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Ammonia emission factor modelling for naturally ventilated dairy housing

Ammonia emission factors for a naturally ventilated cubicle loose housing system with solid floors and an exercise area were calculated based on our emission measurements on six dairy farms using the tracer ratio method. A model-based calculation with bootstrapped variance components was used to calculate yearly averaged emission factors for mountain and plain regions and two wind speeds. The model input was based on milk urea contents from commercial dairy farms and air temperatures over a five-year period. The calculated NH_3 emission factors, which thus accounted for regional differences due to climatic conditions and feeding levels, range from 22 to 25 g LU^{-1} d^{-1}.

Keywords
Emission factor, ammonia, dairy cattle, modelling

Abstract
Landtechnik 67 (2012), no. 4, pp. 286–290, 2 figures, 2 tables, 13 references

An emission factor is the representative statement of an emission for a specific animal category and system (production system, housing system etc.) over the year. Emission factors, together with activity data, form the basis for the calculation of emission inventories for national and international reporting requirements. As yet there have been no ammonia emission factors (NH_3) for cubicle loose housing with an outdoor exercise area for dairy cows, the system widespread in Switzerland. The aim of this study was to determine overall NH_3 emission factors for a naturally ventilated loose housing system for dairy cows with cubicles, solid floors and an adjacent exercise area.

For emission factor modelling a reliable database is necessary. Measurements taken on only one farm cannot be generalized to an entire housing system [1]. Reliable data for a livestock housing system can only be provided from measurements on several farms [2; 3]. It is not sufficient to calculate an average emission factor based on a single measuring situation; the seasonal variation of climate should be representative for the country and/or region. In addition to reliable and detailed NH_3 emission data, a comprehensive database of relevant influencing variables at high spatial and temporal resolution is needed to calculate emission factors.

Calculation of NH_3 emission factors

NH_3 emission factors for a naturally ventilated cubicle loose housing system with solid floors and an exercise area alongside were calculated based on our emission measurements on six commercial dairy farms using the tracer ratio method [4]. The NH_3 emissions data were mapped with a high temporal resolution (at the level of the measurement cycles: 36 e.g. 50 min). A linear mixed-effects model was used to describe NH_3 emissions by fixed effects and taking account of the hierarchical data structure of measuring day b_{ijk}, measuring period b_{ij}, and farm b_i, in the form of nested random effects:

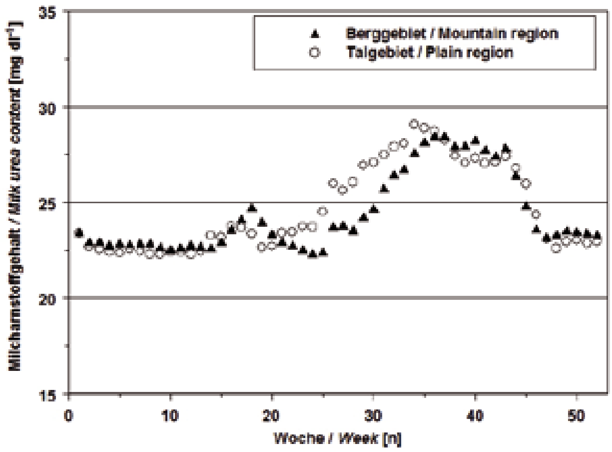
$$E_{iikl} = \mu + b_i + b_{ij} + b_{iik} + \beta_1 OT + \beta_2 UCM + \beta_3 WS + \beta_4 OT \cdot UCM + \varepsilon_{iikl} \quad \text{(Eq. 1)}$$

where E_{ijkl} is the response variable (NH_3 emission), μ the intercept, and the fixed effects are outside temperature OT (°C), wind speed in the housing WS (m s^{-1}) and tank milk urea content UCM (mg dl^{-1}). It was possible to consider the temporal dependence of consecutive measurement cycles using an autoregressive process of order 1 modelled in the residuals. NH_3 emission E_{ijk} was subjected to a logarithmic transformation to satisfy assumptions of normal and homogenous residuals. Graphical residual analysis was used to check the model assumptions. The significant variables influencing NH_3 emissions were the outside temperature ($F_{1,1053}$ = 100,7836; $p < 0.001$), the wind speed in the housing ($F_{1,1053}$ = 99,4947; $p < 0.001$) and the urea content of tank milk ($F_{1,5}$ = 6,9097; $p = 0.046$).

NH_3 emissions co-varied with outside temperature ($F_{1,1053}$ = 100,7836; $p < 0.001$), wind speed in the housing ($F_{1,1053}$ = 99,4947; $p < 0.001$) and the urea content of tank milk ($F_{1,5}$ = 6,9097; $p = 0.046$) [4].

