NITROGEN LEACHING LOSSES ON A VOLCANIC ASH SOIL AS AFFECTED BY THE SOURCE OF FERTILISER

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Pérdidas de nitrógeno por lixiviación por efecto de la fuente del fertilizante en un suelo derivado de cenizas volcánicas

Keywords: fish sludge, dairy slurry, inorganic fertilizer, water quality

ABSTRACT

An intact lysimeters study was carried out to measure the potential nitrogen (N) losses on an andisoil of Southern Chile with different fertilisers. The treatments tested were: fish slurry (FS), dairy slurry (DS), potassium nitrate (IF) and a control treatment (C), with no N addition. An equivalent amount of 150 kg of total N ha^{-1} was applied to each lysimeter and then the equivalent to 1260 mm of rainfall was irrigated over a 90 days period. Leachate samples were analysed for nitrate, nitrite, ammonia and organic N (No). Total N losses were calculated as the product between drainage and the respective N concentration in the leachates. Lowest N losses were obtained in the control and FS treatments (66 kg N ha^{-1}) and the greatest amount was obtained in the IF treatment (261 kg N ha^{-1}). Nitrogen was mainly lost as nitrate and No (each was 49% of the total N losses). High soil organic matter of andisoils can be more relevant than fertiliser for N leaching losses.

Palabras claves: Lodo de pescado, purines de lechería, fertilizante inorgánico, calidad de agua

RESUMEN

Un experimento con lisímetros intactos se llevó a cabo para medir el potencial de pérdida de nitrógeno (N) en un andisol del sur de Chile con diferentes fertilizantes. Los tratamientos evaluados fueron purín de pescado (FS), purín de lechería (DS), nitrato de potasio (IF) y un tratamiento control (C), sin adición de N. Se aplicó una dosis equivalente a 150 kg ha^{-1} de N total a cada lisímetro y luego estos fueron regados con el equivalente a 1260 mm de lluvia distribuida en un periodo de 90 días. Las muestras de lixiviado fueron analizadas para nitrato, nitrito, amonio y N orgánico (No). Las pérdidas totales de N fueron calculadas como el producto del drenaje colectado y su respectiva concentración de N en la muestra. Las pérdidas más bajas de N se obtuvieron en el tratamiento control y en el tratamiento FS (66 kg N ha^{-1}), y las pérdidas más altas se obtuvieron el tratamiento IF (261 kg N ha^{-1}). El nitrógeno fue perdido principalmente como nitrato y como No (cada uno representó el 49% del total de las pérdidas). El alto contenido de materia orgánica de un andisol puede ser más relevante para las pérdidas de N por lixiviación que el tipo de fertilizante utilizado.

INTRODUCTION

The Lake Region of southern Chile (39 to 44 S and 71 to 74 W), has suitable climatic conditions and soil types for cattle production. Consequently, 56% of the national cattle herd is concentrated in this maritime temperate climatic region, grazed on natural and improved pastures. These cattle produce 60% of the country's milk and 45% of the meat (INE, 1997).

Volcanic soils are widespread in southern Chile accounting for 60% of the nation's arable land. They are characterised by low nutrient availability, high phosphorus (P) fixation capacity, high organic matter (OM) content and a pH-dependent cation exchange capacity (Escudey *et al.*, 2001).

In developed countries the environmental impact of livestock systems has been widely studied because of the important role of this activity on water, soil and air pollution (Jarvis and Oenema, 2000). It has been estimated that agriculture contributes 37% to 82% of the N input into surface waters of Western Europe (Isermann, 1990). International literature commonly reports information on N leaching losses after inorganic fertiliser addition (*i.e.* Di *et al.*, 1998) or different animal manure applications (*i.e.*, Misselbrook *et al.*, 1996), but no published information exists on fish sludge effect on N losses.

Despite the importance of livestock production in southern Chile and the fact that N is a strategic nutrient for grassland production, there is little information about N leaching losses (i.e. Salazar, 2002; Nissen and Daroch, 1991). Most of the studies carried out worldwide have focussed on nitrate leaching (*i.e.* Misselbrook *et al.*, 1996); however, recent studies have shown organic N leaching occurring from soils (*i.e.,* Hawkins and Scholefield, 2000; Murphy *et al.*, 2000), with no published information about it under Chilean conditions.

