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Long term measurements on ammonia emissions from layer breeding stables and mitigation options

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Long term measurements on ammonia emissions from two forced ventilated layer breeding stables and essential determining factors on emission levels are described in this paper. The emissions of both stables with 432–523 heads were recorded by an automatic working online measuring device in the period from 2017 to 2021. As the measurements show, the dung removal has significant influence on emission levels. While former measurements at the same stables with a dung removal once a week showed emissions of 148 ± 29 g NH_3 a^{-1} TP^{-1}, the mean emission was only 35.2 g NH_3 a^{-1} TP^{-1} when dung removing was done twice a week. On inspection of a dung removal free time period up to 84 hours, the results show on average a duplication of emissions every 24 hours. Therefore, shortening of the dung removal intervals is a very effective option to mitigate ammonia emissions from layer breeding stables. Beyond that the partial exhaust air cleaning with approved techniques with cleaning only 60% of the maximum designed air flow secures an ammonia removal of at least 40% over the year at a given dung removal interval.

Keywords
Ammonia, emissions, layer breeder, laying hens, mitigation measures

Agriculture in Germany accounts approximately for 95% of the national ammonia emissions. More than 70% of it derives directly from animal husbandry. Exceeding ammonia depositions into the environment cause acidification and eutrophication processes as well as changes and a decrease in biodiversity. Ammonia is an indirect effective greenhouse gas which will be converted to nitrous oxide. Furthermore, ammonia contributes to the formation of particulate matter. Germany has committed to reduce ammonia emissions by about 29% till 2030 in relation to the reference year 2005 to mitigate negative environmental impacts. On the basis of long term measurements, the present contribution proves how ammonia emissions can be reduced effectively in poultry keeping.

Test record

The measurements to record emissions and determining essential emission factors from two forced ventilated and identical operated layer breeding stables with 423–523 heads (33% cooks, 67% hens) were carried out in the time period from 2017 to 2021. The keeping periods changed between 176 and 369 d. A direct attribution of the housing type with regard to the national assessment framework (KTBL 2000) is not possible because of the test and research equipment of the stables. The maximum volume flow of each stable was about 12.000 m^3 h^{-1}. The volume flows of each stable were controlled to achieve a target temperature of 18 °C. During winter time an additional heating was used. There

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was no additional equipment for cooling at summery temperatures. Each stable has a length of 30 m and a width of 6 m. Feeding was realised with laying hen sole feed ad libitum (Golddott Landgolt, 17.5% crude protein) via feed chains. Water was available by nipple drinkers. Dung removal was carried out with non-aerated manure belts twice a week during the time period from 2017 to 2021.

Analytics and data processing

Ultrasonic anemometers (Thies, Karlsruhe), installed in the vent stacks, were used to record the volume flow. A FT-IR gas monitoring system (gasmet, Karlsruhe) was used for measuring the ammonia concentrations (Table 1).

Table 1: Measurement categories and used devices for detecting exhaust air composition

Parameter	Measuring device
Ammonia	FT-IR Cx 4000, gasmet, Karlsruhe
Volume flow	Thies Ultrasonic anemometer 1 D, Göttingen
Temperature	Vaisala HUMICAP HMT 330, Helsinki
Relative humidity	Vaisala HUMICAP HMT 330, Helsinki

For detecting temperature and relative humidity Vaisala sensors (HMT 330, Helsinki) were used. The online monitoring system is equipped with an automatic working gauge head selector switch and a daily zero balance. After three prior measurements at the sampling point the system generates a measuring value every 80 seconds. The measuring pipes are heated to 70 °C and the measuring cell operates at 80 °C. All in all 8 sampling points are sampled sequentially so that any single sampling point generates every 640 s a measuring value in the normal case. These data are collected with other measuring data. For calculating the emissions from the stables measuring sample points, which confirms to standards, in the vent stacks are used. This procedure leads to 135 data sets every day. These data sets were converted into two-hour, daily and monthly mean values. The emission factors were calculated by cumulating the daily emission data over the single keeping periods, taking into account the average animal heads. For the calculation 365 keeping days were taken as a basis. The monthly data were normalised to 30 days in terms of comparability. The generated data were related to 500 animal places to ensure the comparability of both stables.

Results of emission measurements

Annual course of NH_3 emissions and volume flows

The range of mean ammonia emissions in the identical operated stables 1 and 2 showed seasonal effects (Figure 1). Comparatively low NH_3 emissions occurred from November until March while increased emissions were measured in April and May in particular and as well as in the time period from August until October. It should be noted that a total of 8 different monthly values were available for evaluation for December and January, while there were only two for June, due to the keeping periods. The mean NH_3 emissions from stable 1 varied over the year between 683 g NH_3 in 30 days per 500 animal places in February and 2,014 g NH_3 in 30 days per 500 animal places in August. At stable 2 the range of fluctuation was between 994 g in February and 2,627 g NH_3 in 30 days per 500 animal places in August.

