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Effects of acidification and injection of pasture applied cattle slurry on ammonia losses, N_2O emissions and crop N uptake

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ABSTRACT

Surface application of cattle slurry on grassland is characterized by a high risk of ammonia (NH_3) losses. Different techniques and measures to lower these emissions are available, but reported abatement efficiencies vary substantially among studies. Therefore, a direct comparison of five different slurry application techniques was conducted in a two year field trial (2012–2013) on perennial grassland in Southern Denmark (sandy soil) and Northern Germany (marsh, clay soil). The techniques included open slot injection of cattle slurry with different distances between double disc injectors (0.166 m injection close, IC; 0.33 m injection wide, IW) and bandspreading of cattle slurry acidified to pH 6.5 (acid low, AL) and 6.0 (acid high, AH) as well as band spreading as reference (BS). For evaluation of N efficiency of slurry treatments, mineral fertilizer equivalents (MFE) were derived by comparison with a mineral N yield response curve. NH_3 emissions were measured with the combination of passive flux sampling and a dynamic chamber method. Nitrous oxide (N_2O) emissions were determined with a static chamber method at the marsh site. Grass dry matter yield and N yield were determined in all treatments. Ammonia losses were significantly reduced compared to BS treatment by 31, 61, 42 and 79% by IC, IW, AL and AH, respectively. Slurry application techniques had no significant effect on dry matter yield at both study sites. Only treatment AH resulted in higher N uptake among slurry treatments on sandy soil (2012) or clay soil (2013). Except for AH with highest MFE values at Waygaard, MFE values of slurry treatments were higher at sandy soil (53–62%) than at clay soil (39–88%). N_2O emissions were at a low level in 2012 (0.12–0.38% of N_{total}) and showed no significant differences among application methods. In 2013, N_2O emissions were higher (0.07–0.75% of N_{total}) compared to 2012 and IW resulted in significantly higher emissions than BS. Treatment AH (acidification to pH 6.0) showed lowest NH_3 losses, highest yields while N_2O emissions were not-significantly increased. Acidification and injection methods proved to reduce NH_3 losses reliably but trade-offs like increased N_2O emissions from IW and high acid requirement from AH of 4.8 l t^{-1} slurry have to be taken into consideration.

1. Introduction

Ammonia (NH_3) losses to the atmosphere result in several environmental problems such as the formation of inorganic particulate matter ($PM_{2.5}$), which is highly relevant for human health (Paulot and Jacob, 2014), and other adverse effects including nitrogen (N) deposition to N sensitive ecosystems (Bobbink et al., 2010) and indirect N_2O emissions (Eggleston et al., 2006). In Europe agriculture accounts for approximately 90% of total emitted NH_3 (Erisman et al., 2008), with field application of manures accounting for a large proportion of this (Haenel et al., 2014). Therefore, the field application of slurries plays a central role for measures to reduce NH_3 emissions. Reported losses of total ammoniacal nitrogen (TAN) from cattle slurry applied to grassland by band spreading range widely between 5% and more than 90% due to site, slurry properties and weather conditions (Sommer et al., 2006; Smith et al., 2000; Misselbrook et al., 2002; Rodhe and Rammer, 2002; Rodhe and Etana, 2005). In addition NH_3 losses may reduce the utilization of slurry N by crops (Quakernack et al., 2012).

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Various operational procedures aimed at reducing NH_3 losses include minimizing the time slurry lies on the soil surface by incorporation through harrowing or injection. In addition, band spreading and trailing shoe application aim to increase proportion of slurry that infiltrates the soil while also reducing the surface area and maximizing canopy cover. Also dilution and separation of slurry into a liquid and a solid fraction aim to increase the rate and proportion of slurry infiltration (Frost et al., 1990; Stevens et al., 1992a, 1992b; Frost, 1994; Mattila and Joki-Tokola, 2003; Matsunaka et al., 2008). In recent years, a system for field based acidification of slurry has been established in Denmark. During field application the slurry pH is lowered to a target pH value by addition of sulfuric acid which shifts the equilibrium between NH_3 and NH_4^+ in favor of NH_4^+. This results in a low NH_3 concentration in the slurry and lowers potential losses. Currently, injection of slurry in grassland is regarded to be the best technique and has proven to be most effective in reducing NH_3 losses (Feilberg and Sommer, 2013). However, concerns regarding crop damage and lower yields, especially in cereals, and high draught forces limiting the working width and restrict its widespread adoption (Nyord et al., 2010).

The efficiency to which individual techniques reduce NH_3 loss will likely depend upon a combination of local site and environmental conditions. Yet, comparisons of different abatement methods under same conditions are scarce and usually limited to one method compared to a standard application technology, e.g. injection compared to surface broadcast. This study aimed at providing data for four abatement technologies tested simultaneously at different sites under varying weather conditions.

However, some studies state a reduction of NH_3 losses after slurry injection may result in higher N_2O emissions. In a field trial on grassland Ellis et al. (1998) found short-term threefold increases in N_2O emissions after injection compared to broadcast application. Thomsen et al. (2010) reported N_2O emissions that were three to fourfold higher after injection compared to band spreading. In a field study on two different textured soils (clay and sand) Velthof and Mosquera (2011) found significant higher N_2O emissions on grassland after open slot injection compared to broadcasting of cattle slurry while highest N_2O emissions were always observed from calcium ammonium nitrate (CAN) application.

