diversity and activity.

Methodology

Eight intact monolith lysimeters (50 cm diameter; 70 cm deep) were taken from each of two sites within the Lincoln University cropping farm (Canterbury, New Zealand) (43°38'S; 172°27'E). Both areas had the same soil type (Udic Ustochrept, USDA; free draining to 70 cm) and comparable chemical and physical soil properties. At the time of collection, the sites had been under either organic or conventional management for at least 25 years. For the following 30 months, four lysimeters from each site were managed under the original production system, while the other four were managed under the alternative management system, resulting in four treatments distinguished by farming history and current management practice (Table 1).

Table 1: Details of treatments included in the lysimeter study.

Treatment ID	Soil origin (past management)	Current management
B ORG	BHU (organic)	organic
B CON	BHU (organic)	conventional
L ORG	LCF (conventional)	organic
L CON	LCF (conventional)	conventional

Hand weeding was used for all treatments and pesticide application was unnecessary during the trial period; the fertilisation regime was, therefore, the main distinguishing factor between the organic and conventional managed lysimeters. The lysimeters were cultivated under identical cropping regimes (three main crops plus a lupin green manure) and managed according to best organic and conventional practices, receiving the same amounts but different forms of fertiliser (mineral vs. BioGro approved; no additional N in ORG treatments) (BioGro New Zealand 2001).

Leachate was collected from the lysimeters after irrigation or significant rainfall events and analysed for total mineral nitrogen. Soil samples (0-15 cm) were taken at the beginning and the end of the experiment and analysed for total carbon (C_{tot}) and nitrogen (N_{tot}) (Leco® CNS-2000 elemental analyser), microbial biomass carbon (C_{mic}) and nitrogen (N_{mic}) by fumigation extraction (Sparling & West 1988), arginine deaminase activity (ADA) (Alef & Nannipieri 1995), and fluorescein diacetate hydrolysis (FDA) (Adam & Duncan 2001). Genetic diversity of the bacterial communities was determined by DNA extraction, followed by PCR amplification of 16S rRNA genes and denaturing gradient gel electrophoresis (DGGE) (e.g. Heuer *et al.* 2001).

Data was analysed by general linear model analysis of variance and least significant differences ($LSD_{0.05}$) were calculated using GenStat (Release 7.1). DGGE patterns were analysed by cluster analysis according to Ward (1963) using Quantity One 1-D Analysis Software (Bio-Rad, USA).

Results and brief discussion

All treatments showed comparable leaching patterns over the course of the experiment with cumulative mineral N losses ranging from 20.8 to 29.1 kg ha^{-1} ($LSD_{0.05}$=10.9), although both ORG treatments showed lower losses than the CON treatments (Figure 1). This suggests that the lack of N inputs in the organically managed lysimeters reduced the leaching of mineral N; however, the duration of the experiment was too short to allow for definite conclusions regarding trends. Most researchers' findings suggest that differences in soil properties can only be observed after 5 years or more following conversion to an organic farming system (e.g. Mäder *et al.* 1996; Stolze *et al.* 2000).

At the initial sampling, LCF had significantly higher levels of C_{mic}, C_{tot} and higher C_{mic}:C_{tot}, while ADA was significantly higher in BHU, suggesting a relatively smaller but more active microbial community. N_{mic} and FDA were higher in LCF (not significant) (Table 2). Consistent with the differences in activity and biomass size, DGGE banding patterns showed differences in community composition indicating that differences in management practices are reflected in the microbial community which is consistent with other researchers' findings (e.g. Marschner *et al.* 2003).

At the end of the experiment, no significant differences between treatments were measured in microbial biomass size (C_{mic} and N_{mic}), i.e. previously measured differences were lost over time mainly in response to management practices that were the same for all treatments (i.e. addition of a legume green manure and crop rotation) by increasing C_{mic} and N_{mic} in BHU soils and counteracting possible negative effects of mineral fertilisers in CON treatments (cf. Robertson & Morgan 1996; Johnson *et al.* 2003). As expected, C_{mic}:C_{tot}, C_{tot} and N_{tot} were less variable and more strongly affected by past (BHU vs. LCF) compared to current (ORG vs. CON) management (Table 2). However, measured differences were negligible. Microbial activity was affected by past as well as current management. While FDA was significantly higher in LCF and CON soils, ADA was higher in BHU and CON; however, for ADA, differences between ORG and CON were not significant (Table 2 and Table 3). Similar to the microbial biomass measurements, DGGE banding patterns showed no differences between the treatments, indicating comparable community structures. This implies that similarly sized and structured microbial communities can express varying activities.

