Small scale dispersion of ammonia around animal husbandries

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Summary

Animal production is one of the main sources of ammonia emissions. Ammonia emissions are part of international strategies of prevention of air pollution but also part of national regulations. At the present time reliable data of emission flows and reduction efficiencies are only available from stables with forced ventilation. Reflecting to naturally ventilated stables or free range husbandries, measurements of the ammonia concentration in ambient air in the vicinity of such sources may give a contribution to solve this problem.

A simple and cheap method is the use of passive samplers. Units with four single Ferm samplers each were mounted in the vicinity of houses with poultry, pigs, a dairy cow shed as well as close to a free range calf husbandry. In all cases concentration levels ranged between 1 µg/m³ and more than 300 µg/m³. Normally concentration decreased faster with distance from keeping than assumed. This result can be of interest if minimum distances are required between a livestock enterprise and e.g. forests or residential districts.

Aim of the study is to provide data on farm level. These data may be used in models to estimate source strength.

Keywords: animal husbandry, ammonia, load, passive (diffusive) sampler

Zusammenfassung

Kleinräumige Ausbreitung von Ammoniak in der Nähe von Tierhaltungen

Die Tierhaltung zählt zu den hauptsächlichen Quellen von Ammoniakemissionen. Diese Emissionen sind Teil internationaler Strategien zur Reinhaltung der Luft, aber auch Teil nationaler Bestimmungen zu ihrer Begrenzung. Zur Zeit sind belastbare Daten über die Emissionen und die Effizienz möglicher Minderungsmaßnahmen nur bei zwangsbelüfteten Ställen verfügbar. Hinsichtlich natürlich belüfteter Ställe und der Freilandhaltung können Messungen der Ammoniakkonzentration in der Nähe dieser Einrichtungen einen Teil zur Lösung des Problems beitragen. Eine einfache und kostengünstige Methode ist der Einsatz von Passivsammlern. Einheiten aus vier Sammlern vom Typus Ferm wurden in der Nähe zweier Geflügelställe und um eine Kälberhaltung im Freiland aufgestellt und im 14-Tage-Rhythmus gewechselt. In der Geflügelhaltung mit Zwangslüftung und der Schweinemast betrug der Messzyklus sieben Tage. Die gemessenen Konzentrationen lagen im Bereich von 1 µg/m³ bis über 300 µg/m³. Der Abfall der Konzentration mit dem Abstand von der Tierhaltung fiel im Einzelfall unterschiedlich aus, war aber deutlich stärker als allgemein angenommen. Ziel der Studie war es, Daten auf Hofebene bereitzustellen, die auch zur Quellstärkenbestimmung herangezogen werden können.

Schlüsselworte: Tierhaltung, Ammoniak, Belastung, Passivsammler

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1. Introduction

In the past ammonia in the air of livestock buildings was seen as a problem of man and animal health and welfare only. But since a couple of years ammonia from animal husbandry is considered as one key pollutant. Agriculture becomes part of large scale air pollution and control strategies e.g. the UN ECE Convention on Long Range Transboundary Air Pollution (UN ECE 1979). In different protocols national emission ceilings are given. Some countries keep the limits others exceed them.

Emissions of air pollutants may be measured directly as fluxes but mostly indirectly as the product of air flow rate and airborne concentration. At the present time reliable data of emission flows and reduction efficiencies are only available from stables with forced ventilation. Reflecting to naturally ventilated stables or free range keeping, measurements of the ammonia concentration in the vicinity of such sources may give a contribution to solve this problem by backwards calculation of the emissions (Gärtner et al. 2004).

From the view of possible nuisance of neighbourhood and problems within authorization of new or enlarging existing stables the ammonia concentration itself is the relevant measure. Certain distances between source and acceptor are requested to ensure a low level concentration of ammonia. To establish functions of ammonia concentration vs. distance from the animal enterprise and to give numbers which may be used to verify dispersion models, ammonia concentration was measured in different distances and with respect to the main wind direction. A first impression of the dispersion of ammonia behind an agricultural source may be given by figure 1.

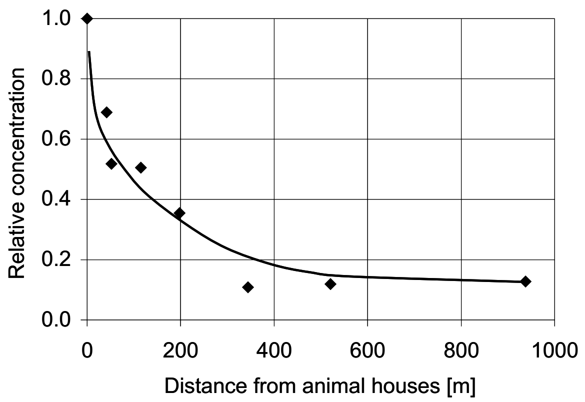


Figure 1:

Dispersion of ammonia downwind from animal houses acc. to Dämmgen 2007

One of the main problems is how to measure ammonia concentration in ambient air.

A simple and cheap measuring method is the use of passive samplers. Investigations using this technique were initiated 2002 and 2003 on a broiler and a turkey barn. Meanwhile others, e.g. calves and pigs are tackled.

In the following the procedure and results are presented at the example of turkey, broiler, pig, dairy and calf enterprises. Some of previously published results (Hinz et al., 2004, 2005, 2006, Müller et al., 2006) must be corrected to lower values by new findings concerning the sampling efficiency and analysis of the samplers used (Dämmgen, 2007).

2. Methods and Material

The investigations were carried out in three commercial poultry farms, one commercial pig farm, an experimental free range husbandry of calves in the former FAL (since 2008 vTI) and on a farm with dairies:

1) Fattening turkeys in a stable with natural ventilation and a veranda
2) Fattening broilers (1) in a stable with forced ventilation and free range
3) Fattening broilers (2) in a stable with forced ventilation
4) Fattening pigs in a stable with forced ventilation
5) Calves in free range husbandry with hutches
6) Dairy cows in a naturally ventilated cow shed

To measure ammonia concentration passive samplers were used. In all cases four samplers each were mounted on different numbers of pales in a height of approximately 2.5 m above ground. The function of the samplers is described in chapter 2.7.

