Döhler, Helmut; Vandré, Robert; Rößler, Regina and Wulf, Sebastian

Ammonia emissions: Abatement costs for the application of liquid manure

The KTBL has updated calculations of the costs of measures to reduce ammonia emissions. In the present paper the results for liquid manure application are presented. Depending on the annual amount of slurry and on the techniques used application costs range from 2.5 to 10 €/m³. Considering small amounts of pig or cattle slurry, notably the separate incorporation of the slurry with conventional soil cultivation equipment is cost effective (0,6–0,8 €/kg NH_3). At high annual amounts of manure to be spread, ammonia abatement by the use of a slurry cultivator is more cost effective (0,4–0,6 €/kg NH_3).

Keywords
Ammonia emissions, ammonia abatement, costs, liquid manure, slurry application

Abstract
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Ammonia emissions contribute to the acidification and eutrophication of ecosystems and have an indirect effect on the climate. In Germany, 95 % of these emissions come from agricultural sources with livestock farming accounting for 82 % [1; 2]. In order to observe the annual limit of 550 kt NH_3 determined for Germany under international agreements sustainably and reliably, effective emission abatement measures must be taken in agriculture. Techniques are available for the abatement of ammonia emissions from livestock farming during feeding as well as in housing and manure management. In the frame of a project financially supported by the Federal Ministry of Food, Agriculture and Consumer Protection as well as the Federal Environment Agency, the KTBL reevaluated abatement measures and calculated the abatement costs [3]. The present article describes the results for the application of liquid manure. The use of emission-reducing techniques and organizational measures allow ammonia losses during manure application to be reduced. In addition to the conventional spreading with splash plate, the use of trailing hose and trailing shoe as well as slot injector, incorporation and dilution were calculated.

Ammonia abatement costs: methods

The abatement of ammonia emissions is determined as the difference between a technique without the application of abatement measures (reference system) and a technique with abatement measures. The reference system for liquid manure application is an even, application without incorporation (splash plate). The application of cattle and pig slurry on areas without a plant cover or covered by low plants is considered. At a temperature of approximately 15 °C at the time of application, an NH_3 loss of 50 % of the ammonium nitrogen for cattle slurry and 25 % for pig slurry must be expected for the reference system [4].

In order to determine the abatement costs, all extra costs caused by an abatement measure are considered [5; 6]. They equal the difference between the annual costs with and without the application of the abatement measure. For calculation, the cost differences of all varying process steps are added up. If individual process steps serve other purposes in addition to ammonia abatement, the costs must be attributed proportionally to the different purposes (allocation). This is the case if the soil is cultivated intermittently after liquid manure application, for example. If the manure was incorporated one hour after application, 50 % of the additional expenses for ammonia abatement were allocated. If incorporation took place within four hours, the allocated share was 30 %.

The extra costs can be fully or partially compensated for by cost savings resulting from the abatement measure. These savings are stated separately and set off against the extra costs if they are directly related to the process steps of the abatement measure.

Liquid manure application

Five techniques were defined which approximately reflect the range of the slurry application techniques used in practice with annual process outputs of 1,000 to 100,000 m³ **(Table 1)**. The 1,000 m³ technique characterizes an economically suboptimal single-farm variant with individual mechanization. 3,000 m³ correspond to a slightly larger farm or a cooperative of several

Table 1

Characterization of the calculated spreading techniques

Insgesamt ausgebrachte Güllemenge pro Jahr ***Total annual slurry quantity*** **[m³/a]**	**Verfahren** ***Technique***	**Verfahrenskomponenten** ***Components of the technique***
1 000	kontinuierlich *continuous*	traktorgezogener Pumptankwagen, 10 m³ *tractor-drawn pump tanker, 10 m³*
3 000	kontinuierlich *continuous*	traktorgezogener Pumptankwagen, 10 m³ *tractor-drawn pump tanker, 10 m³*
10 000	kontinuierlich *continuous*	traktorgezogener Pumptankwagen, 15 m³ *tractor-drawn pump tanker, 15 m³*
30 000	geteilt *discontinuous*	Transport: traktorgezogener Pumptankwagen, 21 m³ *transport: tractor-drawn pump tanker, 21 m³*
		Ausbringung: traktorgezogener Pumptankwagen, 10 m³ *application: tractor-drawn pump tanker, 10 m³*
100000	geteilt *discontinuous*	Transport: traktorgezogene Pumptankwagen, 21 m³ *transport: tractor-drawn pump tanker, 21 m³*
		Ausbringung: Trägerfahrzeug, 21 m³ *application: self-propelled spreader, 21 m³*

