DOI:10.3220/LBF_2013_285-302

Estimate of methane, volatile solids and nitrogen excretion rates of German suckler cows

Ulrich Dämmgen *, Hans-Dieter Haenel *, Claus Rösemann *, Nicholas John Hutchings **, Wilfried Brade *** and Ulrich Meyer ****

Abstract

German beef production is increasingly based on suckler cows. At present, the determination of greenhouse gas and air pollutant emissions from suckler cows are calculated using standard assumptions and IPCC default values. In this work, a national procedure and relevant values are derived from the detailed dairy cow model used in the German agricultural emission inventory. In addition, herd composition data, data concerning animal weights, milk yields and diet composition were collated from literature and evaluated to deduce the excretion rates of volatile solids and nitrogen from which greenhouse gas and air pollutant emissions could be obtained. As a result, suckler cows of the single genotypes found in Germany could be described satisfactorily.

Cow weight, milk yield and feed composition were identified as most important input parameters.

In the inventories, emissions have to be reported as time series. However, time series of important data needed to describe the overall German suckler cow management could not be established, in particular the distribution of genotypes in the national herd. Hence, the characterisation and the resulting excretion rates of the "mean German suckler cow" rely on recent data only. Some of our findings contradict the recommendations given in German standard textbooks, in particular for the milk yield of suckler cows.

Keywords: *methane, volatile solids, nitrogen, excretion, suckler cows, model*

* Johann Heinrich von Thünen Institute, Institute for Climate-Smart Agriculture, Bundesallee 50, 38116 Braunschweig, Germany

** Aarhus University, Department of Agroecology, PO Box 50, Research Centre Foulum, 8830 Tjele, Denmark

*** University of Veterinary Medicine Hannover, Institute for Animal Breeding and Genetics, Bünteweg 17p, 30559 Hannover, Germany; present affiliation: Leibniz Institute for Farm Animal Biology (FBN), Wilhelm-Stahl-Allee 2, 18196 Dummerstorf, Germany

**** Friedrich Loeffler Institute (FLI), Federal Research Institute for Animal Health, Institute of Animal Nutrition, Bundesallee 50, 38116 Braunschweig, Germany

Contact: ulrich.daemmgen@daemmgen.de

Zusammenfassung

Schätzung der Ausscheidungsraten von Methan, organischer Trockensubstanz ("volatile solids") und Stickstoff von deutschen Mutterkühen

Die Mutterkuhhaltung ist ein Wirtschaftszweig in der deutschen Rindfleischproduktion, der zunehmend Bedeutung gewinnt. Emissionen von Treibhausgasen und luftverschmutzenden Gasen aus der Mutterkuhhaltung wurden in Deutschland bisher unter Verwendung von Standard-Annahmen (IPCC „default values") beschrieben. In der vorliegenden Arbeit wird die Quantifizierung der für die Emissionen wichtigen Ausscheidungen von Mutterkühen von dem Milchkuh-Modell abgeleitet, das im nationalen Emissionsinventar verwendet wird. Daten zur Herdenzusammensetzung wurden ausgewertet und Literaturdaten zu Tiergewichten und zur Milchleistung sowie zur Fütterung zusammengestellt, um die für die Berechnung der Emissionen wichtigen Ausscheidungsraten von „volatile solids" und Stickstoff bestimmen zu können.

Kuhgewicht, Milchleistung und Futterqualität wurden dabei als die wichtigsten Eingabeparameter identifiziert.

In den Inventaren müssen Emissionen als Zeitreihen berichtet werden. Für wichtige Parameter der deutschen Mutterkuh-Haltung insgesamt, insbesondere die Verteilung der Genotypen, konnten diese nicht im gewünschten Umfang erstellt werden. Daher beschränkt sich die Beschreibung der Ausscheidungsraten der deutschen „mittleren Mutterkuh" auf die Darstellung der gegenwärtigen Situation. Die beschriebenen Ergebnisse widersprechen teilweise den in den gängigen deutschen Handbüchern gemachten Empfehlungen, insbesondere der Milchleistung der Mutterkühe.

Schlüsselwörter: *Methan, volatile solids, Stickstoff, Ausscheidung, Mutterkühe, Modell*

1 Introduction

Cattle are the main source of air pollutants and greenhouse gases in German agriculture. In 2011, about 64 % of the 529 Gg a^{-1} NH_3 emitted from German agriculture originated from the manure management of cattle, and 92 % of agricultural CH_4 emissions from cattle (enteric fermentation and manure management). The share of suckler cows is small but not negligible: 6.4 % of cattle NH_3 emissions and 6.7 % of cattle CH_4 emissions are at present related to suckler cows. They represent about 15 % of the number of dairy cows in Germany (with varying shares, e.g. Bayern: 6.1 %; Brandenburg: 37.3 %, see Lorz, 2010).

Suckler cows produce offspring without producing milk as commodity. As a rule, these animals are kept on marginally profitable grassland areas where the production of beef is coupled to landscape maintenance and preservation (e.g. Weiher, 1994; Bauer et al., 1997; Hochberg, 2007). With decreasing dairy cow numbers and decreasing numbers of births per dairy cow (ADR, 1993 ff), beef production with suckler cow herds is likely to increase to meet the demand. Until now, the various production processes with different genotypes have not been analyzed with respect to their typical emissions of greenhouse gases and air pollutants. Such an attempt presupposes the availability of a set of models describing the whole production line, i.e. suckler cows, heifers for replacement and female and male beef cattle. This has to be performed using a consistent and coherent set of models that reflect animal performance and feed properties.

This work aims at a description of suckler cows excretion and emission rates. The dairy cow model used in the German agricultural emission inventory is adapted to describe the performance and feed data of suckler cows, to enable the derivation of excretion rates of volatile solids (VS) and nitrogen (N). As production characteristics have changed with time, calculations aim at a time series of typical mean excretion rates of German suckler cows. It is not intended to provide a spatial resolution, e.g. for German federal states.

Hence, the approach comprises the following steps:

- Step 1: establishing the suckler cow model by adaptation of the original dairy cow model
- Step 2: identification and provision of input parameters used to run the suckler cow model
- Step 3: sensitivity analysis

The application of the adjusted model to describe typical German suckler cows then presupposes:

- Step 4: establishing the national herd composition (share of different breeds)
- Step 5: identification of relevant national performance data (as time series)
- Step 6: quantification of excretion rates using national input data sets
- Step 7: discussion of representativeness and valuation of uncertainties

2 The suckler cow model

The suckler cow model is derived from the dairy cow model as described in Rösemann et al. (2013; for further details see Dämmgen et al., 2009, 2011) used in the German agricultural emission inventory model GAS-EM. It differs from the dairy cow model in three respects.

(1) Changes in the quantification of maintenance energy requirements

For suckler cows producing beef calves ("Fleischrassen"), the constant $\eta_{nel,\,m}$ (see Equation (1)) differs from that for dairy cows; energy requirements are about 20 % less than for dairy cows (Equation 1.4.1 in GfE, 2001; see also Steinwidder and Häusler, 2004):

$$nel_{m} = \eta_{nel,\,m} \cdot w_{unit} \cdot \left(\frac{w}{w_{unit}}\right)^{0.75} \qquad (1)$$

where

nel_m mean daily net energy required for maintenance (in MJ cow^{-1} d^{-1} NEL)
$\eta_{nel,\,m}$ constant
  dairy cows: $\eta_{nel,\,m,\,dc} = 0.364$ MJ kg^{-1} d^{-1} NEL
  suckler cows: $\eta_{nel,\,m,\,sc} = 0.293$ MJ kg^{-1} d^{-1} NEL
w_{unit} unit value of animal weight (w_{unit} = 1 kg cow^{-1})
w animal weight averaged over lifetime (in kg cow^{-1})

(2) Changes in the calculation of suckler cows' mean live weights and weight gains (see Appendix I).

(3) The use of variable calf birth weights for the quantification of energy requirements related to the development of the conception products (see Appendix II).

3 The input parameters required

The various suckler cow model sub-modules make use of an input data set that differs from the dairy cow model:

- For the assessment of *energy requirements and feed intake rates* the model requires information on live weight, live weight gain, milk yield, milk fat and protein contents, calf weight and number of calves per year.
- As the feed intake rate is also depending on the energy content of the diet, the energy contents of the diet constituents (expressed as NEL and ME contents[1] are needed as well.
- *Methane (CH_4) emissions* from enteric fermentation depend on diet composition. Hence, the crude fibre (CF),

[1] The German valuation system of feed quality differentiates between dairy cows and other cattle. For dairy cows the NEL system is used (NEL: net energy for lactation), for other cattle the ME system (ME: metabolizable energy) is applied in the respective calculations. Hence, both NEL and ME intakes are shown in the following Tables.

nitrogen (N) free extracts (NFE), crude protein (CP) and crude fat (ether extract, EE) contents of the diet have to be taken into account.

- Usually methane emission rates are characterized by the so-called *methane conversion rate* (MCR), i.e. the ratio of the energy equivalent of the methane released to the gross energy (GE) intake. Hence, the GE content of the diet has to be known.
- The quantification of CH_4 *emissions from manure management* according to IPCC (1996, 2006) presupposes the quantification of VS excretion rates. For their calculation feed ash content and digestibility of organic matter are needed.
- N is excreted as *organic N* with faeces and as *total ammoniacal N* (TAN) with urine. In order to estimate their excretion rates, information on feed dry matter intake, feed N content, digestibility of N in feed, overall N contents of both cows and the calves, milk yield and N content of milk protein is required.