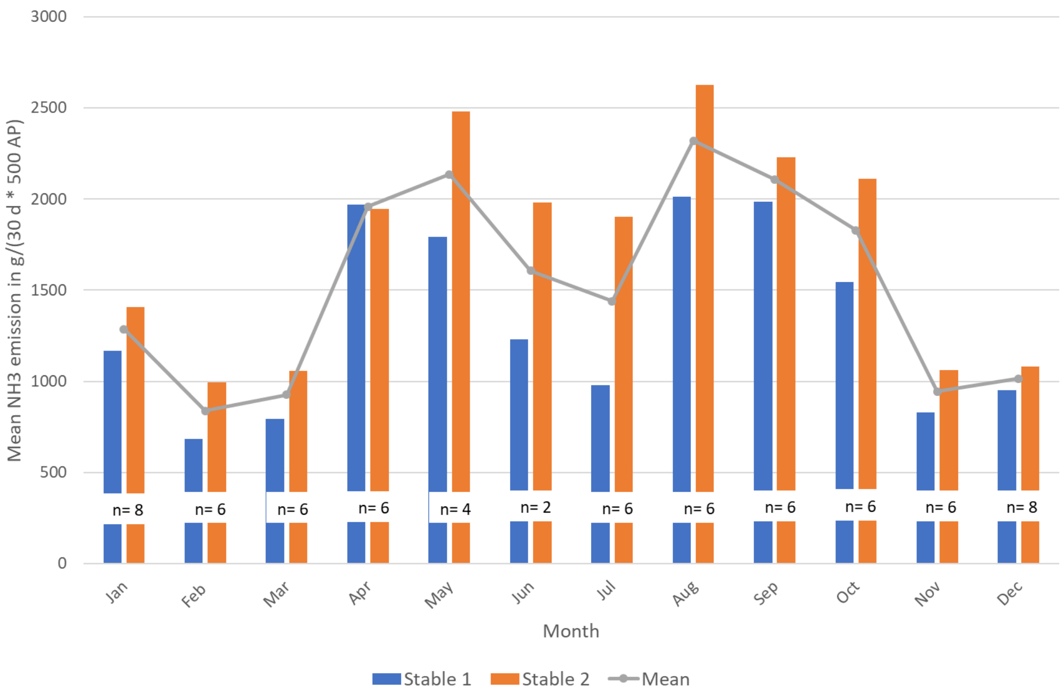

Figure 1: Annual courses of mean NH_3 emissions over a time period from 2017 - 2021

The mean air flows also showed clear seasonal effects (Figure 2). The lowest mean air flow was measured in stable 1 in February with 807 m^3 air per hour and 500 animal places, the highest with 8,594 m^3 per hour and 500 animal places in August. At stable 2 the lowest mean air flow was 1,012 m^3 per hour and 500 animal places in November, the highest was 8,200 m^3 per hour and 500 animal places in June.

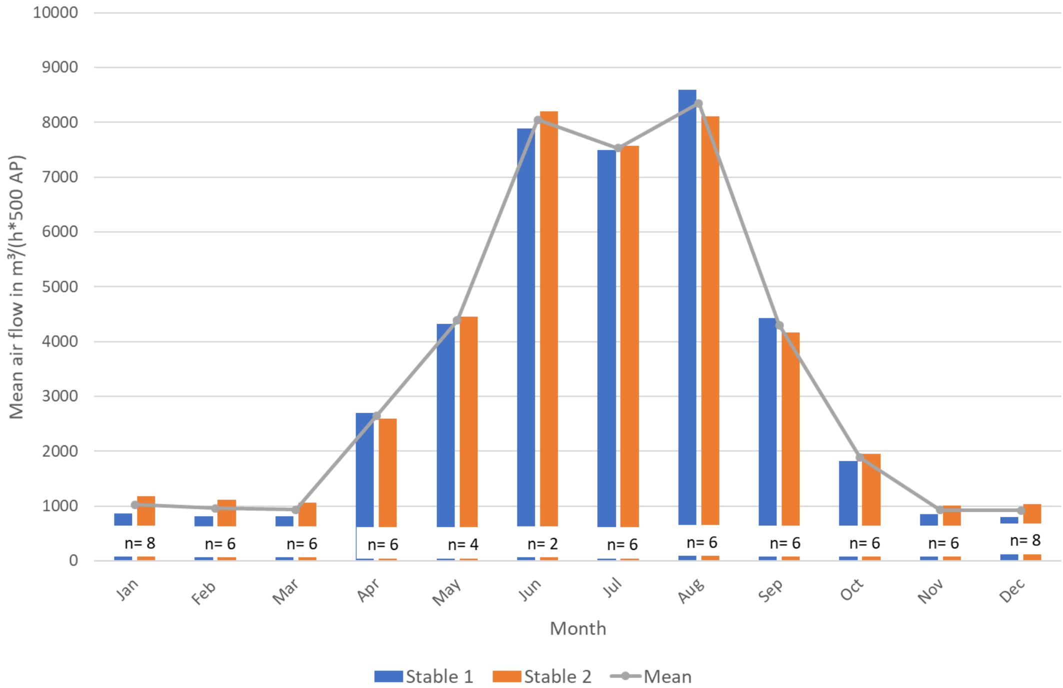

Figure 2: Annual courses of the mean air flows over a time period from 2017 - 2021

The mean NH_3 emissions showed a functional relation with the mean air flow (Figure 3).