2.1 Fattening turkeys

Figure 2 gives the arrangement of the pales around the turkey houses. In the South of the male birds house a veranda is situated.

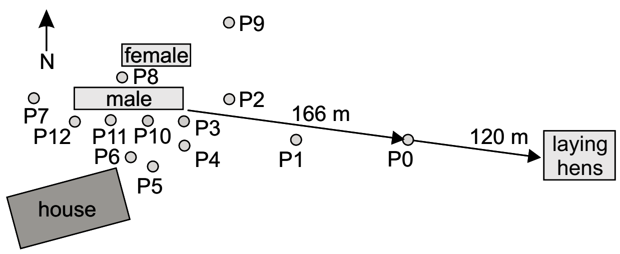


Figure 2:

Pale positions on the turkey farm

On the turkey farm up to 13 pales were situated around the two barns in which 3700 male and 3200 female turkeys were housed. The distance of the pales varied from 2 m near the curtains up to 166 m from the front wall of the barn.

In the region of this turkey farm the main wind direction is west but, especially in winter time must be noted east. It is to consider that in a distance of about 300 m from the turkey barn a lot of laying hens are housed. To get the information about wind speed and wind direction an ultra sonic anemometer was installed between the both turkey houses on a silo over roof height.

2.2 Fattening broilers (1) in a stable with forced ventilation and free range

In the vicinity of the broiler house seven measuring devices were located in different distances, cf. figure 3. In the stable with mechanical ventilation 3500 birds were kept. In front to the pasture, openings allowed the birds the use of a free range.

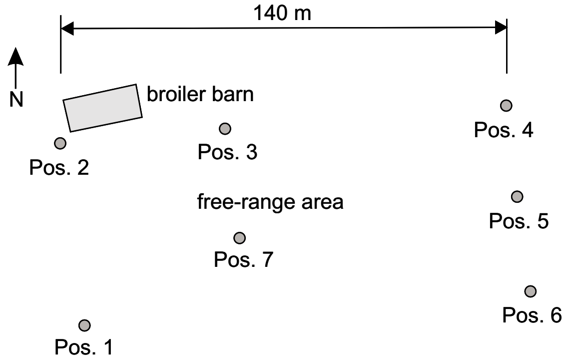


Figure 3:

Pale positions around the broiler barn (1) with free range (pasture)

2.3 Fattening broilers (2) in a stable with forced ventilation

2.3.1 Investigated Broiler farm

The broiler farm 2 consists of 12 single broiler houses, cf. figure 4.

The farm 2 is divided into two parts:

Old part: nine houses. Size: length: 88.0 m; width: 12.0 m; height: 3.5 m. Number of broilers: 21,800 in each house. Floor keeping. Litter: wood shavings. Manure removal: after every cycle. Forced (cross) ventilation. One side wall equipped with flaps and the other side wall equipped with fans.

New part: Three houses – each of them divided into two compartments. Size: length: 93.0 m; width: 29.0 m; height: 4.5 m. Number of broilers: 31,000 in each unit. Floor keeping. Litter: wood shavings. Manure removal: after every cycle. Forced (cross) ventilation. Side wall equipped with flaps and near the middle wall of a compartment nine stacks through the roof of the building equipped with fans.

The emission mass flow of ammonia was measured by a multi gas monitor (ammonia concentration) and measuring fans (air volume flow).

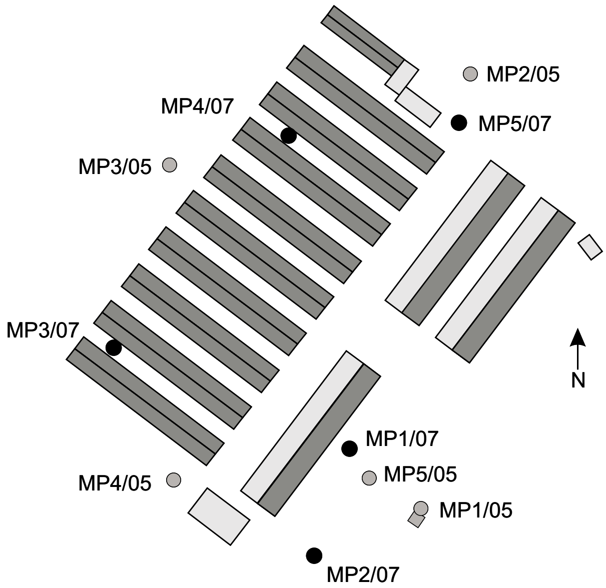


Figure 4:

Broiler farm 2 and measurement points for outdoor parameters of measuring periods 2005 (MP…/05) and 2007 (MP…/07)

- MP1: Measurement point of meteorological parameters, passive sampler and NH_3 converter.
- MP2 – MP5: Measurement points of passive samplers for ammonia

2.3.2 Immission measurements

The weather conditions play an important roll regarding the dispersion of emitted substances in the surrounding of livestock buildings. These parameters were measured by a weather station (figure 5): air temperature in different levels, air humidity, solar radiation, precipitation, air velocity and wind direction at different positions.

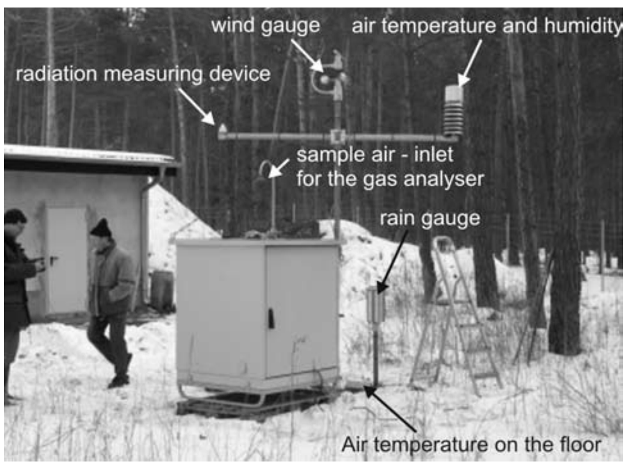


Figure 5:

On-line measurement of ammonia concentration by NH_3 converter and weather station for monitoring outside climate parameters (broiler farm 2)

The course of the ammonia concentration was measured by an NH_3 converter at one location (figure 5). The system is designed for measurements of concentration in the air. With this measuring method, NH_3 is measured indirectly while it is converted to NO. The transforming process from NH_3 into NO can be recorded by a chemiluminescence analyser (KTBL, 2001). The instrument was calibrated before and sometimes during the running measurements.

