The effect of feed composition and feeding strategies on excretion rates in German pig production

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Abstract

In order to improve the methods and update the data for the German agricultural emission inventory, a survey was made among pig nutrition experts to obtain representative diet compositions and feeding strategies. The analysis shows that the introduction of phase feeding results in reduced excretion rates of volatile solids. Contrary to expectations, the direct effect on all other excretion rates is comparatively small. However, phase feeding with its typical all-in-all-out management results in extended production cycles as fattening of new animal groups commences after cleansing and disinfection, and these do not commence before the last animal left the respective compartment. This leads to a reduction of emissions per place. The effect of diets adjusted to crude protein demands is obvious. Improvement of standard diet is a clear option to reduce emissions.

As the emissions of methane from manure management, as well as those of all nitrogen species, are directly related to the respective amounts excreted, the calculations using detailed information on feed composition will result in reduced emission rates from pig production.

Keywords: pigs, feed, phase feeding, production cycles, excretion, methane, volatile solids, nitrogen, TAN

Zusammenfassung

Der Einfluss von Futterzusammensetzung und Fütterungsstrategien auf die Ausscheidungsraten in der deutschen Schweineproduktion

Zur methodischen Verbesserung und Aktualisierung der deutschen landwirtschaftlichen Emissionsinventare für Schweine wurden repräsentative Futterzusammensetzungen und Daten zu Fütterungsstrategien bei Fütterungsexperten erfragt. Die Auswertung zeigt, dass mit der Einführung der Phasenfütterung die Ausscheidungen von umsetzbarem Kohlenstoff (volatile solids) verringert werden. Der direkte Einfluss auf alle anderen Ausscheidungen ist wider Erwarten gering. Bedingt durch das Mastmanagement der Rein-Raus-Methode verlängern sich die Produktionszyklen. Eine neue Tiergruppe kann erst eingestallt werden, wenn das letzte Tier das Stallabteil geräumt hat und die Reinigung und Desinfektion erfolgt ist. Dies verringert die Emissionen pro Platz erheblich. Der Effekt von N-angepasster Fütterung ist klar zu erkennen, ebenso das Potential, das bei verbesserter Standardfütterung noch ausgeschöpft werden kann.

Da die Mengen der Ausscheidungen linear die Menge der Emissionen von Methan aus dem Lager sowie sämtlicher Stickstoff-Spezies beeinflusst, werden die Berechnungen unter Verwendung detaillierter Futterzusammensetzungen zu niedrigeren Emissionen aus der Schweine-Produktion führen.

Schlüsselwörter: Schweine, Futter, Phasenfütterung, Produktionszyklen, Ausscheidung, Methan, „volatile solids", Stickstoff, TAN

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1 Introduction

Pig production is an important sector in German agriculture. It is also a key source of greenhouse gas and ammonia emissions. During the past decades, methods in pig production have changed. This has been due to changes in genetics, feeding, housing, and manure management. According to Good Practice Rules, emission reporting has to reflect these changes as far as possible.

Changes in genetics have been reflected in the performance data used to describe energy intake (Haenel et al., 2011). Housing and manure management as well as the role of air scrubbers have been dealt with in recent publications (Dämmgen et al., 2010; 2011a, b). Changes in feeding practices have not been taken into account yet.

The purpose of this work is the compilation of regional data on feed composition and feeding regimes in a way that allows their incorporation into emission inventories.

In order to illustrate the effects of changing feeding practices, the feed intake rates and excretion rates are calculated for standard animals (see below).

2 Modelling procedures and data requirements

The first step in the calculation of emissions from animal husbandry is the assessment of energy requirements and feed intake rates. Both guidance documents (IPCC, 1996; 2006; EEA, 2009) presuppose that animals are fed according to energy requirements. The second step is the calculation of relevant excretion rates. Methane (CH_4) is directly released as a consequence of enteric fermentation in the digestive tract. Excretions of volatile solids (VS) lead to the emissions of CH_4 from the storage of animal faeces. Excretion of total nitrogen (N) and total ammoniacal nitrogen (TAN) govern the release of ammonia (NH_3), nitrous and nitric oxides (N_2O, NO), and di-nitrogen (N_2) in the animal house, during manure storage and during and after its application. Here, the guidance documents outline the procedure; they also suppose the use of national approaches and data as far as possible.

2.1 Energy intake rates

Energy requirements are the entities governing feed intake rates. The German system makes use of the metabolizable energy (ME) requirements that are calculated according to Flachowsky et al. (2006) as described in Haenel et al. (2011).

The methodology distinguishes between the following subcategories of livestock:

Sows and suckling pigs are treated together. Energy requirements are calculated for two gravidity phases, for the lactating period and the period between weaning and mating. The number of piglets raised, their final weight and the mean weight of the sow are taken into account.

The *standard sow* used in this work has a mean weight of 200 kg animal^{-1}. No weight gain is considered. 23 piglets are raised and weaned at a weight of 8.5 kg animal^{-1}.

Weaners, fattening pigs and boars (mature males for reproduction) are treated in a similar manner. Their weight and weight gains are considered as drivers for energy requirements. For details see Haenel et al. (2011).

The *standard weaners* have a mean weight gain of 410 g animal^{-1} d^{-1} and a final weight of 28.5 kg animal^{-1}. The number of production cycles per year takes a service and disinfection period of 8 d round^{-1} into account.

Standard fatteners are assumed to have a mean weight gain of 750 g animal^{-1} d^{-1} and a final weight of 110 kg animal^{-1}. Service and disinfection periods are variable.

Standard boars have a mean weight of 180 kg animal^{-1}. A weight gain is not taken into account.

2.2 Feed intake rates and feed properties

In addition to the differentiation of subcategories, feeding-phases[1], and administrative region (e.g. federal state or – within Niedersachsen (Lower Saxony) – rural districts) are taken into account. Unless stated otherwise, variables should be subscripted accordingly; a given variable $X_{i,j,k}$ would therefore relate to livestock subcategory i in the feeding phase j and for the region k. Any element of an equation that is constant across livestock category, feeding phase and region is indicated as constant.

Calculation of weighted means. The livestock diets commonly consist of a mixture of constituents. The characteristics of the complete diet (specific ME content etc.) are calculated using a weighted average, so for a given characteristic Z in a diet containing N constituents, the value for the complete diet is:

$$Z = \sum_{n=1}^{N} (Z_n \cdot X_n) \qquad (1)$$

where

Z weighted mean of a given characteristic Z
Z_n value of the characteristic for the *n*th constituent
X_n proportion that the *n*th constituent contributes to the mass of the complete diet (in kg kg^{-1})

and

$$\sum_{n=1}^{N} X_n = 1 \qquad \sum_{a=1}^{A} X_a = 1 \qquad (1a)$$

[1] A feeding-phase is defined as a period during which the composition of a diet is kept unchanged. Both beginning and end of a feeding-phase are defined by animal weights.