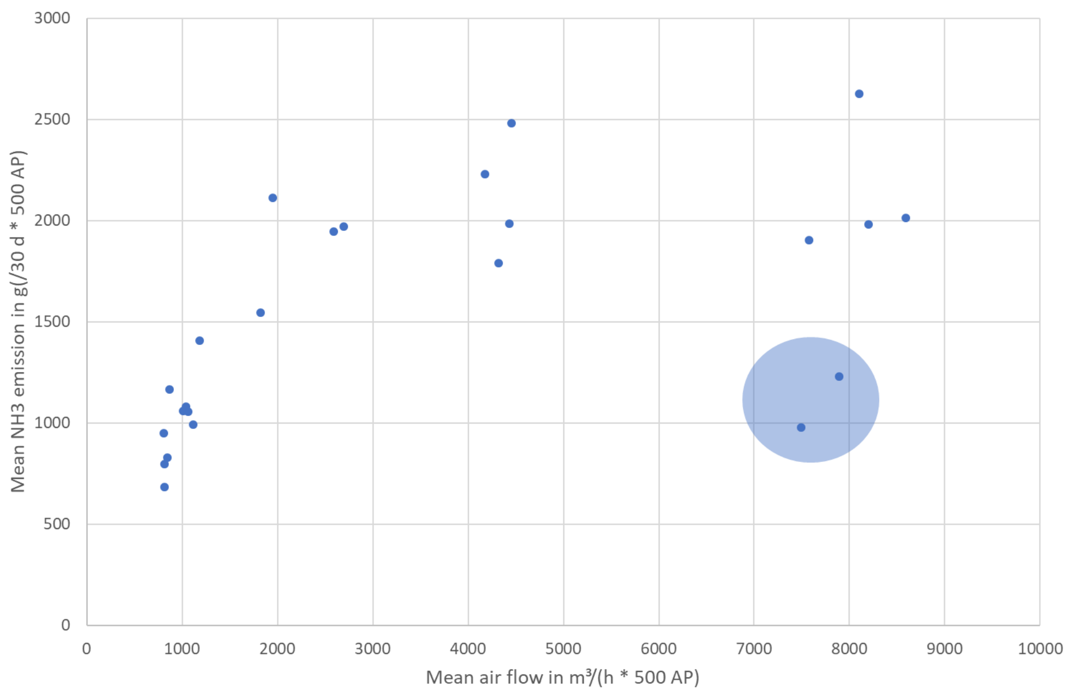

Figure 3: Relation between the mean NH_3 emissions and mean air flow rates in the time period from 2017 - 2021

The mean air flow rates were calculated from two-hour mean values and converted to monthly mean values. At low air flow rates up to 2,000 m^3/(h*500 animal places), the NH_3 emission increased linearly on trend with the air flow rate. At higher air flow rates the NH_3 emission hardly increased at all. The conspicuous low NH_3 emissions (blue marked circle in Figure 3) were measured in stable 1 in June and July and can not be explained with the present data. Data from stable 2 which were measured in parallel did not show comparably low NH_3 emissions.

Diurnal variations of NH_3 emissions and volume flow rates

The layer breeder stables showed typical diurnal variations in terms of emission behaviour. Two diurnal courses from stable 2 are shown in Figures 4 and 5 for April 13 and August 3 in example. Only Mondays were compared to exclude influences of manure removal (on Tuesdays and Fridays) from the results. All shown data are two-hour averages.

While the air flow rates showed only slight variations with 1,028–1,315 $m^3\ h^{-1}$ in April a distinct variation was obvious in August with air flow rates between 1,202 and 11,212 $m^3\ h^{-1}$. The highest values were measured in the time period between 2:00 and 8:00 pm, while the lowest were observed between 4:00 and 8:00 am. Additional results in terms of diurnal variations are shown in Table 2 for September, October and February.

The NH_3 concentrations in the exhaust air from the stables showed only a slight diurnal course with highest concentrations of 5 to 5.5 ppm NH_3 between 6:00 and 8:00 am in April. During August clearly lower NH_3 concentrations were measured. The highest concentrations were found with 1.7–2.2 ppm between 6:00 and 10:00 am.

The daily variations in stable temperature were low with 18.3 to 20.7 °C in April. During August the temperature variations were slightly higher with 20.2 to 24.6 °C. The highest temperatures were measured in the time period from 4:00 to 8:00 pm.

However, the relative humidity in the stable exhaust air showed a distinct diurnal variation during April. Relative high values were observed with 51.6 to 52.6% in the time period from 2:00 to 6:00 am. During the day, the relative humidity decreased to 30% at 8:00 pm. During August the values were 55.1 to 62.7% at 2:00 to 12:00 am. The relative humidity decreased to 41.3% around 6:00 pm.

The NH_3 mass flow showed only a slight diurnal variation in April. Highest values were recorded at 6:00 am with 4.9 g NH_3/(h*500 AP). On the other hand, there was a clear diurnal variation in August with highest values of 9.4 g NH_3/(h*500 AP) around 2:00 pm. At night the values decreased to 0.9 g NH_3/(h*500 AP).

