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Low nitrogen leaching losses following a high rate of dairy slurry and urea application to pasture on a volcanic soil in Southern Chile

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ABSTRACT

Dairy slurry is an important plant nutrient source. However, mismanagement (e.g. high application rate) can lead to nutrient losses to the wider environment. There are few data on slurry management and its effect on nitrogen (N) losses specific to Southern Chile, although existing studies suggest that N leaching on volcanic Chilean soils might be expected to be low. The objective of this study was to evaluate the effect of heavy dairy slurry application on N leaching losses and compare it with an inorganic fertiliser on a volcanic soil of Southern Chile. A field experiment was carried out at the Agricultural Research Institute, Remehue Research Centre, on a volcanic soil of Southern Chile (40°35′S, 73°12′W) from March 2008 to March 2010. There were two N application treatments, with a target application rate of 400 kg N ha^{-1} yr^{-1} as either dairy slurry (S) or urea (U) split into four even applications over the year. Additionally, a control (C) treatment with no N addition was included. N leaching was measured using ceramic suction cups (3 per plot), with samples taken every 100 mm of drainage during the drainage season. Despite the high N rate and application time, N leaching losses were small with no significant differences between treatments in either year ($P > 0.05$). Concentrations of NO_3^-–N for each sampling period never exceeded c. 5.5 mg L^{-1} and annual mean values were below 0.5 mg L^{-1} for all treatments. Cumulative N leaching losses were small at 1.4 and 1.2 kg ha^{-1} yr^{-1} (C), 2.8 and 4.2 kg ha^{-1} yr^{-1} (S) and 2.4 and 3.3 kg ha^{-1} yr^{-1} (U) for 2008 and 2009, respectively. We suggest that this could be explained mainly by the unique N retention properties of volcanic soils in Southern Chile and/or gaseous N losses.

1. Introduction

Dairy slurry is an important plant nutrient source on farms, supplying partial or total requirement for grass fertilisation. However, mismanagement, such as high application rate or inappropriate application time during the year, can lead to nutrient losses to the wider environment (Smith and Chambers, 1993). In dairy production systems one of the most important pathways of nitrogen (N) losses is leaching, for which greater losses have been reported from a grazed pasture than for a cut sward in New Zealand (Di and Cameron, 2002), and which may equal or exceed the range observed in arable production systems (Nissen and García, 1997; Salazar et al., 2005).

Most of the pollution problems associated with the land spreading of livestock manures are due to inappropriate management practices (e.g. high application rates), applications at times of low crop demand or inadequately calibrated equipment. Losses of manure nutrients following application to the field are difficult to eliminate, but can be reduced by considering N requirements of the crops and the timing of manure application. Significant improvements can be made in these areas on most farms with proper manure storage facilities and sufficient land area on which to apply the manure (Pain, 2000).

In most European countries, recommendations on manure application rates are based on the total N applied per year. For example, the Code of Good Agricultural Practice (Defra, 2009) applied in England recommends up to 250 kg N ha^{-1} yr^{-1}, although application rates are further restricted in Nitrate Vulnerable Zones according to the EC Nitrates Directive (91/676/EEC). In Chile there is no legislation to regulate slurry application on farms, and application rates can be as high as 300 m^3 ha^{-1} yr^{-1} (Salazar et al., 2003).

High manure application rates increase the risks of N losses through leaching, volatilisation and denitrification (e.g. Benoit, 1994; Chambers et al., 2000). In general, when comparing cattle slurry and inorganic fertiliser based on similar total N application rates, studies have shown lower N leaching losses with slurry (e.g. Di et al., 1998). This could be explained by the low input from manures of the available N forms, which can be taken up by plants or lost to the wider environment, mainly as nitrate.

In recent years, pasture-based dairy production has intensified in Southern Chile, with increasing stocking rates and nutrient

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Table 1
Characterisation of dairy slurry used in the study and application rates for 2008 and 2009.

Year	Date of application	Dry matter (%)[a]	N Kjeldahl ($kg\,t^{-1}$)[a]	N–NH_4 ($kg\,t^{-1}$)[a]	Application rate ($m^3\,ha^{-1}$)	N applied (kg N)	N applied (kg NH_4^+–N)
2008	March 31st	4.6	1.5	0.5	80	117	41
	July 25th	4.8	1.4	0.4	80	108	33
	September 29th	4.1	1.6	0.6	60	94	36
	November 27th	4.1	1.8	0.7	60	108	42
	Average	4.4	1.5	0.6	70	107	
	Total					427	152
2009	March 26th	4.7	1.8	0.7	70	127	47
	July 27th	4.8	1.9	0.7	50	93	34
	September 28th	5.2	1.2	0.3	90	110	23
	December 07th	1.7	1.3	0.4	65	47	24
	Average	4.9	1.6	0.5	69	94	
	Total					377	128

[a] Presented data for each application date represent the mean of the 3 replicate samples.

application by purchased fertilisers and cattle slurry (Alfaro et al., 2006). Surveys on manure management have shown that farmers use a high rate of manure application (up to 300 $m^3\,ha^{-1}\,yr^{-1}$) distributed in different seasons throughout the year (Salazar et al., 2003), with a potential risk for ground water pollution due to leaching during winter (Olson et al., 2009).