Feed intake rates (dry matter, DM) are deduced from energy intake rates according to Equation (2):

$$m_{\mathrm{DM,\,feed,\,i,\,j,\,k}} = \frac{ME_{\mathrm{i,\,j.\,k}}}{\eta_{\mathrm{ME,\,i,\,j,\,k}}} \qquad (2)$$

where

$m_{\mathrm{DM,\,feed,\,i,\,j.\,k}}$	feed intake rate (DM) for an animal subcategory i in a feeding phase j and a region k (in kg animal^{-1} d^{-1} DM)
$ME_{\mathrm{i,\,j,\,k}}$	ME requirements of an animal subcategory i in a feeding phase j and a region k (in MJ animal^{-1} d^{-1})
$\eta_{\mathrm{ME,\,i,\,j,\,k}}$	specific ME content of feed for an animal subcategory i in a feeding phase j and a region k (in MJ kg^{-1})

Nitrogen intake rates are obtained by combining feed intake rates with N contents of the feed constituents:

$$m_{\mathrm{N,\,feed,\,i,\,j,\,k}} = \frac{ME_{\mathrm{i,\,j.\,k}}}{\eta_{\mathrm{ME,\,i,\,j,\,k}}} \cdot \eta_{\mathrm{N,\,feed,\,i,\,j,\,k}} \qquad (3)$$

where

$m_{\mathrm{N,\,feed,\,i,\,j.\,k}}$	rate of N intake (dry matter) for an animal subcategory i in a feeding phase j and a region k (in kg animal^{-1} d^{-1} DM)
$ME_{\mathrm{i,\,j,\,k}}$	metabolizable energy requirements for an animal subcategory i in a feeding phase j and a region k (in MJ animal^{-1} d^{-1})
$\eta_{\mathrm{ME,\,i,\,j,\,k}}$	specific ME content of feed for an animal subcategory i in a feeding phase j and a region k (in MJ kg^{-1})
$\eta_{\mathrm{N,\,feed,\,i,\,j,\,k}}$	mean N content of feed of an animal subcategory i in a feeding phase j and a region k (in kg^{-1} kg^{-1})

The mean N contents are weighted means obtained in analogy to Equations (1) and (1a).

Mean feed properties (such as mean gross energy contents $\eta_{\mathrm{GE,\,i,\,j,\,k}}$, mean ash contents $X_{\mathrm{ash,\,i,\,j,\,k}}$ are also weighted means calculated from the respective feed constituents' properties as in Equation (1).

With few exceptions, standard specific ME, GE, N, and ash contents and digestibilities are obtained from Jentsch et al. (2004), crude protein (XP) contents from the lists provided by LfL (2009) and DLG (2011).

The relevant properties of the diet constituents considered are listed in Table 1.

Regional feed compositions were supplied by experts (see Chapter 3).

2.3 Methane excretion from enteric fermentation

IPCC (1996) relates the amount of CH_4 released from enteric fermentation to the gross energy (GE) intake. With data available for German pig production this relation reads:

$$E_{\mathrm{CH4,\,ent}} = \frac{ME}{\eta_{\mathrm{ME}}} \cdot \eta_{\mathrm{GE}} \cdot \frac{x_{\mathrm{CH4}}}{\eta_{\mathrm{CH4}}} \cdot \alpha \qquad (4)$$

where

$E_{\mathrm{CH4,\,ent}}$	rate of CH_4 excretion (emission) from enteric fermentation (in kg place^{-1} a^{-1} CH_4)
ME	intake rate of metabolizable energy (in MJ place^{-1} d^{-1})
η_{ME}	ME content of feed (in MJ kg^{-1})
η_{GE}	GE content of feed (in MJ kg^{-1})
x_{CH4}	methane conversion rate (x_{CH4} = 0.006 MJ MJ^{-1})
η_{CH4}	energy content of methane (η_{CH4} = 55.65 MJ (kg CH_4)$^{-1}$)
α	time units conversion factor (α = 365 d a^{-1})

2.4 Volatile solids excretion rates

VS excretion rates are derived from the intake rates of metabolizable energy, the energy, and the ash contents of feed and the digestibility of organic matter, as expressed in Equation (5) [2].

$$VS_{\mathrm{faeces}} = \frac{ME}{\eta_{\mathrm{ME}}} \cdot \left(1 - X_{\mathrm{ash,\,feed}}\right) \cdot \left(1 - X_{\mathrm{DOM}}\right) \qquad (5)$$

where

VS_{faeces}	volatile solids excretion rate with faeces (in kg place^{-1} a^{-1})
ME	intake rate of metabolizable energy (in MJ place^{-1} a^{-1})
η_{ME}	ME content of feed (in MJ kg^{-1})
$X_{\mathrm{ash,\,feed}}$	ash content of feed (in kg kg^{-1})
X_{DOM}	apparent digestibility of organic matter (in kg kg^{-1})

2.5 Nitrogen excretion rates

The general N balance is used to assess the rates of overall N excreted:

$$m_{\mathrm{excr}} = \frac{ME}{\eta_{\mathrm{ME}}} \cdot \eta_{\mathrm{N}} - m_{\mathrm{l}} - m_{\mathrm{g}} - m_{\mathrm{p}} \qquad (6)$$

where

m_{excr}	rate of N excreted (kg place^{-1} a^{-1} N)
ME	ME intake rate with feed (kg place^{-1} a^{-1} N)
η_{ME}	ME content of feed (in MJ kg^{-1})
η_{N}	N content of feed (in kg kg^{-1}), derived from XP content

[2] This approach differs from the methodology previously used in German inventories (Rösemann et al., 2011). For details see Dämmgen et al. (2011a).

m_l rate of N excreted with milk (kg place^{-1} a^{-1} N)
m_g rate of N retained in the animal (kg place^{-1} a^{-1} N)
m_p rate of N in offspring produced (kg place^{-1} a^{-1} N)

and

$$\eta_N = \frac{\eta_{XP}}{X_N} \quad (6a)$$

where
η_N N content of feed (in kg kg^{-1})
η_{XP} crude protein content of feed (in kg kg^{-1})
X_N N content of crude protein in feed (X_N = 1/6.25 kg kg^{-1})

For sows with suckling-pigs m_l is ignored in the inventory as the N balance covers the unit of a sow with her litter. Also, for sows, mean weight gains are not taken into account. Hence, m_g is zero for sows. The N content of growing pigs is 0.0256 kg kg^{-1}.

2.6 Total ammoniacal nitrogen excretion rates

It is assumed that TAN is excreted with urine only, whereas all organic N is contained in faeces[3].

$$m_{urine} = \frac{ME}{\eta_{ME}} \cdot \eta_N \cdot X_{DN} - m_l - m_g - m_p \quad (7)$$

where
m_{urine} rate of N excreted with urine (kg place^{-1} a^{-1} N)
ME ME intake rate with feed (kg place^{-1} a^{-1} N)
η_{ME} ME content of feed (in MJ kg^{-1})
η_N N content of feed (in kg kg^{-1})
X_{DN} apparent digestibility of N (in kg kg^{-1})
m_l rate of N excreted with milk (kg place^{-1} a^{-1} N)
m_g rate of N retained in the animal (kg place^{-1} a^{-1} N)
m_p rate of N in offspring produced (kg place^{-1} a^{-1} N)

3 Data base

A survey was made in 2010 to provide information on feeds for sows with piglets, weaners, fatteners, and boars (for reproduction). This survey provided information about typical animal feed compositions among regions as well as on the frequency distribution of feeding phases, the share of diets with reduced N contents (RAM feed[4]), and the number of animal rounds per year for each German federal state and each year from 1990 to 2009.