Starting from the presented statistical model (Equation 1), the calculation of NH_3 emission factors was carried out by bootstrap point estimates. Milk urea levels from commercial farms, air temperatures at two altitudes (mountain region, plain re-

Fig. 1



Milk urea content patterns [mg dl⁻¹] as averages per calendar week calculated from individual cow data aggregated at regional level (mountain and plain region) as a database for the model-based calculation of emission factors [5]

gion), and two different wind speeds in the housing formed the underlying data for this model-based calculation. Four variants have been defined. Because of the missing database it was not possible to take pasture grazing and alpine grazing into account. The point estimates were made using the coefficients of the fixed effects in the model. In order to account for the random effects (farm, measuring period, measuring day), randomly selected values were drawn from the normal distribution across the different hierarchical levels and added to the point estimates. From this, an arithmetic mean (g LU^{-1} d^{-1}) was calculated on an extrapolated per year basis. The bootstrap sample was carried out 1 000 times per variant. Statistical analysis and the bootstrap point estimate were carried out with the S-Plus ® Version 7.0 statistics program for Windows.

Database of relevant influencing variables

Milk urea levels on an individual animal basis were available for the whole of Switzerland from the milk recording data issued by the Swiss Brown Cattle Breeders' Federation, the Swiss Fleckvieh Cattle Breeders' Federation and the Swiss Holstein Breeders' Association for 2004 to 2008. The model-based calculation was founded on calendar week averages over all the breeders' associations and years separately for the mountain and plain region. The average calendar week milk urea levels varied between 22 and 29 mg dl^{-1}. They showed a clear seasonal dynamic. The nitrogen level in feed was lower during the winter feeding period. There was a short-term drop in milk urea content at the beginning of the grazing season. In the course of the summer feeding period the urea content reached maximum values. In the winter feeding period and in the autumn the values in the mountain region were slightly above those of the plain region in most years. In early summer milk urea levels in the plain region were higher than those in the mountain region, as the plain region grazing season started earlier (**Figure 1**).

The temperature data for 2004 to 2008 were provided by MeteoSchweiz, the Federal Office of Meteorology and Climatology. These were hourly average air temperatures at a height of 2 m from 17 mountain region weather stations and 26 plain region weather stations. In order to show the high temporal resolution of the emission data in the model (Equation 1), the calculation with bootstrapped variance components was based on hourly averages, in each case as diurnal variations per calendar week over the years 2004 to 2008. The temperature data revealed a clear daily dynamic course. This was less distinct in winter than in the warmer seasons. The mountain and plain region temperature curves followed a parallel course. The mean temperature in the plain region was around 4 °C higher than the mean temperature in the mountain region. The mountain