In addition to these on-line measurements the ammonia concentration was determined around the buildings on farm level with a passive sampler technique. The sampler holders with four samplers each were mounted on pales in approximately 2 m height above ground on five positions. The function of the samplers is described in chapter 2.7.

The wind is a very important parameter regarding the dispersion of emissions in the surrounding of the farm. At the 10 m high mast (figure 6) different sensors are mounted to measure the temperature and the wind speed in different heights with a time resolution of 10 Hz. In 10 m height, CO_2 and NH_3 concentrations are measured in spring 2007. Besides this measurement point the wind speed is measured at four other points in about 4 m height. The aim is to characterize the flow field around the farm. These special measurements will be analyzed and published later.

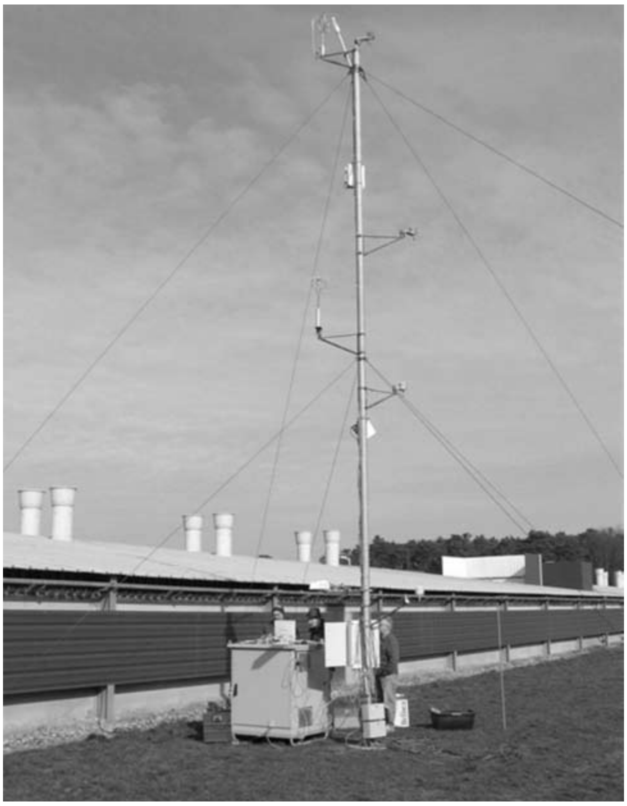


Figure 6:

Weather station beside of one of the new broiler houses (farm 2). At the 10 m high mast, besides other sensors, ultra sonic sensors in different heights are mounted.

2.4 Fattening pigs in a stable with forced ventilation

The commercial piggery had a stock of 50,000 fattening pigs. The single pig houses were forced ventilated by a lot of exhaust openings on the roof. All houses covered an area of approximately 230 x 390 m. Four pales for measuring ammonia concentration were positioned near the stable in line and up to 240 m distance as shown in figure 7. At position C, the on-line measuring converter technique was installed to get information about time dependencies of ammonia concentration.

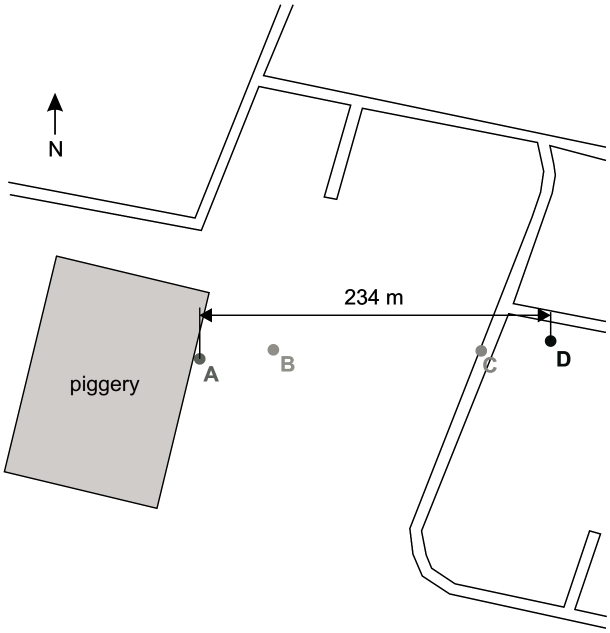


Figure 7:

Pales at the piggery

2.5 Calf keeping in free range and hutches

In calf keeping the pales stood inside (P1) and at the border of the range (P2-P6).

In this range 24 calves were kept for a study of 12 months to investigate the air quality in the hutches and the acceptance of the hutches by the animals. Ammonia was one part of these investigations. As an additional environment related issue, the ammonia concentration was observed on six locations as given in figure 8. As usual the samplers were changed every 14 days.

