An improved data base for the description of dairy cows in the German agricultural emission model GAS-EM

Ulrich Dämmgen*, Hans-Dieter Haenel**, Claus Rösemann**, Wilfried Brade*, Maria Müller-Lindenlauf***, Brigitte Eurich-Menden****, Helmut Döhler**** and Nicholas J. Hutchings*****

Summary

The application of the previously published detailed model describing dairy cow husbandry in the German agricultural emission model requires an extended and improved data base. This concerns animal weights, weight gains, regional feed regimes, feeding requirements and feed properties as well as a revision of ammonia emission factors for animal houses and the storage and application of animal manure.

Animal weights, weight gains and the regional distribution of feeding regimes can be derived from official statistics. Compositions of both roughage and concentrates can be described as a function of animal performance. The knowledge of hitherto unpublished data allows for a recalculation and revaluation of nitrogen excretions and ammonia emission factors.

Keywords: Dairy cows, model, energy balance, nitrogen, feeding requirements, feed composition, emission factors, emission inventory

Zusammenfassung

Eine verbesserte Datenbasis zur Beschreibung von Milchkühen im deutschen landwirtschaftlichen Emissionsinventar

Die Anwendung des zuvor beschriebenen detaillierten Modells zur Beschreibung von Milchkühen im deutschen landwirtschaftlichen Emissionsinventar erforderte eine Erweiterung und gründliche Überarbeitung der Datenbasis. Dies betrifft die Ermittlung von Tiergewichten und Gewichtszunahmen, regionsspezifische Futtermengen und Futterzusammensetzung sowie eine Überarbeitung der Ammoniak-Emissionsfaktoren für Stall, Lagerung und Ausbringung von Wirtschaftsdüngern.

Tiergewichte, Gewichtszunahmen und die räumliche Verteilung von Fütterungsregimen lassen sich auf statistisch erfasste Größen zurückführen. Die Zusammensetzung von Grund- und Kraftfutter lässt sich regionstypisch und leistungsabhängig beschreiben. Einsicht in bisher unveröffentlichte Datensätze erlaubt eine Rückrechnung und Neubewertung von Stickstoff-Ausscheidungen und Emissionsfaktoren für Ammoniak.

Schlüsselwörter: Milchkühe, Modell, Energiehaushalt, Stickstoff, Futterbedarf, Futterzusammensetzung, Emissionsfaktoren, Emissionsinventar

* University of Veterinary Medicine Hannover, Institute for Animal Breeding and Genetics, Buenteweg 17p, 30559 Hannover, Germany

** Johann Heinrich von Thünen-Institut (vTI), Institute for Agricultural Climate Research, Bundesallee 50, 38116 Braunschweig, Germany

*** Statistisches Bundesamt (DESTATIS), Graurheindorfer Str. 198, 53117 Bonn, Germany. New affiliation: ifeu - Institut für Energie- und Umweltforschung Heidelberg GmbH, Wilckensstr. 3, 69120 Heidelberg, Germany

**** Association for Technology and Structures in Agriculture (KTBL), Bartningstr. 49, 64289 Darmstadt, Germany

***** University of Aarhus, Research Centre Foulum, PO box 50, 8830 Tjele, Denmark

Correspondence should be sent to: dieter.haenel@vti.bund.de

1 Introduction

The modelling of emissions of nitrogen and carbon species presupposes the knowledge of the respective excretions. These are dependent on animal performance and amounts and properties of animal feed. It is obvious that a model that is to be used for the development of emission reduction policies has to reflect the national reality as best as possible. As both animal performance and feeds vary with time and region, data sets have to be generated that are suitable to match the needs of the emission model.

Dairy cattle are the most important single source of agricultural trace gas emissions. Hence, a detailed model to describe the carbon and nitrogen excretions is of the highest priority.

The German agricultural emission model GAS-EM to be used in future relies on data sets for animal weights and feed properties with an adequate accuracy and an adequate resolution in time and space. So far, animal weights of dairy cows have been deduced from slaughter statistics. However, it is obvious that these underestimate the true weights.

In the German emission reporting, mean feed properties were used which were nevertheless depending on animal performance, in particular on milk yield. Dämmgen et al. (2009b) illustrated to what extent feeding influences emissions. The supply of roughage differs considerably and has been changing in the past two decades.

The paper presented here describes the modifications used to establish a data set matching the requirements of the dairy cow module (CDC09) in GAS-EM.

2 Animal weights

The knowledge of animal weights and weight gains is needed for the assessment of energy requirements and feed dry matter (DM) intake.

2.1 Present situation

2.1.1 Final weights

Animal weights in Germany vary considerably due to the fact that the mix of races is different within regions. The animal weights used in previous inventories were derived from carcass weights obtained from the German slaughter statistics (Statistisches Bundesamt, FS3, R4.2.1) by using standard slaughter yields proposed by the Federal Ministry for Nutrition, Agriculture and Consumer Protection (BMELV).

The slaughter yield is the ratio between live weight before slaughtering and the carcass weight.

$$w_{\text{carcass}} = c_{\text{w}} \cdot w_{\text{fin}} \qquad (1)$$

where

w_{carcass}	carcass weight (in kg cow^{-1})
c_{w}	slaughter yield (in kg kg^{-1})
w_{fin}	final animal live weight (in kg cow^{-1})

The mean carcass weight w_{carcass} for an animal category is obtained from the cumulative carcass weight and the number of animals slaughtered.

$$w_{\text{carcass}} = \frac{m_{\text{slaughtered}}}{n_{\text{slaughtered}}} \cdot \beta \qquad (2)$$

where

w_{carcass}	carcass weight (in kg cow^{-1})
$m_{\text{slaughtered}}$	total mass of slaughtered animals (in Mg a^{-1})
$n_{\text{slaughtered}}$	number of slaughtered animals (in a^{-1})
β	mass units conversion factor (β = 10^3 kg Mg^{-1})

The data obtained from these calculations differ from those reported by ADR (1992 ff). They also differ from any data published in the literature. Both sources indicate higher animal weights.

2.1.2 Weight gains

Weight gains are not reported by statistics. Hitherto, the relevant weight gain is calculated using the final live weight of cows and the final live weight of heifers. The weight gain rate is derived from the weight gain by dividing it by the time span between the age of slaughtering and the age of first calving.

$$\frac{\Delta w_{\text{dc}}}{\Delta t} = \frac{w_{\text{fin, dc}} - w_{\text{fin, bf}}}{\left(\tau_{\text{fin, dc}} - \tau_{\text{calf}}\right) \alpha} \qquad (3)$$

where

$\Delta w_{\text{dc}}/\Delta t$	mean weight gain rate of dairy cows (in kg cow^{-1} d^{-1})
$w_{\text{fin, dc}}$	slaughter weight of dairy cows (in kg cow^{-1})
$w_{\text{fin, bf}}$	slaughter weight of heifers (in kg heifer^{-1})
$\tau_{\text{fin, dc}}$	slaughter age of dairy cows (in a)
τ_{calf}	age at first calving (in a)
α	time units conversion factor (α = 365 d a^{-1})

The final weights were derived from carcass weights according to Equation 1 using constants c_{w} = 0.52 kg kg^{-1} and 0.49 kg kg^{-1} for heifers and dairy cows, respectively.

