

## Effects of past and current management practices on crop yield and nitrogen leaching—a comparison of organic and conventional cropping systems

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**Abstract** Farming practices can have significant effects on important soil processes, including nitrogen (N) dynamics and nitrate leaching. A lysimeter experiment was conducted to determine differences in N leaching resulting from past and current crop management practices. Intact monolith lysimeters (50 cm diam. × 70 cm deep) were taken from sites of the same soil type that had either been under long-term organic or conventional crop management. These were then managed according to established organic and conventional practices over 2½ years using the same crop rotation (barley (*Hordeum vulgare* L.), maize (*Zea mays* L.), rape (*Brassica napus* L. ssp. *oleifera*) plus a lupin green

manure (*Lupinus angustifolius* L.)) and two fertiliser regimes, resulting in four treatments based on soil management history and current fertilisation strategy. Dry matter yield of each crop was determined after harvest and leachates were collected after significant rainfall events and analysed for total mineral N concentrations. Mineral fertilisation had a clear positive effect on yields of the first crop, whereas there were no considerable differences between treatments for the last crop owing to a significant positive effect of green manure incorporation on yields. Although there was a trend of lower mineral N leaching from organically fertilised soils (organic management: 24.2 kg N ha<sup>-1</sup>; conventional management: 28.6), differences in N losses were not statistically significant between treatments. This shows that under the experimental conditions, leaching losses and crop yields were more strongly influenced by crop rotation and green manuring than by the presence or absence of mineral fertilisation. Overall, the study highlights the benefits of including a green manure in the crop rotation of any farming system.

**Keywords** past and current crop management; organic and conventional farming practices; green manure; intact monolith lysimeters; mineral N leaching; crop yield

## INTRODUCTION

Amongst other goals, organic farming practices aim to increase environmental sustainability of farming by reducing pesticide residues on crops, improving biodiversity in the soil, avoiding leaching losses and run-off, and reducing soil erosion by enhancing soil structure (e.g., Lampkin 1994; BioGro New Zealand 2002; IFOAM 2005). Lower nitrate leaching losses have been measured under organic compared to conventional farming systems resulting from lower nitrogen (N) inputs and/or lower stocking densities (Dalgaard et al. 1998; Shepherd et al. 2003). However, alternative farming systems may not be

sustainable *per definitionem*. Incorporation of leys, legumes or animal manures, for example, can lead to a nitrate surplus and cause leaching or run-off (Greenland 2000). In some studies no differences or negative effects (e.g., higher leaching losses) of organic management systems were observed when assessing the parameters per unit of yield (Stolze et al. 2000). Most of these findings are site specific, i.e., the system response depends on the particular climate, soil type, and management strategies. This limits our ability to extrapolate from the results and draw conclusions for sites with different soil types and environmental conditions, which means it is necessary to validate the conclusions for different environments including New Zealand (Condrón et al. 2000). Moreover, most lysimeter studies have examined leaching losses from grassland systems (e.g., Fraser et al. 1994; Di et al. 1998; Riley et al. 2002; Toor et al. 2005) and only a limited number have studied losses from cropping soils (e.g., Eriksen et al. 1999; Bergström & Kirchmann 2004).

To reduce overall differences in relevant soil properties that can affect nitrate leaching, intact monolith lysimeters were taken from areas with different farming histories under the same environmental conditions. The lysimeters had the same soil type and were managed under the same crop rotation, which included a leguminous green manure. The practice of year-round grazing in New Zealand is contrasting to European production systems, where livestock are overwintered inside producing large quantities of manure that can be applied to cash crops (Condrón et al. 2000). This

highlights the importance of green manure crops and the dependence on biological processes to supply sufficient amounts of N to crops, especially in organic farming systems in New Zealand. However, including green manures in crop rotations is considered good management practice in any agricultural production system because of their many positive effects on soil fertility and quality. By fixing atmospheric N and adding organic material to the soils, legumes help build and maintain soil fertility, improve the soil structure and water retention capacity, help suppress plant diseases and support the soil microbial population (Doran et al. 1988; Shepherd et al. 2000; Watson et al. 2002). To evaluate the effect of farming history and current crop management on mineral N losses, leachate was collected repeatedly from the lysimeters and total mineral N concentrations were measured. In addition, dry matter yield and N content of each crop was determined.