smaller farms which use the distribution equipment together. The quantity of 10,000 m³ justifies investments in more efficient technology and characterizes a cooperative or a larger farm. 30,000 m³ and 100,000 m³ represent contractors and large farms. These quantities are applied to the land in an economically profitable manner using techniques with separate transport and application units.

Emission-reducing application techniques

In addition to tractor-drawn compressor and pump tankers, carrier vehicles are establishing themselves more and more for slurry application, especially in regions characterized by large field sizes. The carrier vehicles are equipped with appropriate tankers and application equipment. Due to the high investments, these vehicles are suitable only for cooperative use.

Broadcast application (splash plate, rod distributor, swivelling distributor) is still predominantly used today. Especially on large farms and in cooperative use, these techniques are being replaced more and more by the following low-emission application systems which aim to reduce the emitting surface and the dwell time of the slurry on the ground.

The trailing hose deposits the slurry in bands on the soil surface with the aid of hoses. As compared with the broadcast distributor, this allows NH_3 losses to be reduced especially in growing crop stands and during the application of fluid slurry. This technique provides an assumed reduction effect of 30 and 20 % for pig and cattle slurry, respectively [4]. In the case of cattle slurry, this effect is smaller due to the high dry matter content because the slurry bands can dry up without penetrating into the soil. Trailing hose distributors have a working width of 6 to 36 m. The individual hoses are arranged at a distance of 20 to 40 cm.

The trailing shoe distributor is a further development of the trailing hose and suitable for grassland. At the end of each hose, a „shoe-like“ reinforcement pushes the crops aside and the slurry is deposited in the uppermost soil layer (0–3 cm). Like for the trailing hose distributor, the reduction potential for the more fluid pig slurry (50 %) is larger than for cattle slurry (40 %). Trailing hose distributors have a working width of 3 to 18 m.

Slot injectors have even greater potential for the abatement of ammonia losses (60 %) and are suitable for spreading on grassland and in growing crops. The slurry is applied with the aid of a shoe-like reinforcement into a slot opened by a cutting disc or a steel knife installed in front of the reinforcement. Crop soiling is effectively avoided. However, the turf is damaged. The tractive power requirements result in smaller working widths of 6 to 9 m.

Slurry cultivators with working widths of 3 to 6 m have the greatest abatement potential for NH_3 emissions (90 %). The soil is tilled by cultivator tines or hollow discs, whose immediate extension is used to deposit the slurry during cultivation. This requires more tractive power.

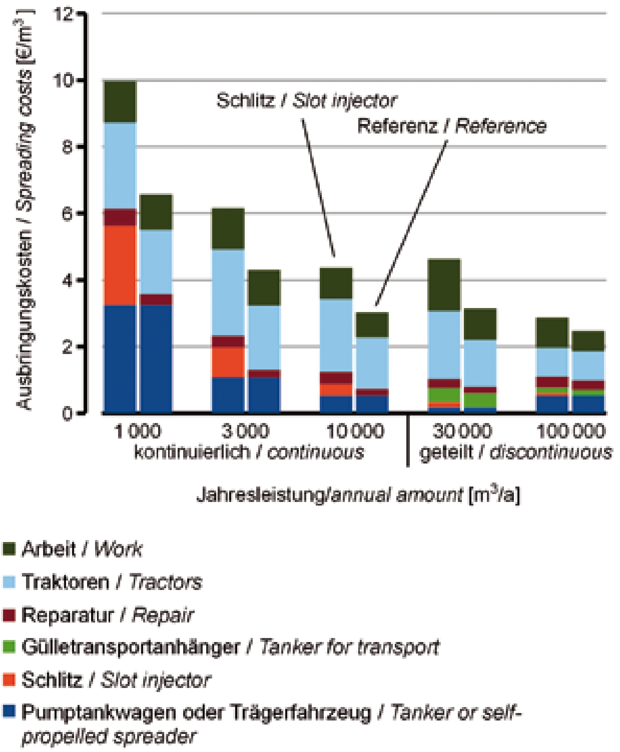
After spreading with the aid of broadcast distributors, it is also possible to carry out intermittent incorporation using conventional tillage equipment. If incorporation takes place within one hour, the abatement potential approximately corresponds to the potential abatement of the slurry cultivator. It is significantly lower at 70 and 50 % for pig and cattle slurry, respectively if incorporation is carried out within 4 hours after spreading.