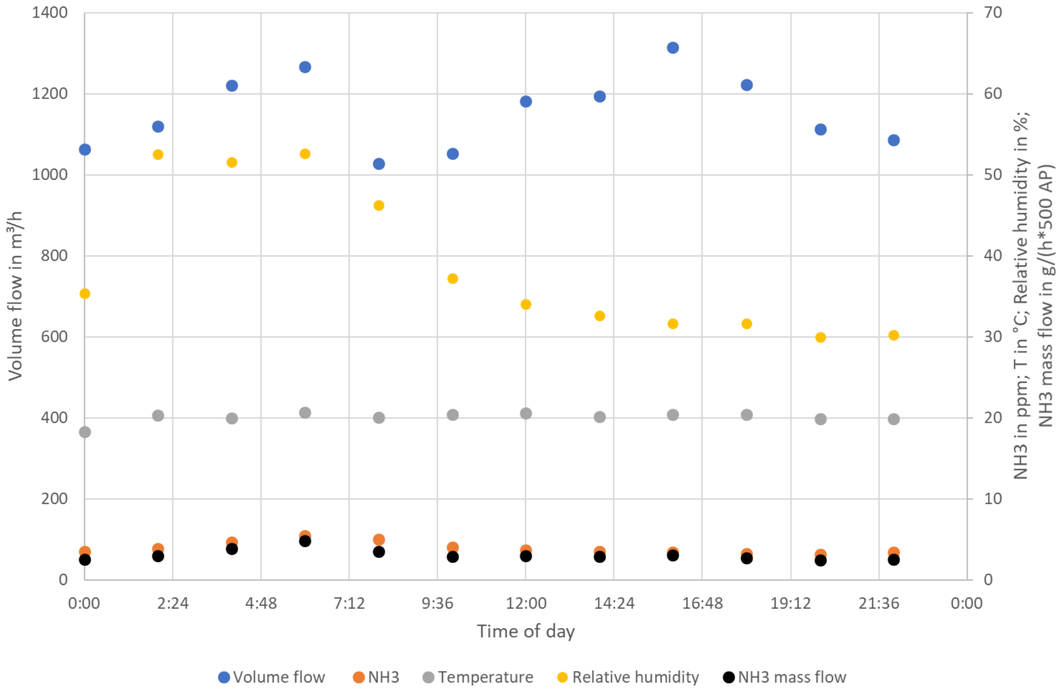

Figure 4: Example of a diurnal course of volume flow rate, ammonia concentration, temperature, relative humidity in stable exhaust air and ammonia mass flow in April

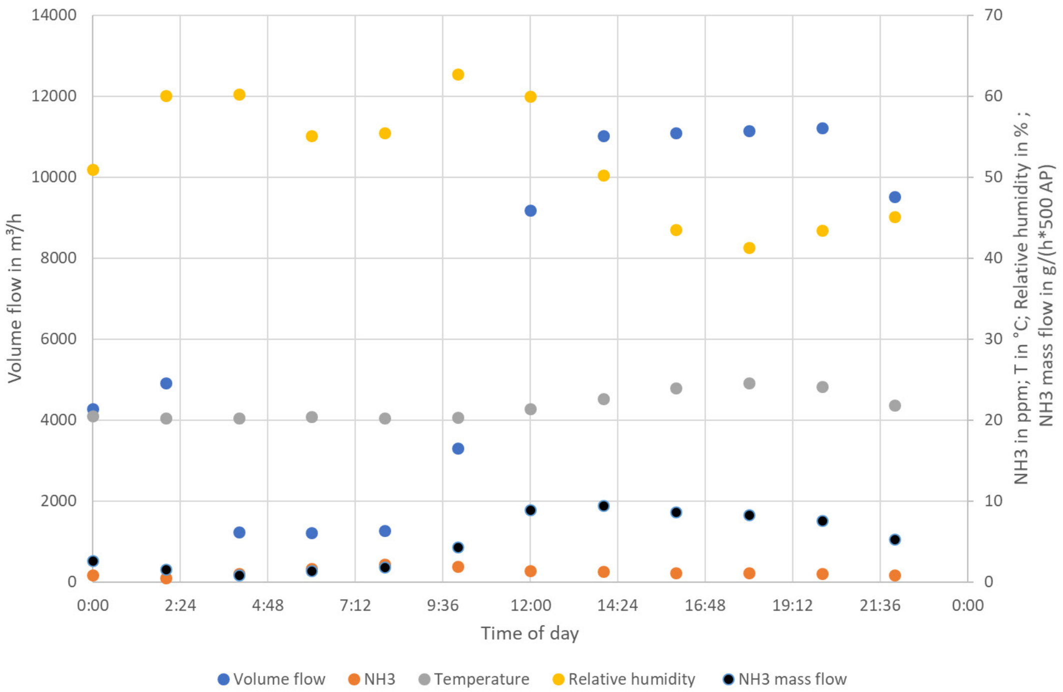

Figure 5: Example of a diurnal course of volume flow rate, ammonia concentration, temperature, relative humidity in stable exhaust air and ammonia mass flow in August

Table 2: Measurement data for volume flow rate, ammonia concentration, temperature, relative humidity in stable exhaust air and ammonia mass flow for different month in the time period from 2017–2021