2.2 Future approach

Matching data sets for live weights (weights at the farm) and carcass weights were reported by a limited number of experimental farms for female cattle[1]. These data (Figure 1) indicate that the use of a linear regression including an intercept is to be preferred to the application of a constant conversion factor.

$$w_{\text{live}} = a + \mathrm{b} \cdot w_{\text{carcass}} \qquad (4)$$

where

w_{live}	live weight of an animal before slaughtering (in kg animal^{-1})
a	constant (a = 221 kg animal^{-1})
b	coefficient (b = 1.46)
w_{carcass}	carcass weight of an animal (in kg animal^{-1})

This relation is used both for heifers and dairy cows.

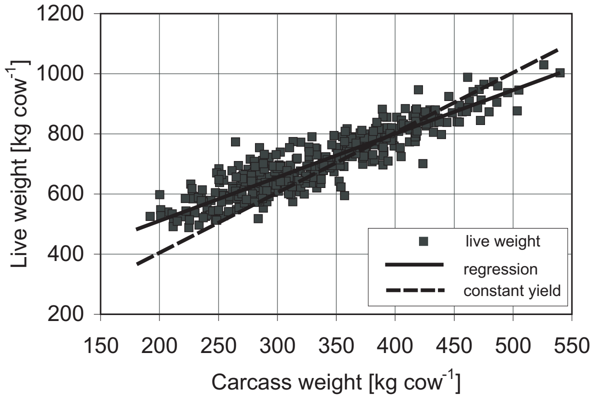

Figure 1:

Matching pairs of live weights at the farm and carcass weights of dairy cows (n = 459, R^2 = 0.831. The dotted line is obtained from the application of equation (1).

Data sets for carcass weights are provided by the Federal Statistical Office (Statistisches Bundesamt) as annual means with a resolution in space of Federal States for heifers and cows.

Weight gains can be obtained from the (corrected) final live weights of heifers and dairy cows, once the lifespan is known.

The relevant weight gain is calculated using the final live weight of cows and the final live weigth of heifers. The weight gain rate is derived from the weight gain by dividing it by the timespan between the age of slaughtering and the age of first calving.

$$\frac{\Delta w_{\text{dc}}}{\Delta t} = \frac{1}{\alpha} \cdot \frac{w_{\text{fin, dc}} - w_{\text{fin, bf}}}{\tau_{\text{fin, dc}} - \tau_{\text{calf}}} \qquad (5)$$

where

$\Delta w_{\text{dc}}/\Delta t$	mean weight gain rate of dairy cows (in kg animal^{-1} d^{-1})
α	time units conversion factor (α = 365 d a^{-1})
$w_{\text{fin, dc}}$	slaughter weight of dairy cows (in kg animal^{-1})
$w_{\text{fin, bf}}$	slaughter weight of heifers (in kg animal^{-1})
$\tau_{\text{fin, dc}}$	slaughter age of dairy cows (in a)
τ_{calf}	age at first calving (in a)

The ages of first calving and of slaughtering are published by ADR and taken from their annual reports (ADR, 1992ff). These data originate from sample surveys. In this inventory, a linear regression of ages versus time was used to describe weight gain rates. The same procedure is also used to close data gaps.

There is no differentiation between Federal States or race. Data are compiled in Table 1. Data obtained from linear regressions ($\tau_{\text{fin, bf, lin}}$, $\tau_{\text{calf, lin}}$, Δt) are written in italics.

Table 1:

Dairy cows, slaughter ages, ages at first calving and resulting lifspans (in a)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
$\tau_{\text{fin, bf ADR}}$				5.70	5.60	5.70	5.70	5.50	5.50	5.50	5.40	5.40	5.40	5.30	5.40	5.40	5.40	5.40	5.40
$\tau_{\text{fin, bf, lin}}$	*5.71*	*5.69*	*5.67*	*5.65*	*5.63*	*5.60*	*5.58*	*5.56*	*5.54*	*5.51*	*5.49*	*5.47*	*5.45*	*5.43*	*5.40*	*5.38*	*5.36*	*5.34*	*5.31*
$\tau_{\text{calf, ADR}}$			2.55	2.55	2.55	2.53	2.50	2.51	2.51	2.59	2.50	2.51	2.48	2.47	2.46	2.45	2.43	2.39	2.39
$\tau_{\text{calf, lin}}$	*2.59*	*2.58*	*2.57*	*2.56*	*2.55*	*2.54*	*2.53*	*2.52*	*2.51*	*2.50*	*2.49*	*2.48*	*2.47*	*2.46*	*2.45*	*2.44*	*2.43*	*2.42*	*2.41*
Δt	*3.13*	*3.11*	*3.10*	*3.09*	*3.08*	*3.06*	*3.05*	*3.04*	*3.03*	*3.01*	*3.00*	*2.99*	*2.98*	*2.96*	*2.95*	*2.94*	*2.93*	*2.91*	*2.90*

Source: ADR, 1992 ff, Tables 61a, 48 or 4.9 (τ_{calf}), Tables 68a, 53 or 4.14 (τ_{fin})

[1] Landwirtschaftskammer Niedersachsen, Versuchsstation Infeld; Friedrich-Loeffler-Institute, Federal Research Institute for Animal Health, Institute of Farm Animal Genetics, Neustadt; and Landwirtschaftliches Zentrum Baden-Württemberg, Aulendorf

3 Milk yields

The assessment of energy and nutrient requirements presupposes the knowledge of actual milk yields. These include colostral milk and any other milk not delivered to the dairies. This may also include milk from diseased cows, cows that are treated with antibiotics, milk that is used in the farm for whatever purposes and milk sold directly to consumers.

The Federal Statistical Office provides actual milk yields for Federal States on an annual basis. Milk yields for single districts are available every second or third year (1990, 1992, 1994, 1996, 1999, 2001, 2003). Hitherto, missing data were replaced by those reported for the respective previous year. In view of the gap filling procedure used for the assignment of feeding regimes (see Chapter 4.2.2.6) in future data gaps between existing district data will be closed by linear interpolation. If district data is not available, the means reported for the Federal States will be used.

4 Feed properties

4.1 Present situation

The German emissions inventory used feed properties that were constant with time and space. Grazing was taken into account for emission calculations, but not with respect to feed properties. As a reduction of grazing intensities is likely and included in the German emission projections (Osterburg and Dämmgen, 2009), a data set describing the period between 1999 and 2010 will be generated that describes the situation adequately. This data set will be adapted to the agricultural census data in 2011.

4.2 Future approach

4.2.1 Concept

In Germany, dairy cows are fed using combinations of concentrates and roughage. Their respective amounts depend on the performance of the cows and on the composition of both concentrates and roughage. It is assumed that two basic types of feeding have to be considered (Dämmgen et al., 2009a):

- a diet based on grass silage and concentrate with a low protein content
- a diet based on maize and grass silage and a concentrate with a high protein content

The frequency distribution is a function of the maize for silage harvested in each district. For each district, the ratio of grass and grass/maize fed cows is deduced. The share of cows fed with grass based or mixed ration, respectively, is determined based on the farm survey data obtained from official statistics.

Mean diet compositions also vary with milk yields. The mean properties of feed are calculated and used to assess the amounts of roughage and concentrates consumed (see Dämmgen et al., 2009a). The feed composition will also be used to assess the mean metabolizability and digestibility needed for the calculation of the CH_4 emissions from enteric fermentation and from manure management and the N inputs in order to generate data for renal and faecal N excretions.

4.2.2 Attribution of feeding regimes

It is common practice in Germany to differentiate between grass based feeds and mixed feeds, the latter based on roughage consisting of maize and grass silage of about even shares. This is also reflected by the German decree on fertilizers (Düngemittelverordnung, 2007). In accordance with DLG (2005), the decree on fertilizers considers that farms where roughage DM production consists of more than 75 % grass and grass based products (silage and hay) to be grassland farms.