4 Sensitivity analysis

The applicability of the model was tested in a sensitivity analysis that was based on data as provided in various German recommendations and textbooks (Bach, 1990; Bauer et al., 1997; Weiß et al., 2005; KTBL, 2006; DLG, 2009; KTBL, 2010) and covers the respective ranges of input parameters found in the literature.

4.1 Default values for the sensitivity analysis

Standard properties for the calculation of energy requirements are:

- mean cow weight 700 kg cow^{-1}
- mean weight gain 0 kg cow^{-1}
- birth rate 1 calf cow^{-1} a^{-1}
- calf birth weight 40 kg calf^{-1}
- milk yield 2,500 kg cow^{-1} a^{-1}
- milk fat content 0.040 kg kg^{-1}
- milk protein content 0.034 kg kg^{-1}
- feed quality during grazing 5.5 MJ kg^{-1} NEL in DM
- duration of the grazing period 210 d a^{-1} with 24 h d^{-1}

These properties are varied during the sensitivity analysis.

4.2 Output parameters

The following tables (Tables 2 to 10) list relevant input parameters such as feed intake as well as their variation and the resulting excretion rates as well as common key parameters as output entities. Feed intake is usually characterized by energy (NEL and ME) and dry matter (DM) intake rates. CH_4 is released from enteric fermentation (characterized by MCR) and from manure storage (characterized by B_o and MCF). The latter is governed by the excretion rates of VS. As explained above, emissions of N species from the manure management system, such as NH_3, nitric oxide (NO) and nitrous oxide (N_2O) originate from total N and TAN available in the system. The ratio of TAN excreted to total N excreted is used as an indicator value[2].

In Tables 2 to 10, input data for the standard suckler cow used in the sensitivity analyzes are written in bold figures.

The number of digits given in the tables does not reflect the uncertainty of the respective modelled parameter.

4.3 Variation of animal weights and weight gains

Maintenance energy requirements are governed by **animal weight**. Table 1 depicts the range of mean weights that can be found for German suckler cows (see also Table 12 below).

The effect of the mean cow weight on mean energy requirements and excretion rates

Mean weights differ from the final weights. They depend on the final cow weight and the life-span of the suckler cow. For details see Appendix I. Table 2 expresses the mean weights as percentage of the final weight.

Table 1
The effect of the mean cow weight on mean energy requirements[A] and excretion rates

mean cow weight	kg cow^{-1}	500	600	700	800	900
NEL intake rate	MJ cow^{-1} d^{-1}	46.6	51.8	**56.9**	61.7	66.4
ME intake rate	MJ cow^{-1} d^{-1}	79.5	88.4	**97.0**	105.3	113.4
DM intake rate	kg cow^{-1} d^{-1}	8.5	9.4	**10.3**	11.2	12.1
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	97.2	105.6	**113.6**	121.4	128.9
MCR	MJ MJ^{-1}	0.097	0.095	**0.093**	0.091	0.090
VS excreted	kg cow^{-1} a^{-1}	937	1,043	**1,144**	1,242	1,337
N excreted	kg cow^{-1} a^{-1}	56.4	62.9	**69.2**	75.2	81.0
TAN excreted	kg cow^{-1} a^{-1}	40.9	45.3	**49.5**	53.4	57.2
TAN/N_{excr}	kg kg^{-1}	0.725	0.720	**0.715**	0.711	0.706

[A] The model presupposes that animals are fed according to requirements.

[2] It is customary to derive TAN excretion rates from total N excretion rates using this ratio. It is listed in the emission reporting guidance documents, e.g. EMEP (2009), as a default value.

Table 2
The effect of the duration of the useful life-span on the mean animal weight (expressed as percentage of the cows' final weight)

life-span	a	3	5	7	9
mean weight	% of final weight	91.6	93.0	93.6	93.9

As shown in Table 3, weight gain requires additional energy (and feed) and retains more N.

Table 3
The effect of the mean weight gain on mean energy requirements and excretion rates

mean weight gain	kg cow^{-1} a^{-1}	0	10	20	30
NEL intake rate	MJ cow^{-1} d^{-1}	**56.9**	56.9	57.0	57.1
ME intake rate	MJ cow^{-1} d^{-1}	**97.0**	97.1	97.4	97.5
DM intake rate	kg cow^{-1} d^{-1}	**10.3**	10.4	10.4	10.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	**113.6**	113.7	113.9	114.1
MCR	MJ MJ^{-1}	**0.093**	0.093	0.093	0.093
VS excreted	kg cow^{-1} a^{-1}	**1,144**	1,145	1,148	1,150
N excreted	kg cow^{-1} a^{-1}	**69.2**	69.0	68.4	68.0
TAN excreted	kg cow^{-1} a^{-1}	**49.5**	49.1	47.9	47.1
TAN/N_{excr}	kg kg^{-1}	**0.715**	0.712	0.700	0.693

The energy requirements for the growth of the **conception products** vary with the calves' birth weights (see Appendix II). The amount of nitrogen retained is more than compensated by the additional feed intake (Table 4).

4.4 Variation of milk yield and composition

As data from the literature suggest, wide ranges of milk yields and milk fat and protein contents have to be considered. Table 5 illustrates the importance of the knowledge of reliable milk yields. The synthesis of milk fat is an energy-consuming process. This is reflected in Table 6. Changes in milk protein contents have little effect on the energy requirements but do affect the N balance (Table 7).

In this model, the duration of the lactation period has no effect on energy demands or excretion rates, as the annual total of the milk yield is used.

Table 5
The effect of the annual milk yield on mean energy requirements and excretion rates

milk yield	kg calf^{-1}a^{-1}	1,500	2,000	2,500	3,000	3,500
NEL intake rate	MJ cow^{-1} d^{-1}	53.9	55.4	**56.9**	58.3	59.8
ME intake rate	MJ cow^{-1} d^{-1}	92.0	94.5	**97.0**	99.5	102.0
DM intake rate	kg cow^{-1} d^{-1}	9.8	10.1	**10.3**	10.6	10.9
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	108.9	111.3	**113.6**	116.0	118.3
MCR	MJ MJ^{-1}	0.094	0.093	**0.093**	0.092	0.092
VS excreted	kg cow^{-1} a^{-1}	1,085	1,115	**1,144**	1,174	1,203
N excreted	kg cow^{-1} a^{-1}	65.5	67.3	**69.2**	71.0	72.8
TAN excreted	kg cow^{-1} a^{-1}	46.6	48.0	**49.5**	50.9	52.3
TAN/N_{excr}	kg kg^{-1}	0.712	0.713	**0.715**	0.717	0.719

Table 6
The effect of milk fat content on mean energy requirements and excretion rates

milk fat content	kg kg-1	0.035	0.040	0.045	0.050
NEL intake rate	MJ cow^{-1} d^{-1}	56.8	**56.9**	56.9	56.9
ME intake rate	MJ cow^{-1} d^{-1}	97.0	**97.0**	97.0	97.1
DM intake rate	kg cow^{-1} d^{-1}	10.3	**10.3**	10.3	10.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	113.6	**113.6**	113.6	113.7
MCR	MJ MJ^{-1}	0.093	**0.093**	0.093	0.093
VS excreted	kg cow^{-1} a^{-1}	1,144	**1,144**	1,144	1,145
N excreted	kg cow^{-1} a^{-1}	69.1	**69.2**	69.2	69.2
TAN excreted	kg cow^{-1} a^{-1}	49.4	**49.5**	49.5	49.5
TAN/N_{excr}	kg kg^{-1}	0.715	**0.715**	0.715	0.715

Table 4
The effect of the calf birth weight on mean energy requirements and excretion rates

calf birth weight	kg calf^{-1}	20	25	30	35	40	45
NEL intake rate	MJ cow^{-1} d^{-1}	55.0	55.5	55.9	56.4	**56.9**	57.3
ME intake rate	MJ cow^{-1} d^{-1}	93.9	94.7	95.4	96.2	**97.0**	97.8
DM intake rate	kg cow^{-1} d^{-1}	10.0	10.1	10.2	10.3	**10.3**	10.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	110.7	111.4	112.2	112.9	**113.6**	114.4
MCR	MJ MJ^{-1}	0.093	0.093	0.093	0.093	**0.093**	0.093
VS excreted	kg cow^{-1} a^{-1}	1,107	1,117	1,126	1,135	**1,144**	1,154
N excreted	kg cow^{-1} a^{-1}	67.4	67.9	68.3	68.7	**69.2**	69.6
TAN excreted	kg cow^{-1} a^{-1}	48.2	48.5	48.8	49.2	**49.5**	49.8
TAN/N_{excr}	kg kg^{-1}	0.715	0.715	0.715	0.715	**0.715**	0.715

Table 7

The effect of milk protein content on mean energy requirements and excretion rates

milk protein content	kg kg^{-1}	0.031	0.034	0.037	0.040
NEL intake rate	MJ cow^{-1} d^{-1}	56.8	**56.9**	56.9	56.9
ME intake rate	MJ cow^{-1} d^{-1}	97.0	**97.0**	97.0	97.0
DM intake rate	kg cow^{-1} d^{-1}	10.3	**10.3**	10.3	10.3
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	113.6	**113.6**	113.6	113.6
MCR	MJ MJ^{-1}	0.093	**0.093**	0.093	0.093
VS excreted	kg cow^{-1} a^{-1}	1,144	**1,144**	1,144	1,144
N excreted	kg cow^{-1} a^{-1}	69.2	**69.2**	69.1	69.1
TAN excreted	kg cow^{-1} a^{-1}	49.5	**49.5**	49.5	49.4
TAN/N_{excr}	kg kg^{-1}	0.715	**0.715**	0.715	0.715

4.5 Variation of energy contents of pasture

Feed quality varies considerably. We have chosen different pasture types that are typical for German suckler cow production. Pastures with NEL contents of about 5.2 MJ kg^{-1} can be found in extensive systems but NEL contents of 6.3 MJ kg^{-1} are considered typical for dairy cows. The mean pasture quality is taken to be 5.5 MJ kg^{-1} (LFZ Raumberg-Gumpenstein, 2011; Bauer and Grabner, 2012). Details of the feed composition assumed are shown in Table 8.