3.1 Feed composition

3.1.1 Results of the survey

A survey was made to assess typical feed compositions for all regional feed types. As a rule, the local agricultural advisors provided various diets for each pig subcategory. So, in all, 288 diets were described, of which 86 were fed to sows, 66 to weaners and 122 to fattening pigs. Boars were normally fed on sow feed. The spatial resolution was to reflect the variability in German pig production that is obviously governed by soil properties and markets as well as tradition. For Niedersachsen, the federal state with the highest pig density, 11 regions were identified where the feed composition was likely to vary. All other federal states were assumed to be homogeneous with respect to their pig feed composition and feeding strategy.

Some advisors considered their information confidential. Hence, results will be anonymized.

3.1.2 Gap filling

One federal state did not provide data. Here, those data from the neighbouring federal states were used that would result in the most unfavourable excretion rates. This was to avoid underestimation of emissions.

For the city states of Hamburg, Bremen (with Bremerhaven), and Berlin data for Schleswig-Holstein, Niedersachsen, and Brandenburg were used, respectively. Saarland was described in the same way as Rheinland-Pfalz.

3.1.3 Temporal representativeness

The composition of feeds is assumed to have changed only to a lesser extent.

From 1996 onwards, the use of grain in the feed manufacturing industry has steadily increased from 35 percent in average over all kind of feed varieties to 44 percent (DVT, 2011). Grain replaced starch-rich by-products like manioc, imported from third countries, as well as by-products from the grain-milling industry like maize gluten feed. In December 2000 the use of by-products from animal origin which was used as protein and energy source in some feed for pigs and poultry was banned because of the BSE crisis. These feedstuffs were replaced by an increased use of, for instance, soya bean meal.

Figure 1 illustrates that the main properties have changed little over the last two decades.

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[3] The method used in Rösemann et al. (2011) was slightly modified by replacing the digestibility of energy by that of N.

[4] RAM: Rohprotein-angepasste Mischung: mixture adjusted to crude protein demands

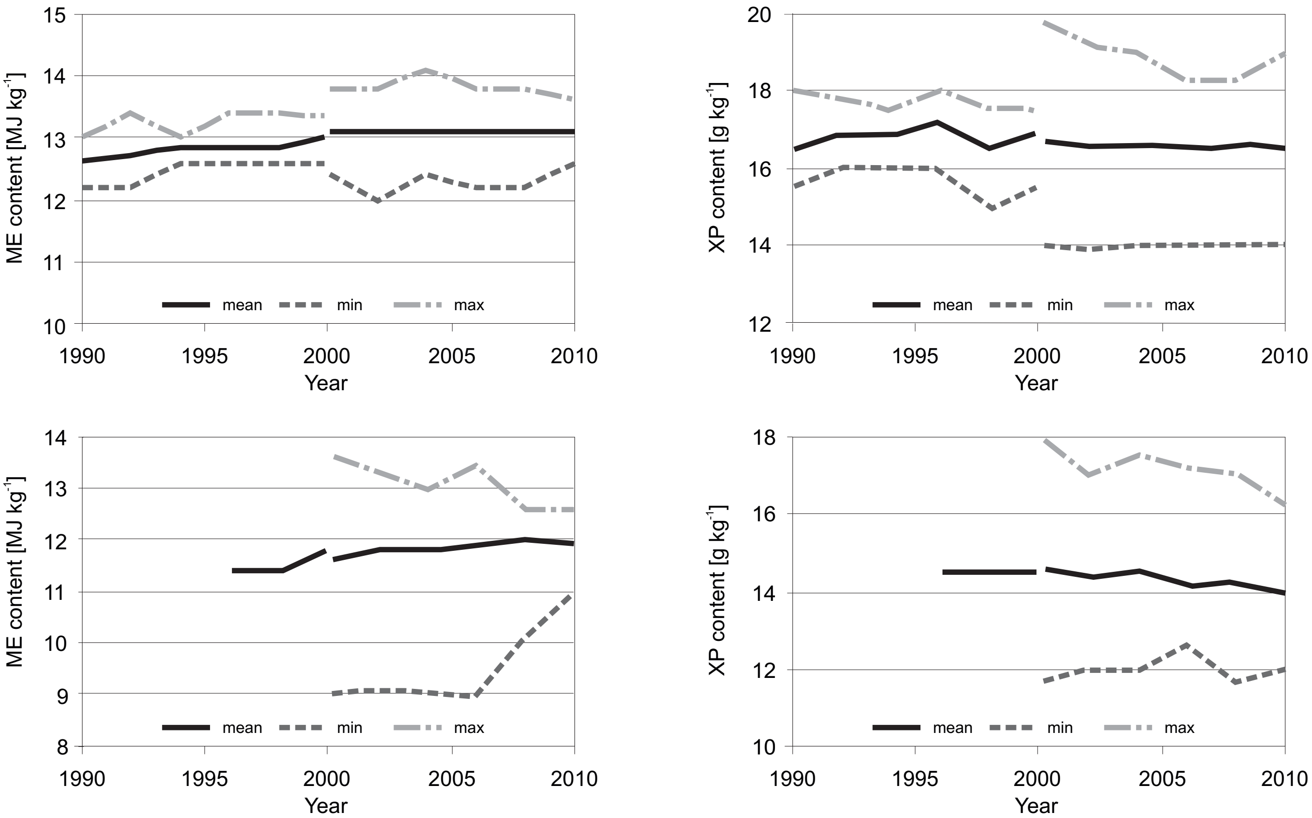

Figure 1

Temporal variation of ME and XP contents of various feeds. Above: fattening pig feeds; below: farrowing sow feeds. Data courtesy of K.-H. Grünewald, contents before 2000 from a limited number of samples, data after 2000 from about 300 to 250 and 140 to 200 samples per year for fattening pigs and sows, respectively.