The objective of this study was to assess N leaching losses on an andisoil of Southern Chile with the application of different types of fertilizer.

MATERIALS AND METHODS

Lysimeter and experimental design

An intact lysimeters study was carried out at the Remehue Research Centre (INIA), in southern Chile (40°55' S, 73°08' W),

between April and December of 2003 with four treatments distributed on a randomised design with three replicates. The treatments tested were a control (C) with no fertiliser addition, lake fish sludge (FS), dairy slurry (DS) and an inorganic source (IF) (KNO_3; 15% N, 14% K_2O). The fertilised treatments received an equivalent to 150 kg total N ha^{-1}.

Lake fish sludge was collected from the bottom of the fish farming cages in the area of the study in October 2002 and was kept at room temperature until the time of application. Dairy slurry was collected a week before the experiment started, from the dairy unit at the Remehue Research Centre, and kept at 5-7ºC until required. At the moment of the application the dry matter content, pH, total N concentration and ammonium N concentration of the FS and DS were 13.7%, 7.3, 0.09% and 0.02% for FS and 6.8%, 7.4, 0.09% and 0.06% for DS, respectively.

The soil used in this experiment belongs to the Osorno soil series (Typic Hapludands; CIREN 2003), being characterised by more than 1 m depth and free drainage. The soil was collected from a site with permanent grassland over the last 20 years, which has not been used for grazing for a year and had received no fertiliser application.

Lysimeters were collected manually at 0.60 m depth (04th of March 2003) in PVC tubes type 10 with 200 mm of external diameter and 190 mm of internal diameter. A perforated lid (holes of 5 mm diameter) was placed at the bottom of each lysimeter to allow drainage. This lid was covered in the inside by one filter (nylon net ASTM 18-1000) and one membrane (nylon net ASTM Nº120/125), to avoid contamination of leachate samples. Expandable sponge was used at the soil surface level to avoid preferential flow by the lysimeters' wall. Lysimeters were carefully transported to the laboratory after collection and kept under control conditions. Prior to the experiment the grass cover was cut to surface level (10

mm residue). After this, grass did not grow enough to allow ulterior cuts, so that no N uptake was observed during the experimental period.

The fertiliser application was carried out the 6th of June 2003. Rainfall started the following day with the use of distilled water. The total amount of rainfall applied was of 1260 mm, distributed over a 12 weeks period, so that the soil was permanently saturated. This amount of rainfall is the average for the last 28 years in the area of study. Daily evapotranspiration data in the laboratory was determined with the use of an evaporation tray. Leachates samples were collected daily from the bottom of the lysimeters in polyethylene bottles (150 ml) which were rinsed twice before final collection. Bottles were kept at 5-7ºC until analysis for the different N forms.

Chemical analysis and evaluations

A soil chemical characterisation was made (0-20, 20-40 and 40-60 cm) before the experiment started (Olsen P, water pH, cation exchange capacity) according to Sadzawka (1990). The bulk density of each soil layer was determined by the cylinder method (Rowell, 1997).

At the end of the experimental period the soil of the lysimeters was samples and analysed for available N (N-NH4$^+$ and N-NO$_3^-$) at 0-20, 20-40 and 40-60 cm depth according to Sadzawka (1990). Also, soil from the 0-20 cm layer was used to determine the amount of potential N mineralization, according to Lober and Reeder (1993).

Leachate samples were analysed for ammonium-N (NH4$^+$-N), nitrate-N (NO$_3^-$-N), nitrite-N (NO$_2$-N) and dissolved organic N (No). Nitrate and ammonium concentrations were determined in a Skalar autoanalyser. Nitrate was measured using the salicylic acid method (Robarge *et al*., 1983), and ammonium was determined

through the indophenol methodology (Mulvaney, 1996). Nitrite was determined by the colorimetric method with Cd and Cu reductive column and No with the macro-Kjeldahl method (Bremmer and Mulvaney, 1982). Because of the low nitrite concentrations detected during the first weeks of measurements, this was stopped at the end of the first month of sampling. Organic N was measured during the first month of sampling and, because the high correlation with nitrate concentration in the samples, this relationship was used to predict No in the following samples. The total amount of N lost (kg N ha^{-1} yr^{-1}) was estimated as the product between the daily amount of drainage and the concentration of each of the different N forms in those samples. Because the amount of rainfall irrigated during the experiment corresponded to the average of the total annual rainfall registered in the area and because this was irrigated over a three months period, N losses reported in this study are the estimated potential N losses for the area.