Grass silage and barley are fed when the cows are housed. A constant ratio of 90 to 10 % fresh matter (or about 96 to 4 % of DM, in accordance with the proposal in Weiß et al., 2005) is fed. The winter diet fed has about the same nutritional value as the standard grass feed used in our calculations (pasture grass 3). Hence the amounts fed can be related to the duration of grazing.

The resulting DM and NE intake and excretion rates are collated in Table 9.

Table 9

The effect of feed quality on excretion rates

pasture NEL content	kg cow^{-1} a^{-1}	5.2	5.5	5.8	6.3
NEL intake rate	MJ cow^{-1} d^{-1}	56.9	**56.9**	56.9	56.9
ME intake rate	MJ cow^{-1} d^{-1}	97.5	**97.0**	96.2	92.2
DM intake rate	kg cow^{-1} d^{-1}	10.7	**10.3**	10.0	9.4
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	107.2	**113.6**	98.9	88.3
MCR	MJ MJ^{-1}	0.085	**0.093**	0.084	0.080
VS excreted	kg cow^{-1} a^{-1}	1,306	**1,144**	998	893
N excreted	kg cow^{-1} a^{-1}	66.1	**69.2**	71.9	85.3
TAN excreted	kg cow^{-1} a^{-1}	46.5	**49.5**	52.1	65.2
TAN/N_{excr}	kg kg^{-1}	0.704	**0.715**	0.724	0.765

4.6 Variation of grazing times

In Germany, the duration of the grazing period for suckler cows varies between 190 and 280 d a^{-1} with a mean between 210 and 220 d a^{-1} (Rösemann et al., 2013, data on CD enclosed). The sensitivity analysis makes use of a default value of 210 d a^{-1} and steps of 20 d a^{-1}. The animals are kept outdoors 24 h d^{-1} in any case.

As differences in feed composition between grazing and housing are minor, the changes in excretion rates small (Table 10).

4.7 Summary of findings

It can be seen from the above that cow weight and milk yield have the highest impact on energy intake and excretion rates. Changes in calf birth weights have little influence on excretion rates. Almost no effect can be identified for milk fat and protein contents. Due to the small difference between the energy contents of pasture and silage/barley, the duration of the grazing period has but a small effect on excretion rates.

Hence, as a matter of priority, typical cow weights and milk yields are to be identified for the national emission inventory.

Table 8

Properties of the feed constituents used (DM: dry matter; NEL net energy for lactation; ME: metabolizable energy; CP: crude protein; CF: crude fibre; NFE: nitrogen free extracts; EE: ether extracts - crude fat; Ash: ash content). (Data sources: Beyer et al., 2004; DLG, 2009)

		energy contents [B]		feed constituent contens [B]				
	DM [A] kg kg^{-1}	NEL MJ kg^{-1}	*ME* MJ kg^{-1}	CP kg kg^{-1}	CF kg kg^{-1}	NFE kg kg^{-1}	EE kg kg^{-1}	Ash kg kg^{-1}
pasture grass 1	0.18	6.30	10.00	0.183	0.225	0.425	0.042	0.125
pasture grass 2	0.21	5.80	9.81	0.141	0.272	0.455	0.039	0.093
pasture grass 3	0.25	5.48	9.38	0.118	0.288	0.508	0.026	0.060
pasture grass 4	0.30	5.20	8.97	0.115	0.304	0.473	0.034	0.074
grass silage	0.350	5.24	8.99	0.144	0.272	0.435	0.037	0.112
barley (winter)	0.880	8.08	12.84	0.124	0.057	0.765	0.027	0.027

[A] DM related to fresh matter. [B] All information related to DM.

Table 10
The effect of the duration of the grazing period on mean energy requirements and excretion rates

grazing period	d a^{-1}	170	190	210	230	250	270
NEL intake rate	MJ cow^{-1} d^{-1}	56.3	56.6	**56.9**	57.1	57.4	57.7
ME intake rate	MJ cow^{-1} d^{-1}	95.9	96.5	**97.0**	97.6	98.1	98.7
DM intake rate	kg cow^{-1} d^{-1}	10.2	10.3	**10.3**	10.4	10.5	10.5
CH_4 emission (enteric)	kg cow^{-1} a^{-1}	110.9	112.2	**113.6**	115.0	116.4	117.9
MCR	MJ MJ^{-1}	0.092	0.092	**0.093**	0.093	0.094	0.094
VS excreted	kg cow^{-1} a^{-1}	1,125	1,134	**1,144**	1,154	1,164	1,174
N excreted	kg cow^{-1} a^{-1}	68.4	68.8	**69.2**	69.5	69.9	70.3
TAN excreted	kg cow^{-1} a^{-1}	49.1	49.3	**49.5**	49.6	49.7	49.9
TAN/N_{excr}	kg kg^{-1}	0.718	0.717	**0.715**	0.713	0.711	0.710

Note: The NEL requirements during the cows' dry period are here taken as constant irrespective of the cows' weight. GfE (2001) state that this is related to a live weight of 650 kg cow^{-1}. Bauer and Grabner (2012) apply it to all suckler cows. However, the NEL requirements during the dry period are small compared to the overall annual NEL requirements. This shortcoming will not affect the results.

5 Derivation of input parameters describing the mean German suckler cow

In contrast to dairy cows, where only a few genotypes contribute to the overall milk production, the suckler cow population consists of a high number of genotypes which differ considerably in their properties such as weight and milk yield. For most input parameters used in the model, no official data are available.

An attempt is made to derive a complete and representative set of input parameters to describe the "mean German suckler cow". These are listed at the end of each respective chapter.

5.1 Herd composition

About 40 genotypes are considered in German beef cattle herdbooks[3], 10 of them covering 90 % of the whole population[4]. For these, the Federation of German Cattle Breeders (Arbeitsgemeinschaft Deutscher Rinderzüchter, ADR) provides the number of herdbook cows of beef genotypes ("Herdbuchtiere nach Rassen: Fleischrassen"). Data for the composition of the whole German suckler cow population are available from 2008 onwards (Table 11). It shows that the majority of this population consists of crossbred animals: Many of today's suckler cows are derived from dairy cattle. In northern Germany in particular, they often are the result of (repeated) cross-breeding of Beef-Simmental bulls on black and white dairy cows (Holstein German). In southern Germany, Simmental cows were partly crossed with French beef breeds. Today, most crossbreds show properties of modern Beef-Simmentals. This is partly due to the availability of low-cost Simmental bulls in Germany.

It should be kept in mind that regional herd compositions may deviate considerably from the national mean, see e.g. Roffeis et al. (2006) for Brandenburg.

Table 11
German suckler cows' herd composition (data from ADR, 2009 to 2012)

year	2008 heads	2009 heads	2010 heads	2011 heads	mean share of breed X_{heads}
crossbreds	216,599	224,524	228,402	224,703	0.45
Angus, German	36,292	36,134	35,693	34,567	0.07
Blonde d'Aquitaine	----- [A]	-----	-----	-----	
Charolais	58,655	57,423	55,567	52,511	0.11
Galloway	18,693	17,889	17,675	16,945	0.04
Hereford	-----	-----	-----	-----	
Highland	14,326	14,518	14,826	14,490	0.03
Limousin	62,893	63,290	63,136	61,924	0.13
Simmental	43,839	45,128	45,619	45,765	0.09
Uckermärker	-----	-----	-----	-----	
other	40,270	39,682	39,334	38,914	0.08

[A] no information available

5.2 Typical cow live weights

Table 12 collates cow weights in the early 1990s and in 2010; it is assumed that the latter represent the present situation. Mean weights are calculated as the arithmetic means of the respective lower and upper values. An overall increase can be observed for most genotypes, although this change is

3 For the information provided in (regional) German herdbooks see e.g. RSA (2003) or FVB (2010).

4 For a comprehensive description of the genotypes bred in Germany see Hampel (1995).

doubted by some experts. One potential explanation for increased body weights is that breeding for higher weight gain of the offspring will also result in also higher body mass of their mothers. Improved feeding may be another explanation. In addition, genetic gains have been achieved in the feed conversion rate.

It is obvious that mean weights have increased for some breeds. However, their use as input parameters is coupled to the knowledge of the herd composition, which remains unknown before 2008. Hence the following derivation of the mean German suckler cow is confined to the period after 2008. 2010 is chosen as a reference year.

The weighted mean weight of the national suckler herd (w_m) in 2010 as calculated from the respective share of heads $x_{n,g}$ of a genotype (Table 11) and the mean weight of the genotype w_g (where crossbreds are treated as Simmentals) according to

$$w_m = \sum_g x_{n,g} \cdot w_g \qquad (2)$$

and

$$\sum x_{n,g} = 1 \qquad (3)$$

amounts to 736 kg cow $^{-1}$.

It remains unclear whether the dataset in Table 12 refers to mean live weights or slaughter weights. As can be deduced from Table 2, the difference may be reasonable.