3.2 Feed properties

3.2.1 Properties of feed constituents

Based on the equations provided in Chapter 2, the calculation of excretion rates for CH_4, VS, N, and TAN presupposes knowledge of the following feed properties

- metabolizable energy content, η_{ME}, for all animals (feed intake rates)
- gross energy content, η_{GE} (assessment of emissions from enteric fermentation)
- digestibility for organic matter, X_{DOM}, (assessment of VS excretion rates)
- crude protein content, η_{XP} (N intake rate)
- digestibility of N, X_{DN} (assessment of TAN excretion rates)

In Europe, properties and composition of commodities have to be declared to some extent (EC, 2002). This covers the percentages of pig feed constituents as well as the mean ME, XP, and ash contents of the mix. Properties of feed constituents can be obtained from various data collations:

- DLG (2005) is considered to be the official expert judgement for Germany and national consent (Spiekers, head of the group of authors, pers. comm.). Table 3a in DLG (2005) is confined to the most important feed and contains DM, ME, and crude protein (XP) contents.
- LfL (2009) is an almost comprehensive data base. The information used for this work comprises the DM, ME, and XP contents.
- KTBL (unpublished) uses a collation of feed properties that contains the digestibilities X_{DOM} and X_N in addition to DM, ME, and XP contents.
- Jentsch et al. (2004) is a comprehensive and very detailed data base. Apart from GE, DE, ME, and ash contents it provides information on the digestibilities X_{DE}, X_{DOM} and X_{DN}.

3.2.2 Harmonization and data gap closing for feed constituents

The backbone of Table 1 is the data provided by Jentsch et al. (2004). In order to meet the "official" information in DLG (2005), weighted means had to be produced from Jentsch et al. (2004) data, such as a mixture of various wheat qualities (wheat, full grains, 55 %; wheat, full grains, protein rich, 25 %; wheat, flat grains, 20 %). This applies to green meal, barley, wheat and oat, wheat and rye brans, rape seed expeller, and fish meal.

For some feed constituents (soya and rape seed oils) some properties could be extracted from DLG Futtermittelnet (DLG, 2011).

Properties of corn steep could be deduced from information provided by the manufacturer (Beuker, undated).

Some less frequently used feed constituents were left without any or an inconsistent data set. They were replaced by similar constituents:

- maize flakes by maize (all properties)
- rape seed and sunflower oils by soya oil (digestibilities only)
- soya protein by soya beans (all properties)
- soya pulp by legume seed hulls (all properties)
- fish oil by fish juice (all properties)
- lignocellulose by grain straw (all properties)
- rice gluten feed by wheat gluten feed (all properties)
- palm butter by peanut oil (all properties)

Table 1:
Nutritional properties of feed constituents in pig production.

Feed constituent		DLG/LfL			Jentsch et al.						
		η_{ME}	η_{XP}	η_N	η_{ME}	η_N	η_{GE}	η_{ash}	X_{DE}	X_{DOM}	X_{DN}
English	German	MJ kg^{-1}	%	kg kg^{-1}	MJ kg^{-1}	kg kg^{-1}	MJ kg^{-1}	kg kg^{-1}	MJ MJ^{-1}	kg kg^{-1}	kg kg^{-1}
green meal	Grünmehl	7.72	18.71	0.026	7.76		18.24	0.097	0.54	0.57	0.48
wheat	Weizen	15.45	13.75	0.022	15.45		18.51	0.027	0.85	0.88	0.83
triticale	Triticale	12.73	12.05	0.019	15.59		18.26	0.021	0.87	0.90	0.82
rye	Roggen	15.34	10.23	0.016	15.19		18.29	0.021	0.85	0.88	0.76
barley	Gerste	14.43	12.39	0.020	14.57		18.46	0.025	0.81	0.84	0.83
oat	Hafer	12.73	12.05	0.019	12.72		19.09	0.037	0.68	0.70	0.79
CCM	CCM	14.89	10.00	0.016	14.61		18.91	0.020	0.80	0.82	0.76
maize	Mais	16.02	10.57	0.017	16.00		18.88	0.017	0.86	0.89	0.79
maize flakes	Maisflocken	16.02	10.57	0.017	16.00		18.88	0.017	0.86	0.89	0.79
millet	Hirse	14.67	12.95	0.021	15.80		18.68	0.019	0.86	0.90	0.75
linseed	Leinsamen	18.33	24.84	0.040	20.00		26.75	0.050	0.81	0.79	0.86
potato peel	Kartoffelschalen	13.97	15.45	0.025	11.16		17.06	0.075	0.71	0.76	0.20
potato chips	Kartoffelchips				15.50	0.014	15.61	0.045	0.90	0.94	0.65
sugar beet pulp	Trockenschnitzel	9.04	10.04	0.016	8.98		18.02	0.055	0.74	0.79	0.38
sugar beet pulp with molasses	Melasseschnitzel				9.77	0.017	17.49	0.050	0.77	0.82	0.42
bakery waste	Backabfälle	16.65	12.09	0.019	14.38		19.26	0.030	0.80	0.83	0.80
wheat bran	Weizenkleie	9.43	16.02	0.026	9.46		18.91	0.064	0.59	0.60	0.70
rye bran	Roggenkleie	10.09	16.36	0.026	10.06		13.13	0.068	0.63	0.66	0.72
oat flakes	Haferflocken	16.56	12.86	0.021	16.32		19.04	0.025	0.89	0.91	0.90
oat bran	Haferschälkleie	6.20	7.49	0.012	6.76		18.76	0.055	0.39	0.40	0.55
wheat gluten feed	Weizenkleber				10.87	0.023	20.26	0.030	0.66	0.68	0.70
maize gluten feed	Maiskleberfutter	12.15	26.16	0.042	11.72		19.11	0.045	0.68	0.70	0.65
distillers dried grains with solubles	Weizenschlempe	11.33	36.93	0.059	11.06		20.05	0.065	0.70	0.71	0.76
maize starch	Maisstärke				16.81	0.001	17.30	0.010	0.95	0.98	0.00
maize germs	Malzkeime	8.68	29.57	0.047	11.08		18.65	0.066	0.69	0.71	0.72
apple pomace	Apfeltrester				6.06	0.009	19.23	0.030	0.43	0.43	0.00
molasses	Melasse	13.28	12.84	0.021	12.79		15.23	0.110	0.90	0.93	0.30
peanut oil	Erdnussöl				36.65	0.006	39.80	0.000	0.97	0.98	0.00
soya oil	Sojaöl	37.36	0.00	0.000							
rape seed oil	Rapsöl	36.62	0.00	0.000							
sunflower oil	Sonnenblumenöl	36.62	0.00	0.000							
sugar	Zucker	15.16	1.45	0.002	14.75		16.00	0.000	0.95	0.96	0.00
peas	Erbsen	15.68	25.11	0.040	15.63		18.75	0.038	0.85	0.89	0.88