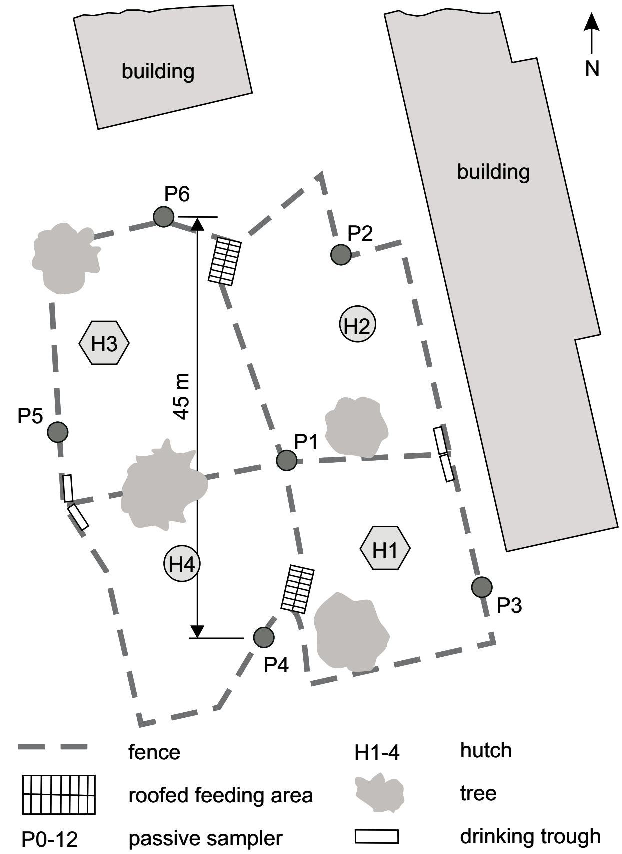


Figure 8:

Pale positions at calf keeping

2.6 Dairy cows in a naturally ventilated cow shed

In the cow shed the same measuring equipment was used inside and outside the building like in case of the fattening broilers (2). The measuring positions of the passive samplers and the NH_3 analyser are shown in figure 9.

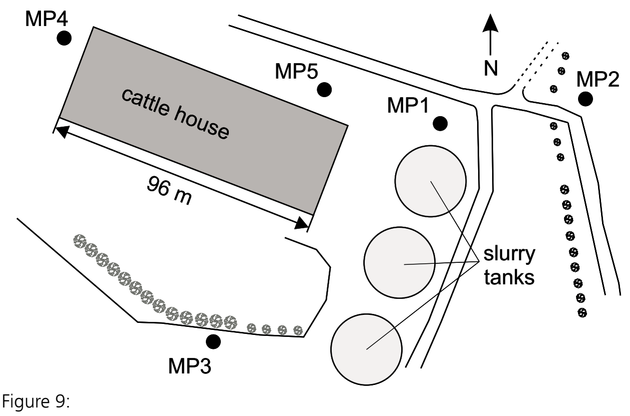


Figure 9:

Cow shed and measurement points for outdoor parameters of measuring period 2007.

- MP1: Measurement point of meteorological parameters, passive sampler and NH_3 converter
- MP2 – MP5: Measurement points of passive samplers for ammonia

2.7 Passive sampling technique

To observe ammonia concentrations in such wide field of observations an applicable technique was found in the use of passive samplers working on the principle of diffusion.

The samplers were constructed according to Ferm (1991), cf. figure 10.

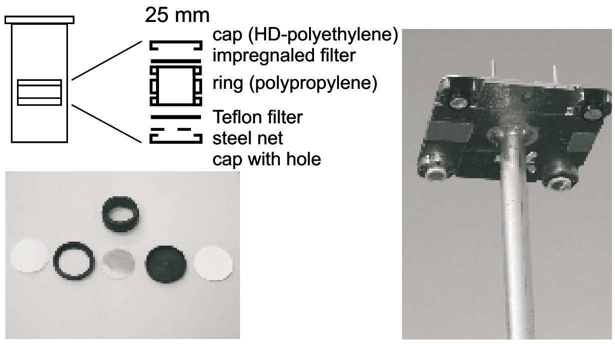


Figure 10:

Assembly of passive sampler according to Ferm

Ferm constructed this type of sampler short, broad and therefore sensitive for relatively low concentrations in ambient air. In the near of animal husbandries levels of ammonia concentration are much higher. Before starting the investigations in the vicinity of stables with a gas mixing chamber a possible upper limit for the use of Ferm sample was checked to be in the range of 1 ppm (Hinz, Scholz-Seidel 2005).

A thin porous membrane filter was used to avoid turbulent diffusion inside the sampler. A filter impregnated with citric acid takes up the ammonia.

After sampling the filter is extracted and analysed. The result is an averaged concentration related to the sampling time. Normally the samplers were exposed for 14 days. Once, the passive samplers were changed after 24 h during mucking out and cleaning of the turkey house.

The relative span width is defined as ratio of the difference of the maximum and minimum value and the average of the four replicates taken at each single measurement location. The frequency distribution of these deviations is shown in figure 11. The deviations were mainly in the range of 20 %.

Duration of the measuring campaigns was different with 4 weeks for broilers, 8 weeks for pigs, 9 months for calves and long termed from 2003 to 2007 on the turkey farm. At the dairy farm it was more or less a hot spot only.

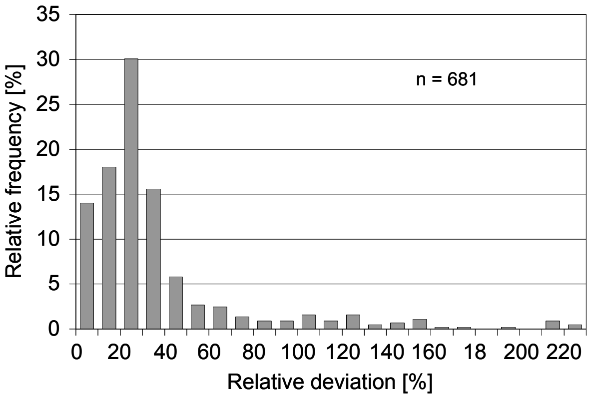


Figure 11:

Relative span width of samples

3. Results and Discussion

In the following the main results will be presented more comprehensively for turkeys and quite brief for broilers, pigs, calves and dairies.

In an overall view measured concentration ranged from below 1 µg/m³ up to more than 300 µg/m³. There was a more or less sharp decrease of concentration with increasing distance from the source. A comparison of the 14 days results of the passive samplers with calculated averages from the converter measurements showed sufficient conformity.

3.1 Turkey farm

Depending on strength of the ammonia source and the large variety of the pale locations with respect to the distance from the houses, ammonia concentration was measured in a range between 1 µg/m³ and 250 µg/m³.