For the purpose of emission inventories, the actual share of animals fed a grass-based diet needs to be known. However, data on diet composition does not exist so this share is derived from the amounts of feed produced and the amounts required.

4.2.2.1 Areas used for roughage production

Roughage can be produced from

- permanent grasslands (Dauerwiesen, Mähweiden, Dauerweiden, Almen),
- extensively managed grasslands (Streuwiesen und Hutungen),
- fodder produced on arable land comprising grass, grass clover mixtures, grass alfalfa mixtures (Feldfutterbau von Gras, Gras-Klee-Mischungen, Luzerne und Gras-Luzerne-Mischungen)
- maize for silage (Silomais)

The Federal Statistical Office provides a data set with a temporal resolution of one year and a resolution in space of districts. Calculations are based on grassland areas (permanent grassland, extensively managed grassland) that are reported in a census every second year (2007, 2005 etc.) and in a sample survey every other year. The area of fodder produced on arable land is reported in a census every forth year and in a sample survey for the other years. The standard error in years of sample surveys is below 5 % on the state level.

4.2.2.2 Yields

Yields are reported annually to the Federal Statistical Office in crop production reports carried out by district survey agents. Grassland yields are reported as amount of hay per hectare. Maize for silage is reported as amounts of silage per hectare. The DM yield is calculated assuming a DM content of 88 % for hay and 30 % for silage. For extensively managed grasslands, half of the yields of permanent grass-land are assumed.

For city states yield data may not always be available. In these cases, the yields of the surrounding territorial states are used.

4.2.2.3 Overall roughage and grass available

The amount of roughage available in each farm is obtained as

$$m_{\text{rough, total}} = \sum A_{\text{rough, grass, i}} \cdot y_{\text{grass, i}} + \sum A_{\text{rough, other, j}} \cdot y_{\text{other, j}} \quad (6)$$

where

$m_{\text{rough, total}}$ total mass of roughage DM produced on a farm (in Mg a^{-1})
$A_{\text{rough, grass, i}}$ area of the *i*th grassland type on a farm (in ha)
$y_{\text{grass, i}}$ DM yield of the *i*th grassland type (mean for a federal state) (in Mg ha^{-1})
$A_{\text{rough, other, j}}$ area of the *j*th roughage other than grass on a farm (in ha)
$y_{\text{other, j}}$ DM yield of the *j*th roughage other than grass (mean for a federal state) (in Mg ha^{-1})

4.2.2.4 Roughage required for animals other than dairy cows and heifers

The roughage available on a farm is used for feeding other pasture livestock or for energy production, in addition to the feeding of dairy cows. To estimate the share of grass not available for dairy cows and heifers, standard roughage intakes are used for other livestock.

lambs	0.7 kg $place^{-1}$ d^{-1} DM
sheep other than lambs	1.4 kg $place^{-1}$ d^{-1} DM
heavy horses	5.7 kg $place^{-1}$ d^{-1} DM
ponies	3.7 kg $place^{-1}$ d^{-1} DM
suckler cows	9.0 kg $place^{-1}$ d^{-1} DM

It is assumed that sheep, horses and suckler cows are fed with a grass based diet containing no maize silage:

$$m_{\text{sh, ho, sc}} = \alpha \cdot \sum_{\text{i}} n_{\text{i}} \cdot f_{\text{i}} \quad (7)$$

where

α time units conversion factor (α = 365 d a^{-1})
$m_{\text{sh, ho, sc}}$ amount of grass DM fed to sheep, horses and suckler cows in a district (kg a^{-1})
n_{i} number of animals per district of category i, (i = sheep, horses, suckler cows) (animals per district)
f_{i} daily roughage DM intake of animals of category i, (kg $animal^{-1}$ d^{-1})

4.2.2.5 Share of grass in dairy cows' and heifers' diets

The share of grass in dairy cows' and heifers' diets is obtained as

$$x_{\text{rough, grass}} = \frac{\sum A_{\text{rough, grass, i}} \cdot y_{\text{grass, i}} - m_{\text{sh, ho, sc}}}{\sum A_{\text{rough, grass, i}} \cdot y_{\text{grass, i}} - m_{\text{sh, ho, sc}} + \sum A_{\text{rough, other, j}} \cdot y_{\text{other, j}}} \quad (8)$$

where

$x_{\text{rough, grass}}$ share of grass in dairy cows and heifers' roughage (kg kg^{-1} DM)
$m_{\text{sh, ho, sc}}$ amount of grass needed to fed sheep, horses and suckler cows (kg a^{-1})

If $x_{\text{rough, grass}}$ exceeds 0.75, the farm is considered to practice a grass-based feeding, otherwise mixed feeding, irrespective of the fact that an unknown amount of maize silage is used for energy production.

The share of dairy cows feed with a grass based ration per district j is calculated by adding up the numbers of dairy cows in farms practicing grass based feed.

$$x_{\text{CDC, grass}} = \frac{\sum n_{\text{grass, k}} + \sum n_{\text{lackland, i}} \cdot \dfrac{\sum n_{\text{grass, k}}}{\sum n_{\text{mixed, j}} + \sum n_{\text{grass, k}}}}{\sum n_{\text{lackland, i}} + \sum n_{\text{mixed, j}} + \sum n_{\text{grass, k}}} \quad (9)$$

where

$x_{\text{CDC, grass}}$ share of grass fed dairy cows in a district (in animal $animal^{-1}$)
$n_{\text{lackland, i}}$ number of dairy cows on farms i without an area to produce feed
$n_{\text{mixed, j}}$ number of dairy cows on farms j fed mixed diets ($x_{\text{rough, grass}} \leq 0.75$)
$n_{\text{grass, k}}$ number of dairy cows on farms k fed grass based diets ($x_{\text{rough, grass}} > 0.75$)

The share of dairy cows fed a mixed diet is

$$x_{\mathrm{CDC,\,mixed}} = 1 - x_{\mathrm{CDC,\,grass}} \qquad (10)$$

where

$x_{\mathrm{CDC,\,mixed}}$ share of animals fed a mixed diet in a district (in animal animal^{-1})

$x_{\mathrm{CDC,\,grass}}$ share of animals grass fed animals in a district (in animal animal^{-1})

4.2.2.6 Data gap closure

Almost complete data sets for the shares of animals fed a mixed diet, $x_{\mathrm{CDC,\,mixed}}$, were provided by the Federal Statistical Office for 1991, 1995, 1999, 2003 and 2007. For 1991, no data on district level were available for the new federal states.

For the new federal states, 1991 district data were obtained from 1995 district data and data sets on federal state level using the following relation:

$$x_{\mathrm{CDC,\,mixed,\,i,\,91}} = \frac{X_{\mathrm{CDC,\,mixed,\,j,\,91}}}{X_{\mathrm{CDC,\,mixed,\,j,\,95}}} \cdot x_{\mathrm{CDC,\,mixed,\,i,\,95}} \qquad (11)$$

where

$x_{\mathrm{CDC,\,mixed,\,i,\,91}}$ share of dairy cows feed with a mixed diet in district i 1991 (animal animal^{-1})

$x_{\mathrm{CDC,\,mixed,\,i,\,95}}$ share of dairy cows feed with a mixed diet in district i 1995 (animal animal^{-1})

$X_{\mathrm{CDC,\,mixed,\,j,\,91}}$ share of dairy cows feed with a mixed diet in federal state j 1991 (animal animal^{-1})

$X_{\mathrm{CDC,\,mixed,\,j,\,95}}$ share of dairy cows feed with a mixed diet in federal state j 1995 (animal animal^{-1})

The following procedures were used for data gap filling in census years (1991, 1995, 1999, 2003 and 2007) and single districts:

(A) gap filling using data of subsequent census year

(B) gap filling using data of preceding census year

(C) If no data were available, $x_{\mathrm{CDC,\,mixed}}$ was set to 1. This occurs very rarely and is restricted to districts with small animal populations.