			DLG/LfL			Jentsch et al.						
Feed constituent			η_{ME}	η_{XP}	η_{N}	η_{ME}	η_{N}	η_{GE}	η_{ash}	η_{DE}	η_{DOM}	η_{DN}
English	German		MJ kg^{-1}	%	kg kg^{-1}	MJ kg^{-1}	kg kg^{-1}	MJ kg^{-1}	kg kg^{-1}	MJ kg^{-1}	kg kg^{-1}	kg kg^{-1}
faba bean	Ackerbohne		14.77	29.77	0.048	14.84		18.95	0.040	0.83	0.85	0.85
soya bean	Sojabohne		17.57	40.43	0.065	18.45		23.96	0.050	0.83	0.86	0.89
soya protein	Sojaeiweißkon-zentrat		17.57	40.43	0.065	18.45		23.96	0.050	0.83	0.86	0.89
linseed expeller	Leinexpeller		12.08	37.49	0.060	13.51		20.69	0.065	0.75	0.76	0.82
rape seed expeller	Rapsexpeller		14.13	36.37	0.058	13.19		20.28	0.080	0.75	0.75	0.81
soy pulp	Sojaschalen		7.52	12.78	0.020							
rape seed extraction meal	Rapsextraktions-schrot		11.24	39.89	0.064	12.08		19.24	0.085	0.73	0.73	0.81
sunflower extraction meal	Sonnenblumen-extraktionsschrot		11.99	45.49	0.073	10.79		19.55	0.070	0.63	0.63	0.79
soya bean extraction meal 48 % XP	Sojaextraktions-schrot 48 %, getoastet		16.18	54.83	0.088	15.77		20.05	0.065	0.90	0.91	0.92
soya bean extraction meal 44 % XP	Sojaextraktions-schrot 44 %, getoastet		14.66	50.23	0.080	14.82		19.96	0.065	0.88	0.89	0.89
potato protein	Kartoffeleiweiß		18.45	83.50	0.134	18.63		22.46	0.024	0.91	0.90	0.92
sweet whey	Molke, Süß-, frisch		14.06	13.64	0.022	14.72		16.07	0.088	0.93	0.96	0.90
acid whey	Molke, Sauer-, frisch		13.33	15.00	0.024	14.31		15.91	0.115	0.90	0.95	0.90
whey protein	Molkeneiweiß, frisch					16.00	0.114	19.56	0.160	0.92	0.91	0.91
skimmed milk powder	Milchprodukte (Magermilch-pulver)					15.47	0.060	17.72	0.081	0.93	0.94	0.91
whey concentrate	Molke, Süß-, getrocknet					13.92	0.021	15.71	0.095	0.92	0.94	0.87
fish meal 64 % XP	Fischmehl 64 % RP		15.00	67.78	0.108	11.98		18.84	0.205	0.72	0.71	0.72
yeast	Bierhefe, Wein-hefe (Vinasse)		13.86	52.11	0.083	14.23		20.05	0.085	0.69	0.68	0.75
corn steep	Maisquellwasser	Beu-ker	13.40	43.00	0.069				0.019			
fish oil	Fischöl				0.000				0.000			
lignocellulose	Lignocellulose				0.001				0.030			
rice gluten feed	Reiskleber											
palm butter	Pflanzenfett											
formic acid	Ameisensäure					5.54	0.000	5.54	0.000	1.00	1.00	0.00
propionic acid	Propionsäure					21.81	0.000	21.81	0.000	1.00	1.00	0.00
calcium phosphate	Calciumphosphat					0.00	0.000	0.00	1.000	0.00	0.00	0.00
lime (calcium carbonate)	Kohlensaurer Kalk					0.00	0.000	0.00	1.000	0.00	0.00	0.00
sodium bicarbonate	Natriumhydro-gencarbonat					0.00	0.000	0.00	1.000	0.00	0.00	0.00
salt	Viehsalz					0.00	0.000	0.00	1.000	0.00	0.00	0.00

Dark gray cells indicate data gaps.

3.2.3 Gap closure for a missing diet digestibility of organic matter

One federal state did not report feed composition data but overall feed properties. These did not cover digestibility of OM. The diet digestibility of OM cannot be derived from the digestibility for energy by a simple regression analysis (see Figure 2). Hence, the reported digestibilities for energy were used as a substitute.

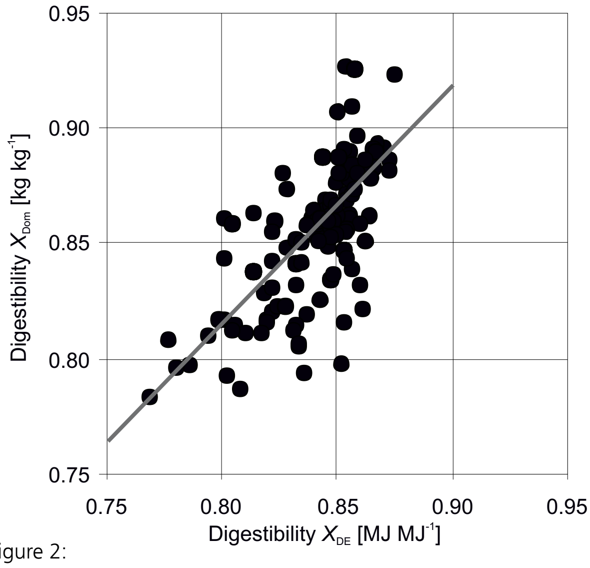

Figure 2:

Comparison between the diet digestibilities for energy X_{DE} and organic matter X_{DOM}. Data pairs calculated for the various exemplar German districts.

3.2.4 Exemplary feed composition and properties

The experts communicated feed compositions and properties as listed with the advice notes. The weighted mean was formed if more than one feed composition was available. Table 2 shows an example.

Table 2:

Composition of fattening pig feeds in a district. Feeds for fattening pigs in Schleswig-Holstein, weights 45 to 85 kg animal^{-1}. Feed properties related to fresh matter (FM) (DM content of FM 0.88 kg kg^{-1}).

feed constituent	feed 1	feed 2	feed 3	feed 4	feed 5	mean	unit
barley	25	25.2	26.4	20	28	24.9	%
triticale	0	0	0	5	5	2.0	%
wheat	40	54.2	43.8	49	42	45.8	%
wheat bran	2.4	0	4.3	1	0	1.5	%
maize	3.5	0	0	0	0	0.7	%
millet	5.1	0	0	0	0	1.0	%
rape seed extraction meal	2	2	4.3	0	0	1.7	%
rape seed expeller	6	6	2.5	8	8	6.1	%
soya bean extraction meal 48 % XP	11	10	14	13.4	13.1	12.3	%
molasses	0.5	0.4	1.7	0	0	0.5	%
palm butter	1.4	0.5	2.1	0.5	0.9	1.1	%
lime (calcium carbonate)	1.17	1.1	1.1	1.13	1.12	1.1	%
calcium phosphate	0.12	0.3	0.1	0.13	0.16	0.2	%
salt	0.39	0.4	0.4	0.41	0.45	0.4	%
weighting factor	0.2	0.2	0.2	0.2	0.2		
ME content	13.4	13.4	13.4	13.4	13.4	13.4	MJ kg^{-1}
XP content	0.170		0.175	0.17	0.17	0.171	kg kg^{-1}
ash content	0.047	0.047	0.047	0.047	0.047	0.047	kg kg^{-1}

3.3 Feeding strategies

For sows and weaners, single and two-phase feedings are considered. Fattening pigs are assumed to be fed in one, two or three phases; big modern enterprises feeding continuously varying feeds are included in three-phase feeding. In Niedersachsen, special diets are fed with reduced N contents. An example result of the inquiry is shown in Table 3.

