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Short communication

Cold season ammonia emissions from land spreading with anaerobic digestates from biogas production

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HIGHLIGHTS

- NH_3 emission of AD land spreading measured by open path FTIR and a dispersion model.
- Continuous monitoring of NH_3 fluxes in 15-min resolution over 6 days.
- 33% of ammonium in AD emitted as NH_3 after application on predominantly frozen soil.
- To our knowledge first report on NH_3 emissions from AD land spreading in winter.

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ABSTRACT

Anaerobic digestates (AD) from biogas production are applied to agricultural land as organic fertilizers, but pose an ammonia (NH_3) emission source. However, data about NH_3 emissions of cold season AD land spreading is still lacking. Therefore, in the present study NH_3 emissions of AD application under winter conditions were determined. AD was applied via trail hoses to a field plot of 27 ha in Northern Germany during the winter with temperatures around the freezing point and partly frozen soil. NH_4^+ N application rate was, including a preceding urea application, 123 kg NH_4^+ and urea N ha^{-1}. The NH_3 volatilization was monitored using Open Path Fourier Transform Infrared spectroscopy in combination with a micrometeorological transport model. Cumulative NH_3 volatilization during the six day measurements was 17.5 kg NH_3 N ha^{-1} which corresponds to 33.1% of the NH_4^+ N in applied AD. This NH_3 loss is relatively high for low temperature conditions and was most likely caused by the frozen soil restricting AD infiltration.

1. Introduction

Biogas production by anaerobic fermentation of energy crops and organic wastes like animal slurries for generating electricity is explicitly promoted as renewable energy source in several European countries (Herrmann and Rath, 2012). The by-products of the biogas fermentation process, anaerobic digestates (AD), are generally applied to agricultural land as organic fertilizers to return nutrients into the production cycle. In previous studies it has been shown that during land spreading of AD large amounts of NH_3 can be emitted to the atmosphere (Amon et al., 2006; Quakernack et al., 2012) and pose not only a loss of nitrogen (N), but also environmental threads. A large proportion of NH_3 is deposited locally and may affect natural ecosystems (Sutton et al., 1998, 2011; Hertel et al., 2013). Furthermore, it may be assumed that about 1% of NH_3 deposited to soils is transformed by microbial processes to nitrous oxide (N_2O) (IPCC, 2007), a potent greenhouse gas and ozone depleting substance, whereas NH_3 is considered a secondary greenhouse gas. As there exists substantial emission potential in AD management (Amon et al., 2006), these emissions could significantly reduce GHG savings of biogas energy.

Most studies on NH_3 emissions during AD management including field application only cover the growing season, i.e. the period between spring and early autumn. To our knowledge no data exists on NH_3 emissions from AD land spreading under cold winter conditions

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so far. This is in contrast to the common practice in Germany to apply slurry after snow melt but on still frozen soil. This is due to a better trafficability, assumed low NH_3 emissions because of low temperatures, and limitations in manure storage capacities. Later in spring slurry application may be hampered by moist soil conditions and crop damage may be comparatively high. In many cases these slurry applications are combined with the application of synthetic N fertilizers to meet crop N demand supplied by the first N dose. Therefore, a profound database about these emissions is essential for consulting on good practice in AD and slurry management.

Recently, optical remote sensing techniques combined with micrometeorological transport models are becoming more widespread for trace gas emission studies in agricultural context (e.g. Flesch et al., 2007; Jones et al., 2011). These techniques usually integrate fluxes from much larger source areas than for example chamber techniques and are rather robust against 'hot spots' and heterogeneous emission sources (Denmead, 2008).

In the present study we determined NH_3 emissions during and after AD land spreading under practical conditions using Open Path FTIR and a micrometeorological dispersion model during the winter season.

2. Materials and methods

2.1. Description of field site and fertilizer application

The field site was located in Northern Germany in the federal state of Schleswig-Holstein near the coast of the Baltic Sea (+54°26′31″, +9°56′46″). The soil was a sandy loam soil, classified as Stagnic Luvisol, and was cropped with winter rye, which had a height of approximately 5 cm at the time of the field trial. The dimension of the field plot, positions of instrumentation, and relative orientation to each other were determined by GPS (TopCon GRS-1, Topcon Positioning Systems Inc., Livermore, CA, USA), corrected by the SAPOS® high precision real-time positioning service (HEPS; ≤2 cm; http://www.sapos.de/).

The measurement campaign was carried out in co-operation with a local farmer in the winter season during the last week of February 2013. Air temperatures were fluctuating around the freezing point (average 0.2 °C), but slightly increasing towards the end of the measuring period. The soil was mainly frozen to a depth of 8–10 cm, but the top 0.5–2 cm of the soil surface were occasionally thawing during the day. Average wind speed during the six days after AD application was 2.9 m s^{-1}. Temperature and wind speed over time are shown in Fig. 1. During the night from February 24th to 25th there was 0.7 mm of precipitation in form of snow, which melted during the following day.