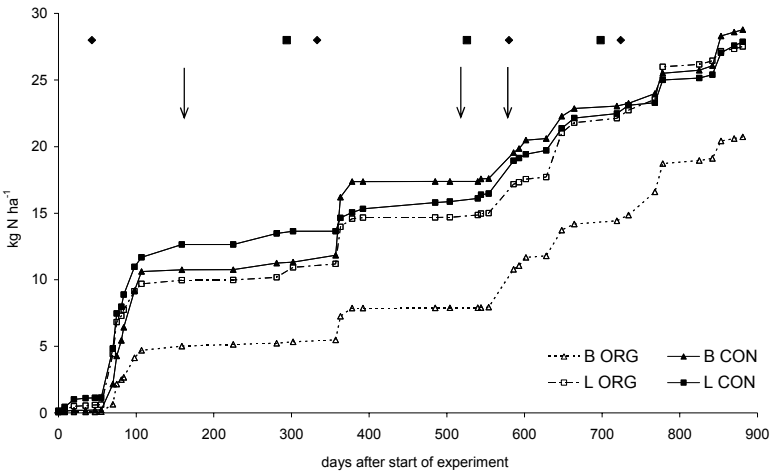

Figure 1: Mean cumulative mineral N leaching losses (kg ha^{-1}) over the course of the lysimeter study. Diamonds, time of sowing; Squares, time of harvest; arrows, fertilisation (days 127 and 600) and lupin incorporation (day 526), respectively. N=4.

Table 2: Effect of past organic (BHU) and conventional (LCF) management on mean concentrations of soil properties at the beginning and the end of the lysimeter study.

soil property	Beginning of experiment			End of experiment		
	BHU	LCF		BHU	LCF	
C_{mic} (µg C g^{-1})	494 (25.0)	596 (26.4)	***	551.8 (10.4)	553.7 (11.0)	NS
N_{mic} (µg N g^{-1})	50.1 (3.42)	47.6 (2.49)	NS	45.9 (1.85)	42.8 (1.88)	NS
ADA (µg NH_4-N g^{-1} h^{-1})	2.86 (0.10)	1.91 (0.08)	***	2.95 (0.28)	1.81 (0.10)	***
FDA (µg fluorescein g^{-1} h^{-1})	115 (9.3)	123 (12.1)	NS	228.3 (8.96)	283.2 (6.95)	***
C_{mic}:C_{tot} (%)	1.93 (0.05)	2.25 (0.04)	**	2.03 (0.04)	1.87 (0.03)	**
C_{tot} (%)	2.77 (0.01)	2.93 (0.04)	**	2.72 (0.02)	2.96 (0.04)	***
N_{tot} (%)	0.24 (0.001)	0.24 (0.003)	NS	0.22 (0.002)	0.23 (0.002)	*

***, $p<0.001$; **, $p<0.01$; *, $p<0.05$; NS, not significant. Standard error of means in parentheses. N=3 at initial sampling. N=8 at the end of the experiment.

Table 3: Effect of current organic (ORG) and conventional (CON) management on mean concentrations of soil properties at the end of the lysimeter study.

	ORG	CON	
C_{mic} (µg C g^{-1})	557 (9.6)	549 (11.5)	NS
N_{mic} (µg N g^{-1})	43.4 (1.98)	45.2 (1.87)	NS
ADA (µg NH_4-N g^{-1} h^{-1})	2.16 (0.30)	2.60 (0.27)	NS
FDA (µg fluorescein g^{-1} h^{-1})	237 (11.6)	274 (10.6)	***
C_{mic}:C_{tot} (%)	1.97 (0.05)	1.93 (0.04)	NS
C_{tot} (%)	2.83 (0.05)	2.85 (0.06)	NS
N_{tot} (%)	0.23 (0.002)	0.23 (0.003)	NS

***, $p<0.001$; NS, not significant. Standard error of means in parentheses. N=8.

While microbial biomass and community composition were strongly and permanently affected by the addition of organic matter, enzyme activity seemed to be a more inherent, resilient soil property. Only FDA was significantly affected by past as well as current management, but for both enzyme activities the differences detected between the two soils at the beginning of the experiment could be measured after 30 months. These differences were observable even after addition of mineral fertilisers (as in B CON). For FDA, this result agrees with findings that enzyme activities are rapidly affected by changes in management practices and can, hence, serve as soil quality indicators (Bandick & Dick 1999; Bending *et al.* 2004). However, it also indicates that microbial activity continues to be influenced by soil history for several years after management has changed. This observation of "residual activity" questions the suitability of enzyme activities as an early indicator for changes in soil quality.

Conclusion

After 30 months under the same crop rotation and cultivation regime, no major differences between treatments were detected in mineral N losses and soil microbial biomass size and community composition. However, past management was reflected in measurable differences in chemical soil properties, which are expected to change slowly, and microbial activity. This indicates that in the short term, microbial community size and composition are mainly influenced by management practices such as crop rotation and green manuring that were the same for all treatments. Management history, on the other hand, has a lasting effect on enzyme activities with initial differences remaining visible after conversion to organic and re-conversion to conventional, respectively.

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