Table 3:
Fattening pigs – feeding strategies (% of animal places). Example results obtained for Emsland rural district.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1 phase	30	25	20	15	10	5	5	5	5	5
2 phases	65	66	67	68	69	70	70	70	70	70
of which N reduced	0	0	5	7.5	10	12.5	15	20	25	25
3 phases	5	9	13	17	21	25	25	25	25	25
of which N reduced	0	0	5	7.5	10	12.5	15	20	25	25

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 phase	3	3	3	3	3	3	3	3	3	3
2 phases	70	65	60	55	50	45	45	45	45	45
of which N reduced	30	40	50	60	70	70	75	80	85	85
3 phases	27	32	37	42	47	52	52	52	52	52
of which N reduced	30	40	50	60	70	70	75	80	85	85

3.4 Animal rounds

A distinction is made between the assessments of animal rounds for single and multi-phase feeding. Experts agree on the fact that, in single phase feeding, it had been German practice to replace animals without the thorough cleansing procedure that has become standard for "all-in-all-out" production in two- and three-phase feeding. They also agree that in single phase feeding the mean duration of the period during which the place is empty, is about 5 d round^{-1} (see also KTBL, 2006, pg, 503). This is assumed to be constant over the whole period considered. In contrast multi-phase feeding is typically related to "all-in-all-out" production. Here, service, cleansing, and disinfection vary with time.

3.4.1 Expert judgement

German experts were asked to contribute the time series of animal rounds for their respective region. Results from almost all German federal states could be obtained. Some data was extracted from reports of breeders' institutions, other was derived from weight and weight gain data and local times for service, cleansing, and disinfection. As some of the data were communicated confidentially, the results shown in Table 4 have to be presented anonymously.

3.4.2 Data gap closure

Numbers of animal rounds are required for each single federal state as complete time series. However, some of the time series were incomplete. The analysis of the data provided by the experts revealed that the assumption of a linear reduction of the time span during which places were empty for any reason from 22 d round^{-1} in 1990 and 15 d round^{-1} resulted in the smallest scatter. Hence, these time spans in combination with reported weights and weight gains were used to assess the number of animal rounds.

One federal state did not supply data. The lowest number of animal rounds obtained for its direct neighbours was used instead.

Information about animal performance is non existent or rare for the smaller states. Again, it is assumed that Hamburg can be treated in the same way as Schleswig-Holstein, Bremen as Niedersachsen, Berlin as Brandenburg, and Saarland as Rheinland-Pfalz.

The results for the various federal states are collated in Table 4.

Table 4:
Fattening pigs, number of animal rounds in two- and three-phase feeding. Reported data upright, data achieved from gap filling in italics.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1	*2.49*	*2.55*	*2.45*	*2.40*	*2.49*	*2.42*	2.53	2.54	2.44	2.49
2	*2.18*	*2.55*	*2.45*	*2.40*	*2.49*	2.44	2.52	2.51	2.53	2.50
3	2.47	2.49	2.45	2.40	2.49	2.42	2.47	2.44	2.44	2.49
4	2.33	2.34	2.25	2.27	2.37	2.39	2.46	2.49	2.52	2.56
5	2.33	2.34	2.25	2.27	2.37	2.39	2.46	2.49	2.52	2.56
6	*2.47*	*2.49*	*2.48*	*2.46*	2.55	2.46	2.47	2.44	2.44	2.52
7	2.60	2.70	2.70	2.60	2.70	2.70	2.70	2.60	2.70	2.50
8	*2.47*	*2.49*	*2.48*	*2.46*	2.55	2.46	2.47	2.44	2.44	2.52
9	*2.18*	*2.55*	*2.45*	*2.40*	*2.49*	*2.42*	2.52	2.47	2.57	2.56
10	2.33	2.34	2.25	2.27	2.37	2.39	2.46	2.49	2.63	2.56
11	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67
12	*2.40*	*2.40*	*2.41*	*2.41*	*2.35*	2.31	2.35	2.36	2.38	2.44
13	*2.35*	*2.31*	*2.33*	*2.34*	*2.37*	*2.35*	*2.35*	*2.41*	*2.46*	*2.53*
mean	2.39	2.44	2.42	2.41	2.43	2.40	2.43	2.44	2.48	2.50

	2000	2001	2002	2003	2004	2005	2006	2007	2008
1	2.60	2.82	2.56	2.55	2.80	2.57	2.49	2.57	2.65
2	2.55	2.42	2.77	2.43	2.48	2.55	2.76	2.76	2.94
3	2.60	2.66	2.50	2.55	2.56	2.57	2.49	2.57	2.65
4	2.56	2.58	2.60	2.56	2.50	2.46	2.41	2.55	2.58
5	2.56	2.58	2.60	2.56	2.50	2.46	2.41	2.55	2.58
6	2.63	2.66	2.50	2.58	2.56	2.63	2.54	2.62	2.66
7	2.60	2.70	2.70	2.60	2.70	2.70	2.70	2.70	2.70
8	2.63	2.66	2.50	2.58	2.56	2.63	2.54	2.62	2.66
9	2.59	2.56	2.56	2.58	2.61	2.65	2.68	2.73	2.78
10	2.59	2.61	2.60	2.69	2.35	2.34	2.41	2.55	2.71
11	2.67	2.69	2.69	2.69	2.69	2.69	2.69	2.68	2.68
12	*2.56*	2.48	2.49	2.50	2.54	2.57	2.61	*2.61*	*2.62*
13	2.51	2.54	2.50	2.46	2.51	2.53	2.57	2.57	2.55
mean	2.56	2.57	2.55	2.52	2.55	2.56	2.58	2.61	2.62

4 Results

Examples of excretion rates for standard animals are calculated for the years 1994, 2001, and 2007. They are compared with the results obtained with the previously used feeding strategies and diet compositions. Hitherto, no regional differentiation was made. All sows, weaners, and fattening pigs had been treated as being fed with two phases. Reduced-N feed had been taken into account for some districts in Niedersachsen. For details see Rösemann et al. (2011).

Similar calculations had been performed for Niedersachsen and fattening pigs (Dämmgen et al., 2011c) partly using the same data source as this work. After completion of these calculations, the calculation procedures for VS and N excretion rates used hitherto were checked and modified (Dämmgen et al., 2011a). Hence, the results obtained in the work at hand may differ from those published earlier.

4.1 Methane excretion rates (enteric fermentation)

Emissions from enteric fermentation depend on the GE intake and on the methane conversion factor. The latter is assumed to be constant for all pigs (IPCC, 1996, Table A-4 provides a methane conversion factor of 0.006 MJ MJ^{-1} for developed countries, which is used in the German emission inventory). As the GE contents of feeds are almost constant for the major feed constituents (Table 5), hardly any changes are expected as a result of changed feeding practices (Table 6).