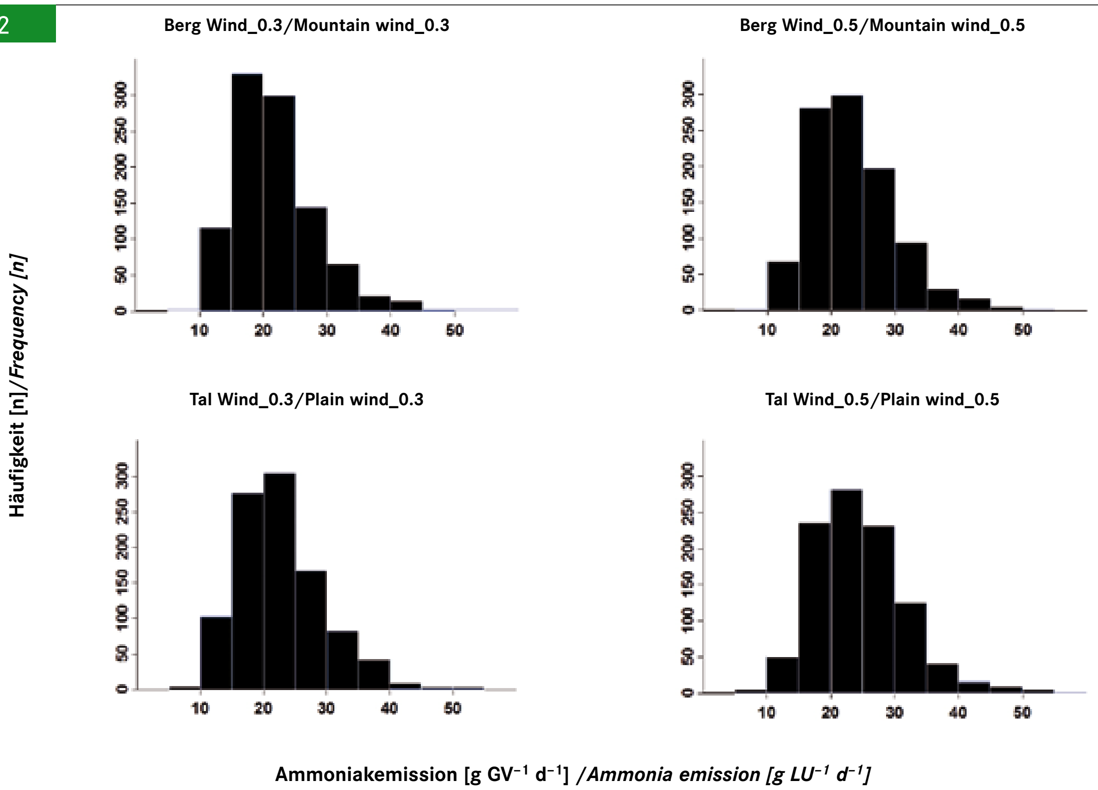
Table 1

NH_3 emission factors for dairy housing in naturally ventilated cubicle loose housing with solid floors and an outdoor exercise area alongside, by reference to the model-based calculation for both mountain and plain region and for two wind speeds [5]

Variante: Region und Windgeschwindigkeit *Variant: Region and wind speed*	NH_3-Emissionsfaktor pro Tag[1)] Arithm. Mittel (95-%-Konfidenzintervall) *NH_3 emission factor per day[2)] Arithm. mean (95 % confidence interval)*		NH_3-Emissionsfaktor pro Jahr[1)] Arithm. Mittel (95-%-Konfidenzintervall) *NH_3 emission factor per year[2)] Arithm. mean (95 % confidence interval)*	
m s⁻¹	g Tier⁻¹ d⁻¹ *g animal⁻¹ d⁻¹*	g GV⁻¹ d⁻¹ *g LU⁻¹ d⁻¹*	kg Tier⁻¹ a⁻¹ *kg animal⁻¹ a⁻¹*	kg GV⁻¹ a⁻¹ *kg LU⁻¹ a⁻¹*
Berg Wind_0.3 *Mountain wind_0.3*	28,9 (16,4; 49,9)	21,8 (12,3; 37,5)	10,6 (6,0; 18,2)	8,0 (4,5; 13,7)
Berg Wind_0.5 *Mountain wind_0.5*	31,1 (17,4; 52,9)	23,4 (13,0; 39,8)	11,4 (6,4; 19,3)	8,5 (4,8; 14,5)
Tal Wind_0.3 *Plain wind_0.3*	30,1 (16,0; 50,4)	22,7 (12,0; 37,9)	11,0 (5,8; 18,4)	8,3 (4,4; 13,8)
Tal Wind_0.5 *Plain wind_0.5*	32,6 (17,8; 54.0)	24,5 (13,4; 40,6)	11,9 (6,5; 19,7)	8,9 (4,9; 14,8)

1) Berechnet mit dem GV-Schlüssel des KTBL [8]/*Calculated using the KTBL LU Code [8].*
2) GV Großvieheinheit; 1 GV = 500 kg Lebendmasse/*LU = Livestock unit; 1 LU = 500 kg live weight.*

Fig. 2



NH_3 emission [g GV^{-1} d^{-1}] frequency distribution [n] of the model-based calculation with bootstrapped variance components depicted as variants (sample size n = 1 000)

Table 2

Comparison of NH_3 emission factors from the model-based calculation of this study with dairy housing emission factors from the literature [5]