After completing the census years, missing data for years without agricultural census were obtained using

(D) gap filling using data of linear interpolation be tween existing census years

(E) for 1990, data for 1991 are used, for 2008, data for 2007 are used

Figure 2 illustrates the results of the gap filling procedure.

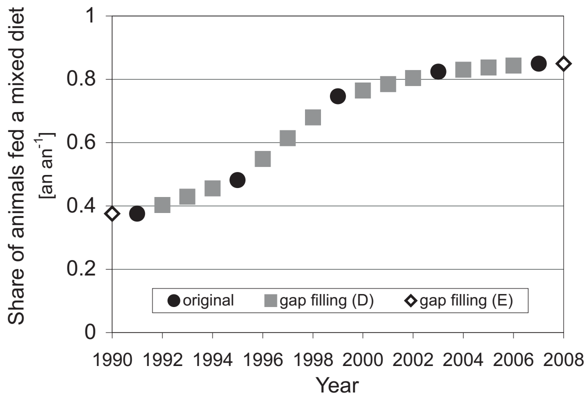

Figure 2:
Gap filling procedure for the attribution of animals in a district to feeding regimes

4.2.2.7 Exemplary results

Changes in the proportion of grass or grass silage in dairy cow diets have a major impact on the resulting N excretion rates and thus on the implied emission factors of all N species. Figure 3 illustrates that there have been significant changes in this proportion between 1991 and 2009.

4.2.3 Diet composition

Dairy cow diets consist of roughage and concentrates, plus mineral supplements. The properties of the various constituents are listed in Table 2. According to the analyses performed by LUFA Nord-West (expert judgement Küster), these mean properties have not varied with time and region.

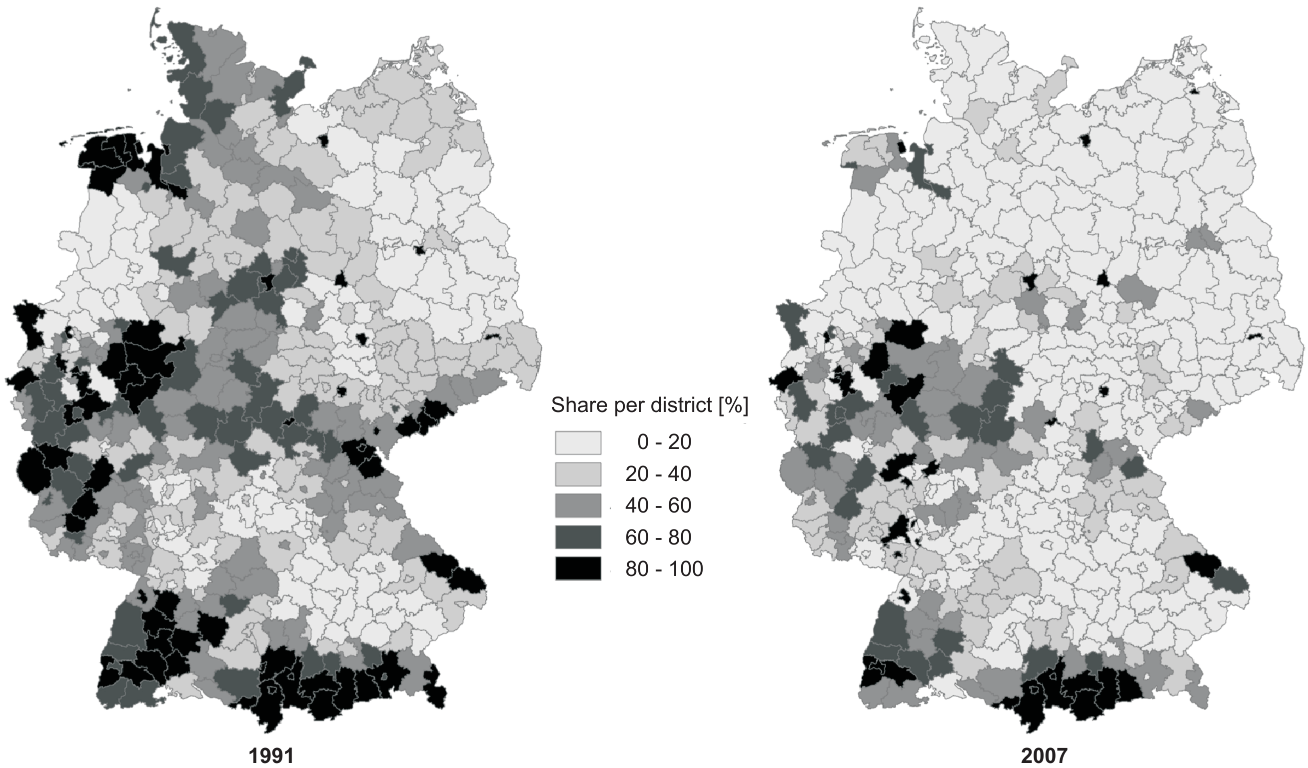

Figure 3:

Share of dairy cows and heifers fed predominantly roughage consisting of grass and grass silage (share of $x_{\text{CDC, grass}}$ > 0.75 animal animal^{-1}) in 1991 and 2007

Table 2:

Properties of standard diet constituents (all data related to DM contents) (Sources: DLG 2005, LUFA Nord-West, expert judgement Küster, LWK-Nds)

Feed constituent	DM content	ME in DM	NEL in DM	DE in DM	GE in DM	XP in DM
	kg kg^{-1}	MJ kg^{-1}	MJ kg^{-1}	MJ kg^{-1}	MJ kg^{-1}	kg kg^{-1}
grass (pasture)	0.19	10.6	6.4	14.1	18.45	0.16
grass silage	0.40	10.0	6.0	12.55	17.94	0.16
maize silage	0.30	10.8	6.5	12.8	18.00	0.075
straw (barley)	0.86	6.4	3.5	8,62	18.20	0.04
concentrate MLF 18/3	0.88	12.27	7,6	15.57	18.86	0.205
wheat	0.88	13.41	8,52	16.36	18.52	0.138
rape seed expeller	0.90	11.8	7.2	15.2	20.3	0.396

ME metabolizable energy; NEL net energy for lactation; DE digestible energy; GE gross energy; XP crude protein

4.2.3.1 Annual intake of concentrates

The derivation of the compositions of both standard grass based and mixed diets makes use of the data set produced for the comparison of the DLG (2005) data set and CDC09 (Dämmgen et al., 2009a). This data set provides the amounts of concentrates consumed for milk yields of 6000, 8000 and 10000 kg cow^{-1} a^{-1}. With respect to the needs of the inventory, the amounts given are extrapolated to 3000 kg cow^{-1} a^{-1} milk using a linear function of the type

$$X_{\text{constituent}} = a_{\text{constituent}} + b_{\text{constituent}} \cdot Y_{\text{m}} \qquad (12)$$

where

$X_{\text{constituent}}$ ratio of the respective constituent in concentrates or roughage (in kg kg^{-1})
$a_{\text{constituent}}$ constant (in kg kg^{-1})
$b_{\text{constituent}}$ coefficient (in kg^{-1} cow a)
Y_{m} milk yield (in kg cow^{-1} a^{-1})

Both the DLG and CDC09 data is listed in Tables 3 and 4, in addition the adjusted mean and the extrapolated shares.