Statistics give the live weight at the slaughter house or the carcass weight, from which final live weights can be derived. However, these weights cannot be used directly to derive the mean weights needed for the calculation of *ME* or NEL requirements for maintenance, as the animals grow considerably during their life-span as suckler cows. Furthermore, their weight oscillates with the reproduction cycles.

Recommendations regarding the productive life-span of suckler cows vary considerably. KTBL (2010) assumed four lactations as base for their economic data set. Weiß et al. (2005) assumed 6 lactations. 7.7 lactations are reported for organic farming in Böttcher (2010). Brändle and Krieg (2008) as well as Bauer et al. (2007) mention 6 to 7 lactations. By definition, suckler cows are called suckler cows after having given birth for the first time. Hence, if one assumes a mean of 6 births per cow, the lifetime of the mean suckler cow comprises 6 lactation periods and 5 births. With a mean life-span as suckler cows of 5 years, the mean annual weight gain is almost 3 % of the final weight.

A detailed procedure to derive suckler cow mean weights from a known weight is described in Appendix I.

A final live weight of 750 kg cow $^{-1}$ is assumed for the mean German suckler cow.

5.3 Typical calf birth weights

Calf birth weights vary with genotype, as Table 13 illustrates. As a rule, heavier cows give birth to heavier calves. It should be noted that the German genotypes may differ considerably from foreign breeds carrying the same names (which may be different genotypes). Consequently, the abundant information provided in the foreign literature was not used for comparisons; we constricted ourselves to data from German genotypes.

A weighted mean calf weight for 2010 was obtained from this data using the same procedure as for suckler cows (Equations (2) and (3)). Then, the mean calf weight relevant to calculate the energy requirements of suckler cows is 35.9 kg calf $^{-1}$.

A mean calf birth weight of 36 kg calf $^{-1}$ is assumed for the derivation of intake and excretion rates of the mean German suckler cow.

Table 12

Typical lower, upper and average cow weight margins of genotypes in 1990 and 2010.
Sources: Bach (1990) for about 1990 and in Waßmuth et al. (2006) and Fischer et al. (2011)

	typical suckler cow (in kg cow $^{-1}$)					
	lower margin		upper margin		mean[A]	
	1990	2010	1990	2010	1990	2010
Angus, German	550	550	700	700	625	625
Blonde d'Aquitaine	750	850	1,000	950	875	900
Charolais	750	800	900	1,000	825	900
Galloway	450	550	550	550	500	550
Hereford		600		700		650
Highland	400	450	450	550	425	500
Limousin	650	650	750	750	700	700
Simmental	650	700	750	800	700	750
Uckermärker		850		800		850

[A] arithmetic mean of range

Table 13

Typical male and female calf birth weights of genotypes provided in Bach (1990) and ADR (1993) (Table 81) and ADR (2011, Table 5.2, Fleischleistungsprüfung) for about 1990 and 2010, respectively, as well as mean weights (arithmetic mean of the respective male and female calves)

	typical calf birth weights (in kg calf $^{-1}$)					
	male		female		mean	
	1990	2010	1990	2010	1990	2010
Angus, German	550	550	700	700	625	625
Blonde d'Aquitaine	750	850	1,000	950	875	900
Charolais	750	800	900	1,000	825	900
Galloway	450	550	550	550	500	550
Hereford		600		700		650
Highland	400	450	450	550	425	500
Limousin	650	650	750	750	700	700
Simmental	650	700	750	800	700	750
Uckermärker	----- [A]	-----	-----	-----	-----	-----

[A] no information available

A time series of mean calf weights cannot be calculated as the actual herd composition is unknown for most of the time from 1992 onwards. Deriving the composition of the national herd from numbers of herdbook cows would be misleading, as the herdbooks overrepresent the rarer breeds.

5.4 Nitrogen contents of suckler cows and calves

Due to lack of data on the N content of suckler cows and calves, the respective N contents of dairy cows and their calves are used. According to DLG (2005), these amount to 0.0256 kg kg^{-1} N for cows and 0.0296 kg kg^{-1} N for calves.

5.5 Milk yield, milk composition and duration of lactation

Suckler cows give birth to one calf per year. Their milk production is governed by the milk required by their calves. As can be seen from Table 14, these amounts vary to an extent that makes the formation of a mean milk yield impossible. Again, foreign animals of the genotypes bearing identical names may differ with respect to their milk yield as well as to the percentages of milk fat and milk protein.

German recommendations also differ with respect to **mean milk yields**. Bach (1990) mentions 8 months of suckling with an average milk yield of 10 kg cow^{-1} d^{-1}, which sums to about 2,450 kg cow^{-1}. Weiß et al. (2005) assume a milk yield of about 2,500 kg cow^{-1} in 6 to 8 months of lactation. Hampel (1995) substantiates his energy requirement estimates with milk yields between 1,800 and 2,500 kg cow^{-1}. Irrespective of genotype and animal weight, DLG (2009) start from the assumption of about 3,000 kg cow^{-1} for a lactation period of 210 d a^{-1} [5]. However, Steinwidder and Häusler (2004) show (experimental) milk yields between 5 and 10 kg cow^{-1} d^{-1} for various genotypes including crossbreds, which results in a milk yield of about 1,500 kg cow^{-1} a^{-1}.

It has to be kept in mind that milk yields increase with the age of the suckler cow. Petit and Liénard (1988) refer to unpublished results of Ménissier (1987) where the milk yields of the lactations of the second and subsequent calvings exceed those of the first calving by 30 to 50 %. However, the cumulative milk yield for 210 d of lactation never exceeded 1,300 kg cow^{-1} a^{-1}.

With respect to suckler cows' milk yields, literature data and German recommendations disagree to an extent that requires special consideration (see Appendix III).

The information available on milk fat and protein contents is even more sparse. Hence the calculations make use of the respective mean properties of cows' milk, i.e. 41 g kg^{-1} fat and 34 g kg^{-1} protein (see Tables 4.10 and 4.11 in Rösemann et al., 2013), as also suggested in Steinwidder and Häusler (2004).

Weaning occurs between 6 and 10 months of age. A determining factor is the beginning sexual maturity of the calves (males at about 250 kg calf^{-1}, females at about 280 kg calf^{-1}, Steinwidder and Häusler, 2004), i.e. after about 7 months.

Conservative assumptions of a lactation period of 210 d, a milk yield of 1,500 kg cow^{-1} and milk fat and protein contents of 41 and 34 g kg^{-1}, respectively are made here.

5.6 Diet composition and feed properties

It is typical for the suckler cow production line to feed roughage as grass, grass silage or hay only, sometimes combined with small amounts of straw. Energy contents fall below those of the feed used for dairy cows (Bach, 1990; Steinwidder and Häusler, 2004; Häusler et al., 2011; Bauer and Grabner, 2012). Average *NEL* contents are approximately 5.5 MJ kg^{-1} (annual mean). Some barley may be added in winter when the silage quality is insufficient.

5 DLG (2009) extends their table to 12 months. As weaning is proposed to happen after 7 months, the following period is not taken into consideration.

Table 14
Milk yields and milk fat and protein contents – results of a literature survey.

genotype	cow weight kg cow^{-1}	milk yield kg cow^{-1} a^{-1}	milk fat content g kg^{-1}	milk protein content g kg^{-1}	source
Angus, German		2,500 - 3,000			Fleischrinderzüchter (undated)
Angus, red	470	1,745			Freetly and Cundiff (1998)
Angus, red		1,164			Scholz et al. (2001)
Angus		1,454			Marston et al. (1992)
Angus			45	33	Sinclear et al. (1998)
Blonde d'Aquitaine	-----	-----	-----	-----	
Charolais		1,350			Petit and Liénard (1988) [A]
Charolais	628	1,520			Petit and Liénard (1988)
Charolais	640	1,630			Petit and Liénard (1988)
Charolais	607	1,250			Petit and Liénard (1988)
Charolais			49	37	Sinclear et al. (1998)
Charolais	about 700	1,656			Murphy et al. (2008)
Charolais		1,596			McGee et al. (2005)
Charolais		1,318			McGee et al. (2005)
Galloway	-----	-----	-----	-----	
Hereford		950			Petit and Liénard (1988)
Hereford	480	1,060			Freetly and Cundiff (1998)
Hereford	594	768	2.59	36.0	McMorris and Wilton (1986)
Hereford		about 1,550			Kress et al. (1996)
Highland	-----	-----	-----	-----	
Limousin		1,130			Petit and Liénard (1988)
Limousin	515	1,160			Petit and Liénard (1988)
Limousin	556	1,210			Petit and Liénard (1988)
Limousin	595	1,250			Petit and Liénard (1988)
Limousin	469	1,080			Petit and Liénard (1988)
Limousin		1,891	43.0	36.5	Scholz et al. (2001)
Limousin	about 600	1,320			Murphy et al. (2008)
Simmental		3,750	40.9	34.9	Scholz et al. (2001)
Simmental	700	1,364	30.9	36.9	McMorris and Wilton (1986)
Simmental		1,724			Marston et al. (1992)
Simmental	543 - 685	3,351	32.0	30.0	Häusler et al. (2011)
Simmental		3,329			Steinwidder et al. (undated)
Uckermärker	-----	-----	-----	-----	

[A] Milk yields in Petit and Liénard are listed in kg cow^{-1} d^{-1} for a lactation period of 6 to 7 months. Here, they were multiplied with 220 d of lactation.

Hence we use pasture grass 3 (5.5 MJ kg^{-1} NEL) and the silage / barley mixture (9 to 1) as described in Table 8.