Month	Parameter	Volume flow rate $m^3\ h^{-1}$	NH_3 ppm	T °C	Relative humidity %	NH_3 mass flow $g\ NH_3\ h^{-1}\ 500\ AP^{-1}$
April	Minimum	1,027.9	3.2	18.3	30.0	2.4
	Maximum	1,315.1	5.5	20.7	52.6	4.8
	Mean	1,155.3	3.9	20.1	38.8	3.1
	SD[1)]	91.4	0.7	0.6	9.2	0.7
	Median	1,150.1	3.6	20.2	34.7	3.0
August	Minimum	1,211.6	0.5	20.2	41.3	0.9
	Maximum	11,212.2	2.2	24.6	62.7	9.4
	Mean	6,613.3	1.2	21.7	52.3	5.1
	SD[1)]	4,285.7	0.5	1.7	7.6	3.4
	Median	7,042.9	1.1	20.9	53.0	4.8
September	Minimum	942.1	0.7	19.4	52.6	0.7
	Maximum	10,522.0	1.5	22.0	61.9	6.9
	Mean	4,169.7	1.1	20.5	58.6	2.7
	SD[1)]	3,972.0	0.3	0.8	2.9	2.4
	Median	1,640.7	1.1	20.3	59.5	1.5
October	Minimum	201.8	2.3	19.4	52.9	0.7
	Maximum	1,312.0	5.7	20.6	62.2	2.9
	Mean	981.2	3.5	19.9	56.6	2.1
	SD[1)]	356.2	1.0	0.3	2.6	0.6
	Median	1,124.7	3.1	19.9	56.6	2.2
February	Minimum	1,154.0	2.1	17.6	45.4	1.9
	Maximum	1,417.3	3.5	20.6	53.1	3.0
	Mean	1,295.4	2.9	19.6	50.0	2.5
	SD[1)]	72.6	0.4	1.1	2.5	0.4
	Median	1,304.8	3.0	20.0	50.6	2.6

[1)] Standard deviation

Influence of dung removal on ammonia emissions

The dung removal in stables 1 and 2 was carried regularly out twice weekly on Tuesdays and Fridays. In some weeks, only one dung removal was carried out, for example around Christmas time. These data remained disregarded in terms of evaluating the emission behaviour with two dung removals in a week. All data were then sorted by calendar day and added to weekly sum data to assess the influence of dung removals on ammonia emissions. In this way, 143 week sum data were calculated for stable 1 and 2. The ammonia emission data on the individual calendar days were converted into percentages and related to the weekly total data (= 100%).

The results show a clear correlation between dung removal and ammonia emissions for both stables (Figure 6). After dung removal on Tuesdays and Fridays the ammonia emissions decreased considerably and increased again after dung removals. This effect becomes particularly clear when looking at the data from Tuesday and Wednesday. Due to the dung removal on Tuesday the ammonia emissions decreased by almost 50% in stable 1 and 53% in stable 2.

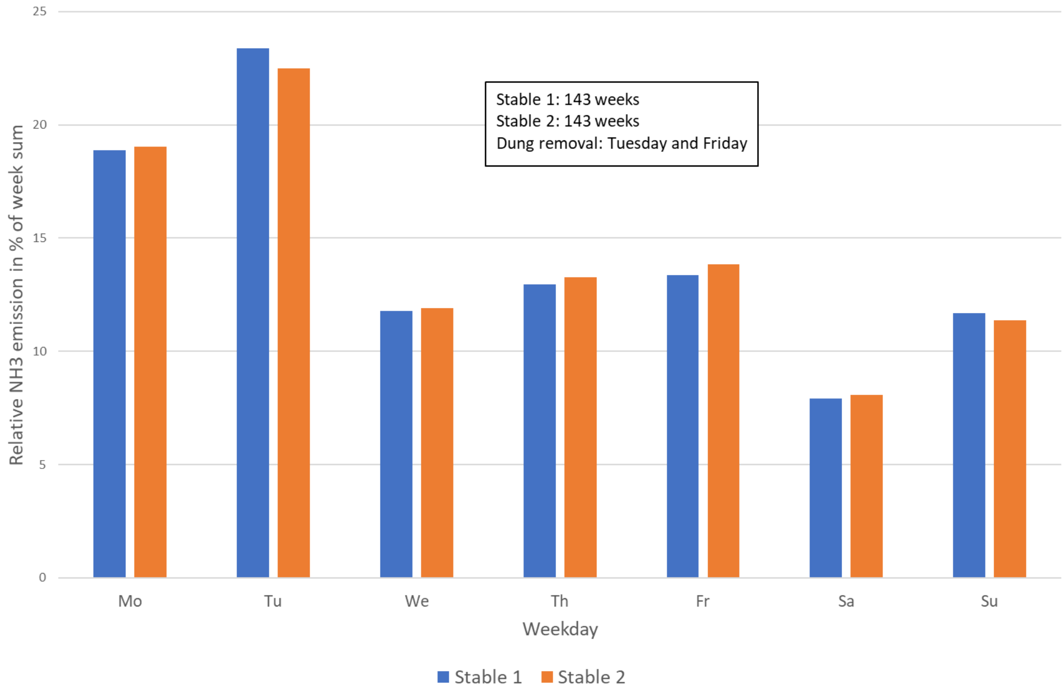

Figure 6: Course of mean ammonia emissions depending on weekday in the stables 1 and 2 in the time period from 2017 – 2021 (dung removal on Tuesdys and Fridays)

The increase in the mean relative ammonia emissions is particularly evident when considering the period from Saturday midnight to Monday midnight without any dung removal (Figure 7). The figures in Figure 7 are based on 141 periods each between Saturday and Monday of the two stables. The total ammonia emissions for this time period were determined at 100% for the stables 1 and 2 respectively. It is striking that the increase in relative ammonia emissions was similar in both stables. Assuming that the dung removal was finished at 12 noon on Fridays, the ammonia emission after 36 hours was 21.8 and 22.6%, respectively, in relation to the maximum possible emission of 100% (Monday midnight). After 60 h (Sunday midnight) 50.3 and 51.3%, respectively, of the maximum emissions were released.

