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Ammonia emissions from different fertilizing strategies in Mediterranean rainfed winter cereals

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HIGHLIGHTS

- Dry matter of slurry (PS) and soil water content control NH_3 losses in dryland systems.
- PS dry matter (DM) around 4% is associated to the highest percentage of TAN losses.
- Low slurry DM (0.8%) accounts for similar NH_3 losses and yields than NH_4NO_3 fertilizer.
- NH_3 losses from well managed PS (the highest yields) can be in between 8 and 20 kg N ha^{-1}.
- PS applied only at tillering achieved maximum yields in dryland systems.

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ABSTRACT

Anthropogenic ammonia (NH_3) emissions mainly result from agricultural activities where manure spreading plays a significant role. For a Mediterranean rainfed winter cereal system there is a lack of data regarding NH_3 emissions. The aim of this work is to provide field data on N losses due to NH_3 volatilization as a consequence of the introduction of slurries in fertilization strategies and also, to assess the influence of environmental conditions and slurry characteristics on emissions. The fertilizing strategies include the use of slurry from fattening pigs (PS), sows (PS^S) and/or mineral fertilizer (M) as ammonium nitrate. Fertilizers were spread over the calcareous soil at sowing and/or at tillering at rates from 15 to 45 kg NH_4^+–N ha^{-1} for M and from 48.8 to 250.3 kg NH_4^+–N ha^{-1} for slurries. The NH_3 emissions were quantified during three cropping seasons. Average losses from the total ammonium nitrogen applied ranged from 7 to 78% for M and from 6 to 64% for slurries and they were not directly proportional to the amounts of applied ammonium. The best results on NH_3 volatilization reduction were registered when soil water content (SWC, 0–30 cm) was below 56% of its field capacity and also, when slurry dry matter (DM) was in the interval of 6.1–9.3% for PS or much lower (0.8%) for PS^S. High slurry DM favoured crust formation and the lower rates promoted infiltration, both of which reduced NH_3 emissions. Nevertheless, at tillering, the lower DM content was the most effective in controlling emissions (<9 kg NH_3–N ha^{-1}) and equalled M fertilizer in cumulative NH_3 loss ($p > 0.05$). A single slurry application at tillering did not negatively affect yield biomass. The combining of recommended timing of applications with slurry DM content and SWC should allow producers to minimize volatilization while maintaining financial benefits.

1. Introduction

Ammonia volatilization is a physical process influenced by the concentration of total ammonium nitrogen in the soil solution (TAN; NH_3–N plus NH_4^+–N) and by the resistance of NH_3 to movement from the soil matrix (Sommer et al., 2004). In agriculture, the consequence of such processes is the reduction of the fertilizer value of manures (Jarvis and Pain, 1990; Sørensen and Amato, 2002; Sommer et al., 2006) but also, once this volatilized NH_3 deposits, it becomes a threat to the environment through

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Abbreviations: CEC, cation exchange capacity; DM, dry matter; M, mineral fertilizer; NH_3, ammonia; NH_4^+, ammonium; PS, slurry from fattening pigs; PS^S, slurry from sows; S, sowing; T, tillering; TAN, total ammonium nitrogen; SWC, soil water content.

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acidification, eutrophication or direct toxic effects (Pearson and Stewart, 1993). According to the European Directive 2001/81/CE relating to air protection and thresholds on national emissions, it is necessary to establish the temporal and cumulative emissions of NH_3 derived from fertilization practices. Furthermore, from liquid manure systems in Europe, differences exist between the models used for national agricultural NH_3 emission inventories (Reidy et al., 2008) due to the influence of soil characteristics as well as to other factors such as weather or slurry composition (Sommer et al., 2003).

Different techniques have been employed to measure NH_3 losses and all of them have limitations (Sintermann et al., 2011). The most used are semi-static chambers because they easily adapt to small plots, they permit monitoring multiple treatments in the same crop season, have a low cost, and require reagents and materials commonly available (Grant et al., 1996). However, absolute estimates of NH_3–N loss can be underestimated (Pozzi et al., 2012) because according to Søgaard et al. (2002) wind speed increases, by 4% per m s^{-1}, total NH_3 volatilization.

For Mediterranean areas, information on ammonia emissions is scarce. However, NH_3 volatilization is an important environmental issue as calcareous soils favour NH_3 volatilization. Soil carbonate reacts with water to form bicarbonate (HCO_3^-) and the hydroxyl radical ($OH^{-}\bullet$) reacts with NH_4^+–N to form NH_3 gas and water: such processes may act over different periods depending on other soil characteristics, environmental conditions, and fertilizer management (Bouwmester et al., 1985; Kissel and Cabrera, 2005).

For Mediterranean conditions, articles from Génermont and Cellier (1997), Morvan et al. (1997) and Sanz et al. (2010) dealing with NH_3 volatilization from slurry applied on bare soil are available. They generally involve parameters such as slurry application times (March, June, September–October) or dry matter (DM) content (between 1.4 and 4.7%) which do not cover the current application times or the actual range of slurry composition in the Spanish regions being studied (Yagüe et al., 2012). The DM content of slurry is an important factor as it can greatly alter the amount of NH_3 volatilized (Misselbrook et al., 2000; Sommer and Hutchings, 2001; Thompson and Meisinger, 2002).