5.7 Housing and grazing

Statistisches Bundesamt supplied data describing the overall distribution of the grazing management. 24 % of all animals are kept outdoors all year round; 76 % are kept on pasture part of the day, 23.6 h d^{-1} over a grazing period of 227.5 d a^{-1}. **This data is used in the suckler cow model.**

6 Resulting energy requirements, feed intake and excretion rates – discussion and conclusions

If the data set described above is input into the suckler cow model, one obtains the results shown in Table 15. This table also allows for a comparison with the data set used in the German agricultural emission inventory (Rösemann et al., 2013, data on CD enclosed).

Table 15
Energy requirements, dry matter intake and excretion rates of the mean German suckler cow

	unit	mean German suckler cow (this work)	German inventory 2010 (Rösemann et al., 2013)
mean weight	kg cow $^{-1}$	750	650
NEL intake rate	MJ cow $^{-1}$ d $^{-1}$	50.7	
ME intake rate	MJ cow $^{-1}$ d $^{-1}$	86.2	98.6
DM intake rate	kg cow $^{-1}$ d $^{-1}$	9.2	9.8
CH_4 emission (enteric)	kg cow $^{-1}$ a $^{-1}$	88.2	76.2
MCR	MJ MJ $^{-1}$	0.089	0.065
VS excreted	kg cow $^{-1}$ a $^{-1}$	987	881
N excreted	kg cow $^{-1}$ a $^{-1}$	57.6	82
TAN excreted	kg cow $^{-1}$ a $^{-1}$	36.9	
TAN/Nexcr	kg kg $^{-1}$	0.641	0.60

The data used in the German emission inventory stem from various standard textbooks, table books and guidance documents for emission inventories. The assumptions with regard to ME and DM intake rates as well as the N excretion rates exceed those found in the work at hand; whereas the VS fall below those established in this work.

In the inventory, the CH_4 emission rates from enteric fermentation are calculated using the MCR provided in the IPCC (2006) Guidebook. It can be shown that this MCR underestimates emission rates for low milk yields under German conditions (Dämmgen et al., 2012). The feed quality assumed for suckler cows in the work at hand reflects the fact that suckler cows are mainly kept on marginally profitable grasslands, which produce herbage with low energy and high fibre contents. This also explains the low N excretion rate found in this work. Many pastures do not receive N in the form of fertilizer or manure, so rely on the recycling of the N excreted and the N fixation of legumes to support production. The ratio of TAN to N excreted as used in the present inventory is the default value provided in EMEP (2009). Its application would result in a TAN excretion rate of 49 kg cow $^{-1}$ a $^{-1}$. However, the suckler cow model calculates this ratio from feed properties, which results in a lower TAN excretion rate than in the present German inventory.

The estimates of energy intake obtained in this work are compared with a range of recommendations published in Germany in Table 16. This comparison suffers from an inadequate description of the parameters governing the energy input in the published recommendations. In particular, it is likely that the published recommendations incorporate a safety margin, to ensure that the energy requirements are always fulfilled, despite inter-animal variations in the herd. The high milk yields assumed explain why the energy requirements given in the literature exceed those determined in the work at hand. The values from KTBL (2006, 2010) are closest to the findings in this work but no performance data are included in this publication.

The discussion of the uncertainties of the results obtained for the mean German suckler cow reflects the uncertainties of the suckler cow excretion model and the data.

The dairy cow model from which the suckler cow model was derived passed international review processes within the IPCC and EMEP review processes successfully. Comparisons with measured data are still sparse. However, the CH_4 module derived from Kirchgeßner et al. (1995) illustrates the natural scatter of results from which we estimate an uncertainty of about 10 % (valid input parameters provided).

It remains difficult to address the uncertainties of the output parameters produced in the work at hand, as no uncertainties are available for the input parameters. Only the animal numbers provided by Statistisches Bundesamt can be claimed correct.

If the cow weights are taken to have a range as shown in Table 12, an uncertainty of about 20 % may be deduced for single genotypes. If one assumes an error of 50 kg cow $^{-1}$ for the “mean cow” (i.e. about 7 % of a 750 kg cow) in the estimate of the mean weight, an error of about 4 % results for the excretion rates. Furthermore, it is unclear which type of animal weight is listed (mean weight, weight before slaughtering). The information provided in Table 2 suggests another uncertainty of about 5 %.

As shown in Table 3, weight gains are unlikely to have a significant effect on uncertainties.

Calf weights are recorded from measurements and can be considered accurate, as are the reported weight gains. The derivation of energy requirements for calves, however, relies on data and methods for which uncertainties are unknown. However, Table 4 indicates that errors in the assumption of mean calf birth weights (which will be in the order of a few kg

Table 16
Comparison of modelled energy requirements with published German recommendations (rounded data)

Source	milk yield kg cow $^{-1}$ a $^{-1}$	animal weight kg cow $^{-1}$	energy intake unit	energy intake source	energy intake this work
Bach (1990)	2,500	650	NEL (GJ cow $^{-1}$ a $^{-1}$)	28	18.5
Weiß et al. (2005)	2,500	650	NEL (MJ cow $^{-1}$ d $^{-1}$)	69	50.7
KTBL (2006)	---	---	GE (GJ cow $^{-1}$ a $^{-1}$)	54	60.0
DLG (2009)	4,000	600 - 750	NEL (MJ cow $^{-1}$ d $^{-1}$)	76	50.7
KTBL (2010)	---	---	ME (GJ cow $^{-1}$ a $^{-1}$)	36	31.4

calf [-1]) will not lead to significant errors in the excretion rates of the suckler cows.

The suckler cow model makes use of assumptions on feed quality. As Table 9 shows, a change of the NEL content by 0.1 MJ kg^{-1} (about 2 %) may result in changes of about 5 % for the excretions.

With so many inadequacies in the input parameters, we are unable to rigorously calculate the overall uncertainty of the excretion rates of the mean German suckler cow. We estimate that – given a well characterized set of input data – the model is able to produce plausible results with an uncertainty of less than 20 %.

7 Representativeness of the "mean German suckler cow"

In principle, the suckler cow model can be used to describe single farm situations as long as the set of input parameters can be established satisfactorily. The use of mean values as established above restricts the meaningfulness of resulting excretion and emission rates to the nation as a whole. A higher resolution in space, e.g. the application of the model to single administrative districts, is not allowed.

Appendix I

Determination of mean weights and weight gains of suckler cows

Mean cow weights

Suckler cows are first bulled when they reach about 65 % of the mature cow weights (Bach, 1990; Waßmuth et al., 2006; EBLEX, 2008; Bauer and Grabner, 2012). At their first calving, they have reached about 86 % of their final (mature) cow weights and about 96 % after the birth of their second calves. After the third calf no substantial further weight gain is observed. Cows lose about 10 % of their weight at calving in the form of the calf and afterbirth. This weight is regained in the period by the next calving.

These experimental findings are depicted in the model. Figure A1 illustrates the development of a cow's live weight as considered in this work.

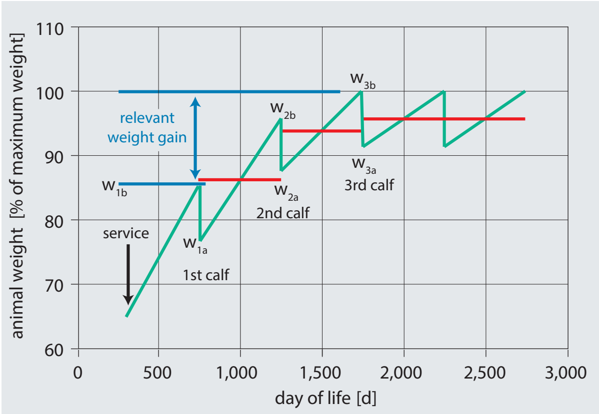

Figure A1
Example live weight development of a suckler cow (green line) (modified after EBLEX, 2008, and related to the German situation using Brade's expert judgement), the annual mean weights (red lines) and the relevant weight gain (blue).

The relevant weight is the mean weight of the animal w_{mean}.

$$w_{\text{mean}} = \left(\frac{w_{1a} + w_{2b}}{2} \cdot 1 + \frac{w_{2a} + w_{3b}}{2} \cdot 1 + \frac{w_{3a} + w_{\text{fin}}}{2} \cdot \left(n_{\text{life-span}} - 2 \right) \right) \cdot \frac{1}{n_{\text{life-span}}} \quad \text{(A1)}$$

with

$$w_{1a} = a \cdot w_{1b} \quad \text{(A2)}$$
$$w_{1b} = b \cdot w_{\text{fin}} \quad \text{(A3)}$$
$$w_{2a} = a \cdot w_{2b} \quad \text{(A4)}$$
$$w_{2b} = c \cdot w_{\text{fin}} \quad \text{(A5)}$$
$$w_{3a} = a \cdot w_{3b} \quad \text{(A6)}$$
$$w_{3b} = w_{\text{fin}} \quad \text{(A7)}$$

resulting in

$$w_{\text{mean}} = \left(\frac{a \cdot b \cdot w_{\text{fin}} + c \cdot w_{\text{fin}}}{2} \cdot 1 + \frac{a \cdot c \cdot w_{\text{fin}} + w_{\text{fin}}}{2} \cdot 1 + \frac{a \cdot w_{\text{fin}} + w_{\text{fin}}}{2} \cdot \left(n_{\text{life-span}} - 2 \right) \right) \cdot \frac{1}{n_{\text{life-span}}} \quad \text{(A8)}$$

or

$$w_{\text{mean}} = \left(a \cdot b + c + a \cdot c + 1 + [a+1] \cdot \left(n_{\text{life-span}} - 2 \right) \right) \cdot \frac{w_{\text{fin}}}{2\, n_{\text{life-span}}} \quad \text{(A8a)}$$

where

w_{mean} relevant mean weight (in kg cow $^{-1}$)
w_{1a} weight immediately after the first calving (in kg cow $^{-1}$)
w_{2b} weight immediately before the second calving (in kg cow $^{-1}$)
w_{2a} weight immediately after the second calving (in kg cow $^{-1}$)
w_{3b} weight immediately before the third calving (in kg cow $^{-1}$)
w_{3a} weight immediately after the third calving (in kg cow $^{-1}$)
w_{fin} final weight at the end of the cow's life (in kg animal $^{-1}$)
$n_{\text{life-span}}$ life-span from first calving to slaughtering (in a)

and

w_{1b} weight immediately before the first calving (in kg cow $^{-1}$)
a constant (a = 0.90 kg kg $^{-1}$) (see text above)
b constant (b = 0.86 kg kg $^{-1}$)
c constant (c = 0.96 kg kg $^{-1}$)

