Ammonia emission after field application of biogas digestates: measurements in two energy crop rotations across 5 sites in Germany

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Abstract

A national study was set up at 5 sites in different agro-climatic regions of Germany investigating NH_3 emissions from identical crop rotations consisting of dominant German biogas crops fertilized with biogas digestates (AD). In a first trial the effect of different levels of AD fertilization on yield and NH_3 losses of silage maize (*zea mays*) was studied while in the second trial emissions were quantified in a 4 annual rotation consisting of 5 biogas crops. Ammonia losses were determined quantitatively by a calibrated dynamic chamber method with and without combination with passive samplers for replicated measurements. There existed a strong variation between NH_3 emissions (2 – 45% NH_4^+-N) after application of AD between crops and study sites. Emissions could be controlled on a low level when slurries were incorporated instantaneously. Further detailed statistical analysis and analysis with a dynamic model is required for comprehensive understanding of the observed variation in NH_3 losses.

Introduction

In Germany biogas production has become the second most important pathway of bio-energy production. Acreage used for producing crop co-substrates has increased to about 1 mio ha (8% of arable land). This has resulted in an amount of 40 mio m³ of anaerobic digestates (AD) produced in addition to about 190 mio m³ slurries from animal farming [1]. The major quantity of the additional slurry originates from maize silage as the dominant biogas substrate. As silage maize is grown in monoculture and is associated with negative effects on soil fertility and the environment (nitrate leaching) alternative crops and rotations are investigated to partially replace maize as biogas substrate.

It was shown that ammonia (NH_3) emissions from AD with large shares of crop substrate are specifically higher (% NH_4^+-N applied) as those from conventional slurries, mainly due to high pH of AD [2]. It is still unclear how additional quantities of AD affect the German NH_3 budget. The overall effect probably depends on the acreage of different crops grown for fermentation and their associated N fertilization by AD, applied at specific dates and doses. Potential NH_3 losses are modified by the AD application technique used.

On that background, a national study was funded by the FNR (German Agency for Renewable Resources) investigating NH_3 emissions from identical crop rotations consisting of the major biogas crops grown in Germany at 5 sites in different agro-climatic regions of Germany. Working hypothesis was that study sites and crops with their specific N-demand have significant effects on NH_3 emissions from field applied AD.

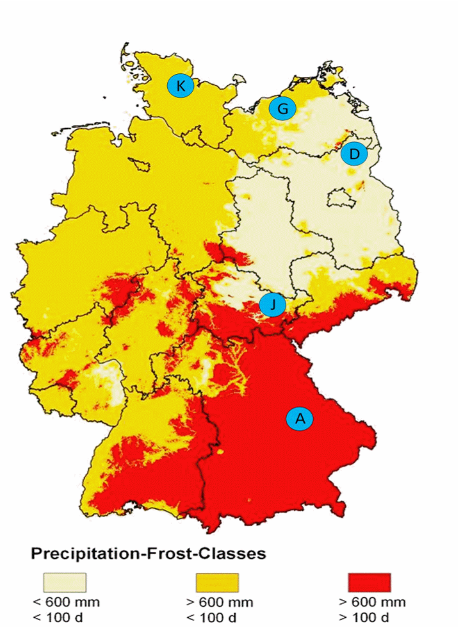

Figure 1: Location and climatic conditions of the 5 study sites included in thes study; K = Kiel, G = Guelzow, D = Dedelow, J = Dornburg, A = Ascha

Material and Methods

Field experiments

Two field trials were established in 2011 and 2012 in Kiel (North), Guelzow (North east), Dedelow (East), Dornburg (central East) and Ascha (South East). Locations and climatic conditions are shown in Fig. 1. In the first trial the effect of different levels of AD fertilization (8 N-levels ranging from 0 – 200% of optimal N supply) on yield and NH_3 losses of silage maize (*zea mays*) was studied. Optimum N and the other N levels differed between sites due to climatic and soil conditions limiting maize yield potential. AD were applied before seeding by trail hoses and incorporated after application by cultivators. At Guelzow AD was injected into the soil.