Moreover, the Ebro river basin contains a concentration of about 49% (11.3 million pigs) of the total pig Spanish herd (MARM, 2013). Slurry is usually spread by splash-plate on the fields as fertilizer, mainly on bare soil (before sowing) followed by harrowing or, less frequently, it may be applied on the winter cereal crop before tillering as a top dressing, although at this cereal stage the most popular practice is to apply mineral fertilizer (i.e. ammonium nitrate). Slurry application at tillering has recently started to be used in Spain as a strategy to reduce fertilizer costs or as an attempt to improve slurry management over the year by splitting the time of application.

A few studies related to the evaluation of the use of pig slurries in winter cereals were found: Petersen (1996) and Sieling et al. (1998) studied N use efficiency, Sommer et al. (1997) and Meade et al. (2011) measured NH_3 losses at tillering or from mid-tillering onwards but under North European soil and weather conditions.

The quantification of NH_3 volatilization in semiarid areas has not been reported either in combined applications at sowing and at tillering, or when using different fertilization strategies which include slurry and/or mineral fertilizers. The use of available models for NH_3 emission estimation cannot be generalised, due to the importance of management practices (Smith et al., 2008; Sheppard and Bittman, 2013). A key point, when applying slurry as a fertilizer dressing, is NH_3 volatilization because slurries cannot be buried into the soil immediately after their application. Besides, if a previous application has been made it might increase NH_3 losses, as it is well known that the long-term application on soil of other liquid wastes affects soil water repellence and reduces infiltration capacity (Wallach et al., 2005; Vogeler, 2009).

The present work was set up in the framework of rainfed Mediterranean agricultural systems and it includes a wide range of applied NH_4^+–N during the winter cereal cropping season. The main objective was to provide basic field data on N losses due to NH_3 volatilization, but also to include the assessment of high yielding fertilizer strategies for the area, in which pig slurry must be taken into account. In this work, we focused on fertilizer dressing applications. The specific environmental objectives of this research were: i) at tillering, to assess the influence, on NH_3 volatilization from fertilizers, of pig slurry which has been previously applied at sowing; ii) at tillering, to compare NH_3 losses between pig slurries and mineral fertilization applied at different rates; and iii) to quantify, as a reference for slurry applied at tillering, other NH_3 losses from other fertilization strategies: minerals or slurries applied at sowing.

The evaluation of NH_3 volatilization from slurries will also increase the predictability of their nitrogen fertilizer value and will allow us to improve the recommendations on slurry use in fertilizer management plans.

2. Materials and methods

2.1. Description of the experimental site

This work was set up in the Ebro river basin (Spain, 41° 52′ 29″N, 1° 09′ 10″E; 443 m asl) and was included in a broad experiment about N fertilization strategies. The soil of the site was classified as a Typic Xerofluvent (Soil Survey Staff, 1999), well drained, with a silty loam texture in the surface layer. The main top soil layer (0–0.30 m) has a low organic matter content (<2%), is non saline (electrical conductivity, 1:5 w/v, is 0.18 dS m^{-1}), the pH is 8.2 (soil:water; 1:2.5), the cation exchange capacity (CEC) is 11.1 $cmol^+ kg^{-1}$ and the soil has a high carbonate content (close to 30%). Gravimetric soil water content at field capacity is 0.27 (w/w).

The climate is semiarid Mediterranean (Fig. 1), with high summer average temperatures (>20 °C), low annual precipitation (<450 mm yr^{-1}) and high average reference crop evapotranspiration (1013 mm yr^{-1}).

2.2. Experimental set up

The size of plots receiving pig slurry was 274 m^2 (11 m wide and 25 m long) and the size of the control plot and plots receiving mineral fertilization was 174 m^2 (7 m wide and 25 m long). Soil

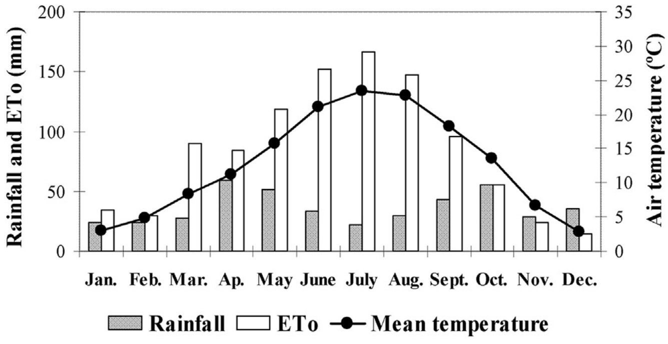

Fig. 1. Monthly rainfall, reference crop evapotranspiration (ET_0, FAO Penman–Monteith equation) and mean air temperature averages from an automatic meteorological station located in the experimental field (period 2000–2010).