## MATERIALS AND METHODS

### Site description and weather conditions

Lysimeters were collected from two sites (c. 2 km apart) under the same environmental conditions within the Lincoln University Cropping Farm, Canterbury, New Zealand (43°38'S; 172°27'E). The soil at both sites was a Wakanui silt loam (Mottled Immature Pallic Soil, NZ classification; Udic Ustochrept, USDA) with broadly comparable fertility levels. Some chemical and physical topsoil (0–15 cm) properties of the two sites are presented in Table 1. At the time of sampling, one site had been farmed organically for 25 years (BHU), and the other conventionally for over 100 years (LCF).

The BHU lysimeters were from a low input area that had been under a 6-year rotation until 1999 and had been under herb-ley (14 species including perennial ryegrass (*Lolium perenne*), chicory (*Cichorium intybus*), lucerne (*Medicago sativa*), red clover (*Trifolium pratense*), and white clover (*Trifolium repens*)) between 1999 and the time of sampling in 2001. The rotation included a 1-year mixed herb-ley followed by potatoes (*Solanum tuberosum*) or *Brassica* spp., *Allium* spp., corn (*Zea mays*), beans (*Phaseolus vulgaris*), squash (*Cucurbita* spp.), beet (*Beta vulgaris*), and lettuce (*Lactuca sativa*). There are no records of any inversion ploughing and most of the residues were left on the surface. The area had never been grazed, nor had it received any mineral fertilisers or pesticides.

**Table 1** Chemical and physical soil properties of BHU (site farmed organically for 25 years) and LCF (site farmed conventionally for over 100 years) topsoil samples (0–15 cm) taken before the start of the lysimeter experiment.

Soil property	BHU	LCF
C ( $\mu\text{g g}^{-1}$ )	0.27	0.29
N ( $\mu\text{g g}^{-1}$ )	0.0024	0.0024
S ( $\mu\text{g g}^{-1}$ )	260	300
pH	6.1	5.7
Total P ( $\mu\text{g g}^{-1}$ )	813	771
CEC ( $\text{cmol}_c \text{ kg}^{-1}$ )	14	14
Ca ( $\text{cmol}_c \text{ kg}^{-1}$ )	7.3	7.0
Mg ( $\text{cmol}_c \text{ kg}^{-1}$ )	0.79	0.56
K ( $\text{cmol}_c \text{ kg}^{-1}$ )	0.76	0.39
Na ( $\text{cmol}_c \text{ kg}^{-1}$ )	0.17	0.19
Water holding capacity (%) (w:w)	27.2	31.6
Bulk density ( $\text{g cm}^{-3}$ )	1.44	1.38

The LCF site had been under pasture for almost 2 years when the lysimeters were taken and before that had been under an 8-year rotation including oats (*Avena sativa*) for grazing, spring wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), ryegrass (*Lolium perenne*), vining peas (*Pisum sativum*), and pasture. During the rotation, residues were incorporated to a depth of 15 cm by ploughing. The total average annual amount of N applied during the 8-year rotation was 70 kg N per ha, and a total of 16 kg phosphorus (P) per ha and year was applied (mainly as water-soluble monocalcium phosphate).

During the trial period, weather conditions at Lincoln deviated from the long-term means on several occasions (Fig. 1). In 2003, rainfall was well below average for most of the year and, in 2002 and 2004, precipitation was less than average for the winter period.