Table 5:
GE contents of feed, annual national means

	1994	2001	2007	previous calculations [1]	unit
sows (including suckling piglets)	18.32	18.28	18.31	18.45	MJ kg^{-1} GE
weaners	18.76	18.77	18.78	18.45	MJ kg^{-1} GE
fattening pigs	18.71	18.67	18.65	18.45	MJ kg^{-1} GE
boars	18.32	18.33	18.34	18.45	MJ kg^{-1} GE

[1] using the methodology described in Rösemann et al. (2011)

Table 6:
Methane excretion rates (enteric fermentation), annual national means

	1994	2001	2007	previous calculations [1])	unit
sows (including suckling piglets)	2.07	2.07	2.08	2.13	kg $place^{-1}$ a^{-1} CH_4
weaners	0.42	0.42	0.42	0.43	kg $place^{-1}$ a^{-1} CH_4
fattening pigs	1.21	1.18	1.17	1.32	kg $place^{-1}$ a^{-1} CH_4
boars	1.75	1.74	1.75	1.73	kg $place^{-1}$ a^{-1} CH_4

[1] using the methodology described in Rösemann et al. (2011)

Table 7:
Digestibilities of organic matter, annual national means

	1994	2001	2007	previous calculations [1]	unit
sows (including suckling piglets)	0.84	0.84	0.84	0.81	kg kg^{-1}
weaners	0.86	0.85	0.87	0.85	kg kg^{-1}
fattening pigs	0,86	0.86	0.86	0.82	kg kg^{-1}
boars	0.83	0.84	0.83	0.83	kg kg^{-1}

[1] digestibilities of energy in MJ MJ-1, using the methodology described in Rösemann et al. (2011)

Table 8:
Ash contents of feed, annual national means

	1994	2001	2007	previous calculations [1]	unit
sows (including suckling piglets)	0.062	0.059	0.059	0.02	kg kg^{-1}
weaners	0.058	0.058	0.058	0.02	kg kg^{-1}
fattening pigs	0.056	0.056	0.056	0.02	kg kg^{-1}
boars	0.057	0.056	0.057	0.02	kg kg^{-1}

[1] using the methodology described in Rösemann et al. (2011)

Table 9:
Volatile solids excretion rates, annual national means

	1994	2001	2007	previous calculations [1]	unit
sows (including suckling piglets)	155	161	163	205	kg $place^{-1}$ a^{-1} VS
weaners	26.0	26.2	26.5	31.6	kg $place^{-1}$ a^{-1} VS
fattening pigs	80.5	79.3	79.4	117	kg $place^{-1}$ a^{-1} VS
boars	128	129	128	145	kg $place^{-1}$ a^{-1} VS

1) using the methodology described in Rösemann et al. (2011)

Table 10:
Nitrogen excretion rates, annual national means

	1994	2001	2007	previous calculations [1)]	unit
sows (including suckling piglets)	25.7	25.3	25.2	26.3	kg place^{-1} a^{-1} N
weaners	3.5	3.4	3.4	3.0	kg place^{-1} a^{-1} N
fattening pigs	11.9	11.5	11.3	13.9	kg place^{-1} a^{-1} N
boars	27.0	27.1	27.0	27.5	kg place^{-1} a^{-1} N

[1)] using the methodology described in Rösemann et al. (2011)

Table 11:
Total ammoniacal nitrogen excretion rates, annual national means

	1994	2001	2007	previous calculations [1)]	unit
sows (including suckling piglets)	19.4	19.1	19.0	20.1	kg place^{-1} a^{-1} TAN
weaners	2.3	2.3	2.3	2.1	kg place^{-1} a^{-1} TAN
fattening pigs	8.6	8.2	8.0	10.2	kg place^{-1} a^{-1} TAN
boars	21.4	21.4	21.3	22.2	kg place^{-1} a^{-1} TAN

[1)] using the methodology described in Rösemann et al. (2011)

4.2 Volatile solids excretion rates

Major changes can be observed for VS (Table 9). The small differences in digestibilities (Table 7) have a large effect on VS excretion rates, which is far more important than the trebling of the ash contents (Table 8).

4.3 Nitrogen and TAN excretion rates

The effect of reduced N input and the reduction of production cycles lead to a significant reduction in N excretion rates for fattening pigs, compared to the previous method. The changes in N excretion rates for the other subcategories are smaller. A significant increase is observed for weaners (Table 10). This applies also to TAN excretion rates (Table 11). The use of the digestibility of crude protein (XP) N instead of the digestibility of energy reduces TAN excretion rates.

5 Discussion

For sows, nutrition requirements (energy, protein) vary significantly among the different stages of the piglet production cycle. For growing pigs (weaners and fatteners) the ratio of crude protein to energy decreases continually with age. Hence, it has become general practice to reflect this in the diets by phase feeding as this is also economically beneficial.

In Niedersachsen, special measures have been taken to reduce the N and phosphorus loads on the environment by introducing special diets with reduced XP and phosphorus contents.

An example detailed analysis of the influence of the various input parameters is made for Niedersachsen, as here feeding practices are more differentiated than in other federal states. Five feeding types were distinguished:

- 1 single phase feeding
- 2S two-phase feeding, standard XP contents
- 2R two-phase feeding, reduced XP contents
- 3S three-phase feeding, standard XP contents
- 3R three-phase feeding, reduced XP contents

The comparison is performed for sows with litter and fattening pigs, as the contribution to emissions from weaners and boars is of minor importance. The 2007 data set is used.

Changes are negative for reductions and positive for increases.

5.1 Sows with litter

Due to the fact that the feed intake is governed by energy requirements, the energy intake is not affected by phase feeding. As CH_4 emissions from enteric fermentation are derived from energy intake, they are also not affected by phase feeding (Table 12).

Table 12:

Sows plus litter. CH_4 excretion rates (emissions) per animal place as a function of feeding strategy.

Feed type	1	2S	2R	unit
CH_4 excretion rate	2.1	2.1	2.1	kg place^{-1} a^{-1} CH_4
changes compared to "1" due to adjusted XP content			+ 0.0	kg place^{-1} a^{-1} CH_4
introduction of phase feeding		+0.0	+0.0	kg place^{-1} a^{-1} CH_4

The energy content of feeds is adjusted to the requirements of lactating and non-lactating sows. This results in a considerable reduction in VS excretions. The reduction of the XP content has a small negative effect (Table 13).

Table 13:

Sows plus litter. VS excretion rates per animal place as a function of feeding strategy.

Feed type	1	2S	2R	unit
VS excretion rate	165	142	147	kg place^{-1} a^{-1} VS
changes compared to "1" due to adjusted XP content		0	+5	kg place^{-1} a^{-1} VS
introduction of phase feeding		-23	-23	kg place^{-1} a^{-1} VS

A minor effect on N excretion rates can be observed as a result of phase feeding. However, the reduction of feed XP contents is clearly visible (Table 14).

Table 14:

Sows plus litter. N excretion rates per animal place as a function of feeding strategy.