The objective of this study was to evaluate the efficiency of different treatments of open-slot injection and acidification of cattle slurry applied to grassland in lowering NH_3 losses and their effects on N_2O emissions. Considering that in Germany both, broad casting and band spreading of slurry are commonly used, band spreading was applied as reference technique. For comparison of effects of different site conditions (soil texture, wind speed), a two year field trial was established in 2012 at two sites in Northern Germany (clayey loam soil) and Denmark (sandy soil) under similar climatic conditions. Five hypotheses were put forward: i) Wider slot widths during injection of slurry results in lower NH_3 losses. ii) Field based (single point) acidification of slurry will lower NH_3 emissions. iii) Acidification of slurry is a more robust, i.e. less variable, reduction of NH_3 emissions due to a smaller influence of environmental conditions on the efficacy of the technique compared to slurry injection. iv) Injection of slurry leads to higher N_2O emissions whereas N_2O emissions are unaffected by slurry acidification. V) Decreased NH_3 emissions translate in higher grass yields or higher N use efficiency.

2. Material and methods

2.1. Site characteristics and weather data

The field trial was carried out at two perennial grassland sites from spring 2012 until autumn 2013. The experimental site "Waygaard" is located in Northern Germany close to the North Sea (54°43′N, 8°51′E). The soil is classified as Gleyic Fluvisol (calcaric) with a texture (0–0.3 m) of 22.9% clay, 35.3% silt, 41.8% sand with 4.3% soil organic carbon (SOC), a soil pH of 7.3 and 48% pore volume. The annual average temperature, precipitation and windspeed (2 m) are 9.3 °C, 845 mm and 4 m s^{-1}, respectively. The experimental site "Jyndevad" is located in Southern Denmark (54°54′N, 9°07′E) at a distance of approximately 35 km in North Eastern direction from Waygaard. The soil at Jyndevad is classified as Podsol and has a particle size distribution (0–0.3 m) of 3.1% clay, 3.8% silt, 93.1% sand with 2.5% SOC and a soil pH of 6.1. The annual average temperature, precipitation and windspeed are 8.8 °C, 874 mm and 3.4 m s^{-1}, respectively. In the years preceding the field trial, both sites were fertilized with organic livestock residues. Thus, deficiency in any of the base nutrients P and K was not expected. On both sites long established grass sward existed, consisting of a mixture of early, mid-late and late cultivars of perennial ryegrass (*Lolium perenne)*.

2.2. Field trial design

In spring 2012, a one-factorial field trial with five different cattle slurry application techniques was established as a randomized block design (n = 4) at both sites with a plot size of 9 m × 9 m. The following treatments of cattle slurry application were tested: i) Band spreading (BS) as reference method, ii) open-slot injection with an double disc injector of 0.166 m (injection close, IC) and iii) of 0.33 m (injection wide, IW) slot distances as well as acidification of slurry to target pH values of iv) 6.5 (acid low, AL) and v) 6.0 (acid high, AH), also applied by band spreading. Hose distance for band spreading and acidified slurry was 0.25 m. To avoid neighboring effects by NH_3 drift on NH_3 sampling, distances of 9 m between the plot rows and between the single plots as guard areas were necessary, resulting in a 'chessboard design' (Ni et al., 2014). The guard areas were not fertilized.

For the evaluation of the fertilizer N efficiency of the different slurry treatments, yield response curves were fitted to yield data from mineral N fertilizer (CAN) treatments. CAN was applied with increasing N doses (3 levels) and an unfertilized control was included (Table 1). These treatments were included in 4 replicates in the field study design. At Waygaard, four fertilization dates and four grassland cuts were investigated in both years, while at Jyndevad two organic fertilization events were tested in 2012 as well as four in 2013.

To avoid interactions with nutrient effects due to the sulphur from sulfuric acid applied in treatment AL and AH, all plots which had not been fertilized with acidified slurry (BS, IC, IW and CAN treatments) received mineral sulphur. At Jyndevad at all fertilization dates an appropriate amount was applied by a 24-7 NS-fertilizer to all slurry treatments. At Waygaard a fertilization of 50 kg S ha^{-1} (kieserite, $MgSO_4 \cdot H_2O$) was given in spring before the onset of grass growth. Due to a higher yield potential at Waygaard higher mineral N (CAN) levels were applied than at the less productive sandy site in Jyndevad. The slurry application rate was at site specific optimum and calculated according to NH_4^+ concentrations in slurries applied. An application rate of 320 kg and 200 kg NH_4^+ N ha^{-1} a^{-1} was expected to be the site specific optimum N supply for Waygaard and for Jyndevad, respectively (Table 1). Due to common agricultural practice in Denmark mineral N (NS 24-7) was added to plots fertilized with slurry a few days after slurry application in 2012. In 2013, for better comparison mineral N application was restricted to the mineral N treatments at both sites. At Waygaard, mineral N application was done the same day or the day after slurry application, whereas at Jyndevad the mineral N was applied after finishing of NH_3 loss measurements, i.e. about three or four days after slurry spreading.

Harvest of the plots was done by cutting a defined area of grass of approximately 10 m^2 at a cutting height of 0.07 m using a forage crop harvester (Haldrup, Type F-55, Ilshofen, Germany). Representative sub samples were dried up to weight constancy to determine grass dry matter content. Determination of plant N concentration was done by Kjeldahl analysis. At both sites plots were harvested four times a year