Table 3:

Composition of concentrates in standard grass based diets (all data related to DM contents) (Sources: DLG 2005, Dämmgen et al., 2009, expert judgement Küster, LWK-Nds)

milk yield	$kg\ cow^{-1}\ a^{-1}$	3000	4000	5000	6000	7000	8000	9000	10000
conc DLG 2005	$Mg\ cow^{-1}\ a^{-1}$				1.36		1.80		2.42
conc CDC09	$Mg\ cow^{-1}\ a^{-1}$				1.48		2.50		2.73
adjusted mean	$Mg\ cow^{-1}\ a^{-1}$				1.42		2.15		2.54
extrapolated	$Mg\ cow^{-1}\ a^{-1}$	0.6367	0.9167	1.1967	1.4767	1.7567	2.0367	2.3167	2.5967
shares									
wheat	$kg\ cow^{-1}\ d^{-1}$	1.2	1.6	2.0	2.0	2.0	2.0	2.0	2.0
	$Mg\ cow^{-1}\ a^{-1}$	0.3854	0.5139	0.6424	0.6424	0.6424	0.6424	0.6424	0.6424
MLF 18/3	$Mg\ cow^{-1}\ a^{-1}$	0.2571	0.4077	0.5584	0.8375	1.1166	1.3957	1.6749	1.9540
ratios									
wheat	$kg\ kg^{-1}$	0.61	0.56	0.54	0.43	0.37	0.32	0.28	0.25
MLF 18/3	$kg\ kg^{-1}$	0.39	0.44	0.46	0.57	0.63	0.68	0.72	0.75

4.2.3.2 Standard grass based feeds

The representative diet consists of variable amounts of grass and grass silage and standard concen-trate MLF 18/3[2]. The respective shares are calculated using the relation between DM intake and the NEL contents of roughage and concentrate as provided by DLG (2005). A constant amount of wheat is fed (2 kg $cow^{-1}\ d^{-1}$) to which variable amounts of MLF 18/3 are added. The annual duration of lactation is assumed to be constant (321.2 days).

Table 3 allows the derivation of a steady function relating the respective ratio to milk yields as shown in Figure 4:

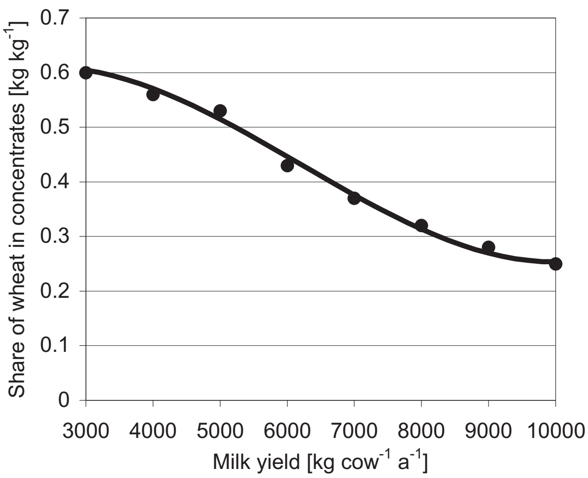

Figure 4:

Adjusting a steady function to the share of wheat in total concentrates in standard grass based feeds

[2] MLF: Milchleistungsfutter

The resulting equation reads:

$$X_{\text{wheat, grass}} = a_{\text{wheat, grass}} + b_{\text{wheat, grass}} \cdot Y_{\text{m}} + c_{\text{wheat, grass}} \cdot Y_{\text{m}}^2 + d_{\text{wheat, grass}} \cdot Y_{\text{m}}^3 \quad (13)$$

where

$X_{\text{wheat, grass}}$ ratio of wheat in total concentrates, grass based diet (in kg kg^{-1})
$a_{\text{wheat, grass}}$ constant ($a_{\text{wheat, grass}}$ = 0.47054 kg kg^{-1})
$b_{\text{wheat, grass}}$ coefficient ($b_{\text{wheat, grass}} = 1.238 \cdot 10^{-4}$ kg^{-1} cow a)
Y_{m} milk yield (in kg $cow^{-1}\ a^{-1}$)
$c_{\text{wheat, grass}}$ coefficient ($c_{\text{wheat, grass}} = -3.1446 \cdot 10^{-8}$ kg^{-2} $cow^2\ a^2$)
$d_{\text{wheat, grass}}$ coefficient ($d_{\text{wheat, grass}} = 1.688 \cdot 10^{-12}$ kg^{-3} $cow^3\ a^3$)

Note that this equation is not valid for milk yields above 10000 kg a^{-1}. For simplicity, $X_{\text{wheat, grass}}$ is made a constant with the value obtained for 10000 kg a^{-1} for milk yields beyond this threshold.

The share of standard concentrate MLF 18/3 is

$$X_{\text{MLF, grass}} = 1 - X_{\text{wheat, grass}} \quad (14)$$

where

$X_{\text{MLF, grass}}$ ratio of MLF in total concentrates, grass based diet (in kg kg^{-1})
$X_{\text{wheat, grass}}$ ratio of wheat in total concentrates, grass based diet (in kg kg^{-1})

4.2.3.3 Standard mixed feeds

Roughage consists of grass and maize silages in a mass ratio of grass to maize of 0.45 to 0.55 kg kg^{-1}. Standard concentrate MLF 18/3 is used throughout. The diet is supplemented by rape seed expeller (0.9 kg cow^{-1} d^{-1}) and straw (0.3 kg cow^{-1} d^{-1}).

The steady function can be deduced from Table 4 as shown in Figure 5.

Table 4:

Composition of concentrates in standard mixed based diets (all data related to DM contents) (Sources: DLG 2005, Dämmgen et al., 2009, expert judgement Küster, LWK-Nds)

milk yield	kg cow^{-1} a^{-1}	3000	4000	5000	6000	7000	8000	9000	10000
conc DLG 2005	Mg cow^{-1} a^{-1}				1.50		2.00		2.60
conc CDC09	Mg cow^{-1} a^{-1}				1.09		1.87		2.64
adjusted mean	Mg cow^{-1} a^{-1}				1.29		1.87		2.60
extrapolated	Mg cow^{-1} a^{-1}	0.2827	0.6102	0.9377	1.2652	1.5927	1.9202	2.2477	2.5752
shares									
rape seed ex	Mg cow^{-1} a^{-1}	0.1606	0.3212	0.4497	0.4818	0.4818	0.4818	0.4818	0.4818
MLF 18/3	Mg cow^{-1} a^{-1}	0.1211	0.2937	0.4985	0.7996	1.1329	1.4661	1.7994	2.1326
ratios									
rape seed exp	kg kg^{-1}	0.57	0.52	0.47	0.38	0.30	0.25	0.21	0.18
MLF 18/3	kg kg^{-1}	0.43	0.48	0.53	0.62	0.70	0.75	0.79	0.82