The functional correlation between period after the last dung removal and relative ammonia emissions is shown in Figure 8. As the figure shows, there is a close correlation between both variables. The relative NH_3 emissions increased by a factor of 2.1 every 24 h within the period from 0 to 84 h (Saturday to Monday).

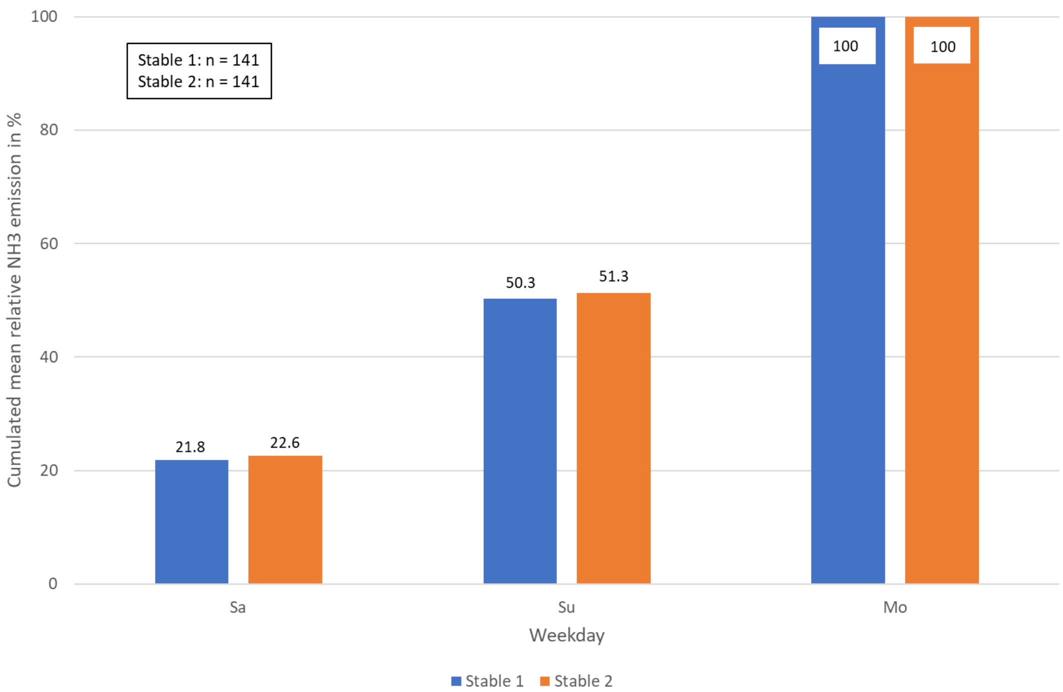

Figure 7: Increase of cumulated relative mean NH_3 emissions in stables 1 and 2 in the time period from 2017 – 2021 without dung removal (sum of relative mean NH_3 emissions from Saturday to Monday = 100%)

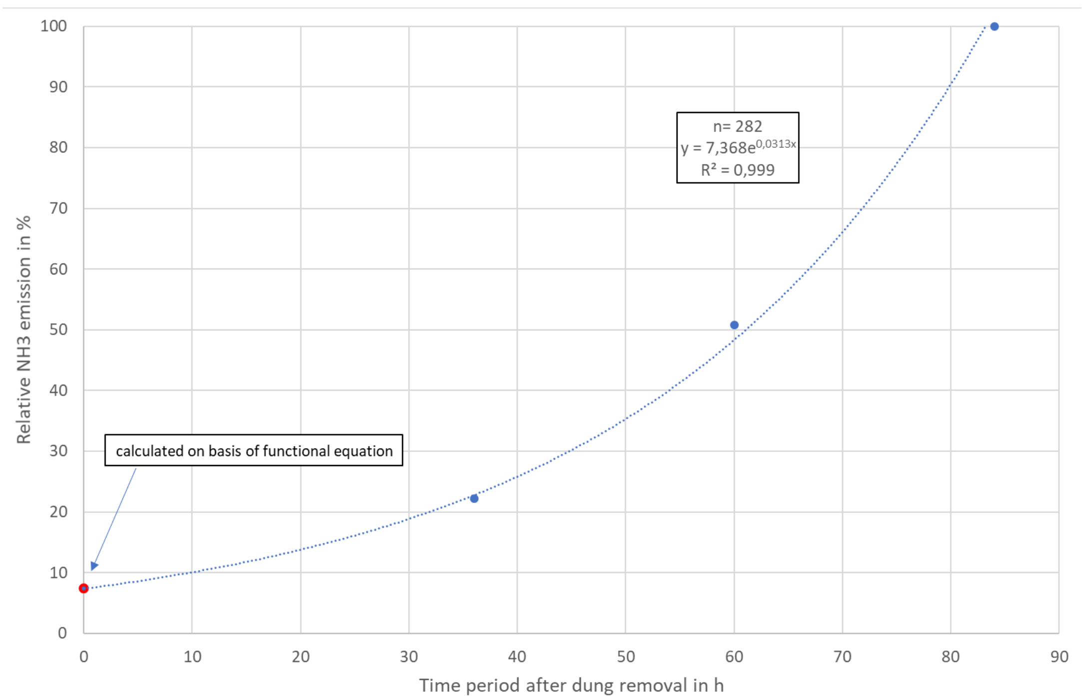

Figure 8: Influence of the time period without dung removal (Saturday to Monday) on the increase of relative NH_3 emissions