Feed type	1	2S	2R	unit
N excretion rate	26.5	26.2	24.3	kg place^{-1} a^{-1} N
changes compared to "1" due to adjusted XP content			-1.9	kg place^{-1} a^{-1} N
introduction of phase feeding		-0.3	-0.3	kg place^{-1} a^{-1} N

In contrast to N excretion rates, TAN excretion rates are reduced by phase feeding. For the diets compared, the effect of the reduced XP contents is adverse, albeit small (Table 15).

Table 15:

Sows plus litter. TAN excretion rates per animal place as a function of feeding strategy.

Feed type	1	2S	2R	unit
TAN excretion rate	19.1	17.3	18.5	kg place^{-1} a^{-1} N
changes compared to "1" due to adjusted XP content			+1.2	kg place^{-1} a^{-1} N
introduction of phase feeding		-1.8	-1.8	kg place^{-1} a^{-1} N

5.2 Fattening pigs

Phase feeding results in a reduced number of animal rounds. This causes a linear reduction in all emissions.

For CH_4 emission rates, the effects of both adjusted energy and XP contents of the feed are of minor importance (Table 16).

Table 16:

Fattening pigs. Methane excretion rates per animal place as a function of feeding strategy.

Feed type	1	2S	2R	3S	3R	unit
CH_4 excretion rate	1.31	1.20	1.18	1.16	1.17	kg place^{-1} a^{-1} CH_4
changes compared to "1" due to adjusted XP content			-0.01		+0.01	kg place^{-1} a^{-1} CH_4
introduction of phase feeding		+0.04	+0.04	-0.00	-0.00	kg place^{-1} a^{-1} CH_4
reduced number of rounds		-0.15	-0.15	-0.15	-0.15	kg place^{-1} a^{-1} CH_4

With VS excretion rates, changes in both energy and XP contents have an adverse effect. This may even overcompensate the gains due to reduced animal rounds in the case of 3R feeding (Table 17).

Table 17:

Fattening pigs. VS excretion rates per animal place as a function of feeding strategy (2007 data set).

Feed type	1	2S	2R	3S	3R	unit
VS excretion rate	84.8	79.2	80.7	84.0	86.7	kg place^{-1} a^{-1} VS
reductions compared to "1" due to adjusted XP content			+1.5		+2.8	kg place^{-1} a^{-1} VS
introduction of phase feeding		+4.3	+4.3	+9.1	+9.1	kg place^{-1} a^{-1} VS
reduced number of rounds		-9.9	-9.9	-9.9	-9.9	kg place^{-1} a^{-1} VS

N excretion rates benefit from all aspects of feeding changes. The introduction of phase feeding alone reduces N excretion rates of about 7 %, which is in line with experimental findings (e.g. Lindermeyer et al., 2010; Anonymus, 2010). Here the reduced N inputs into the animals affect the excretions significantly. Adjusted feeding as a whole has positive effects. There is hardly any difference between 2S and 3S feedings. The combined effects add up to more than 5 kg place^{-1} a^{-1} N (Table 18).

Table 18:

Fattening pigs. N excretion rates per animal place as a function of feeding strategy

Feed type	1	2S	2R	3S	3R	unit
N excretion rate	13.2	10.8	9.9	11.1	7.7	kg place^{-1} a^{-1} N
reductions compared to "1" due to adjusted XP content			-0.9		-3.5	kg place^{-1} a^{-1} N
introduction of phase feeding		-0.9	-0.9	-0.5	-0.5	kg place^{-1} a^{-1} N
reduced number of rounds		-1.5	-1.5	-1.5	-1.5	kg place^{-1} a^{-1} N

The introduction of phase feeding as a measure to adjust feed properties to energy requirements has only a minor effect on TAN excretions rates. However, XP reduction adds a considerable amount of savings (Table 19).

Table 19:

Fattening pigs. TAN excretion rates per animal place as a function of feeding strategy (2007 data set).

Feed type	1	2S	2R	3S	3R	unit
TAN excretion rate	9.1	7.8	6.6	7.8	5.4	kg place^{-1} a^{-1} N
reductions compared to "1" due to adjusted XP content			-1.2		-2.4	kg place^{-1} a^{-1} N
introduction of phase feeding		-0.3	-0.3	-0.2	-0.2	kg place^{-1} a^{-1} N
reduced number of rounds		-1.1	-1.1	-1.1	-1.1	kg place^{-1} a^{-1} N

Both N and TAN excretion rates vary regionally. Figure 3 illustrates the results obtained for the 22 German regions investigated.

6 Conclusions

The German data sets collated for this work show that phase feeding alone results in reduced VS excretion rates. The reduction is achieved in the step from single to two-phase feeding. The introduction of a third phase is far less effective.

Changed feed compositions do not affect CH_4 excretions from enteric fermentation, nor do they show a great effect on N excretions. This contradicts the statements found in the literature with respect to N excretion rates.

In two- and three-phase feeding, the reductions in N and TAN excretions are a side effect of the reduced number of animal rounds that goes with the introduction of phase feeding.

However, N excretion rates for two-phase feeding of fattening pigs range from 10.1 to 13.1 kg place^{-1} a^{-1} N and from 6.4 to 9.8 kg place^{-1} a^{-1} TAN, indicating that there is considerable room for reductions.

A remarkable reduction in the excretion rates of N and TAN can be achieved by adjusting the protein contents of the feed to the requirements.

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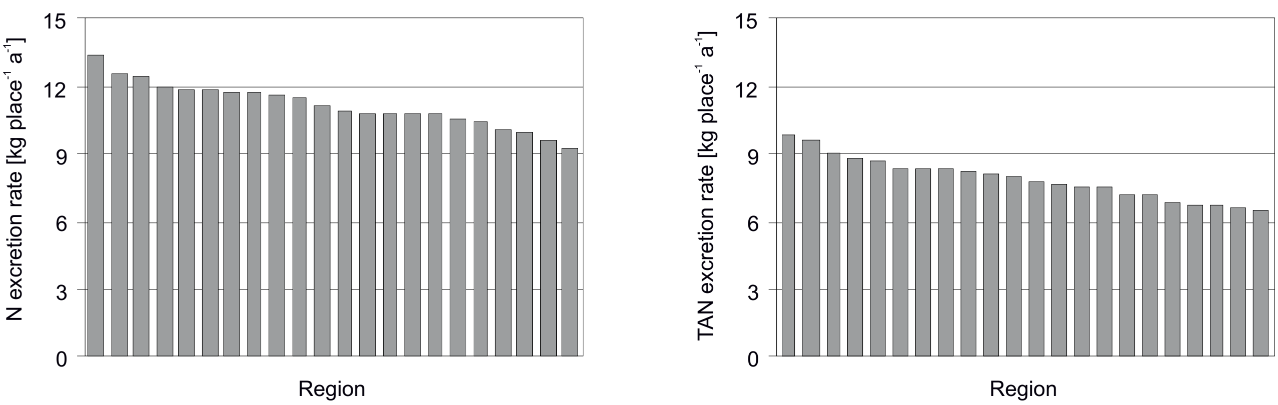

Figure 3.

Variability of total nitrogen (N) and urinary nitrogen (TAN) excretion rates calculated for 22 German regions

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