Importance of injector design on ammonia volatilization and crop yield when soil injecting pig slurry to a winter wheat crop

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Abstract

Three field trials were carried out in 2011 to examine whether soil injection of slurry in winter wheat can be used as an alternative to surface application. Soil injection reduces crop yields significantly when the crop leaves and roots are damaged by the cutting caused by soil injection. Soil injection was not observed to significantly lower ammonia (NH_3) emissions compared to surface application. This surprising result is most likely because of the very low dry matter content of the slurry, meaning that the NH_3 emission potential was very low. To conclude, in this case soil injection of slurry in winter wheat was not beneficial due to the relatively large reduction of crop yield.

Introduction

Reduction of ammonia (NH_3) emissions from agricultural systems is one of the major goals in European and International environmental policies [1]. Soil injection of pig slurry has earlier been shown to significantly reduce ammonia (NH_3) emission compared to surface application [2;3]. On the other hand, soil injection in growing cereal crops tends to reduce crop yield due to crop damage caused by the injection system [4]. However, conclusions from these studies were limited by the lack of sufficient statistical power. Therefore, in 2011 a set of experiments with several replicate plots (n=[77,129]) was conducted in order to address the effect of soil injector type on NH_3 emission and crop yields.

Materials and methods

In all trial pig slurry was applied. The slurry contained 4.3 g/L total N, 2.8 g/L NH_4-N and 1.9% of dry matter. The pH of the slurry was 7.8.

The trials

Two independent yield trials were carried out in winter wheat fields at Research Centre Foulum (56.5ºN, 9.58ºE), on a loamy sand soil (Typic Hapludult). The harvesting plot size was 1.5*10 m. Experiment A evaluated the effect of three different designs of soil injection tools on yield and plant growth variables: 1. Trail hose (*n=122*) 2. Disc coulter injection (*n=129*) 3. A combination of disc coulter and tine injection (*n=128*).

Experiment B evaluated the effect of crop damage on yield caused by the disc and tine injector (similar to no. 3 in Experiment A) with two different travel speeds (3 and 9 km/h) (*n=77*). However in B) only mineral fertiliser was applied.

In Experiment C, ammonia emissions were measured following land spreading of pig slurry using the application methods of Experiment A. NH_3 was measured by applying slurry in experimental plots (36*36 m) located at least 100 m apart and more than 200 m from hedges and forest. NH_3 emission was determined by the micrometeorological mass-balance method [5]. More detailed description of the method can be seen in [6]. NH_3 was collected in 7 consecutive measuring periods: 0-1, 1-3, 3-8, 8-22, 22-48, 48-78, 78-102 hours after field spreading of the slurry.

In A) and B) the crop nitrogen (N) status and crop height were monitored two times (at BBCH growth stages 43 and 51) using a tractor-mounted dual canopy sensor. The sensor combines canopy multi-spectral reflectance and NIR laser range measurements. The spectral reflectance are re-calculated to a vegetation index (RVI) that is proportional to the chlorophyll content of the biomass, while the independent laser range measurements provide information on canopy structure (height and leaf area index, LAI). Hence the combined measurement can be used to evaluate the average chlorophyll or N content at the leaf level, and to estimate the need for additional N fertilizer by the crop.

Both slurry type and climatic conditions are known to influence NH_3 emission rates [7], which can influence the crop yield if the crop lacking N. Soil type affects yield potential and in order to take differences in soil conditions across the trial into account, soil electrical conductivity measurements (EM38) were taken in both experiment A and B. In order to account for differences in the climatic conditions at the time of treatment application, in experiment A, climatic measurements were recorded for each plot at the time of treatment/application of slurry by the means of air temperature 2 m above ground level recorded by a met station, positioned less than 200 m from the experimental field.

All three experiments were carried out using a 1-factorial block design, with plots from adjacent blocks arranged in a Latin square manner