Analysis of Variance (ANOVA) was used to compare the overall average concentrations and total loads for each N form and treatment. It was also used to compare differences in the available N concentration in the soil at the end of the experimental period between treatments and soil layers and differences between treatments in the potentially available N in

Table 1: Initial chemical characterisation of the soil used in the intact lysimeter experiment at three different dephts (cm). Osornosoil series, 20th March 2003($\pm$ sem, n=3)

Cuadro 1: Caracterización inicial del suelo utilizando en el experimento con lisímetros intactos a tres profundidades (cm). Serie de suelo Osorno, 20 de Marzo 2003($\pm$ esm, n=3)

	Soil layer (cm)		
Characteristic	0-20	20-40	40-60
Olsen P (mg kg^{-1})	3 ± 0.4 a	1 ± 0.1 b	2 ± 0.2 b
pH (water)	5.8 ± 0.02 b	6.0 ± 0.08 a	6.2 ± 0.01 a
Cation exchange capacity (mg kg^{-1})	2.9 ± 0.56 a	0.5 ± 0.02 b	0.8 ± 0.07 b
Available Al (mg kg^{-1})	0.2 ± 0.02 a	0.0 ± 0.002 b	0.0 ± 0.001 b
NH$_4^+$-N (mg kg^{-1})	5 ± 0.2 a	4 ± 1.0 a	4 ± 0.4 a
NO$_3^-$-N (mg kg^{-1})	3 ± 0.5 a	1 ± 0.6 b	1 ± 0.6 b
Organic matter (%)	18 ± 0.1 a	17 ± 0.4 a	16 ± 0.7 a
Bulk density (g cm^{-3})	0.6 ± 0.02 a	0.5 ± 0.01 a	0.5 ± 0.02 a

Different letters in columns indicate significant differences (P ≤ 0,05).
± Standard error of the mean

the soil after the mineralization test. SAS was used as statistical package.

RESULTS

Soil

Soil results showed that initial Olsen P concentrations were less than 5 mg kg^{-1} and that the bulk density of the soil did not changed with depth (P>0.05; Table 1).

Lysimeters

The evapotranspiration was 0.1+0.0004 mm day-1 on average, which represented a 0.7% of the rainfall applied daily. The average drainage collected from each replicate was of 35 L, with no significant differences between treatments (P>0.05), this value represented 98.4% of the total amount of rainfall applied. The pattern of drainage was not different between treatments (P>0.05).

Table 2: Average N leachates concentation (ml L^{-1}) and potential N losses (kg ha^{-1}) in different N forms after the application of 150 kg. total N as inorganic or organic fertilizer to intact lysimeters. Total rainfall applied was equivalent to 12600 mm. Experimental period of 90 days (± sem, n=3)

Cuadro 2: Concentración promedio de N en lixiviados (ml L^{-1}) y pérdidas potenciales de N (kg ha^{-1}) para diferentes formas de N después de la aplicación de 150 kg. de N total como fertilizante inorgánico y orgánico a lisímetros intactos. Total de lluvia aplicada equivalente a 12600 mm. Período experimental de 90 días (± esm, n=3)

Fertilizer	N concentration (mg L^{-1})			
	N-NO$_3^-$	No	N-NH$_4^+$	N-NO$_2^-$
Control	1.2 ± 0.32 c	1.2 ± 0.32 c	0.02 ± 0.004 a	0.005 ± 0.0026 a
Dairy slurry	2.3 ± 0.65 b	2.3 ± 0.65 b	0.02 ± 0.004 a	0.005 ± 0.0018 a
Fish Sludge	1.3 ± 0.29 c	1.3 ± 0.29 c	0.01 ± 0.004 a	0.009 ± 0.0068 a
Inorganic fertiliser	4.4 ± 1.22 a	4.4 ± 1.22 a	0.02 ± 0.005 a	0.004 ± 0.0019 a