Total emissions and emission factor

The NH_3 emissions from both stables were measured during the time period from 2017 to 2021 (Table 3). In view of a multitude of influencing factors the calculated emission factors showed a reasonable fluctuation range. However, it is remarkable that the emission data of stable 2 were always higher than those of stable 1. One possible reason for this are increased volume flow rates in stable 2 from November to March (Figure 2). Increasing the volume flow rate, especially at lower volume flow rates of about 1,000 $m^3/(h*500\ AP)$, has a significant effect on the extent of emissions (Figure 3).

Table 3: NH_3 emissions and emission factors from layer breeder stables with twofold dung removal in a week without manure belt aeration

Parameter	**Stable 1**			
	2017–2018	**2018–2019**	**2019–2020**	**2020–2021**
Animal number	478	492	503	473
Keeping period in d	369	176	273	243
NH_3 emission, cumulative in g NH_3	17,501	6,967	9,657	10,718
NH_3 emission factor in g NH3 a^{-1} AP^{-1}	36.0	28.5	25.7	34.9
NH_3 mean in g NH_3 a^{-1} AP^{-1}	31.3			
	Stable 2			
	2017–2018	**2018–2019**	**2019–2020**	**2020–2021**
Animal number	432	446	513	523
Keeping period in d	369	176	273	243
NH_3 emission, cumulative in g NH_3	20,964	7,469	13,567	13,235
NH_3 emission factor in g NH3 a^{-1} AP^{-1}	48.0	34.7	35.4	38.0
NH_3 mean in g NH3 a^{-1} AP^{-1}	39.0			
NH_3-total mean (stable 1 and 2) in g NH3 a^{-1} AP^{-1}	35.2			

AP = Animal place

Taking a dung production of 70 g d^{-1} AP^{-1} and a nitrogen excretion of 2.03 g N d^{-1} AP^{-1} (Brade et al. 2008) as a basis the nitrogen emission amounted to 3.9% related to the nitrogen excretion (Table 4). The overall mean of 35.2 g NH_3 a^{-1} AP^{-1} was used for this calculation (Table 3). Related to nitrogen the emissions were about 29 g TP^{-1} a^{-1} and 0.079 g d^{-1} AP^{-1}.

Table 4: Calculated dung and nitrogen production, measured NH_3 emission data and emission factor in layer keepings

Parameter	**Value in g d^{-1} AP^{-1}**	**Value in kg a^{-1} 500 AP^{-1}**
Dung production	70	12,775
N exretion	2.03	370.48
N emission	0.079	14.42
N emission/N excretion in %	3.9	

The NH_3 emissions from the stable show in tendency a correlation to the calculated dung mass within the stable (Figure 9). The dung mass in the stable decreases with dung removal and the NH_3 emission shows analogous trend over the course of a week from 17 to 24 August 2020.

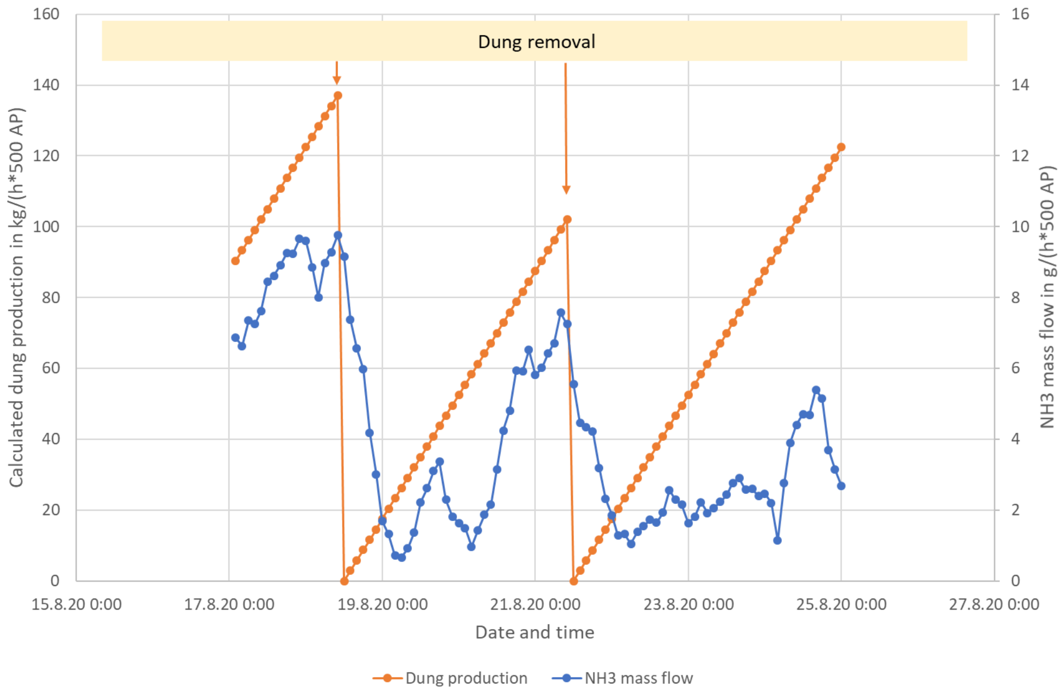

Figure 9: Course of calculated dung production and measured NH_3 emission in the time period from 15 - 27 August 2020