Figure 12 shows the results for three different pales in the years 2003 to 2007.

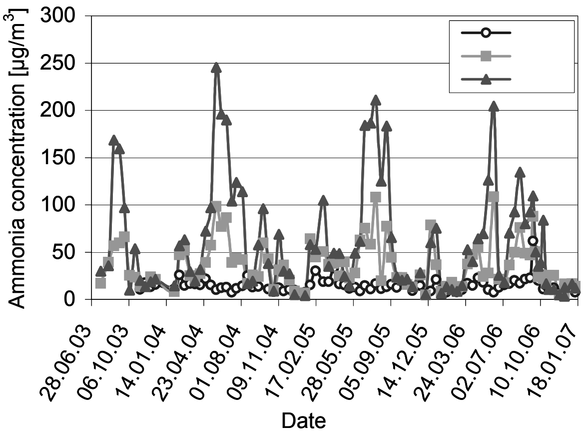


Figure 12:

Ammonia concentration over a three years course, pales 0, 2 and 3

It is obvious that the level of ammonia concentration decreases with the distance and that the course becomes more and more smooth. The strong fluctuations at pale 3 were not really distinct observable at pale 0. These fluctuations with rather high concentrations result mainly from the mucking out procedure at the end of a fattening period. To check this fact the passive sampler had been changed after 14 days with the birds for a three days measurement during cleaning the stable, cf. figure 13.

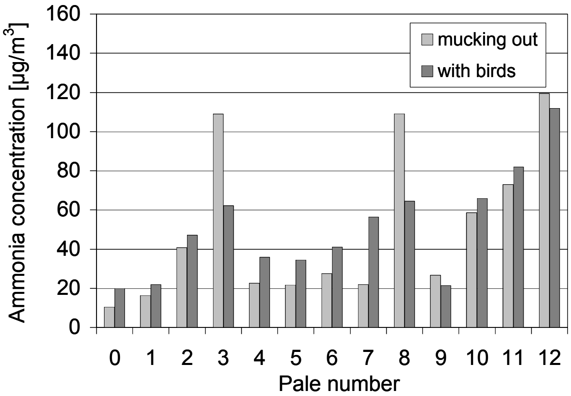


Figure 13:

Influence of mucking out on ammonia concentration

Especially at the nearest pales 3 and 8 the 3d concentration is distinctly higher than that obtained during the 14d period with birds.

From the time series presented in figure 12 annual averages and a three years average were calculated. These annual averages reach values up to more than 80 µg/m³ for the nearest situated pales - pale 3 and pale 8. In figure 14 the annual averages and a three years average are plotted for all pales around both stables.

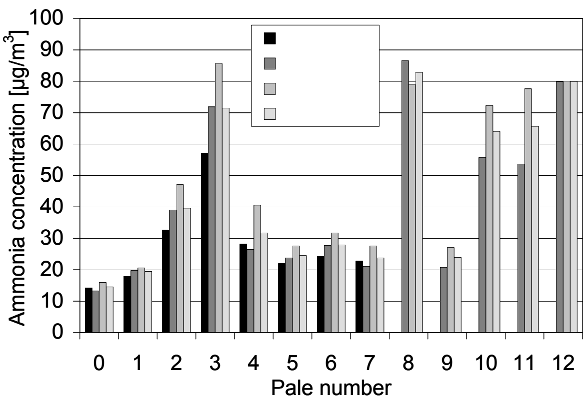


Figure 14:

Averages for all pales, 2003-2005

For the single annual averages and even in comparison with the three years averages the differences are very small.

Based on the three years average the next figures show the distribution of ammonia in the vicinity of the stables.

In figure 15, ammonia concentration measured directly in front of the veranda is plotted. The distance is measured from the left side of the stable.

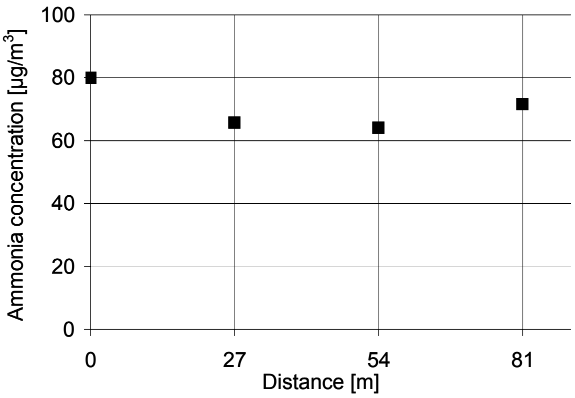


Figure 15:

Ammonia concentration in front of the veranda, P12, P11; P10, P3, position measured from the south-west edge of the stable

The mean concentration was rather constant over the length of the stable with a tendency to higher values at the edges, pale 3 and pale 12.

Of highest interest is the ammonia dispersion in the main direction of wind, which is given in figure 16.

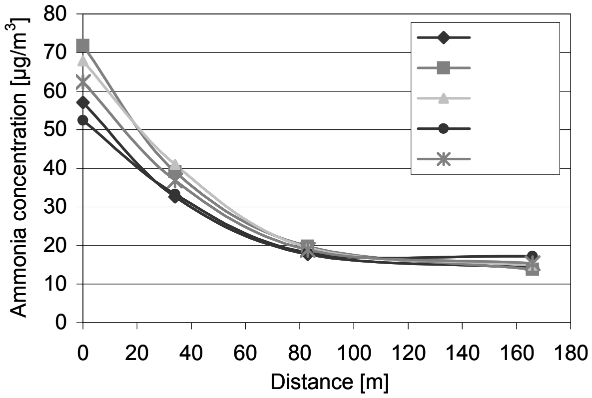


Figure 16:

Ammonia dispersion in main wind direction

Starting with 71 µg/m³ at pale 3 directly beside the stable, ammonia concentration decreased steeply to values below 20 µg/m³. In 166 m distance at pale 0 a tendency for increase was observed. That was caused by the large hen battery. The 50 % cut point was reached after less than 40 m dispersion. This distance is short compared e.g. with values of 280 m and 225 m given by VDI (VDI 4251 Part 1 2007) for the dispersion of germs.