### Lysimeter collection and experimental design

In November 2001, eight replicate intact monolith lysimeters (50 cm diam., 70 cm deep) in steel casings were taken from each site, and installed in the Lincoln University field lysimeter laboratory according to the protocol established (Cameron et al. 1992; Di & Cameron 2002a). For 5 months before data collection, the lysimeters were maintained under their original plant cover (mixed herb-ley (BHU) and pasture (LCF)) and were irrigated on a regular basis to maintain soil moisture levels adequate for plant growth. Four lysimeters from BHU and four from LCF were randomly placed on either side of the lysimeter trench (c. 1.5 m wide) and treatments were allocated to the lysimeters randomly on each side of the trench (Fig. 2).

In April 2002, the original cover was sprayed off with glyphosate (2-(phosphonomethylamino) acetic acid) (CON) or cut (ORG) and cultivated to 15 cm. For the following 3 years, four lysimeters

from each site were managed under the original production system, while the other four were managed under the alternative management system, i.e., conventional lysimeters were converted to an organic system and organic ones were re-converted to conventional cropping. This resulted in four treatments distinguished by farm management history and current management practices (Fig. 2).

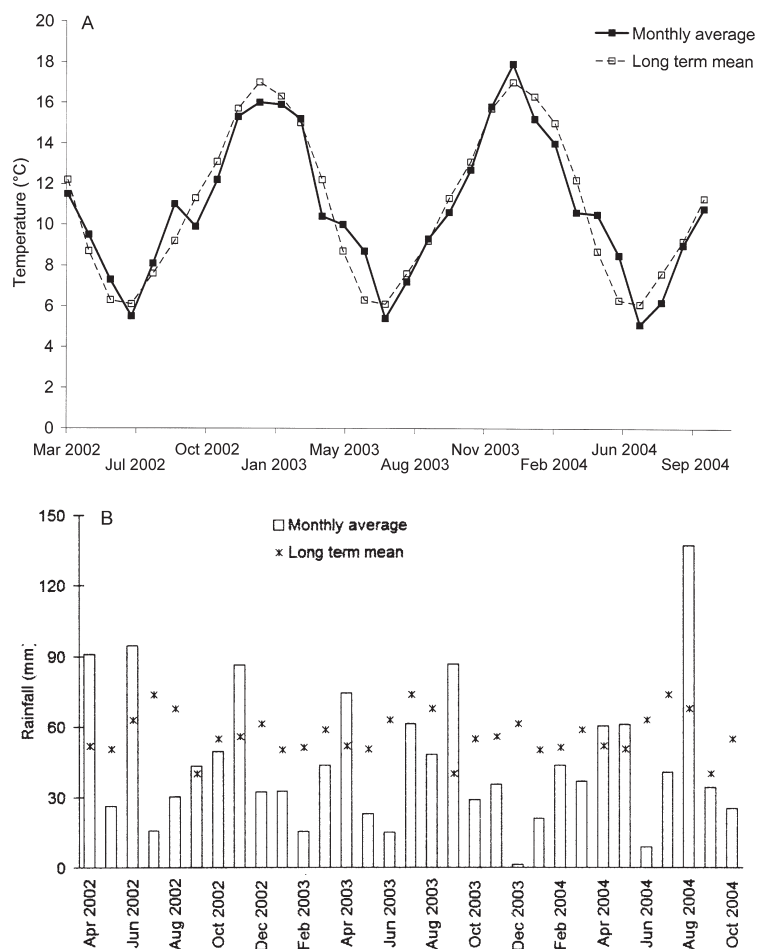
To minimise all differences possibly affecting soil processes, the same cropping regimes were chosen for all treatments consisting of three main crops (barley (*H. vulgare*), maize (*Z. mays*), rape (*Brassica napus* L. ssp. *oleifera*)) and a lupin green manure (*Lupinus angustifolius* L.). Over 2½ years, a total of 720 mm of irrigation was applied by hand according to crop requirements and time of year, usually 20 or 25 mm at a time. Hand weeding was carried out for all treatments and application of pesticides proved unnecessary for the duration of the trial. The conventionally managed lysimeter were fertilised using a commercially available mineral fertiliser (15N/10P/10K/8S) as well as urea (46% N) following the recommended fertilisation regime as used on the Lincoln University Cropping Farm, while under organic management only fertilisers approved by the New Zealand organic certification agency BioGro were applied (BioGro New Zealand 2001) (amounts as outlined in Table 2). The organically managed lysimeters did not receive any additional N and were fertilised with reactive rock phosphate (8.7% P), Patentkali (25K/17S/6 Mg), and elemental sulphur (100% S) at amounts equivalent to those applied to the conventional lysimeters.