Discussion

The present investigations confirm the importance of dung removal with regard to ammonia emissions from forced ventilated layer breeder stables. While during former investigations ammonia emissions of 148 ± 29 g NH_3 a^{-1} TP^{-1} were measured at these stables with only one dung removal per week (Hahne 2010, 2013) actual measurements with two dung removals per week without manure belt aeration show mean ammonia emissions of only 35.2 g NH_3 a^{-1} AP^{-1}. The principal importance of dung removal is also shown by ammonia emission data published by the Landesamt für Umwelt Brandenburg (2020). The authors reported ammonia emissions of 90 g NH_3 a^{-1} AP^{-1} for floor housing with aviaries and a dung removal once per week while the NH_3 emission decreased to 56.5 g NH_3 a^{-1} AP^{-1} with two dung removals per week. Based on the current measurements, the effect of dung removal can be estimated to be even higher than the cited literature data show. The NH_3 emissions will be reduced considerably by increasing the number of dung removals. However, this inevitably leads to increasing nitrogen contents in solid manure and consequently the risk of possible NH_3 emissions increases in case of improper storage. In this respect demands on covering or roofing of solid manure storage facilities in the Technical Instructions on Air Quality Control (TA Luft) are appropriate (Bundesrat 2021). NH_3 emissions from these sources will be reduced if the solid manure is stored as dry as possible and protected against remoistening.

If a farmer keeping layer breeders has to reduce the ammonia emissions, increasing dung removal intervalls in combination with appropriate solid storage facility would be an interesting option based on current research. Based on the correlation between relative NH_3 emissions and time space between dung removal procedures (Figure 8), mean ammonia emissions were reduced by about 58.5% with three dung removals per week (every 56 h) compared to two dung removals per week (every 84 h).

In view of a perspectively increasing poultry keeping in Germany (Deblitz et al. 2021) and the intended reconstruction of livestock husbandry in terms of outside climate contact and more animal welfare (BMEL 2019) the meaning of a low emission handling of different solid manures becomes even more obvious. This is because many housing techniques contribute to an increasing amount of solid manure with the forming of function areas which are assessed to be more animal friendly. Modelling by Krötz and Englert (1999) has shown that lowering the pH value in the solid manure and the reduction of the mass transfer coefficient are essential measures to mitigate NH_3 emissions from solid manure. The reduction of the mass transfer coefficient can also be achieved by lowering the air velocity on the solid manure surface, reducing of material conversions and covering of the storage facility.

If a farmer with layer breeders has to reduce the ammonia emissions by 40% through exhaust air cleaning with a given dung removal management, a partial exhaust air cleaning with a capacity of 60% related to the maximum volume flow required for the livestock would be a promising option. The investigated stables have a maximum volume flow rate of 12,000 m^3/air h^{-1}. Considering the monthly average volume flow rates (Figure 2), it can be seen that the average volume flow rates in the period from October to April amounted to a maximum of 2,695 m^3 h^{-1}. If an exhaust air treatment system would now be designed only with 60% of the maximum capacity, 7,200 m^3 h^{-1} could be cleaned in the current case. Based on these volume rates, it would be possible to clean the total volume flow in the months from October to April and to secure a partial cleaning in the remaining months. With a dimensioning of 7,200 m^3 h^{-1} at least 59% of the NH_3 emissions over the year would be cleaned by the exhaust air treatment system. At a given minimum ammonia reduction efficiency of DLG (Deutsche Landwirtschaftsgesellschaft) approved exhaust air treatment systems in the amount of 70% an ammonia reduction of 41% would be secured from the stable. Against this background, the determinations in the Appendix 11 in the Technical Instructions on Air Quality Control (TA Luft) are factual well-founded (Bundesrat 2020).

Conclusions

The investigations confirm that the dung removal interval in the layer breeder stables is the essential determining factor for the extent of ammonia emissions. During the time without dung removal the ammonia emissions double every 24 h in mean as the investigations over time periods of 84 h show. Therefore and first of all the shortening of dung removal intervals is a promising mitigation measure. However, it should be noted that the NH_3 emissions must not be relocated to solid manure storage. A covering of solid manure storage facilities is indispensable. In particular, the drying of solid manure or the immediate utilisation in biogas plants with proper storage and application of resulting digestates are low emission techniques. The partial exhaust air cleaning with approved techniques can be recommended in view of additional mitigation demands for forced ventilated layer breeder housings. Current investigations show that a partial exhaust air cleaning dimensioned for 60% of the maximum volume flow related to the livestock will secure a complete cleaning of the volume flow in the months from October to April and a partial cleaning in the remaining months. A minimum NH_3 mitigation efficiency of 40% will be secured in this way.

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