The second field trial was a 4 year crop rotation consisting of 6 different crops, all harvested as whole crop for production of silage as biogas substrate: silage maize, winter wheat *triticum aestivum*, winter rye *secale cereale*, winter triticale *triticosecale Wittmack*, rye grass *lolium multiflorum*, sorghum *sorghum sudanense*. Application technique of AD differed between crops: trail hoses (cereals, grass) or incorporation after application by a cultivator or by injection (maize, sorghum). In each year all crops of the rotation were grown simultaneously to study annual weather effects on yields and emissions. AD was applied according to assumed 70% mineral fertilizer equivalents at local optimum N rates. Two strategies of AD application were studied: all N applied as AD or split between AD (1. dose) and synthetic N (2. dose as CAN), resulting in two N levels (low and high) at the first application. Results of this trial (excluded grass) are only reported for the study site Kiel in the North of Germany.

Measurement of NH_3 losses

As the layout of the first field experiment allowed no replicated determination of NH_3 losses by passive sampling at the most study sites, losses were quantitatively determined without replication by a calibrated dynamic chamber method [3] until no emissions were detectable. Ammonia losses were determined in 3 treatments (50%, 100%, 200% N_{opt}).

In the second field trial wide interspaces between fertilized plots (12 m x 12m) allowed a replicated (n = 4) determination of NH_3 losses by semi-quantitative passive samplers, i.e. quantitative determination of relative differences between treatments (e.g. a > b, 30%). These values are scaled to absolute losses by means of a scaling factor obtained by simultaneous measurement with the dynamic chamber [3] and the passive samplers [4] on the same plot. This approach was proven valid by several comparative measurements using a micrometeorological method [4, 5]. Losses were statistically tested for each year by means of Oneway-ANOVA and Tukey LSD post-hoc test.

Results and discussion

First field experiment

In spite of incorporation of digestates in the maize experiment, relative ammonia losses varied strongly between sites and applications dates (0 – 23% NH_4^+-N applied, Fig. 2). High emissions were caused by late incorporation of digestates (>8 h) and weather conditions favourable for NH_3 emissions in the first year 2011. Incorporation times were earlier and more even in the second year. Here, relative losses varied between 2 – 9 % (Fig. 2). The lowest relative emissions were observed after injection at Guelzow site and incorporation in a sandy soil in Dedelow. In addition, differences in digestate pH affected NH_3 losses (lower AD pH in Ascha 2011).

There was no clear trend with respect to height of NH_3-emissions between sites. Loamy soil conditions and high wind speeds at the Northern site in Kiel seemed to favour higher NH_3-emissions. High emissions in Dedelow and Dornburg 2011 were mainly caused by late incorporation. In case of instantaneous incorporation losses were as high as observed after injection. There was a tendency of lower relative NH_3 emissions with higher application rates in both years, in particular in 2011 with exception of the site in Kiel. Deviations from this trend were also observed for the highest N levels (200 % optimum N) in year 2012 for the sites Guelzow and Dornburg, while Kiel showed again an increasing trend of relative losses with increasing application rates. The reduction of NH_3 losses with increasing application rates was also observed in other studies (Sogaard et al. 2002). It can be explained by the nature of the NH_3 loss process occurring at the soil surface which is strongly affected by the ratio of slurry exposed to the atmosphere at the soil-air interface. With increasing N application rates the ratio ‘surface area/volume’ is reduced thus decreasing relative ammonia losses. We hypothesize that this effect is diminished in case of incorporation of very high amounts of slurry. Then, mixing of slurry with soil becomes less efficient and higher amounts of slurry remain at the soil surface resulting in higher relative ammonia losses. However, this relationship varies between sites probably due to incorporation technique and soil conditions.