### Leachate collection

Leachate was collected from the lysimeters after irrigation or significant rainfall events. After establishing total leachate volume, a 100 ml subsample was taken, filtered through a 0.45 µm micropore filter

**Table 2** Cultivars, management practices and fertilisation (NPKS in kg ha<sup>-1</sup>) for crops (barley, *Hordeum vulgare*; lupin, *Lupinus angustifolius*; maize, *Zea mays*; rape, *Brassica napus* ssp. *oleifera*) grown in lysimeters.

	Barley	Lupin	Maize	Rape
Cultivar	County	Fest	Elita (hybrid)	Winfred
Sowing rate (kg ha <sup>-1</sup> )	120	200	50	3
Sowing date	23 May 2002	9 Mar 2003	11 Nov 2003	3 Apr 2004
Harvest or incorporation date	29 Jan 2003	18 Sep 2003: app. 400 kg N ha <sup>-1</sup> added to all treatments	8 Mar 2004	19 Oct 2004
NPKS fertilisation				
conventional	120/ 35/ 35/ 27	not fertilised	80/ 27/ 27/ 21	not fertilised
organic	0/ 35/ 35/ 27	not fertilised	0/ 27/ 27/ 21	not fertilised
date	Aug 2002	n/a	Nov 2003	n/a



**Fig. 1** Monthly average and long-term means for: **A**, temperature (°C); and **B**, rainfall (mm) during the course of the lysimeter experiment (Apr 2002–Oct 2004).

**Table 3** Dry matter yield (DMY) ( $\text{t ha}^{-1}$ ) for each crop (barley, *Hordeum vulgare*; lupin, *Lupinus angustifolius*; maize, *Zea mays*; rape, *Brassica napus* ssp. *oleifera*), cumulative DMY ( $\text{t ha}^{-1}$ ) and cumulative N content ( $\text{kg ha}^{-1}$ ) of all four crops grown as part of a 2½ year crop sequence in lysimeters. (Values are means (standard errors of means);  $n = 4$ .)

Treatments	Barley DMY	Lupin DMY	Maize DMY	Rape DMY	Cumulative DMY	Cumulative N content
BHU-Con	8.96 (0.27)	17.19 (1.39)	14.40 (0.51)	2.76 (0.26)	43.3 (1.89)	737.4 (41.7)
BHU-Org	5.33 (0.11)	20.74 (3.35)	14.16 (0.39)	2.78 (0.13)	43.0 (3.53)	762.4 (92.9)
LCF-Con	10.35 (0.29)	15.78 (2.27)	12.76 (0.76)	2.76 (0.27)	41.6 (3.41)	606.6 (57.1)
LCF-Org	6.14 (0.43)	14.57 (3.06)	10.77 (1.09)	3.07 (0.21)	34.6 (3.89)	530.1 (91.5)
LSD <sub>0.05</sub>	0.92	8.11	2.28	0.69	10.1	228.6

to remove suspended particles before analysis for nitrate ( $\text{NO}_3^-$ )-N, ammonium ( $\text{NH}_4^+$ )-N and nitrite ( $\text{NO}_2^-$ )-N by Flow Injection Analysis (Tecator, Sweden). If immediate sample processing was not possible, the samples were frozen until analysis was carried out.

### Statistical analysis

All data was analysed by general linear model analysis of variance using GenStat Release 7.1. Samples were considered significantly different when  $P < 0.05$  and least significant differences ( $\text{LSD}_{0.05}$ ) were calculated.