Mean cow weight gains

The animal subcategory 'suckler cows' comprises females after their first calving. Overall weight gains have to consider comparable weights reflecting the periodic changes due to pregnancy and calving. It is assumed that cows reach their mature weight after the third calving, and that the weight gained after the first calving is about 10 % of the mature weight, that after the second calving is 4 % [6].

where

Δw_{mean} relevant mean weight gain (in g animal $^{-1}$ d $^{-1}$)
w_{fin} mature weight (at the end of the cow's life) (in kg cow $^{-1}$)
w_{1b} start weight immediately before the first calving (in kg cow $^{-1}$)
β mass units conversion factor (β = 1,000 g kg $^{-1}$)
$n_{\text{life-span}}$ life-span from first calving to slaughtering (in a)
α time units conversion factor (α = 365 d a $^{-1}$)
b constant (b = 0.86 kg kg $^{-1}$)

As illustrated in Figure A1, the relevant annual weight gain is

$$\Delta w_{\text{mean}} = \left(w_{\text{fin}} - w_{\text{1b}} \right) \cdot \beta \cdot \frac{1}{n_{\text{life-span}} \cdot \alpha} = (1-b) \cdot \beta \cdot \frac{w_{\text{fin}}}{n_{\text{life-span}} \cdot \alpha} \quad \text{(A9)}$$

6 This corresponds to Waßmuth et al. (2006) who recommend a weight of about 60 % of the final weight, or about 400 kg cow $^{-1}$ in Bauer et al. (1997).

Appendix II

Derivation of the energy requirements for pregnancy

The energy required to develop conception products are a function of the size of the conception products. For beef cows, the *ME* requirements for pregnancy (in addition to their maintenance requirements) was expressed as a function of the calf's birth weight by Nicol and Brookes (2007) (Table A1).

Table A1
ME requirements for the development of the conception products according to Nicol and Brookes (2007)

calf birth weight	12	8	4	0	total
	weeks before calving				
kg calf^{-1}	MJ cow^{-1} d^{-1}				MJ cow^{-1}
30	6	11	20	34	1,700
40	9	15	26	45	2,300
50	11	18	32	55	2,800

GfE (2001) recommend additional *ME* requirements as shown in Table A2 without mentioning the calf's birth weight.

Table A2
ME requirements for the development of the conception products according to GfE (2001)

weeks before calving 6 to 4		3 to 0		total	
ME	NEL	*ME*	NEL	*ME*	NEL
21	13	30	18	1,071	651

The comparison of the data provided in Tables A1 and A2 in Figure A2 suggests that the German calf birth weights should be about 35 to 38 kg calf^{-1}, which corresponds with the data used in the German agricultural inventory (36 kg calf^{-1}) (Rösemann et al., 2013).

The data set published in GfE (2001) reflects the state of knowledge prior to 1976; it gives just two data points and ignores any requirements in the early stage of the development of the conception products. We therefore prefer to use the more detailed description given in Nicol and Brookes (2007), as there is no principal difference between the metabolisms of beef, dairy and suckler cows.

As shown in Table A1, Nicol and Brookes (2007) also give cumulative additional requirements. Here, the relation between requirements and calf birth weight is linear (Figure A3).

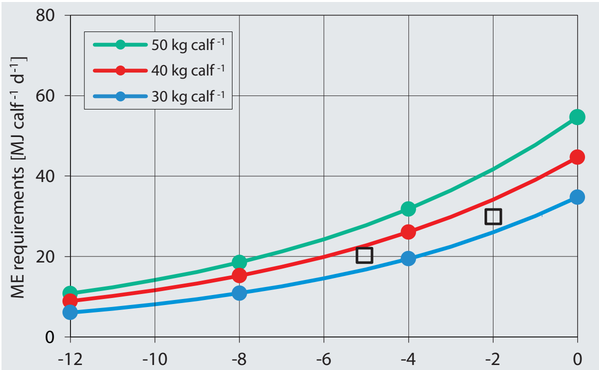

Figure A2
ME requirements for the development of the conception products according to Nicol and Brookes (2007) (lines and markers) and GfE (2001) (squares)

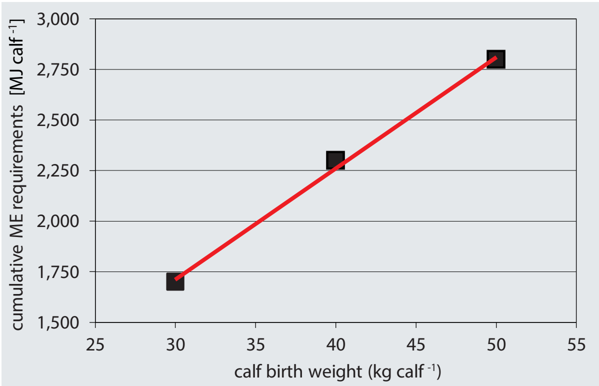

Figure A3
Relation between cumulative *ME* requirements for the development of the conception products according to Nicol and Brookes (2007) and linear regression

Nicol and Brookes (2007) use *ME* to characterize the energy requirements. The GfE (2001) data facilitate the conversion of *ME* requirements to NEL: The fractions deduced from Table A2 for the two time spans are 0.62 and 0.60 MJ MJ^{-1}, respectively; the fraction for the entire 6 weeks is 0.61 MJ MJ^{-1}. Using this as energy units conversion factor χ, cumulative NEL requirements for the development of the conception products can be calculated in *ME* units from the regression in Figure A3 as

$$nel_{p} = \chi \cdot \left(d \cdot w_{calf} + e\right) \quad (A10)$$

where

nel_p cumulative NEL required for the development of the conception products (in MJ animal^{-1} NEL)
χ mean energy units conversion factor (χ = 0.61 MJ MJ^{-1}, see text)
d coefficient (d = 55 MJ kg^{-1} *ME*; slope in Figure A3)
w_{calf} birth weight of calf (in kg calf^{-1})
e constant (e = 66.67 MJ calf^{-1}; offset in Figure A3)

Appendix III

Derivation of milk yields from calves' energy requirements

The estimate of milk yields is obviously of key importance for the quantification of emissions from suckler cows. In principle, milk yields can be derived from calves' energy intake rates if the contribution of suckling is known.

Energy requirements

Energy requirements are calculated separately for calves (weight at day 125, w_{125}, of a 125 kg calf^{-1}) and young beef cattle until weaning after seven months (w210).

According to Dämmgen et al. (2013), the ME requirements of calves from birth to a live weight of 125 kg animal^{-1} gained in 18 weeks or 125 days sum to about 3,200 MJ calf^{-1}

The recommendations provided by GfE (2001, Table 1.5.3) and shown in Table A3 are used to describe energy requirements of young beef cattle.

Table A3

ME intake rates of young beef cattle related to animal weights w_{ybc} and weight gains Δw_{ybc} (GfE, 2001)

live weight w_{ybc} kg animal^{-1}	weight gain Δw_{ybc} g animal^{-1} d^{-1}			
	600	700	800	900
150	32.3	34.1	36.0	
200	39.6	42.0	44.3	46.6
250	46.7	49.6	52.6	55.8
300	53.6	57.6	60.8	64.6

Table A3 is converted to a steady function relating ME requirements to animal weights and weight gains of young beef cattle for weights above 100 kg animal^{-1}.

$$ME_{ybc} = (f \cdot w_{ybc} + g) \cdot \Delta w_{ybc} + (h \cdot w_{ybc} + i) \quad \text{(A11)}$$

where

ME_{ybc}	metabolizable energy required for the life-span of young beef cattle (in MJ animal^{-1} d^{-1})
f	coefficient (a = 0.0001202 MJ g kg^{-1})
w_{ybc}	live weight (in kg animal^{-1})
g	constant (b = 0.000030 MJ g^{-1})
Δw_{ybc}	daily weight gain (in g animal^{-1} d^{-1})
h	coefficient (h = 0.070502 MJ kg^{-1})
i	constant (d = 10.957800 MJ animal^{-1} d^{-1})

The results obtained from the application of this equation match the contents of Table A3 perfectly. Hence, this equation is used to calculate ME requirements for animal weights above 125 kg animal^{-1}.

As the relation of ME requirements with weights and weight gains is linear in both cases, the (slight) extrapolation to higher weight gains seems adequate and was also used in GfE (2001).

Relevant animal weights and weight gains

ADR (1993, and subsequent years) list mature weights and overall weight gains Δw_{total}, for the offspring from herdbook cows that passed performance tests for all years, They also report he weights at day 200, w200, since the year 2000 onwards. The arithmetic means of the weight gains for male and female animals are shown in Table A4.