	Losses (kg ha^{-1})				
	N-NO$_3^-$	No	N-NH$_4^+$	N-NO$_2^-$	Total
Control	33 ± 8.6 c	33 ± 8.6 c	0.2 ± 0.05 a	0.02 ± 0.009 a	66
Dairy slurry	67 ± 13.4 b	67 ± 13.4 b	0.3 ± 0.07 a	0.01 ± 0.004 a	134
Fish Sludge	33 ± 7.3 c	33 ± 7.3 c	0.2 ± 0.05 a	0.01 ± 0.006 a	66
Inorganic fertiliser	131 ± 28.8 a	131 ± 28.8 a	0.3 ± 0.08 a	0.01 ± 0.005 a	262

Different letters in rows indicate significant differences *(P≤0.05)*

Low NH_4^+-N and NO_2-N concentrations were measured in the leachates, average for the experimental period were less than 0.05 and 0.009 mg L^{-1}, respectively (Table 2), with no differences between treatments (P>0.05; Table 2). The contribution of these N forms to total N losses was negligible. The highest N concentrations in the samples were those of NO_3^- and No, being both significantly different between treatments (P≤0.05; Table 2).

Total N losses varied between 66 and 261 kg N ha^{-1}. Lower losses were estimated for the C and FS treatments and the highest loss was measured in the IF treatment (P≤0.05; Table 2).
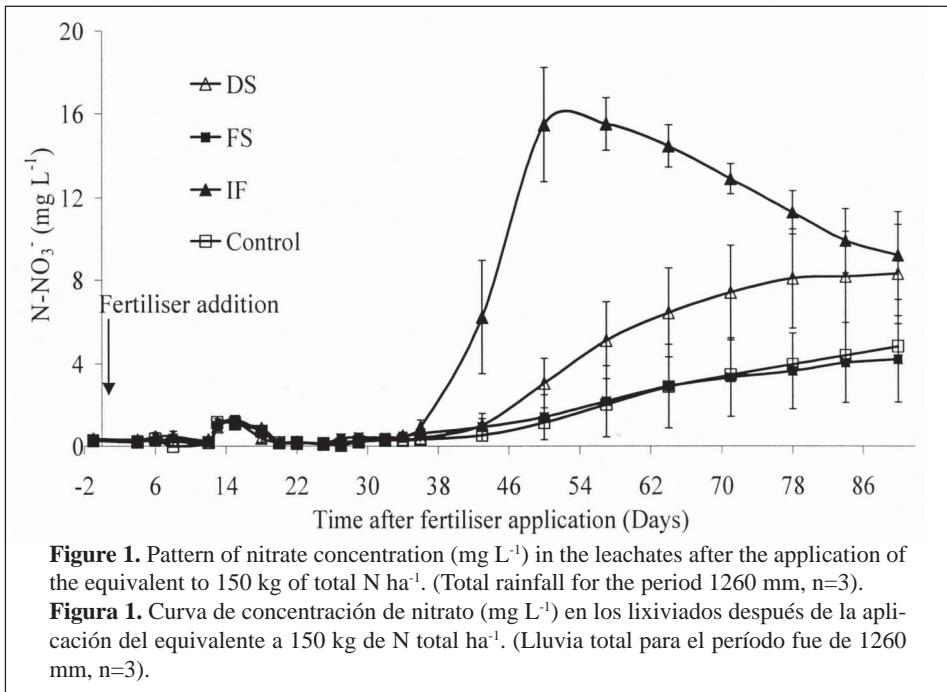
The pattern of the NO_3^- concentration in the leachates was different between treatments over time (P≤0.05), with greater rates and peak in the IF treatment (Figure 1).
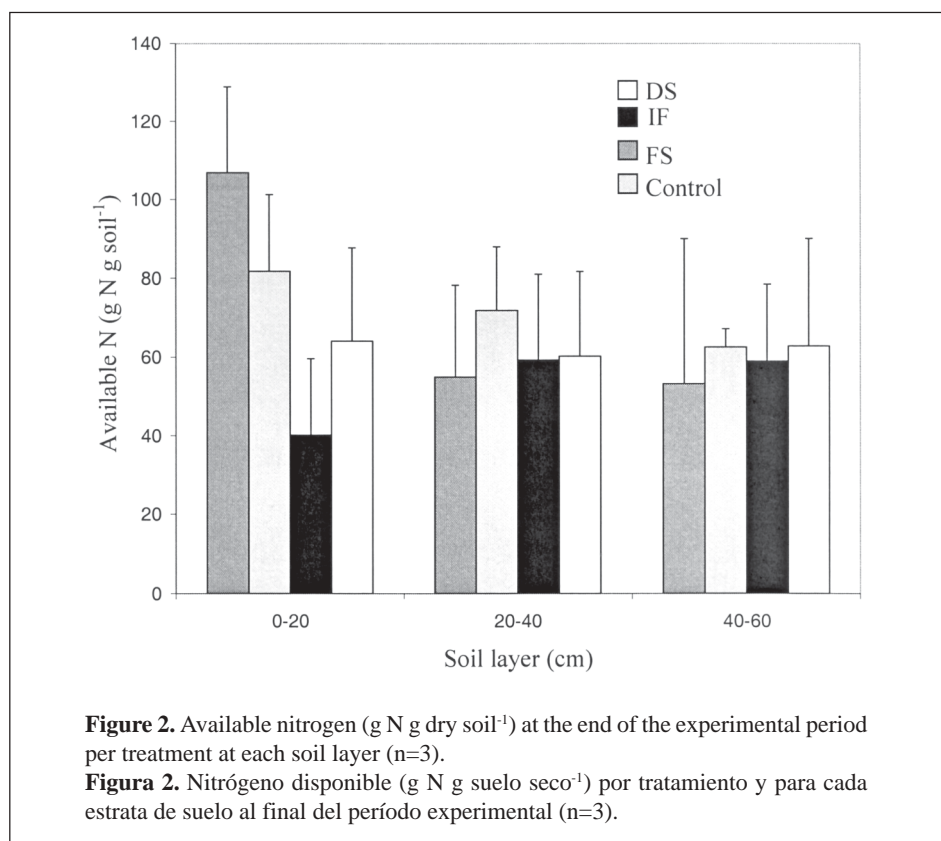
During the first month of sampling, when No was analysed in leachate samples, average N concentration was similar between treatments with 0.58, 0.61, 0.55 and 0.68