## RESULTS

### Dry matter yield and crop N content

The lysimeters originating from LCF (LCF-Org and LCF-Con) ( $P = 0.003$ ) and the lysimeters managed conventionally during the study (BHU-Con and LCF-Con) ( $P < 0.001$ ) showed significantly higher dry matter yields (DMY) for the first crop, barley, compared with those from BHU and those managed organically during this study (Table 3). The differences in dry matter yields of maize and lupin were less pronounced between BHU and LCF. However, maize showed higher yields when grown in BHU soils ( $P = 0.005$ ). There was a strong positive correlation between the maize and lupin yields ( $R^2 = 0.742$ ). Rape yields did not show any variation among treatments (Table 3). The overall (cumulative) crop yield revealed no significant differences among the four treatments (Table 3).

Nitrogen content in barley (in  $\text{kg ha}^{-1}$ ) was significantly higher under conventional management (BHU-Con and LCF-Con) ( $P < 0.001$ ) whereas no significant differences could be found relating to past management (BHU versus LCF). Lupin and maize, in contrast, showed significantly higher N content in the soils from the BHU under both management types (BHU-Org and BHU-Con) ( $P = 0.048$  and  $0.003$  for lupin and maize, respectively). In rape, N levels did not differ significantly between current and past farming practices. The cumulative N content (Table 3) was highest for BHU crops (average of  $750$  compared to  $568 \text{ kg ha}^{-1}$  for LCF), with BHU-Org and BHU-Con showing similar values. Crops

subjected to the LCF-Org treatment had the lowest N content, although the difference was only significant between BHU-Org and LCF-Org.

### Effect of past and current management on mineral N leaching

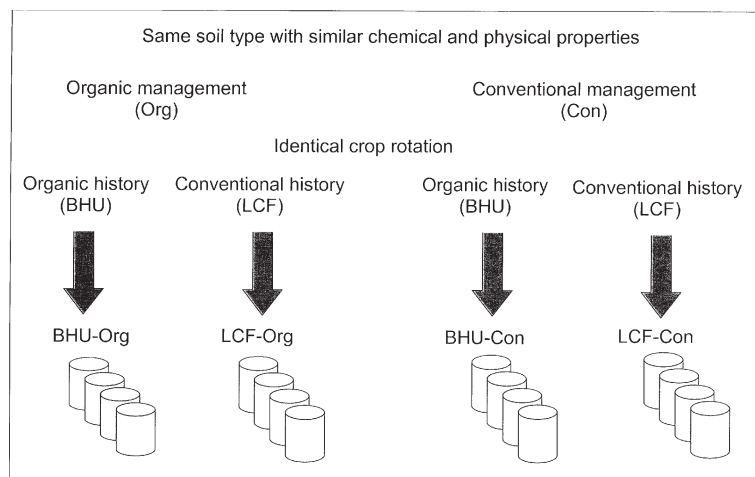
Figure 3 shows that the concentration of mineral N in the leachate varied during the course of the experiment. The highest values were measured for BHU-Con and the lowest for LCF-Org (up to  $35$  and  $23 \text{ mg N litre}^{-1}$ , respectively). A connection between fertilisation or cultivation events and mineral N concentration could be observed with the general trends of the N concentrations in the leachate decreasing when the lysimeters were under crop, and increasing after soil cultivation (April 2002, February 2003, November 2003, and March 2004) and fertilisation (September and November 2003).