Table A4 contains gaps for weights at day 200, w_{200}, for Galloway and Highland cattle, for 2000 and 2010. These had to be filled to construct a weighted mean for the overall herd. Missing values were derived by using a mean ratio $x_{\Delta w,\,g}$ between the overall weight gain, $w_{total,\,g}$, and the weight gain at day 200, $w_{200,\,g}$, for each genotype. The arithmetic mean of the values listed in Table A4 for 2000 and 2010, $x_{\Delta w}$*, were used; values for Charolais and 2010 were omitted as dubious.

Table A4

Ratios $x_{\Delta w}$ of weight gains for genotypes g at day 200, Δw_{200}, and overall weight gains, Δw_{total}

	2000			2010			mean
	Δw_{total}	Δw_{200}	$x_{\Delta w,\,g}$	Δw_{total}	Δw_{200}	$x_{\Delta w,\,g}$	$x_{\Delta w,\,g}$*
Angus, German	1,227	988	0.81	1,264	1,010	0.80	0.80
Blonde d'Aquitaine		1,139		1,345	1,255	0.93	0.93
Charolais	1,403	1,154	0.82	1,418	1,422	1.00	0.91
Galloway	777			776			
Hereford	1,236	904	0.73	1,294	1,059	0.82	0.77
Highland	686			578			
Limousin	1,238	1,016	0.82	1,281	1,107	0.86	0.84
Simmental	1,349	1,114	0.83	1,471	1,197	0.81	0.82
Uckermärker				1,485	1,151	0.77	0.77

The resulting weight gains w_{200} for Galloway and Highland cattle are 639 and 520 g animal^{-1} d^{-1}, respectively.

A weighted mean reflecting the herd composition (numbers of herdbook cows in 2010 of the respective genotype as provided in Table 11 were used) can be obtained from this data.

$$X_{\Delta w} = \sum_{g} x_{\Delta w, g} \cdot x_{n, g} \quad \text{(A12)}$$

and

$$\sum x_{n, g} = 1 \quad \text{(A13)}$$

Calculations yield a mean $X_{\Delta w}$ of 0.82 which happens to be the value obtained for Simmentals.

The relevant mean weights describing the animals between days 125 and 210 were derived from the weight at day 125 (125 kg animal^{-1}) and the weight gained in 85 days as young beef cattle with a weight gain Δw_{200}, the so-called weanlings:

$$w_{wean} = \frac{1}{2} \cdot \left(w_{125} + \left(w_{birth} + (t_{wean} - t_{calf}) \cdot \Delta w_{200} \cdot \beta\right)\right) \quad \text{(A14)}$$

where

- w_{wean} relevant mean weight of the weanling for ME requirement calculations (in kg animal^{-1})
- w_{125} final weight of calves (w_{125} = 125 kg animal^{-1})
- w_{birth} birth weight of calves (in kg calf^{-1})
- t_{wean} time of weaning (in d)
- t_{calf} final day of calves' life-span (in d)
- Δw_{200} daily weight gain until day 200 (in g animal^{-1} d^{-1})
- β mass units conversion factor (β = 0.001 kg g^{-1})

Examples of relevant weights and weight gains are listed in Table A5. Again, weighted means for the year 2010 are calculated to be used for the ME assessment using Equation (A11).

Relevant energy requirements of weanlings

The energy requirements of weanlings at day 210 are the total of the respective requirements of calves and young beef cattle:

$$ME_{wean}{}^{*} = ME_{calf}{}^{*} + ME_{ybc}{}^{*} \quad \text{(A15)}$$

where

- ME_{wean}* ME required for the life-span from birth to weaning (in MJ animal^{-1} ME)
- ME_{calf}* ME required for the life-span from birth to day 125 (ME_{calf} = 2,875 MJ animal^{-1} ME)
- ME_{ybc}* ME required for the life-span from day 125 to weaning (in MJ animal^{-1} ME)

ME_{calf}* is constant and determined according to Dämmgen et al. (2013). ME_{ybc}* is calculated for the various genotypes using ME_{ybs} generated according to Equation (A11):

$$ME_{ybc}{}^{*} = ME_{ybc} \cdot \left(t_{wean} - t_{calf}\right) \quad \text{(A16)}$$

where

- ME_{ybc}* ME required for the life-span from day 125 to weaning (in MJ animal^{-1} ME)
- ME_{ybc} ME required for the life-span of young beef cattle (in MJ animal^{-1} d^{-1})
- t_{wean} time of weaning (in d)
- t_{calf} final day of calves' life-span (in d)

Table A5
Resulting relevant weanling weights w_{wean} and weight gains Δw_{200} for the calculaton of ME

	1992		2000		2010	
	w_{wean}	Δw_{200}	w_{wean}	Δw_{200}	w_{wean}	Δw_{200}
	kg animal^{-1}	g animal^{-1} d^{-1}	kg animal^{-1}	g animal^{-1} d^{-1}	kg animal^{-1}	g animal^{-1} d^{-1}
Angus, German	176	929	183	988	186	1,010
Blonde d'Aquitaine				1,139	215	1,255
Charolais	198	1,088	206	1,154	233	1,422
Galloway	140	628	135	639	144	638
Hereford	175	903	174	904	191	1,059
Highland	134	578	144	564	124	476
Limousin	176	920	187	1,016	198	1,107
Simmental	191	1,043	200	1,114	208	1,197
Uckermärker					203	1,151

Share of milk in calves' diets

Bauer and Grabner (2012) give an estimate of the share in calves' nutrition of ME that is covered by milk. Their information was complemented by the data given in Dämmgen et al. (2013) to provide an example estimate over the whole lactation period.

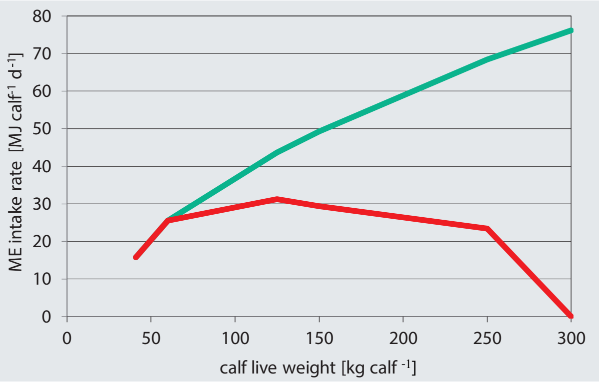

Figure A4
ME intake rate per calf. green: overall ME intake rate; red: ME intake rate as milk

In order to get an overall share the area below the green and red polygons in Figure A4 were calculated. Their ratio, i.e. the fraction of ME intake with milk and the total ME intake is 0.47 MJ MJ^{-1}. This value is used for the derivation of milk yields for all genotypes and all years.

The milk required for the feeding of calves is then calculated as

$$Y_{\text{milk}} = \frac{ME_{\text{ybc}}^{*} \cdot x_{\text{ME}}}{\eta_{\text{ME, milk}} \cdot \eta_{\text{DM, milk}}} \quad \text{(A17)}$$

Y_{milk} milk yield required to nourish one calf (in kg cow^{-1})
ME_{ybc}^{*} ME required for the life-span from day 125 to weaning (in MJ animal^{-1} ME)
x_{ME} share of ME attributed to milk (x_{ME} = 0.47 MJ MJ^{-1})
$\eta_{\text{ME, milk}}$ ME content of milk ($\eta_{\text{ME, milk}}$ = 19.19 MJ kg^{-1})
$\eta_{\text{DM milk}}$ dry matter content of milk ($\eta_{\text{DM milk}}$ = 0.123 kg kg^{-1})

Table A6 gives example results.

Table A6
Modelled milk yields for various genotypes

	1995 kg cow^{-1} a^{-1}	2000 kg cow^{-1} a^{-1}	2010 kg cow^{-1} a^{-1}
Angus, German	1,327	1,359	1,377
Blonde d'Aquitaine			1,579
Charolais	1,480	1,502	1,730
Galloway	1,114	1,104	1,128
Hereford	1,309	1,300	1,413
Highland	1,074	1,080	1,036
Limousin	1,338	1,382	1,456
Simmental	1,415	1,464	1,530
Uckermärker			1,492

For 2010, the weighted mean using animal number provided for the shares of single genotypes in the overall population amounts to 1,501 kg cow^{-1} a^{-1}. Due to lack of animal numbers, it does not include Blonde d'Aquitaine and Uckermärker.