mg L^{-1} for the C, FS, DS and IF treatments (P>0.05), respectively, being closely related to NO_3^- in sample concentrations at that time (Y= 1.00 + 0.029; R^2=0.99), as indicated in the materials and methods section. Because of this, this correlation was used to model No concentration for the remaining of the experimental period. Over the first month, total No losses measured were equivalent to 0.22, 0.24, 0.22 and 0.27 kg No ha^{-1} (P>0.05).

Residual N

Available N concentration in the soil at the end of the experimental period was different between treatments and soil layers, being greater in the 0-20 cm layer and in the FS treatment (P≤0.05; Figure 2). No differences were found between treatments for the mineralization test carried out at the end of the experiment. Values varied between 13 and 17 mg N g soil^{-1} (P>0.05).

Figure 1. Pattern of nitrate concentration (mg L^{-1}) in the leachates after the application of the equivalent to 150 kg of total N ha^{-1}. (Total rainfall for the period 1260 mm, n=3).
Figura 1. Curva de concentración de nitrato (mg L^{-1}) en los lixiviados después de la aplicación del equivalente a 150 kg de N total ha^{-1}. (Lluvia total para el período fue de 1260 mm, n=3).

Figure 2. Available nitrogen (g N g dry soil^{-1}) at the end of the experimental period per treatment at each soil layer (n=3).
Figura 2. Nitrógeno disponible (g N g suelo seco^{-1}) por tratamiento y para cada estrata de suelo al final del período experimental (n=3).

DISCUSSION

The saturation point reached by the soil after the initial irrigations resulted in no significant differences in the amount of total drainage between treatments or lysimeters, so that differences in the total amount of N lost between treatments can be attributed to the particular characteristics of the fertilisers used and not to changes in the hydrology of the soil.

Nitrite and ammonium concentrations were negligible, so that these forms were not relevant for N losses from an andisoil under cut grass, in contrast of grazed areas, in agreement with Alfaro *et al*. (2005).

Greater average N concentrations were those of nitrate and No, but only average daily NO_3^- concentration at the peak from the IF treatment was greater than the 11.3 mg L^{-1}

established as maximum recommendable for drinking water (*i.e.* European Union, 91/676/ EEC), implying a low risk for underground water pollution in grazed areas of southern Chile. Average N fertiliser application in these areas is commonly no more than 45 kg N ha^{-1} per time (Alfaro and Salazar, 2005), so that the widespread risk of underground water pollution in the area is low.