Table 4 shows the cumulative amounts of drainage and total mineral N in the leachate that was collected from the lysimeters over  $2\frac{1}{2}$  years. Although average drainage volume and mineral N content were highest in the first of the three periods (year 1 > year 2 > year 3 for N; year 1 > year 3 > year 2 for drainage), there were no significant differences that can be attributed to past or current management. On average, BHU as well as the currently organically fertilised lysimeters had higher drainage in all three periods. In year 1, mineral N losses were higher from LCF lysimeters (mean of  $12.3$  compared to  $8.5 \text{ kg ha}^{-1}$  for BHU) and CON (mean of  $12.7$  versus  $8.2 \text{ kg ha}^{-1}$  for ORG). Overall, all treatments showed comparable leaching

**Table 4** Mean cumulative drainage (mm) and mineral nitrogen (N) leached ( $\text{kg ha}^{-1}$ ) between April 2002 and October 2004. ( $\text{NO}_3^-$ -N constituted 97–98.8%,  $\text{NH}_4^+$ -N 0.9–2.2%, and  $\text{NO}_2^-$ -N 0.16–0.7% of total mineral N leached;  $n = 4$ ; SEM, standard errors of means; range, range of values measured.)

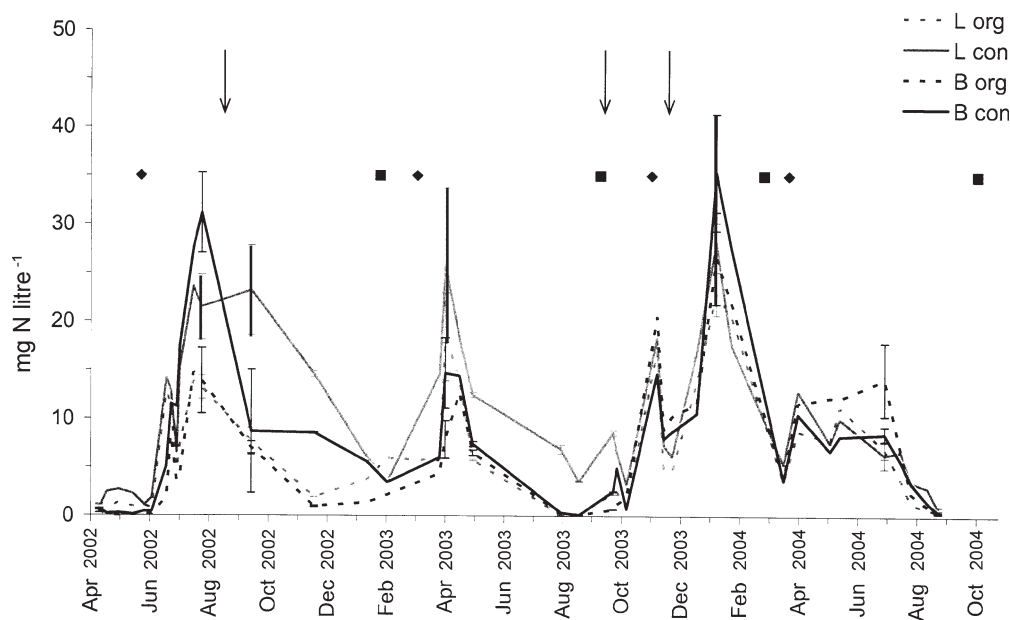
Treatments	Year 1 (Apr 2002–Apr 2003)		Year 2 (Apr 2003–Apr 2004)		Year 3 (Apr 2004–Oct 2004)		Total
	Mean (SEM)	Range	Mean (SEM)	Range	Mean (SEM)	Range	Mean (SEM)
<b>Drainage (mm)</b>							
BHU-Con	167.0 (3.4)	157–172.5	93.8 (18.4)	64.5–170	159.9 (6.9)	148–179	421 (25.6)
LCF-Con	152.9 (7.9)	142–193	66.1 (3.0)	60–70.8	128.4 (15.2)	85.5–157.5	347 (16.2)
BHU-Org*	156.1 (33.4)	57.8–200	80.8 (29.5)	16.8–81.5	144.4 (29.6)	56–178.5	444 (84.9)
LCF-Org	167.1 (11.4)	132–170.3	102.1 (15.6)	70.8–144.5	165.1 (3.3)	158.5–172	434 (17.0)
LSD <sub>0.05</sub>	55.9		58.9		52.6		141.3
<b>Mineral N (<math>\text{kg ha}^{-1}</math>)</b>							
BHU-Con	11.6 (0.57)	10.3–12.6	11.7 (3.05)	6.1–19.9	5.7 (2.91)	2.7–14.5	29.1 (2.74)
LCF-Con	13.7 (3.16)	7.0–21.7	8.9 (1.02)	7.3–11.8	5.4 (2.34)	1.3–12.0	28.0 (4.66)
BHU-Org	5.4 (0.93)	3.7–5.9	9.1 (1.95)	4.0–13.2	6.3 (0.22)	2.5–8.1	20.8 (2.75)
LCF-Org	11.0 (1.96)	5.7–15.0	11.2 (1.50)	7.0–14.1	5.4 (1.10)	2.4–7.2	27.6 (3.18)
LSD <sub>0.05</sub>	6.21		6.24		6.32		10.9