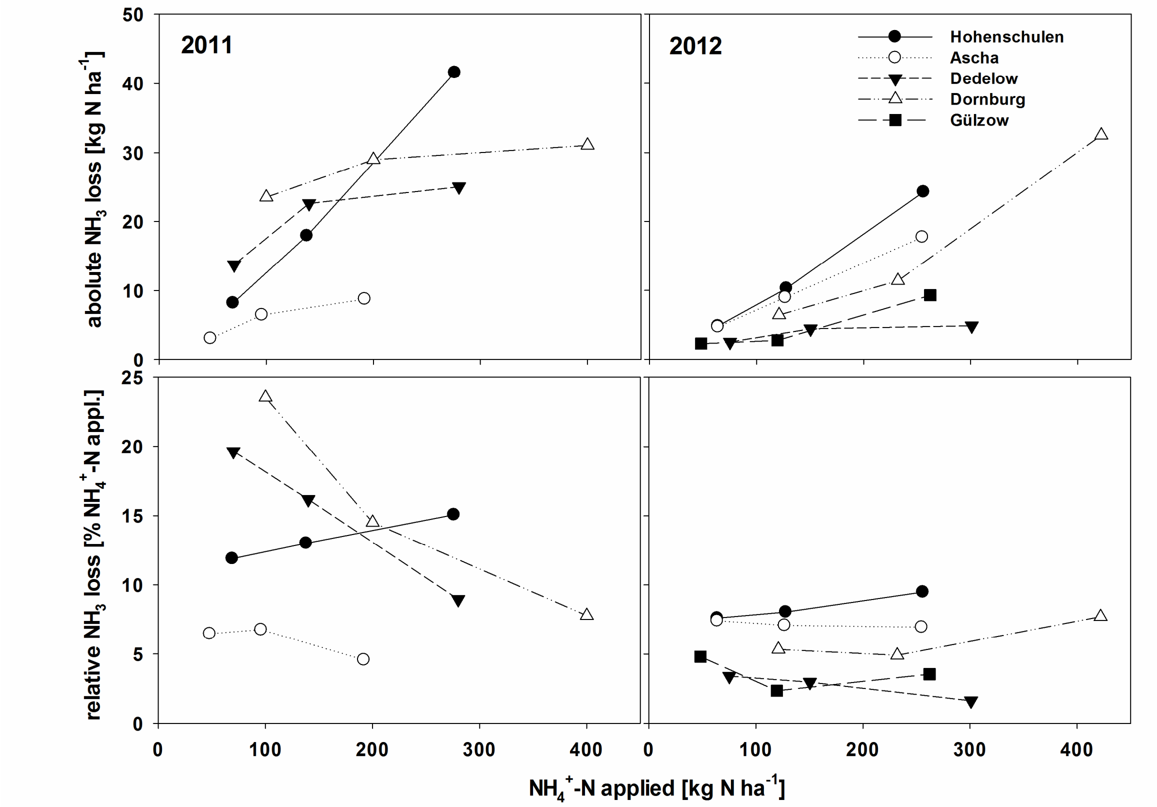

Figure 1: Absolute and relative NH_3 losses after field application of biogas residues at 5 different sites spread over Germany in the years 2011 and 2012.

Second field experiment

In 2011 very high emissions were detected in the rotation trial in Kiel after application of AD to winter cereals by trail hoses (up to 45%), due to relatively warm and windy weather conditions with high vapour pressure deficits (Fig. 3).