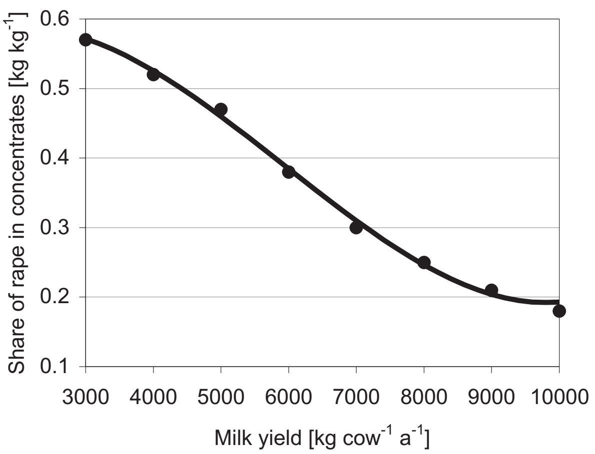

Figure 5:

Adjusting a steady function to the share of rape expeller in total concentrates in standard mixed feeds

The adjusted steady function reads:

$$X_{\text{rape, mixed}} = a_{\text{rape, mixed}} + b_{\text{rape, mixed}} \cdot Y_{\text{m}} + c_{\text{rape, mixed}} \cdot Y_{\text{m}}^2 + d_{\text{rape, mixed}} \cdot Y_{\text{m}}^3 \quad (15)$$

where

$X_{\text{rape, mixed}}$ ratio of rape seed expeller in concentrates, mixed diet (in kg kg^{-1})
$a_{\text{rape, mixed}}$ constant ($a_{\text{rape, mixed}}$ = 0,4879 kg kg^{-1})
$b_{\text{rape, mixed}}$ coefficient ($b_{\text{rape, mixed}}$ = 0.1038·10^{-3} kg^{-1} cow a)
Y_{m} milk yield (in kg cow^{-1} a^{-1})
$c_{\text{rape, mixed}}$ coefficient ($c_{\text{rape, mixed}}$ = -3.043·10^{-8} kg^{-2} cow^2 a^2)
$d_{\text{rape, mixed}}$ coefficient ($d_{\text{rape, mixed}}$ = 1,71·10^{-12} kg^{-3} cow^3 a^3)

The share of MLF 18/3 is

$$X_{\text{rape, mixed}} = 1 - X_{\text{MLF, mixed}} \quad (16)$$

where

$X_{\text{rape, mixed}}$ ratio of rape seed expeller in concentrates, mixed diet (in kg kg^{-1})
$X_{\text{MLF, mixed}}$ ratio of MLF expeller in concentrates, mixed diet (in kg kg^{-1})

Table 5 indicates a constant ratio of the three roughage constituents:

$X_{\text{straw mixed}}$ = 0.02 kg kg^{-1}
$X_{\text{grass mixed}}$ = 0.44 kg kg^{-1}
$X_{\text{maize mixed}}$ = 0.54 kg kg^{-1}

Table 5:

Composition of roughage in standard mixed based diets (all data related to DM contents) (Sources: DLG 2005, Dämmgen et al., 2009a, expert judgement Küster, LWK-Nds)

milk yield	kg cow^{-1} a^{-1}	3000	4000	5000	6000	7000	8000	9000	10000
conc DLG 2005	Mg cow^{-1} a^{-1}				4.40		4.70		5.10
conc CDC09	Mg cow^{-1} a^{-1}				4.52		4.37		4.56
adjusted mean	Mg cow^{-1} a^{-1}				4.46		4.54		4.83
extrapolated	Mg cow^{-1} a^{-1}	4.1493	4.2411	4.3330	4.4249	4.5167	4.6086	4.7005	4.7923
shares									
straw	Mg cow^{-1} a^{-1}	0.0964	0.0964	0.0964	0.0964	0.0964	0.0964	0.0964	0.0964
grass / maize	Mg cow^{-1} a^{-1}	4.0529	4.1448	4.2366	4.3285	4.4204	4.5122	4.6041	4.6960
ratios									
straw	kg kg^{-1}	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
grass	kg kg^{-1}	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
maize	kg kg^{-1}	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54

5 Housing and grazing

The present German emission inventory has made use of frequency distributions of housing, grazing, manure storage facilities and manure application techniques using data provided by the agricultural sector model RAUMIS (**R**egionalisiertes **A**grar- und **U**mweltinformations**S**ystem für Deutschland – regionalized information system for agriculture and environment in Germany, for a short description see Dämmgen et al., 2009b, Chapter 16.2). However, the data base could not be extended beyond 1999. Improvements cannot be expected before the agricultural census in 2010. The present German emission inventory makes use of frequency distributions of housing and manure storage facilities and manure application techniques provided by the model RAUMIS model. Issues associated with this model have been discussed in section 4.1.

6 Derivation of ammonia emission factors for housing and storage

6.1 Present situation

The NH_3 emission factors previously used in the German inventory were obtained by expert judgement based on a survey of experimental data (Döhler et al., 2002, pg. 49). They were expressed as absolute emissions for a dairy cow with a milk yield of 6000 kg cow^{-1} a^{-1}. However, the concept of emission factors assumes that an emission can be related to an amount of matter emitting rather than animal numbers. Hence, the absolute figures have to be transformed into emission factors relating the amount of ammonia (NH_3) emitted to the amount of reactive N present in the house. It is generally assumed that the amount of total ammoniacal nitrogen (TAN) is the decisive entity (Dämmgen and Hutchings, 2008).

Döhler et al. (2002), Table A6, also permits an estimation of a mean N excretion rate using the official calculation procedure proposed by LWK-WE (1997): If one assumes a diet containing 50 % grass and grass silage, an excretion of 104.7 kg cow^{-1} a^{-1} N results. Döhler et al. (2002), Table A8, also provide an estimate of the share of TAN in cattle excreta of 0.50 kg kg^{-1} N. With these assumptions the absolute emissions were transposed into relative emission factors related to TAN excreted.

In a similar procedure, the emission factors for storage were related to the amount of N entering the manure management system (Döhler et al., 2002, pg. 62). Here it was assumed that 48 % of the N available at the beginning of storage being TAN.

6.2 Future approach: use of updated emission factors relative to TAN available

6.2.1 Assessment of N and TAN excretions of the standard cow used

An improved conversion of absolute to relative emission factors is possible if both feed properties and performance data of the underlying "standard cow" are known.

In 2009, the authors of the LWK-WE (1997) document communicated their assumptions with regard to the feed composition resulting in the above mentioned excretion rates.

Animal weight and weight gain were not reported. However, with an assumed mean weight of 630 kg cow^{-1}, a weight gain of 10 kg cow^{-1} a^{-1} and a calf weight of 45 kg calf^{-1} (expert judgements), CDC09 yields an amount of N

Table 6:
Feed properties assumed for the derivation of standard N excretion rates

	amount FM	amount DM	share	NEL	XP
	kg cow^{-1} a^{-1}	kg cow^{-1} a^{-1}	kg kg^{-1}	MJ kg^{-1}	g kg^{-1}
standard concentrate MLF 18/3	1400		0.93	7.0	180.0
soy expeller	100		0.07	6.9	450.0
mean of concentrates				7.0	198.0
grass (pasture)		1000	0.23	6.2	190.0
grass silage		1100	0.25	5.8	160.0
maize silage		2000	0.45	6.4	85.0
straw		300	0.07	3.0	40.0
mean of roughage				6.0	124.5

FM fresh matter; DM dry matter; NEL net energy for lactation; XP crude protein

entering the manure management system of 106.9 kg cow^{-1} a^{-1}. In this case, the amount of TAN excreted was 60.9 kg cow^{-1} a^{-1} TAN, the resulting TAN content 0.57 kg kg^{-1} N.[3]

6.2.2 Conversion of absolute emission factors for housing to emission factors relative to TAN available

Emissions from animal houses are dominated by the fouled area inside the house, the air exchange rate and the temperatures governing the equilibrium and evaporation rates. In the emission inventory, these are related to housing types (with typical exchange rates and typical temperatures). The German agricultural emission model GAS-EM differentiates between two slurry based systems and four litter based systems. Döhler et al. (2002), pg. 48 f, report absolute emission rates $E_{\mathrm{NH3\text{-}N}}$ (in kg cow^{-1} a^{-1} NH_3-N) for each system.