Finally, dilution allows the flowability of cattle slurry to be improved, which promotes faster penetration into the soil. The abatement potential of dilution at a 1 : 1 ratio is 50 %.

Application costs and emission abatement

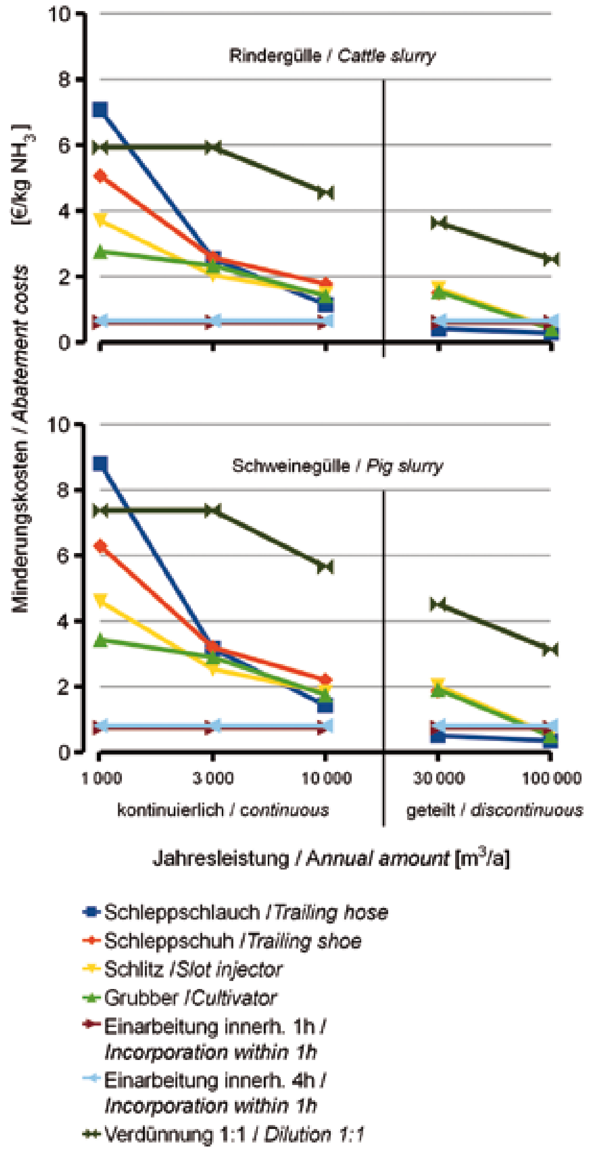
Both, application costs and emission abatement depend on the capacity exploitation of slurry application techniques and the emission abatement technique applied. While the single-farm

Fig. 1



Structur of annual slurry application costs for slot injector (left bars) and reference (broadcast application, right bars)

Fig. 2



Emission abatement costs for cattle slurry (upper chart) and pig slurry (lower chart)

technique used for the application of small slurry quantities (1,000 m³/a) causes expenses of approximately € 7–11 per m³ depending on the chosen technique, the costs decrease to € 3–6 per m³ for 10,000 m³/a and € 2.5–4.5 per m³ for 100,000 m³ with growing annually applied quantities. Single-farm techniques have the advantage that the slurry can be spread under weather conditions (humid and cool) or at daytimes (evening hours) which are favourable with regard to emissions. In addition to the process capacity, different hourly capacities influence total costs. Given a quantity of 3,000 m³/a, for example, this makes a difference of € 1–2 per m³.

