Short communication

Ammonia emissions from urea application to permanent pasture on a volcanic soil

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ABSTRACT

Agriculture is the largest source of ammonia (NH_3) emission to the atmosphere, deriving mainly from livestock urine and manures, but fertilizer applications to pastures and crops also represent an important source. In Chile, where agriculture and cattle production are important activities (accounting for 4.5% of GDP along with the forestry sector), there are very few published data regarding NH_3 emissions from pasture and crop fertilization. This study aimed to provide the first empirical field data for Chile on N losses due to NH_3 volatilization following urea application to permanent pasture on a volcanic soil and to assess the influence of environmental conditions on emissions. Four field experiments were carried out on a volcanic acid soil using the micrometeorological integrated horizontal flux (IHF) mass balance method. Measurements were made in winter 2005 and 2007, and spring 2007 and 2008 following urea N fertilization to a permanent pasture at a rate equivalent to 100 kg N ha^{-1}. Cumulative NH_3 emissions over the measurement period were 1.4 and 7.7 kg N ha^{-1} for winter applications, and 12.2 and 26.7 kg N ha^{-1} for spring dressings. These N losses due to NH_3 volatilization are within the range of emissions reported elsewhere. Consideration of urea application timing in Chile, with regards to weather and soil conditions, could have important consequences on minimising potential N losses via volatilization with associated financial benefits to farmers.

1. Introduction

Ammonia (NH_3) volatilization is associated with a number of environmentally detrimental effects, including eutrophication of aquatic ecosystems, soil acidification problems, loss of biodiversity, formation of fine particulates (with associated human health risks) and secondary emissions of nitrous oxide from NH_3 deposition which contribute to global warming (Erisman et al., 2007; Krupa, 2003). Ammonia is emitted from a large variety of sources such as biomass burning, fossil fuel combustion and human excreta (e.g. Sutton et al., 2000), but agricultural activity is well recognized as the major contributor (Bouwman et al., 1997). In agricultural systems, emissions derive mainly from livestock excreta and subsequent manure management, but N fertilizer applications can also represent a significant source (e.g. Hyde et al., 2003; Misselbrook et al., 2000).

Globally, urea is the predominant source of inorganic N fertilizer used in agriculture, accounting for more than 50% of the total world fertilizer N consumption (Sanz et al., 2008). Ammonia volatilization from urea tends to be greater than from other fertilizer types because of the large pH increase associated with urea hydrolysis (Kissel et al., 2008). Reported losses of N due to NH_3 volatilization from urea fertilizer have exceeded 50% (Sommer et al., 2004). Urea fertilizer can therefore sometimes be associated with low N utilization efficiency by the crop or pasture, potentially leading to over fertilization with increased risk of atmospheric emissions and production costs (Sommer et al., 2004).

In Chile, N fertilizer use in pastures has increased in recent years (Alfaro and Salazar, 2005), which has increased the risk of damage to pristine natural ecosystems at the regional scale (Oyarzún et al., 2002). Despite the importance of pasture production in southern Chile and the fact that N is a strategic nutrient (Luzio et al., 2010), there are few published data regarding N losses. Soils used for agriculture in the area are of volcanic origin, with a low pH and high organic matter content (CIREN, 2005), and information on N losses and transformations from the literature based on other soil types may not be appropriate for local

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conditions. Recent studies in Chile have focused on N leaching (e.g. Alfaro et al., 2006, 2008, 2009) and little is known about gaseous losses (e.g. Martínez-Lagos et al., 2010; Nuñez et al., 2007, 2010; Casanova and Benavides, 2009).

Ammonia emission is related to soil properties and environmental factors (Kissel et al., 2008; Misselbrook et al., 2004). Emissions from soils with low pH might be expected to be small, as a low pH favours the ammonium (NH_4^+) form in the NH_3/NH_4^+ equilibrium in soil solution (Freney et al., 1983). The high organic matter of the soils may also influence emissions from urea as they tend to be associated with a higher urease activity (e.g. Corstanje et al., 2007). However, such soils also have a high Cation Exchange Capacity (CEC), and therefore greater capacity to retain NH_4^+ by adsorption, and higher water holding capacity, influencing the processes of infiltration, hydrolysis and dilution.

The main climate factors influencing the NH_3 emission are temperature, rainfall and wind speed (Sommer et al., 2004). Higher temperatures increase the rate of hydrolysis, and the transfer of NH_3 dissolved in the soil solution to the air. Rainfall will increase the infiltration of urea, or dissolved NH_3, into the soil matrix, lowering the rate of volatilization in comparison to that left at the soil surface. A combination of low temperatures and significant rainfall after a fertiliser application could therefore significantly reduce the rate of volatilization. Higher wind speed increases the mass transfer and air exchange between the soil surface and the atmosphere, increasing the rate of NH_3 volatilization for a short period (Sommer et al., 1991, 2004; McGarry et al., 1987). The objectives of this study were to provide the first empirical field data for Chile on N losses due to NH_3 volatilization following urea application to permanent pasture on a volcanic soil and to assess the influence of environmental conditions on emissions.