The result was mainly influenced by a high frequency of wind coming from 270° ± 20°.

Simultaneous measurements of ammonia concentration at position pale 3 were carried out with passive samplers types Ferm and Radiello (Cocheo et al. 1996) and an NH_3 converter. The converter shows large daily fluctuations but also some differences between the ammonia concentration detected with the passive samplers (average values of two weeks samples). Figure 17 shows the comparison of NH_3 converter and sampler measurements using types Ferm and Radiello. From quasi on-line monitoring with the converter daily and 14 days averages were calculated which were the sampling times of the passive sampler.

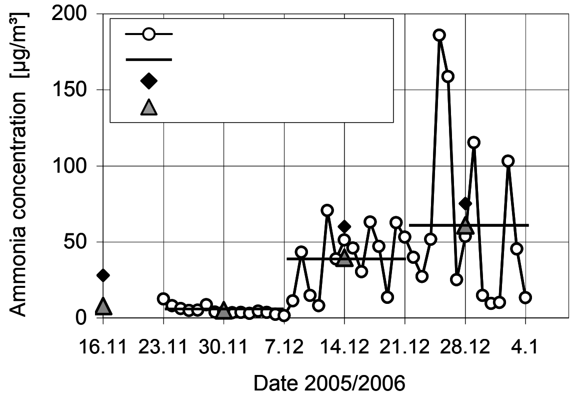


Figure 17:

Comparison of the measurement results obtained by the passive samplers type Ferm and Radiello, the one day averages of the NH_3 converter and the 14 days values of the NH_3 converter

Considering different types of sampling and analysis, small but possibly effective distances between the sampling locations and high fluctuations of the concentration with time the conformity is sufficient. Deviations between the systems are mainly less than the ±25 % which are given as limit of orientating measurements (22. BimSchV 2007). The result confirms findings of a comprehensive study comparing different techniques for measuring ammonia concentration under test (calibration) and field conditions (Spindler et al. 2007).

3.2 Broiler (1) with free range

Around the free range of the broiler barn only two periods of 14 days sampling ammonia were investigated in summer 2000. The results are shown in figure 18.

The detected concentrations were in the range between 30 µg/m³ and below 10 µg/m³ which is regarded to be a limit value with respect to sensitive ecosystems. Concentration decreased with increasing distance from the farm. No explanation can be given for the single high value.

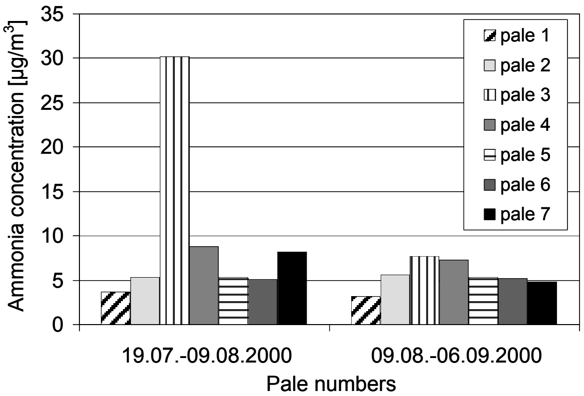


Figure 18:

Ammonia concentration near a broiler stable with free range

3.3 Fattening broiler (2)

The farm was investigated in spring 2005 and spring 2007. In the following results from both periods will be shown.

The measuring results show a direct dependency of the ammonia concentration on the climate parameters outside and the emission mass flow. A strong dependency of the ammonia concentration outside on air temperature, wind velocity and direction could be noticed. Figure 19 shows similar functions versus time for ammonia concentration measured with the converter and the temperature of the ambient air at position 1.

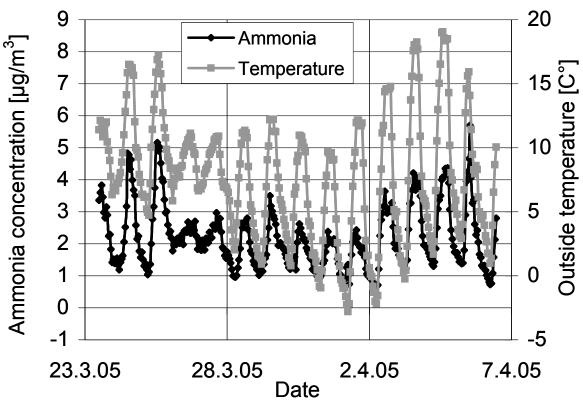


Figure 19:

Course of air temperature and ammonia concentration near the investigated broiler farm

But the daily fluctuations also varied with other climate parameters. More research work is necessary to investigate the influence of the different parameters.

The characteristic of atmospheric dispersion divides between mean transport and turbulent mixing. Both take place in horizontal and vertical direction. So analyses of dispersion in the surrounding of a broiler farm focus on mean values of the wind vector and turbulent deviations from the mean value in vertical and horizontal way and their influences towards the concentration of ammonia in the ambient air.

Figure 20 shows the course of the ammonia emission mass flow which is emitted from the investigated animal house. At the beginning of the fattening period the ammonia emission mass flow was nearly "zero". The flow increased quickly during the first two weeks. Between March 18th and 20th the ammonia emission mass flow reached a certain level and the diurnal fluctuation was well visible. After that time the ammonia emission mass flow increased again up to the end of the keeping period.