AD applied in this field trial derived from a biogas plant which was operated by energy crop silage and pig slurry co-fermentation. Major characteristics of the AD are 6.5% dry matter, 4.97 kg N m^{-3}, 2.64 kg NH_4^+ N m^{-3}, and pH 8.9. About 9 h before AD application, pelletized urea (46% N) was applied to a field plot of c. 27 ha at an application rate of 150 kg urea ha^{-1} (~70 kg urea N ha^{-1}). AD was applied via trail hoses to the field plot on February 22nd, starting in the afternoon. Application was paused overnight and completed in the morning of the following day downwind of our instrumentation and did therefore not affect the measurements. Target application rate was 20 m^3 AD ha^{-1}, which is equivalent to 52.8 kg NH_4^+ N ha^{-1}, adding up to 122.8 kg NH_4^+ and urea N ha^{-1}.

2.2. OP FTIR measurements and flux calculation using 'WindTrax'

NH_3 concentrations were measured by Open Path FTIR for seven days, covering one day before and six days after start of AD land spreading. Measurements were stopped after this time span in order to avoid effects of applied urea N on the NH_3 emissions. Urea hydrolysis is very slow under cold conditions and can be neglected for the first days after application. Measurements were carried out at a height of 1.3 m above ground and 69.95 m optical path length. The deployed FTIR spectrometer (M4411-S, Midac Corporation, Westfield, MA, USA) was equipped with a Stirling cooled mercury cadmium telluride (MCT) detector, ZnSe interferometer optics, and a 10″ Newtonian telescope. A 20″ IR source was placed at the opposite end of the optical path. Single-beam spectra were collected integrating 128 scans at 0.5 cm^{-1} resolution over 1.2 min. The FTIR spectrometer was set up 23.5 h prior to the start of the AD application to measure the atmospheric background concentration of NH_3, which was averaged 3.744 ppb and taken account of in the flux calculation. Wind data were measured using a 3D sonic anemometer (CSAT3, Campbell Scientific Inc., Logan, UT, USA) in the middle of the FTIR measuring path. The anemometer data was recorded at 1 Hz using a data logger (CR800, Campbell Scientific Inc.), while for the other sensors (atmospheric pressure, air temperature, precipitation) 30 s averages were collected.

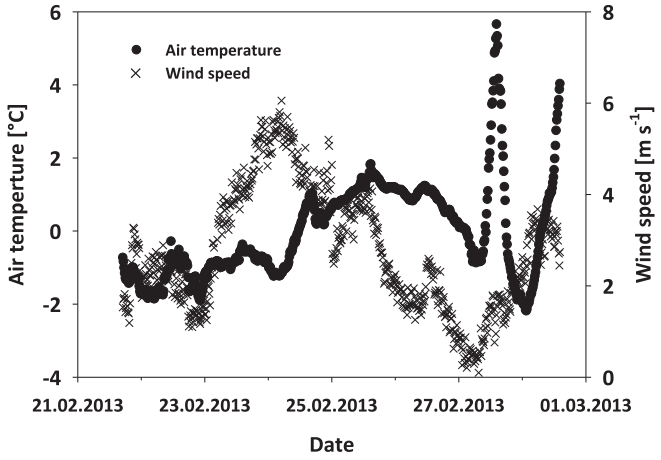

Fig. 1. Air temperature and wind speed during the field campaign. During the day the soil surface thawed occasionally to a depth of c. 0.5–2 cm.

The FTIR spectra were quantitatively analyzed for NH_3 concentrations using NH_3 absorption lines at the 960–980 cm^{-1} spectral window in consideration of ambient air temperature and atmospheric pressure by means of a Multi-Atmospheric Layer Transmission Model (*MALT*; Griffith, 1996). By this model, the measured single-beam spectrum is fitted to an iteratively recalculated spectrum based on line parameters from the *HITRAN* molecular spectroscopic database (2008 edition; Rothman et al., 2009) using a non-linear least square fitting algorithm (Griffith et al., 2012). The retrieved NH_3 concentrations and collected meteorological data were averaged to 15 min means and NH_3 fluxes were estimated using a backward Lagrangian stochastic dispersion model (*bLS*; Flesch et al., 1995, 2004), implemented in the software *WindTrax* (version 2.0.8.8; Thunder Beach Scientific, Edmonton, Alberta, Canada), simulating the displacement of 50,000 particles from the source area through the measuring path. A surface roughness length z_0 of 1.0 cm was assumed, and according to suggestions by Sommer et al. (2005) overall neutral atmospheric stability was chosen.

3. Results and discussion

Cumulated NH_3 emission determined by FTIR was 17.48 kg NH_3 N ha^{-1} over the initial six days after AD land spreading (Fig. 2) which corresponds to 33.1% of the applied NH_4^+ N. Despite low ambient temperatures, these emissions are in a similar range or