The South of Chile has suitable soil and climatic conditions for cattle production. Consequently, 56% of the national cattle herd is concentrated in this maritime temperate climatic region, grazed on natural and improved pastures on volcanic soils. These cattle produce 80% of the country's milk and 50% of the meat (ODEPA, 2007; Anrique, 1999). The volcanic soils are characterised by low nutrient availability, high phosphorus fixation capacity, high organic matter (OM) content, and pH-dependent cation exchange capacity (Escudey et al., 2001). Recent studies of forest volcanic soils of Southern Chile showed that they have very specialised microbial and abiotic retention processes which can reduce the risk of N leaching, despite the high N turnover rates observed (Huygens et al., 2008, 2010). The abiotic processes include dissimilatory nitrate reduction to ammonium (DNRA), which can be responsible for the consumption of more than 99% of the NO_3 available in soil solution, and physical adsorption of NH_4 into clay lattices (Huygens et al., 2007). The former process has been suggested as a widespread N retention mechanism in ecosystems that are N limited and receive high rainfall (Huygens et al., 2007), such as those of temperate pastures of southern Chile.

In Chile there are few studies published relating to N leaching losses from grassland. Alfaro et al. (2006) reported losses from pasture grazed by beef cattle ranging from 3 to 70 $kg\,N\,ha^{-1}\,yr^{-1}$, according to the stocking rates and grazing strategies used, and Nuñez et al. (2010) reported N leaching losses varying between 33 and 59 $kg\,N\,ha^{-1}\,yr^{-1}$ from pastures grazed by non-lactating dairy cows. Also, nitrate leaching losses up to 67 $kg\,N\,ha^{-1}\,yr^{-1}$ have been reported in a lysimeter study with dairy slurry application equivalent to 150 $kg\,N\,ha^{-1}$ (Alfaro et al., 2006). Under cutting regimes, a study using the equivalent to 400 $kg\,N\,ha^{-1}\,yr^{-1}$ as Sodium Nitrate applied in one dressing early in autumn showed very low N leaching losses, which were below 8% of the applied N (Salazar et al., 2010).

The objective of the current study was to evaluate the effect of high rates of dairy slurry application on N leaching losses and compare this with leaching losses from an equivalent N application as an inorganic fertiliser on a volcanic soil.

2. Material and methods

A field experiment was carried out from March 2008 to March 2010 at the Agricultural Research Institute, Remehue Research Center (40°35′S, 73°12′W) in Osorno-Chile. The soil is an Andisol of the Osorno soil series; Typic Hapludands (CIREN, 2003). The Osorno soil series is a young soil of deep to moderately deep profiles originating from modern volcanic ashes deposited on fluvioglacial substrates with a moderate water permeability and good drainage, silty loam texture, slightly plastic, slightly sticky with many fine and medium roots and many fine pores (CIREN, 2003). At the experimental site the soil has more than 1 m depth and high organic matter content (19%).

According to the meteorological station at the site, the 33 years average rainfall for the area is 1270 $mm\,yr^{-1}$, the evaporation is 868 $mm\,yr^{-1}$, the drainage 401 $mm\,yr^{-1}$ and the mean ambient temperature is 11.3 °C (5.8–16.8 °C). The sward was a 10 years old perennial ryegrass (*Lolium perenne*). At the start of the study and the following year, the experimental site was sprayed with Picloram and Dichrolophenoxiacetic acid (Tordon 24% SL Dow AgroSciences, and DM 6 67% SL Dow AgroSciences) in order to eliminate clover and other legumes in the sward to ensure no N input through fixation in this experiment.

There were two experimental treatments, with a target application rate of 400 $kg\,N\,ha^{-1}\,yr^{-1}$ as either dairy slurry (S) or urea (U) split in four even applications during the year: March, July, September and November. Additionally, a control (C) treatment with no N addition was included. The experiment was set up in a randomised block design consisting of 3 blocks with 1 replicate plot per block, each measuring area of 9 m^2.

Urea fertiliser was applied by hand and dairy slurry was applied using watering cans fitted with a small splash plate, which allowed an even distribution of slurry. A baseline fertilisation with P, K and Mg but no N, was applied for all treatments. The dairy slurry was obtained directly from the slurry storage at the INIA-Remehue farm, before each application date, stored in a slurry tank and sampled for analysis. Slurry samples were collected 2 weeks prior to application, in order to determine the application rates to use according to the different N contents of manures. During application, separate samples for each replicate (3) of the different treatments were collected and analysed to determine the actual rate applied. Characteristics of the manures used in the experiment (at application) are shown in Table 1.

Dry matter (DM) contents were determined by drying subsamples of the slurries at 65 °C for 36 h. Inorganic N was extracted by shaking 6 g of fresh dairy slurry with 100 ml of 2 M KCl for 1 h (Keeney and Nelson, 1982). The suspension was then filtered (Whatman N°5) and the filtrate stored <4 °C until analysis of NH_4^+–N. Soluble N (ammonium) was determined by direct distillation and titrimetric method (Gerhard model Vapodest 12) revised by Sadzawka and Carrasco (1985) and Sadzawka (1990,1985). Total N was determined using 10 g of dairy slurry by Kjeldahl digestion (Gerhardt model Vapodest 5) according to the methodology described by AOAC (1990).