Under the conditions of low process capacities, the additional annual costs for emission-reducing application are caused by investments into more sophisticated equipment. If capacities are larger, the additional costs are primarily the result of costs for tractors and labour. This is shown in **Figure 1** using the slot injector as an example.

The additional expenses for emission abatement are compensated for by an increased fertilizer value of the slurry. An emission abatement of 20–90 % for cattle slurry and 30–90 % for pig slurry as compared with the reference system provides nitrogen conservation of € 0.2–1 per m³ of cattle slurry and € 0.3–0.8 per m³ of pig slurry. However, this additional value is not considered in the determination of the abatement costs. If the nitrogen value is included in the calculations, trailing hose application and intermittent incorporation become cost-neutral or save costs if the capacity reaches 30,000 m³/a. At a capacity of 100,000 m³/a, the slot injector and cultivator variants also reach the cost-neutral or cost-saving range.

Under the considered conditions, the emission abatement costs amount to € 0.3–7 per kg of NH_3 for cattle slurry **(Figure 2, above)** and € 0.3–9 per kg of NH_3 for pig slurry **(Figure 2, below)**. In total, the emission abatement expenses for pig slurry are higher than those for cattle slurry because the emissions and consequently the effect of emission abatement from pig slurry are lower than for cattle slurry. A very cost-efficient technique also for single farms with small slurry quantities is incorporation with the aid of a separate tractor with tillage equipment (cultivator, disc harrow). Due to the allocation of the costs to tillage (70 %) and emission abatement (30 % for incorporation within 4 hours), this causes abatement costs of € 0.6 per kg of NH_3 for cattle slurry and € 0.8 per kg of NH_3 for pig slurry. Without allocation, these costs would amount to € 2 and 2.7 per kg of NH_3, respectively. The dilution of cattle slurry with water, however, is an effective, though very expensive variant because larger quantities must be transported and applied.

Given costs of approximately € 3–7 per kg of NH_3, single-farm techniques (1,000 m³/a) with drawn equipment (e.g. trailing hose) are only conditionally suitable for cost-efficient emission reduction. At capacities of 3,000 m³/a, the abatement costs are lower even though they are still at a level of about € 2–3 per kg of NH_3. Apart from intermittent incorporation techniques, a cost level of € 1–2 per kg of NH_3 is reached only at process capacities of 10,000 m³/a or more.

Given low quantities applied per year, the abatement costs for sophisticated techniques (slot injector) are lower than those for the trailing hose. Under the conditions of high annual process capacities, however, the abatement costs of trailing hose techniques are lower than the expenses for those techniques which directly deposit slurry into the soil. Nevertheless, the latter have the advantage that they avoid larger quantities of NH_3 emissions and better exploit the abatement potential.

Conclusions

Suitable techniques and work organization allow ammonia emissions during slurry application to be reduced in a cost-efficient manner. Intermittent incorporation causes abatement costs of significantly less than € 1 per kg of NH_3 regardless of the process capacity and can thus be applied even on smaller farms. Techniques with mounted equipment reach this cost level or remain below it only at high process capacities. Under favourable conditions, i.e. if nitrogen conservation allows the expenses for mineral fertilizer to be reduced, the higher application costs can be almost fully compensated for by saved costs for fertilizer.

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Authors

Dipl.-Ing. Helmut Döhler, **Dr. Robert Vandré**, **Dr. Regina Rößler** and **Dr. Sebastian Wulf** are scientists at the Association for Technologies and Structures in Agriculture (KTBL), Bartningstr. 49, D-64289 Darmstadt, e-mail: h.doehler@ktbl.de

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