The emission factor relative to TAN can be obtained from absolute emissions for a housing type i as follows:

$$EF_{\mathrm{house,\,i}} = \frac{E_{\mathrm{NH3\text{-}N,i}}}{m_{\mathrm{excr}} \cdot x_{\mathrm{TAN}}} \qquad (17)$$

where

$EF_{\mathrm{house,\,i}}$ NH_3 emission factor relative to TAN for the animal house (in kg kg^{-1} N)
$E_{\mathrm{NH3\text{-}N,\,i}}$ absolute amount of NH_3 N emitted in the housing type i (in kg cow^{-1} a^{-1} N)
m_{excr} amount of N excreted in the house (in kg cow^{-1} a^{-1} N)
x_{TAN} TAN content of excreta (in kg kg^{-1} N)

[3] File used: CDC_6000_DLG.xls

Table 7:
Derived emission factors for housing

		kg cow^{-1} a^{-1} N	
N input into house		106.9	
TAN input into house		60.9	
		absolute emission rates	relative emission factor
Housing type (in German)	Housing type (in English)	kg cow^{-1} a^{-1} N	kg kg^{-1} N
Anbindestall, flüssig	tied system, slurry	4	0.066
Anbindestall, fest	tied system, FYM	4	0.066
Liegeboxenlaufstall, flüssig	cubicle house, slurry	12	0.197
Liegeboxenlaufstall, fest	cubicle house, FYM	12	0.197
Laufstall, Tiefstreu	loose housing, deep litter	12	0.197
Laufstall, Tretmist	loose housing, sloping floor	13	0.213

6.2.3 Conversion of absolute emission factors for storage to emission factors relative to TAN available

NH_3 emissions from storage depend on the amount of TAN available, the vapour pressure of NH_3 (as a function of the pH of the slurry and temperature), the surface area of the store and the atmospheric turbulence above the surface. The only entity available for the use in inventories is the amount of TAN entering the storage system. Thus, GAS-EM differentiates between the predominant storage types only.

Döhler et al. (2002), pg. 62, provide NH_3 emission factors for storage related to the amount of N available before storage for each common storage type. For slurry these can be converted to emission factors based on amounts of TAN available using the following equation:

$$EF_{\text{NH3-N, storage, TAN}} = \frac{m_{\text{N, house}} \cdot EF_{\text{NH3-N, storage, N}}}{m_{\text{TAN, house}}} \quad (18)$$

where

$EF_{\text{NH3-N, storage, TAN}}$	NH_3 emission factor relative to TAN for the storage (in kg kg^{-1} N)
$m_{\text{N, house}}$	amount of NH_3 N released from the house (in kg cow^{-1} a^{-1} N)
$EF_{\text{NH3-N, storage, N}}$	NH_3 emission factor relative to N for the storage (in kg kg^{-1} N)
$m_{\text{TAN, house}}$	amount of TAN released from the house (in kg cow^{-1} a^{-1} N)

and

$$m_{\text{TAN, house}} = m_{\text{TAN, excr}} - aE_{\text{NH3-N, house}} \quad (19)$$

where

$m_{\text{TAN, excr}}$	amount of TAN excreted in the house
$aE_{\text{NH3-N}}$	amount of NH_3 N emitted from the house (in kg cow^{-1} a^{-1} N)

6.2.3.1 *Slurry based systems*

For slurry based systems, the application of the conversion leads to different TAN related emission factors for the same storage type due to the different TAN contents of the slurries entering storage (depending the housing type).

With respect to the inadequate experimental data used to establish the emission factor in Döhler et al. (2002), the Swiss TAN related emission factor of 0.15 kg kg^{-1} N (Eidgenössische Forschungsanstalt, 1997) is used as a temporary measure. It is in line with the German emission factor calculated for open tanks.

Emissions from storage facilities other than open tanks (without any natural crust) are achieved by application of reduction factors. The factors listed in Döhler et al. (2002), pg. 63, can also be used to derive TAN related emission factors.

Storage underneath slatted floors is considered to release the same fraction of TAN with NH_3 as slurry stored in open tank with a natural crust (i.e.0.15 kg kg^{-1} N, emission reduction 70 %, resulting in an emission factor of 0.045 kg kg^{-1} N).

Emission factors for the storage of liquid separate and digested slurry related to N were estimated by Döhler (expert judgement). TAN-related emission factors are derived from that of undigested slurry using the rule of three (Table 9).

Table 9:
Derived emission factors for the storage of liquid separate and digested slurry

slurry type	EF relative to N	EF relative to TAN
	kg kg^{-1} NH_3-N	kg kg^{-1} NH_3-N
undigested slurry	0.08	0.15
liquid separate	0.10	0.19
digested slurry	0.12	0.23

6.2.3.2 *Straw based systems*

For solid systems the application of the conversion equation for solid systems leads to inconsistent results. If one calculates NH_3 emissions from farmyard manure using the relative emission factors reported in Döhler et al. (2002), pg. 62, the amount emitted exceeds the amount of TAN available. This is a result of the fact that the experimental data base was poor and immobilisation was not considered in the original approach. However, the calculation procedure used at present assumes an immobilisation rate of 0.40 kg kg^{-1} N of the TAN excreted in the house (in accordance with Kirchmann and Witter, 1989, cf also Webb

Table 8:
Derived emission factors for slurry storage

		excreta released from house		EF relative to N released from house	EF relative to TAN released from house
Slurry storage type (German)	Slurry storage type (English)	kg cow^{-1} a^{-1} N	kg cow^{-1} a^{-1} TAN	%	kg kg^{-1} NH_3-N
Anbindehaltung	tied systems				
Gülle-Rund-/Hochbehälter	open circular tank	99.36	58.06	8	0.1369
Lagune offen	open lagoon	99.36	58.06	15	0.2567
Boxenlaufstall	cubicle houses				
Gülle-Rund-/Hochbehälter	open circular tank	92.38	51.08	8	0.1447
Lagune offen	open lagoon	92.38	51.08	15	0.2713

and Misselbrook, 2004), and an emission factor of 0.60 kg kg^{-1} N of the TAN remaining after immobilisation is derived as follows:

EMEP/EEA (2009) Table B-21 provide an NH_3 emission factor of 0.27 kg kg^{-1}, not including immobilization. The application of this factor results in an emission of 4.9 kg $place^{-1}$ a^{-1} NH_3-N. This value is derived from experiments without taking immobilization into account (Reidy et al., 2009). If one relates the emissions to the amount of TAN left after immobilization, the resulting relative emission factor is 0.61 kg kg^{-1} which is rounded to 0.60 kg kg^{-1}.

In tied systems with straw, cubicle houses and sloping floor housing systems, leachate ("Jauche") is formed and stored separately, usually in underground pits with solid covers. In deep litter systems, formation of leachate is negligible. Döhler et al. (2002) relate emissions from leachate to N left after housing (10 % related to N). The application of Equation (18) yields the results listed in Table 10.