\*Large standard errors for BHU-Org are a result of low drainage from one replicate lysimeter.



**Fig. 2** Schematic representation of the lysimeter trial setup.

**Fig. 3** (below) Mean concentration ( $\text{mg litre}^{-1}$ ) of mineral nitrogen (N) ( $\pm$  standard errors) in leachate collected from lysimeters between April 2002 and October 2004. (Diamonds, time of crop sowing; squares, time of crop harvest; arrows represent times of fertilisation and lupin incorporation (see Table 2 for exact dates and amounts).) ( $n = 4$ .)



losses. In year 2, leaching losses ranged from 8.9 to 11.7  $\text{kg ha}^{-1}$  with a mean of 10.2  $\text{kg ha}^{-1}$ , whereas in year 3 the range was 5.4–6.3  $\text{kg ha}^{-1}$  (mean: 5.7  $\text{kg ha}^{-1}$ ).

Drainage from lysimeter 6 (BHU-Org treatment) was much lower than from the other replicates of the treatment which resulted in large standard errors for the BHU-Org drainage means (standard errors for mineral N loss are similar to those observed for the other treatments) (Table 4). Over the entire trial period, cumulative  $\text{NO}_3^-$ -N losses were similar for BHU-Con, LCF-Con, and LCF-Org whereas

slightly lower amounts were leached from BHU-Org lysimeters compared to the other treatments.

## DISCUSSION

The present study was not based on a systematic whole-farm approach and was not a comparison of farming systems as such. It was instead focusing on how specific farming practices affect mineral N losses and crop yields. In particular, it aimed to assess the effects of past and current organic



and conventional management practices (crop rotation, green manuring, conventional and organic fertilisation) and the result of altering the existing system, i.e., conversion or re-conversion to organic and conventional management, respectively. As microbially mediated soil processes, such as N mineralisation and consequently nitrate leaching, are influenced by inherent soil properties, environmental conditions and anthropogenic activities (O'Donnell et al. 2001), it was important to reduce such external differences between the two systems by choosing two sites of the same environmental conditions and the same soil type and then to subject the soils to the same crop rotation.

The influence of previous (LCF versus BHU) and current (CON versus ORG) management practices was most pronounced for the first crop (barley). The difference in yield (LCF > BHU) might be a result of the different fertilisation regimes before the lysimeters were taken. Although both soils were in a restorative phase in the years leading up to this experiment (pasture and herb-ley for LCF and BHU, respectively), the LCF site was grazed and had been cultivated and fertilised before the pasture phase. In contrast, the BHU area was a low input area and had not been actively managed for c. 3 years before the lysimeters were taken. Hence, it is likely that the LCF soils responded better to the conventional fertilisation (also seen in LCF-Con > BHU-Con) because the microbial community was adapted to this form of nutrient input (Barkle et al. 2001). The higher yields found under conventional management are not surprising and reflect the difference in the amount of N fertilisation applied.