Data management and statistical analyses
Prior to statistical analyses, for both experiment A and B plot-wise average soil electrical conductivity values were calculated from EM38 estimates derived from ordinary global kriging predictions [8] on a 2.2 x 2.2 m grid, using an exsponential variogram model with parameter values estimated by weighted least squares (nugget = 2.43, ς = 4.11, φ = 0.0016).
RVI and LAI measurements taken by the mobile canopy sensor by driving the tram lines between plots were assigned to their relevant plots. RVI and LAI data were used for calculating an N status indicator. In case the N status was unfavourable, an estimated N-requirement was calculated based on a previous calibration equation derived for winter wheat [9].
For each experiment, treatment effects were estimated in the following linear model:

$$y_i = \beta_0 + \beta_1\,\text{block}_i + \beta_2\,\text{EM38}_i + \beta_3\,\text{Temp}_i + \beta_4\,\text{Elevation}_i + \beta_5\,\text{Treatment}_i + e_i,$$

where y_i is the response (yield or N status) in plot *i*, block_i indicates the replicate of plot *i*, EM38 is the plotwise average soil electrical conductivity, Temp is the temperature at ground level at the time of treatment application, Elevation_i is the elevation of plot *i* in m, Treatment_i is the treatment applied to plot *i*, and e is the residual vector that is ~ $N(0,\sigma^2)$. EM38, Temp and Elevation were all treated as factor variables with levels defined according to their centiles.
All statistical analyses were carried out using the R Environment [10].

Results

Both in experiment A and B, the treatment factors were highly significant (p< 2e-16 *** in experiment A, p=9.976e-15 *** in experiment B). In both cases, highest yields were obtained in the trail hose treatment (table 1). The large number of replicates (n=129 in experiment A, and n=77 in experiment B) ensured that treatments effects could be estimated with high precision (table 1), with standard errors of just ±0.3 and ±0.4 hkg ha^{-1} in experiment A and B, respectively, yielding Least Significant Differences (LSD) below 1 hkg ha^{-1} (0.7 and 0.9 hkg ha^{-1}, respectively). Soil electrical conductivity accounted for a significant proportion of the variation only in experiment A (p=0.01159*), with the remaining variables being non-significant except significant block effects in both experiments. A total of 0.78 and 0.75 of the total variation could be explained (R^2) by the linear model in experiment A and B, respectively.

No significant differences among treatments could be found in the analyses of the N status indicator (p=0.27 at growth state 43, p=0.65 at growth state 51).

In Experiment C, emissions of NH_3 following slurry application by trail hoses was about 10% of the applied TAN, which is in good agreement with estimates from the Alfam model [7]. Soil injection did not result in any significant reduction of the emission of NH_3 emission which is surprising when compared with the other experiments (ex. [11]).

Table 1 Average crop yield and total NH_3 emission, following field application of 30 tons/ha of pig slurry. Yield and emission gains are given in reference to the trail hose technique

Treatment	**Crop yield and yield gain (ton grain ha^{-1} and 95% confidence limits)**		**Total NH_3 emission (% of applied TAN and 95% confidence limits)**
	Experiment A	Experiment B	Experiment C
Trail hose	8.15 (8.10,8.21)	7.87 (7.80,7.94)	10.7 (10.1,11.2)
Disc injection	-0.44 (-0.39,-0.49)	-	-0.5 (-3.0,2)
Disc and tine injection (low speed)	-0.4 (-0.35,-0.45)	-0.38 (-0.31,-0.44)	-1.5 (-1.8,-1.2)
Disc and tine injection (high speed)	-	-0.36 (-0.29,-0.42)	-

Discussion

The results showed that significantly higher crop yields were harvested when slurry was applied by trail hoses compared to soil injected slurry (Table1, Experiment A), despite the slightly higher NH_3 emission following trail hose application compared with soil injection. An explanation for the higher yields for trail hose application may be that the injection methods caused crop damage in excess of the potential biomass increase related to the extra N supply from "non-emitted" N. This is supported by Experiment B (Table 1). An additional explanation may be that in all experimental plots the crop was fully supplied with N from the soil, as supported by the analysis of data from the canopy sensor (Unpublished data). This is in line with the relatively high organic N content in the soil due to the cultivation history of the field and the relatively low winter precipitation preceding the experimental season, which could result in a good N supply to the crop.

In Experiment B, there was a clear effect of application method, but no effect of different travel speed. This suggests that the crop damage occurs as soon as the leaves and roots are cut by the disc coulters, regardless whether a tine is fitted after the discs and whether the travel speed is slow or fast.

The minimal difference seen in NH_3 emission between treatments in Experiment C, may be explained by the very low dry matter content in the slurry of only 1.9%. An earlier study [12] showed that low dry matter content typically entails a high infiltration rate of slurry into the soil causing the evaporation period to be relatively short. This reduces the potential NH_3 loss.

Conclusion

In conclusion, if the crop is well supplied with N and emission rates are low, soil injection can cause significant crop damage reducing yields compared to trail hose application, even if injection is performed with disc injectors. Attaching a tine after the discs or increasing travel speed to 9 km/h did not increase the crop damage.

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