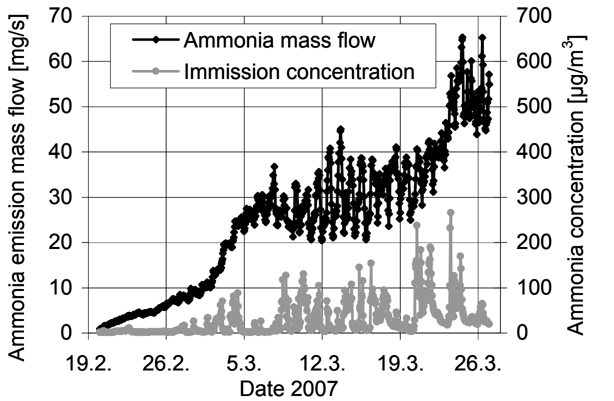


Figure 20:

Ammonia emission mass flow from the investigated broiler house with 30,000 animals and the immission concentration in 10 m height (February/March 2007)

The course of immission concentration can also be seen in figure 20. The heavy fluctuations point out to complex processes, which are influencing the ammonia immissions and which must be investigated more accurately. The correlation between the hourly values of emission and immission was 0.23. For the daily average, the factor was 0.36. That means that only 23 % or 36 % of the immission concentration can be explained by the values of the emission mass flow. It can be assumed that the atmospheric transmission conditions had decisive impact on the immission concentration. Besides the horizontal transport process by the air flow, the vertical dilution of ammonia played an important role for the dispersion process. The main wind direction measured in 10 m height was the southwest. The other local stations on the farm area showed a big influence of the geometry of the livestock buildings. Parallel to the further evaluation of the measuring results, dispersion calculations will be carried out with different dispersion models. Compared to the measuring results, evidence about the accuracy of the different dispersion models might be expected.

3.4 Fattening pigs

Depending on the magnitude of the piggery, the emissions in its vicinity reached sometimes relatively high concentrations. In the first three periods concentrations from 200 µg/m³ up to more than 400 µg/m³ were measured at the nearest pales (A, B, C). At the farthest location at pale D the values exceeded 100 µg/m³ only once.

Figure 21 demonstrates the courses of ammonia concentrations over two months for all pales.

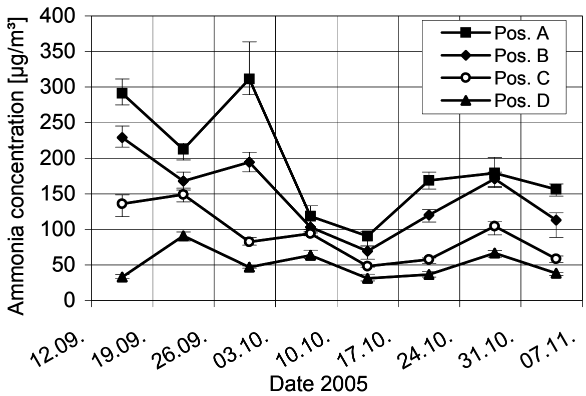


Figure 21:

Ammonia concentrations near the piggery

The time courses of the concentrations showed similar behaviour for pale A, B and pale C, D at the beginning of the measuring campaign.

Although figure 22 contains the information about the dependence of ammonia concentration of the distance from the source, this important information is provided directly in figure 22.

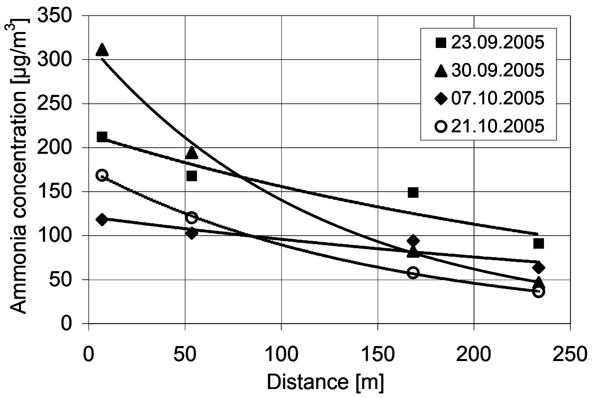


Figure 22:

Ammonia concentration vs. distance from the piggery for different weeks

The dispersion of ammonia behind the piggery leads to different figures compared with the turkey farm, cf. figure 16. The 50 %-distances were longer. This results from the larger size of the source as well as different conditions of dispersion like wind and topography.

At position C the converter technique was used to get time related information about the fluctuation of ammonia concentration. Figure 23 shows the course of the ammonia concentration during a week in September 2005.

The course of this week showed concentrations less than 20 µg/m³ and more than 200 µg/m³ with distinct fluctuations in frequency and amplitude.

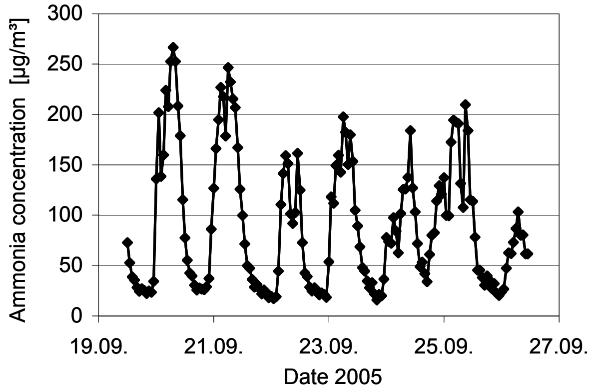


Figure 23:

Ammonia concentration for one week

3.5 Calves in free range keeping

A special situation was given by free range keeping of calves, as can be seen in figure 24.

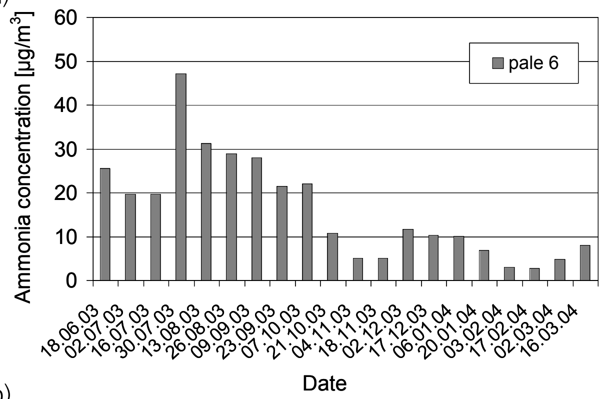
Figure 24:

Free range keeping of calves with cottages

For calves in free range keeping ammonia concentration ranged between 1 µg/m³ and 60 µg/m³. Local dependencies were found with higher values in areas with feeding / mucking sites. The shape of the curves during the period of investigation is very similar and follows mainly the course of temperature.