Although the subsequent crops showed only minor differences in dry matter yields between BHU and LCF treatments, maize yields were significantly higher when grown in BHU soils, despite addition of N in CON. The strong positive correlation between the maize and lupin yields indicates that maize growth was affected by the addition of the green manure crop, which had slightly higher yields in BHU soils. These soils were, therefore, supplied with more carbon (C) and N by addition of greater amounts of organic matter. The effect was particularly evident for the maize yield in the unfertilised BHU treatment (BHU-ORG). Rape yields were similar for all treatments, indicating that the positive influence of the green manure crop on the unfertilised treatments was still noticeable a year after incorporation.

Overall, differences in dry matter yields and N content were small (Table 3). Although there was a

clear positive effect of N fertilisation (CON > ORG for both soils), the treatment under continued organic management (BHU-ORG) responded better to the lack of fertilisation and amendment with organic matter than the treatment that had been converted to organic management as part of the experiment (LCF-ORG), i.e., conversion to organic farming practices resulted in lower crop yields. Crop yields may increase only after 3–5 years following conversion to organic practices, whereas similar yields were found when comparing sites under long-term organic or conventional management (Altieri 1995; Drinkwater et al. 1995; Reganold et al. 2001). This suggests that lower crop yields during the first few years following conversion can be overcome when soils have been under long-term organic management (like BHU-ORG) (Bulluck et al. 2002). This might be related to changes in soil properties resulting from beneficial effects of organic farming practices that allow for better and faster response to organic matter addition and make it possible for the soils to maintain higher fertility despite lack of fertilisation (Robertson & Morgan 1996; Shepherd et al. 2000; Bulluck et al. 2002).

There were no significant differences in mineral N losses between treatments, which indicates that the application of inorganic fertilisers did not result in an increase in N leaching. Several studies have shown that organic farming practices can reduce nitrate leaching (Dalgaard et al. 1998; e.g., Stolze et al. 2000; Stopes et al. 2002), whereas others stress that mineral N losses can be equal or higher from organic farms. Application of animal manures or incorporation of green manures can result in N flushes owing to sudden mineralisation of the organic material (Eriksen et al. 1999; Shepherd et al. 2003). Fraser et al. (1988) reported higher autumn levels of nitrate in soils that received animal manure compared with chemical fertilisers, and attributed this difference to increased mineralisation. This can be a problem when cultivation coincides with warm temperatures (stimulating mineralisation) followed by heavy rain (increasing drainage) or when manures are applied in late autumn when evapotranspiration rates are low and N released from organic matter is lost from the soil by leaching (Di et al. 1999; Shepherd et al. 2003).

In this study, the amounts of annual N leaching observed ( $1.3\text{--}20\text{ kg ha}^{-1}$ ) are comparable to those reported in other studies (Di & Cameron 2002b; Stopes et al. 2002), indicating that addition of N in mineral form had no effect on the leaching patterns nor did incorporation of a leguminous green manure

drastically increase mineral N losses. This might have been a consequence of the lower than average rainfall during the trial period resulting in less drainage than expected for this geographical area. However, in accordance with our results, Stopes et al. (2002) reported similar or smaller losses from organically managed sites compared to conventional systems when under similar cropping. In addition, Drinkwater et al. (1998) and Bergström & Kirchmann (2004) showed that the inclusion of green manure crops in the cropping sequence can improve soil N retention and, consequently, reduce losses.

## CONCLUSIONS

By collecting leachate samples from the lysimeters, the influence of mineral versus organic fertilisers and the effect of a leguminous green manure on mineral N leaching and crop yield were established. Results showed that the application of a mineral fertiliser significantly increased yields of the first crop (barley), whereas the incorporation of a lupin green manure had a positive effect on dry matter yields of subsequent crops. No significant differences were observed in the amount of mineral N leached from organically and conventionally managed soils. Therefore, mineral fertilisation had a negligible effect on mineral N leaching under the experimental conditions and leaching losses were strongly influenced by crop rotation and green manuring, the farming practices that were the same for all treatments. Owing to apparent positive effects on yields and mineral N leaching, including green manures in the crop rotation is advisable in any production system.

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