2. Materials and methods

2.1. Experimental site

The trials were conducted on permanent pasture, with no recent history (3 years) of N fertilization or livestock grazing, located at the Institute of Agricultural Research (INIA Remehue) (40° 31′S, 73° 03′W, 65 m.a.s.l). Soil at the site is an Andosol of the Osorno soil series (IUSS, 2007), greater than 1 m in depth with an organic matter content of 19% and water pH of 5.4–6.4. The pasture was predominantly perennial ryegrass (Lolium perenne L.). The climate is a typical Mediterranean cold weather, with a 33 year mean annual temperature of 11.3 °C and annual precipitation of c. 1279 mm.

Four experiments were conducted between 2005 and 2008, two in winter (early September and August) and two in spring (early December), using a new plot with a grass sward 5 cm height for each experiment. Urea fertilizer was applied at a rate equivalent to 100 kg N ha^{-1} to a single large circular plot (20 m of radius). Urea was used as the N source because it is the most commonly used inorganic fertilizer by local farmers as it has the lowest cost per kg of N. The application rate used was at the upper end of that used by dairy farmers in a single application on pastures (which typically varies between 20 and 100 kg N ha^{-1}), in order to produce an easily measurable signal. Meteorological data (rainfall, temperature and wind velocity) were registered at the INIA-Remehue meteorological station located 200 m from the experimental site. Soil moisture content, pH and CEC of the top soil (10 cm) were determined immediately prior to urea application for the second, third and fourth experiments, according to the methodology revised by Sadzawka (1990). These parameters were not measured for the first experiment.

2.2. Ammonia emission measurements

Ammonia volatilization was measured using the micrometeorological mass balance integrated horizontal flux method (Denmead et al., 1977), employing passive flux samplers (Leuning et al., 1985). Passive flux samplers were made to the same design as given by Leuning et al. (1985), and were independently assessed by Misselbrook et al. (2005). Briefly, two masts each of 3 m height were located in the pasture, one at the centre of the circular plot and a second one upwind of the plot to measure background flux. Five passive flux samplers coated in a 3% solution of oxalic acid in acetone were mounted on the central mast at heights of 2.80, 2.00, 1.20, 0.65, and 0.25 m above the pasture surface, and three samplers were located on the background mast (2.80, 1.20 and 0.25 m) in accordance with methodology used by Misselbrook et al. (2005).

Experimental sites were chosen ensuring flat uniform surfaces with no nearby trees to avoid wind disturbance. In the south of Chile the wind direction is predominantly from the north or the south. The background mast was located accordingly, with its location being changed if necessary during the experiment so that it was always upwind of the treated area.

Emission measurements commenced immediately following urea application. Passive flux samplers were exposed for periods varying between 24 and 72 h within each trial and measurements continued for 8 d for the first experiment and for up to 18 d for the later experiments as it was clear from the first experiment that NH_3 emissions continued beyond 8 d. Following exposure, the passive flux samplers were eluted with 40 mL of deionized water and the extracts were analysed for ammonium content using automated colourimetry (SKALAR, SA 4000, Breda, The Netherlands; Searle, 1984).

The mean horizontal flux, $\overline{uc}$ (mg N m^2 s^{-1}), at each height for each sampling period was calculated from: $\overline{uc} = M/A$ where M is the mass of NH_3–N collected (mg) in the sampler during sampling period and A the effective cross-sectional area of the sampler (m^2) (Leuning et al., 1985). The net horizontal flux of NH_3–N from the treated plot (F, μg m^{-2} s^{-1}) for each sampling period was then obtained by subtracting the integrated horizontal flux of the background mast (uw) from that of the central mast (dw):

$$F = \frac{1}{x}\left[\int_0^z (\overline{uc})_{dw} dz - \int_0^z (\overline{uc})_{uw} dz\right]$$

where x (m) represents the mean fetch length, equated to the radius of the plot. Cumulative emission for the whole experimental period was derived by summing the net emission in each sampling period.

3. Results and discussion

Mean temperatures were very similar for the two winter experiments, at c. 10 °C, and for the two spring experiments at c. 17 °C. The greatest amount of rainfall occurred during the winter 2007 experiment, with very little rainfall during the winter 2005 and spring 2007 experiments. Soil moisture content, pH and CEC were not determined for the first experiment. Initial soil pH and CEC were similar for the other three experiments, while soil moisture was the greatest for the spring 2007 application and the lowest for the winter 2007 application (Table 1).

The highest peak emission rate (5.33 kg NH_3–N ha^{-1} d^{-1}) was observed following the spring 2008 application, while the lowest was following the winter 2007 application (0.38 kg NH_3–N ha^{-1} d^{-1}; Fig. 1). Peak emission rates were reached within