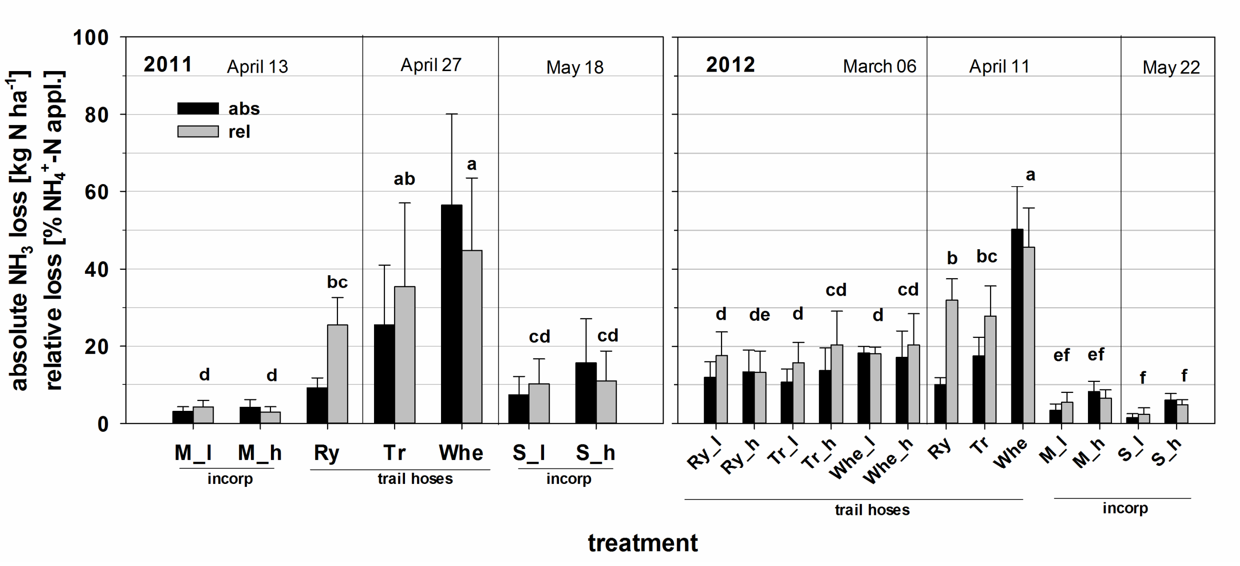

Figure 3: Absolute and relative NH_3 losses after field application of biogas residues to 5 different crops in a bio-energy rotation studied in Kiel, Northern Germany, M = silage maize, Ry = winter rye, Tr = winter triticale, Whe = winter wheat, S = sorghum, l = low N level, h = high N level, incorp. = incorporation, letters = significant differences between relative losses , Oneway ANOVA, Tukey LSD

Also in this trial some variation between NH_3 emissions was observed after incorporation of AD. In this case (maize, sorghum) relative losses were lower than 10%, usually ca. 5 %. Higher relative losses were observed in Sorghum in 2011 due to warm weather conditions. No consistent and significant effect of application rates and crops on relative emissions was observed for these two crops.
With respect to the three winter cereals fertilized with trails hoses strongly varying and partially very high NH_3 emissions were observed. At early application dates NH_3 losses were about 15% NH_4^+-N applied and no significant differences between crop related NH_3 losses were determined. The climate at the study site is characterized by a typical 'spring drought' which triggered very high emissions (up to 45% NH_4^+-N applied) in April in both years. At this application significant differences between crop related relative emissions were detected. Winter wheat showed the highest emissions while winter triticale and winter rye were on a lower level, with winter rye showing a tendency of lower emissions. This can be explained by a faster crop development in triticale and in particular winter rye resulting in a larger expanded leaf area at slurry application. Larger leaf area functions as a barrier for NH_3 emissions to the atmosphere.

Conclusions and perspectives

The field trials showed that there exists a strong variation between NH_3 emissions (2 – 45% NH_4^+-N applied) after field application of AD between crops and study sites. There existed a trend of lower relative emissions with higher application rates, which was inconsistent at specific application dates. With respect to AD incorporation emissions can be controlled on a low level as long as slurries are incorporated instantaneously. However, even a short delay of incorporation can result in high emissions on the level of low emissions after application with trail hoses. Regarding application with trail hoses there are stronger effects of crop and weather conditions on NH_3 emissions, under favourable conditions emissions reached levels of up to 40% ammonium N applied. Here, the intensity of the NH_3 emissions strongly depended on crop development and related N application dates. Crops with faster development as winter rye were characterized by lower relative N emissions as compared to crops with slow development (winter wheat). For the crops with risk of high NH_3 losses new low emissions application techniques are needed (e.g. injection in standing crop, slurry acidification).
The choice of energy crops has a strong effect on NH_3 emissions attached to a biogas production system, predominantly depending on the possibility of AD incorporation and crop development. Absolute NH_3 emissions can be high impacting the environmental benefit of biogas production.
However, the presented results only give first insights in the factors and site effects influencing the process of NH_3 volatilization after AD application. A detailed understanding of the relative importance of components of the NH_3 loss process will be obtained after comprehensive statistical analysis, by further laboratory studies and analysis of the extensive data set with a dynamic model.

References

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