6.3 Emission factors for slurry, farmyard manure and leachate applications

Döhler et al. (2002) relate NH_3 emissions during application to TAN. A conversion is unnecessary.

7 Methane emission factors for storage of farmyard manure

7.1 Present situation

Methane emissions originate from the fermentation of volatile solids (VS) in anaerobic processes. IPCC (2006), pg. 10.41 ff, quantifies these emissions using the modelled amount of VS entering the system, a maximum methane conversion rate B_o and a methane conversion factor MCF that depends on the animal category and the manure storage system.

Table 10:
Derived emission factors for leachate storage

		excreta released from house		EF relative to N released from house	EF relative to TAN released from house
Housing type (German)	Housing type (English)	kg cow^{-1} a^{-1} N	kg cow^{-1} a^{-1} TAN	%	kg kg^{-1} NH_3-N
Anbindehaltung	tied systems	27.54	22.39	10	0.123
Boxenlaufstall	cubicle houses	25.45	20.38	10	0.125
Laufstall, Tretmiststall	loose housing system, sloped floor	13.99	11.13	10	0.126

Considering the data base used to derive emission factors related to N, it seems justified to assume an emission factor of 0.125 kg kg^{-1} N for leachate, as the TAN content of leachate is in the order of 75 %. Döhler et al. (2002) also state that the factor of 10 % applies to uncovered stores. However, leachate is usually stored in underground pits with solid covers. Hence a reduction of 90 % should be achievable. If this reduction potential by solid covers is accepted, a TAN related emission factor of 0.013 kg kg^{-1} N results.

6.2.3.3 Grazing

Misselbrook (2001) compiled the data available for the derivation of an emission factor for grazing cattle. The resulting emission factor of 0.075 kg kg^{-1} N related to the N input into the system cannot be converted to a TAN related factor. However, as there is no need to trace the TAN flow in the soil – N_2O emissions are related to total N rather than TAN – the application of an emission factor based on total N is adequate.

IPCC (2006), pg. 10.42, models the VS inputs exclusively from animal excreta, depending on the gross energy (GE) intake of the animals. GAS-EM hitherto modelled the fermentation of VS entering the system with bedding using a B_o for straw and the MCF for solid manure systems. This view has not been shared by any other nation reporting to UNFCCC.

7.2 Future approach

A comparison of the IPCC (2006) emission factors for N excreted during grazing pasture and for solid manure of 1 % and 2 %, respectively, may reflect the fact that manure heaps develop sites where "oxygen consumption exceeds the oxygen supply" (Hansen et al., 2002) which results in the formation of CH_4. The difference between EFs for liquid and solid may also take into account the straw as an additional source. However, neither fact is commented on in the IPCC (2006) guidelines.

Until further evidence is provided by measurements or guidance documents, the German inventory will stick to IPCC (2006) default values and will not report CH_4 emissions originating from the degradation of straw as bedding material. This was discussed and agreed upon with B. Amon (University of Natural Resources and Applied Life Sciences, Vienna, and UN ECE Agriculture and Nature Panel).

Official Approval

The contents of this paper were checked and approved of by "KTBL Working Group on Emission Factors in Animal Husbandry".

Acknowledgements

The authors wish to thank the following colleagues for their valuable assistance and advice:

Barbara Amon, Department of Sustainable Agricultural Systems, University of Natural Resources and Applied Life Sciences, Vienna, for her advice regarding the treatment of solid storage systems.

Jörg Küster, Bezirksstelle Northeim, Landwirtschaftskammer Niedersachsen, provided data on animal feed composition and feeding practice.

Hubert Spiekers provided access to historic data and considered the progress of this article critically.

Information on live and carcass weight was provided by Landwirtschaftskammer Niedersachsen, Versuchsstation Infeld, Friedrich-Loeffler-Institute, Federal Research Institute for Animal Health, Institute of Farm Animal Genetics, Neustadt, and Landwirtschaftliches Zentrum Baden-Württemberg, Aulendorf.

References

Dämmgen U (2005) Statistical data for animal numbers in German emission inventories. Landbauforsch Völkenrode SH 291:223-229

Dämmgen U, Haenel H-D, Rösemann C, Hutchings NJ, Brade W, Lebzien P (2009a) Improved national calculation procedures to assess energy requirements, nitrogen and VS excretions of dairy cows in the German emission model GAS-EM. Landbauforsch 59(3):233-252

Dämmgen U (2009b) Calculations of emission from German agriculture - National Emission Inventory Report (NIR) 2009 for 2007, Braunschweig : vTI, 410 p. Landbauforsch SH 324

Dämmgen U, Hutchings NJ (2008) Emissions of gaseous nitrogen species from manure management : a new approach. Environ Pollut 154(3):488-497

Döhler H, Eurich-Menden B, Dämmgen U, Osterburg B, Lüttich M, Bergschmidt A, Berg W, Brunsch R (2002) BMVEL/UBA-Ammoniak-Emissionsinventar der deutschen Landwirtschaft und Minderungsszenarien bis zum Jahr 2010. Berlin : Umweltbundesamt, 307 p, Texte / Umweltbundesamt 02/05

DLG (1986) Grundfutteraufnahme und Grundfutterverdrängung bei Milchkühen. Frankfurt a M : DLG, 8 p, DLG-Information 2/1986

DLG (2005) Bilanzierung der Nährstoffausscheidungen landwirtschaftlicher Nutztiere. Frankfurt a M : DLG, 69 p, Arbeiten der DLG 199

Düngemittelverordnung (2007) Bekanntmachung der Neufassung der Düngeverordnung vom 27. Februar 2007. Bundesgesetzblatt : Teil 1 / Bundesminister der Justiz (7):221

EMEP/EEA air pollutant emission inventory guidebook – 2009 (2009) Part B. 4.B Animal husbandry and manure management [online]. To be found in <http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009/part-b-sectoral-guidance-chapters/4-agriculture/4-b/4-b-animal-husbandry-and-manure-management.pdf> [zitiert am 01.06.2010]

Hansen MN, Sommer SG, Henriksen K (2002) Methane emissions from livestock manure : effects of storage conditions and climate. DIAS Rep Plant Production 81:45-63

IPCC (2006) 2006 IPCC guidelines for national greenhouse gas inventories : vol. 4: Agriculture, forestry and other land use [online]. To be found in <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html> [zitiert am 01.06.2010]

Kirchmann H, Witter E (1989) Ammonia volatilization during aerobic and anaerobic manure decomposition. Plant Soil 115:35-41

Menzi H, Frick R, Kaufmann R (1997) Ammoniak-Emissionen in der Schweiz : Ausmass und technische Beurteilung des Reduktionspotentials. Zürich-Reckenholz : FAL, 120 p, SchriftenR FAL 26

Misselbrook TH (2001) Updating the ammonia emissions inventory for the UK for 1999 : final project report AM0108. London : Minist Agric Fisheries Food, 39 p

Osterburg B, Dämmgen U (2009) Annahmen für die Prognose der Gasemissionen aus der deutschen Landwirtschaft im Jahr 2010, 2015 und 2020. Landbauforsch SH 324:397-410

Reidy B, Webb J, Misselbrook TH, Menzi H, Luesink HH, Hutchings NJ, Eurich-Menden B, Döhler H, Dämmgen U (2009) Comparison of models used for national agricultural ammonia emission inventories in Europe : litter-based manure systems. Atmos Environ 43(9):1632-1640

Webb J, Misselbrook TH (2004) A mass-flow model of ammonia emissions from UK livestock production, Atmos Environ 38:2163-2176