Because of differences in the concentration of the different N forms in the samples collected, N was lost mainly as nitrate and No (49% of total N losses each).

The FS and C treatments had the same pattern of N lost as nitrate, so that the low N availability of this fertiliser resulted in a similar behaviour to that of the soil organic matter (OM), with no N addition. The high OM of the soil (Table 1), which suggests a high soil biomass activity, could explain the

high contribution of organic N to total N losses in all treatments (49%), in agreement with Jarvis (2002) and Murphy *et al*. (2000). This implies the need to consider organic N forms when studying the potential effect of fertiliser treatments on N leaching losses, given the high OM content of Chilean soils. These results are the first published data reported in the national literature.

Even though the legislation considers this form as part of the total N fraction, water pollution studies do not consider the presence and reactivity of this N form when assessing N leaching effects. This aspect can be relevant for water eutrophication as it is thought that this form of N is rapidly available for algae grow (Murphy *et al*., 2000). Beside No, nitrate was the other main N form for N loss, in agreement with Alfaro *et al.* (2005) and Ledgard *et al.* (1999).

Total N losses were related to the type of fertiliser used, with greater losses from the inorganic source and lower losses from the organically fertilised treatments. This effect is also supported by the lower available N concentration found at the end of the experimental period in the IF treatment in the 0-20 cm layer, and the greater available N in the organically fertilised treatments at this depth.

Nitrate losses were greater than those reported by Ledgard *et al*. (1999) in dairy grazing systems in New Zealand, with a similar andisoil to that used in the present study, both with no N addition and the addition of 200 kg N ha^{-1} (20-74 and 101 kg ha^{-1} yr^{-1}, respectively). Losses were also greater than those reported by Jaramillo *et al*. (2005) for grazed grass in the same area with the addition of 67.5 kg N ha^{-1} (11-30 kg ha^{-1} yr^{-1}). This was probably because in the present experiment the rainfall applied was equivalent to the annual average rainfall in the area and because this was applied over a short period of time (three months). This was done to establish the potential maximum N loss under soil and grassland conditions of the area. High N losses from the control treatment could be

related to the high OM of the soil, as discussed previously.

Results of the present study showed that No form represented 49% of the total N lost by leaching, in agreement with Jarvis (2002) who found that in grassland systems with low N inputs, as is the case of the present study, No can be up to 50% of the total N lost. The amount of No lost by leaching measured in this experiment agrees with results found in England on permanent pastures receiving up to 200 kg N ha^{-1} yr^{-1} (89 and 272 kg N ha^{-1} yr^{-1}; Hawkins and Scholefield, 2000), probably because in the present study rainfall was concentrated after N addition as fertiliser.

The high OM of the soil could have masked the effect of the fertilisers added, because no differences were found between treatments in the mineralization test carried out at the end of the experimental period. This suggests that in andisoils with high OM content, the soil biomass and the natural soil N mineralization processes could be a key factor in controlling the total N losses by leaching, being more relevant than the addition of fertiliser.

This study has presented novel data about the quantity and types of N loss from a volcanic ash soil in southern Chile. Results showed that soil organic matter can be the main factor controlling N flows from this soil to waters, being more relevant that fertilizer, but further studies are required to fully understand N cycling in this soil type.

CONCLUSIONS

Total N losses were high (66-262 kg N ha^{-1}), probably because the high amount of rainfall applied to the lysimeters (1260 mm) and the high soil organic matter content.

Total losses decreased in the following order IF>DS>FS=C. The high N losses from the control treatment could be related to the soil OM content and biomass activity.

Differences in the amount of total N lost by leaching resulted in differences in the

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amount of available N found at the end of the experimental period in the 0-20 cm soil layer, but did not changed the potential N mineralization test results.

The high OM of the soil could have masked the effect of the fertilisers added. This suggests that in andisoils with high OM content, the soil biomass and the natural soil N mineralization processes could be a key factor in controlling the total N losses by leaching.

Organic N and nitrate were the main forms of N loss (49% each). The high organic matter of the soil could explain the high contribution of organic N to total N losses in all treatments. Because the important contribution of No to total N losses, this N form should be considered in future leaching studies.

ACKNOWLEDGEMENTS

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