Angaben zum Haltungssystem ***Particulars of the housing system***	**NH_3-Emissionsfaktor** ***NH_3 emission factor***	**Region** ***Region***	**Datengrundlage** ***Data basis***	**Autor** ***Author***
Stall/*Indoor housing* Weide/*Grazing*	23,8 g $Tier^{-1}$ d^{-1} / *g $animal^{-1}$ d^{-1}* 10,7 g $Tier^{-1}$ d^{-1} / *g $animal^{-1}$ d^{-1}*	Europa *Europe*	Expertenkonsens basierend auf Literatur *expert judgement based on literature*	[11]
Anbindestall *Tie-stall* Liegeboxenlaufstall *Cubicle loose housing* Tiefstreulaufstall *Deep straw-bedded loose housing* Tretmistlaufstall *Straw flow system housing*	13,4 (9,9–16,7) g $Tierplatz^{-1}$ d^{-1} / *g animal $place^{-1}$ d^{-1}* 40,0 (28,8–49,9) g $Tierplatz^{-1}$ d^{-1} / *g animal $place^{-1}$ d^{-1}* 40,0 g $Tierplatz^{-1}$ d^{-1} / *g animal $place^{-1}$ d^{-1}* 43,3 g $Tierplatz^{-1}$ d^{-1}/ *g animal $place^{-1}$ d^{-1}*	Deutschland *Germany*	Expertenkonsens basierend auf Literatur *expert judgement based on literature*	[9]
Liegeboxenlaufstall, perforierte Laufflächen *Cubicle loose housing, perforated floors*	26,8–47,1 g $Tier^{-1}$ d^{-1} / *g $animal^{-1}$ d^{-1}*	Niederlande *The Netherlands*	Messungen *measurements*	[12]
Wartehof bzw. Laufhof als Fütterungs- oder Lauffläche *Collecting yard or outdoor exercise area as feeding or traffic area*	13,7 g $Tier^{-1}$ d^{-1} / *g $animal^{-1}$ d^{-1}*	Großbritannien *United Kingdom*	Messungen *measurements*	[13]
Liegeboxenlaufstall *Cubicle loose housing* Laufhof, planbefestigt *Outdoor exercise area, solid floor*	53,2 g GV^{-1} d^{-1} / *g LU^{-1} d^{-1}* 32,4 g GV^{-1} d^{-1} / *g LU^{-1} d^{-1}*	Portugal *Portugal*	Messungen *measurements*	[10]
Liegeboxenlaufstall, planbefestigte Laufflächen und Laufhof *Cubicle loose housing, solid floors and outdoor exercise area*	28,9–32,6 g $Tier^{-1}$ d^{-1} / *g $animal^{-1}$ d^{-1}* oder/*or* 21,8–24,5 g GV^{-1} d^{-1} / *g LU^{-1} d^{-1}*	Schweiz *Switzerland*	Messungen und modell-basierte Kalkulation *measurements and model-based calculation*	eigene Studie *own study*

region temperature ranged from -6 to 21 °C and that in the plain region from -2 to 26 °C.

With this detailed database of milk urea levels and temperature data it was possible to describe typical patterns over a five year period. Since no appropriate database was available for wind speed in the housing, two wind speeds were assumed in order to demonstrate the effect of these variables. Values of 0.3 m s^{-1} (wind_0.3) and 0.5 m s^{-1} (wind_0.5) were derived from our measurements on six dairy farms in Switzerland [5] and from studies by [6] in two outdoor climate housing units in Germany and by [7] in four outdoor climate housing units in Switzerland.

Results and discussion

The mean NH_3 emission factor ranged from 28.9 to 32.6 g $animal^{-1}$ d^{-1} or from 21.8 g to 24.5 g LU^{-1} d^{-1} (**Table 1**). In each case the reference value is the animal or the livestock unit LU (1 LU = 500 kg live weight) per day. This is based on a live weight of 650 kg per animal. The emission factor is equivalent to the mean annual value of the NH_3 emissions of the individual variants. The higher values of the NH_3 emission factors from the plain region compared with those in the mountain region can be explained both by the higher temperatures and higher milk urea levels in the plain region. Within the same altitude zone, the emission factor based on the higher wind speed was always larger than that based on the lower wind speed. Differences between the individual variants were small.

Figure 2 shows as histograms the frequency distribution of the individual annual NH_3 emission values from the model-based calculation according to the variants described. Each NH_3 emission class comprises 5 g $LU^{-1} \cdot d^{-1}$. Across all variants the greatest proportion of values occurs in the classes between 15 and 30 g NH_3 $LU^{-1} \cdot d^{-1}$. Whereas in the mountain region with a lower wind speed NH_3 emission class 15 to 20 $LU^{-1} \cdot d^{-1}$ is the largest, class 20 to 25 $LU^{-1} \cdot d^{-1}$ accounts for most of the values in each of the other three variants.

Our calculated NH_3 emission values are lower than the NH_3 emission factor for the cubicle loose housing system in Germany at 40 g animal $place^{-1}$ d^{-1} [9] and for dairy loose housing with an outdoor exercise area in Portugal at 87 g LU^{-1} d^{-1} [10] (**Table 2**). They do, however, exceed the 24 g $animal^{-1}$ d^{-1} NH_3 emission factor of the European Environment Agency [11], which includes tie-stalls and loose housing.

Conclusions

The database for the derivation of an NH_3 emission factor for the described housing system is broadly supported by systematic measurements on six commercial farms at different seasons as well as by the detailed milk urea levels and temperature data available. A higher level of detail would have been desirable in the case of the wind speed parameter. Using the described modelling procedure it was possible to determine regionally differentiated NH_3 emission factors based on widely available underlying data of high temporal and spatial resolution, thereby showing differences in climatic conditions and feeding levels. Further, all the modelled emission factors clearly reflect the importance of wind speed. NH_3 emissions can only be realistically mapped with emission factors which are modelled to differentiate between region, nitrogen supply and housing system. In order to improve the database for NH_3 emissions from dairy cattle housing and to compare housing systems, other housing systems such as cubicle loose housing with perforated floors and multiple-building systems with integrated outdoor exercise areas must be studied.

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