Figure 25 shows time series of ammonia concentration at pales 5 and 6 (acc. to figure 8).

a)



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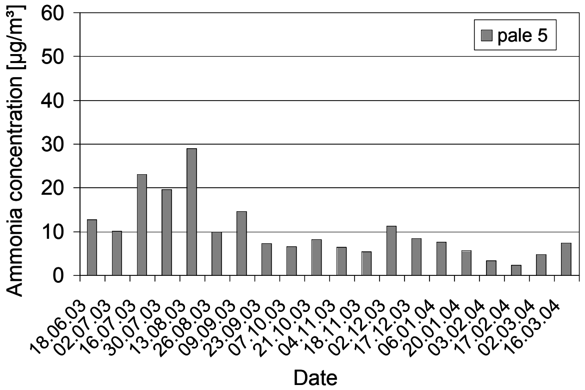

Figure 25:

a) Ammonia concentration at pale 6,
b) Ammonia concentration at pale 5

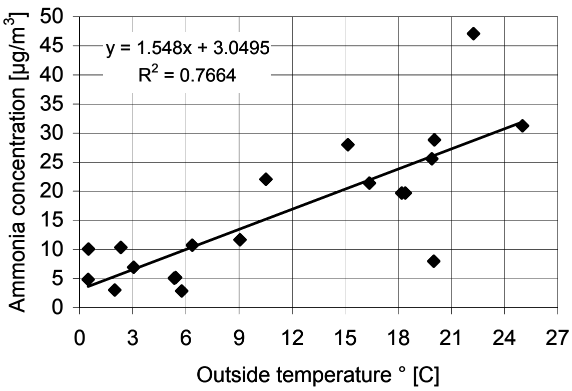

Figure 26:

Ammonia concentration vs. ambient temperature

The decreasing concentration from summer to autumn and winter resulted probably from decreasing temperature of the ambient air.

Concentration varied similarly regarding time, but the level of concentration was higher at pale 6 than at pale 5. Pale 6 was located in the near of one of the roofed feeding area while pale 5 was in a less contaminated area of the pasture.

Figure 26 demonstrates the influence of the temperature of the ambient air on ammonia concentrations that means emissions from calves in free range husbandry.

3.6 Dairy cows

The climatic parameters in the cow shed and the ammonia emission mass flow were investigated in different measuring periods in 2004, 2006 and 2007. The determination of the ammonia emission factors is described by Müller et al. (2008). The dispersion of ammonia was measured during summer 2007. A result is shown in figure 27 for MP 1 and MP 4 with respect to the wind direction. At MP 1 the ammonia concentration increases, if the wind is blowing from west. The MP 1 is eastward located from the cow shed and in this case the emitted air flows directly to the MP 1 (see figure 9). If the wind is blowing from southward direction, then the ammonia concentration decreases. The concentration at MP 4 reacts contrarily because its position is westward from the cow shed. The ammonia concentration achieves higher values at MP 4 compared to MP 1 because of the smaller distance to the building (see figure 9).

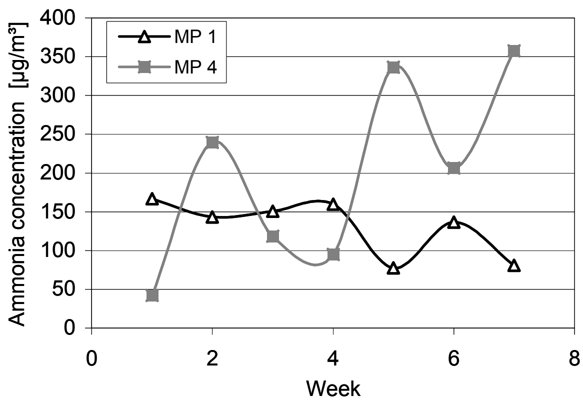

Figure 27:

Ammonia concentrations obtained by the passive samplers (cow shed; 4 July to 22 August 2007)

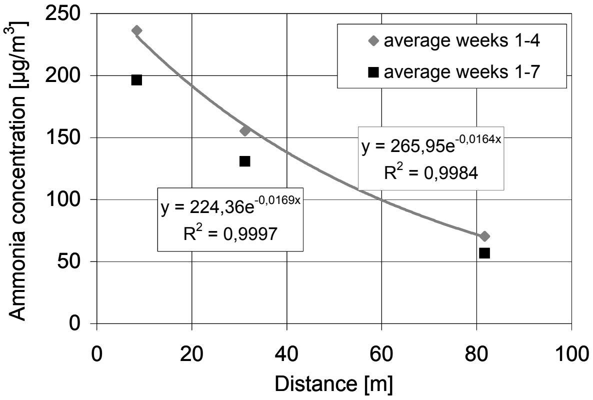

Figure 28:

Ammonia concentration vs. distance from the cow shed, weeks 1-4 and weeks 1-7

The influence of the distance between measurement point and cow shed – see MP5, MP1 and MP2 is shown in figure 28.

A decay curve (exponential function) can be determined for the immission concentration as function of the distance. The concentration decreases rapidly with the distance from the cow shed.

4. Conclusion

The main results of different studies were presented for broiler, pigs, dairies, calves and turkeys. Ammonia concentration ranged between 1 µg/m³ and 300 µg/m³ depending on the species of animals, size of the farms and conditions of dispersion including influences from outside e. g. other sources of ammonia emissions. Regarding authorization procedures and problems with residential areas in the neighbourhood of stables the distance between both and the decrease of ammonia concentration is an important factor. In this study it was found that the decrease is more distinct than normally assumed in the past. As an example the VDI 4251 estimates longer ways of dispersion. That means that according to the model of the guideline ammonia concentration decreases not so steep as found in this study. This effect depends on local situation of emission and dispersion. More of these investigations must be done to get more knowledge on processes. More investigations are also required with view to the used measuring techniques e.g. the comparison of converter and sampling technique. Nevertheless the results show sufficient consistence.

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5. Literature

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