References

ADR – Arbeitsgemeinschaft Deutscher Rinderzüchter (1993, and subsequent years) Rinderproduktion in Deutschland 1992 (and subsequent years). Bonn : ADR

Bach P (1990) Mutterkuhhaltung. Bonn : AID, 32 p

Bauer K, Grabner R (2012) Mutterkuhhaltung. Graz : Stocker, 187 p

Bauer K, Steinwender R, Stodulka P (1997) Mutterkuh-Haltung : Rassenwahl – Herdenführung - Fütterung. Graz : Stocker, 215 p

Beyer M, Chudy A, Hoffmann L, Jentsch W, Laube W, Nehring K, Schiemann R (2004) Rostocker Futterbewertungssystem : Kennzahlen des Futterwertes und Futterbedarfs auf der Basis von Nettoenergie. Dummerstorf : Forschungsinst Biol landwirtschaftl Nutztiere, 392 p

Böttcher J (2010) Datenerhebung in Rindfleisch erzeugenden Ökobetrieben zur Erfassung des Mengen- und Qualitätspotenzials sowie der Vermarktungswege in Rheinland-Pfalz [online]. To be found at <http://www.oekolandbau.rlp.de/Internet/global/themen.nsf/28fd0aad703279efc12570050048c399/3bca3eb40b2cd9e3c125785e002e4461/$FILE/Mutterkuhhaltung_RLP.pdf> [quoted 09.12.2013]

Brändle S, Krieg K (2008) Mutterkuhhaltung – wie sieht es aus im Lande? : Ergebnisse des Mutterkuhreports Baden-Württemberg 2007. landinfo 2:32-35

Dämmgen U, Amon B, Gyldenkærne S, Hutchings NJ, Kleine Klausing H, Haenel H-D, Rösemann C (2011) Reassessment of the calculation procedure for the volatile solids excretion rates of cattle and pigs in the Austrian, Danish and German agricultural emission inventories. Landbauforsch 61(2):105-116

Dämmgen U, Haenel H-D, Rösemann C, Hutchings N J, Brade W, Lebzien P (2009) 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, Meyer U, Rösemann C, Haenel H-D, Hutchings NJ (2013) Methane emissions from enteric fermentation as well as nitrogen and volatile solids excretions of German calves - a national approach. Landbauforsch Appl Agric Forestry Res 63(1):37-46

Dämmgen U, Rösemann C, Haenel H-D, Hutchings NJ (2012) Enteric methane emissions from German dairy cows. Landbauforsch 62(1/2):21-31

DLG - Deutsche Landwirtschaftsgesellschaft (2005) Bilanzierung der Nährstoffausscheidungen landwirtschaftlicher Nutztiere. Frankfurt a M : DLG-Verl, 69 p, Arb DLG 199

DLG-Arbeitskreis Futter und Fütterung (2009) Empfehlungen zur Fütterung von Mutterkühen und deren Nachzucht [online]. To b e found at <https://www.dlg.org/fileadmin/downloads/fachinfos/futtermittel/Stellungnahme-Empfehlungen_Mutterkuehe.pdf> [quoted 12.12.2013]

EBLEX - English Beef and Lamb Executive (2008) Feeding suckler cows and calves for better returns [online]. To be found at <http://www.eblex.org.uk/wp/wp-content/uploads/2013/06/Manual-5-feedingsucklercowsandcalvesforbetterreturns.pdf> [quoted 17.01.2014]

EMEP (2009) EMEP/EEA air pollutant emission inventory guidebook – 2009 [online]. To be found at <http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009> [quoted 09.12.2013]

Fischer C, Gerhardy-Lindner S, von Hennig S, Heutelbeck A, Künne H, Landmann D, Pommerien H, Schulz J (2011) Rinderhaltung. Rinderaufzucht, Milchkuhhaltung, Milcherzeugung, Rindermast und Mutterkühe : Leitfaden [online].To be found at <http://www.nibis.de/nibis3/uploads/2bbs-poelking-oesselmann/files/Leitfaden_Druckversion_02.12.2011.pdf> [quoted 09.12.2013]

Fleischrinderzüchter (undated) Deutsche Angus [online]. To be found at <http://www.fleischrinderzuechter.de/index.php?rassen_12> [quoted 12.12.2013]

Freetly HC, Cundiff LV (1998) Reproductive performance, calf growth, and milk production of first-calf heifers sired by seven breeds and raised on different levels of nutrition. J Anim Sci 76:1513-1522

FVB – Fleischrinder Verband Bayern (2010) Leitfaden zur Herdbuchzucht [online]. To be found at <http://www.lbr.bayern.de/fvb/Leitfaden%20zur%20Herdbuchzucht%20Jan.2010%20Internet.pdf> [quoted 09.12.2013]

GfE – Gesellschaft für Ernährungsphysiologie (2001) Empfehlungen zur Energie- und Nährstoffversorgung der Milchkühe und Aufzuchtrinder. Frankfurt a M : DLG-Verl, 136 p, Energie- Nährstoffbedarf landwirtschaftl Nutztiere 6

Hampel G (1995) Fleischrinder- und Mutterkuhhaltung. Stuttgart : Ulmer, 201 p

Häusler J, Steinwidder A, Eingang D, Gasteiner J, Schauer A, Gruber L (2011) Die Milchleistung von Fleckviehmutterkühen bei einer Säugezeit von 180 bis 270 Tagen. In: 38. Viehwirtschaftliche Fachtagung : Züchtung, Rindfleisch und Mutterkühe, Forschungsergebnisse LFZ, Fütterungstechnik ; gemäß Fortbildungsplan des Bundes, 13. und 14. April 2011. Irdning : LFZ, pp 25-31

Hochberg H, Zopf D, Warzecha H, Bachmann D, Mohring S (1998) Grünlandextensivierung in Thüringen : Ergebnisse der Begleituntersuchungen zum KULAP. Jena : TLL, 114 p

Hochberg H (2007) Grünlandnutzung mit Mutterkühen. Landbauforsch Völkenrode SH 313:174-197

IPCC – Intergovernmental Panel on Climate Change (1996) Revised 1996 IPCC guidelines for national greenhouse gas inventories : vol 3 : Reference manual [online]. To be found at <http://www.ipcc-nggip.iges.or.jp/public/gl/invs6.html> [quoted 11.12.2013]

IPCC – Intergovernmental Panel on Climate Change (2006) 2006 IPCC guidelines for national greenhouse gas inventories : vol 4 : Agriculture, forestry and other land use [online]. To be found at <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html> [quoted 11.12.2013]

Kirchgeßner M, Windisch W, Müller HL (1995) Nutritional factors for the quantification of methane production. In: von Engelhardt W, Leonhard-Marek S, Breves G, Gieseke D (eds) Ruminant physiology : digestion, metabolism, growth and reproduction : proceedings of the eighth International Symposium on Ruminant Physiology. Stuttgart : Enke, pp 333-348

Kress DD, Doornbos DE, Anderson DC, Davis KC (1996) Genetic components for milk production of tarentaise, hereford, and tarentaise x hereford cows. J Anim Sci 74:2344-2348

KTBL – Kuratorium für Technik und Bauwesen in der Landwirtschaft (2006) Betriebsplanung Landwirtschaft 2006/07. Darmstadt : KTBL, 672 p

KTBL – Kuratorium für Technik und Bauwesen in der Landwirtschaft (2010) Betriebsplanung Landwirtschaft 2010/11. Darmstadt : KTBL, 784 p

LFZ Raumberg-Gumpenstein (2011) Mutterkuh [online]. To be found at <http://www.raumberg-gumpenstein.at/c/index.php?option=com_content&task=view&id=962&itemid=371> [quoted 09.12.2013]

Lorz M (2010) Mutterkuhhaltung in Mecklenburg-Vorpommern : Bedeutung, Perspektiven und Probleme [online]. To be found at <http://www.landwirtschaft-mv.de/cms2/LFA_prod/LFA/content/de/Fachinformationen/Tierproduktion/Mutterkuhhaltung_und_Rindermast/18FRT_MV/LorzMutterkuhhaltung.pdf> [quoted 17.01.2014]

Marston TT, Simms DD, Schalles RR, Zoellner KO, Martin LC, Fink GM (1992) Relationship of milk production, milk expected progeny difference, and calf weaning weight in Angus and simmetal cow-calf pairs. J Anim Sci 70:3304-3310

McGee M, Drennan MJ, Caffrey PJ (2005) Effect of suckler cow genotype on milk yield and pre-weaning performance. Irish J Agric Food Res 44:185-194

McMorris MR, Wilton JW (1986) Breeding system, cow weight and milk yield effects on various biological variables in beef production. J Anim Sci 63:1361-1372

Murphy BM, Drennan MJ, O´Mara FP, McGee M (2008) Performance and feed intake of five beef suckler cow genotypes and pre-weaning growth of their progeny. Irish J Agric Food Res 47:13-25

Nicol AM, Brookes IM (2007) The metabolisable energy requirements of grazing livestock. Occ Publ NZ Soc Anim Prod 14:151-172

Petit M, Liénard G (1988) Performance characteristics and efficiencies of various types of beef cows in French production systems. Proc / World Congress on Sheep and Beef cattle Breeding 3:25-51

Roffeis M, Freier E, Münch K, Runnwerth G (2006) Produktions- und Reproduktionsleistungen in Brandenburger Mutterkuhbeständen [online]. To be found at <http://lelf.brandenburg.de/media_fast/4055/Produktions_Reproduktionsleist_BRB_Mutterkuhbe_Roffeis.pdf> [quoted 11.12.2013]

Rösemann C, Haenel H-D, Dämmgen U, Poddey E, Freibauer A, Wulf S, Eurich-Menden B, Döhler H, Schreiner C, Bauer B, Osterburg B (2013) Calculations of gaseous and particulate emissions from German agriculture 1990 – 2011 : Report on methods and data (RMD) Submission 2013. Braunschweig : Johann Heinrich von Thünen-Institut, 390 p, Thünen Rep 1

RSA - Rinderzuchtverband Sachsen-Anhalt (2003) Zuchtbuchordnung und Zuchtprogramm : Abteilung Fleischrinder [online]. To be found at <http://www.rsaeg.de/fileadmin/user_upload/rsaeg/rsaeg_alte_website/zuchtbuchordnung.pdf> [quoted 11.12.2013]

Scholz H, Kovacs AZ, Stefler J, Fahr R-D, von Lengerken G (2001) Milchleistung und -qualität von Fleischrindkühen während der Säugeperiode. Arch Tierz 44:611-620

Sinclair, KD, Yildiz S, Quintans G, Gebbie FE, Broadbent PJ (1998) Annual energy intake and the metabolic and reproductive performance of beef cows differing in body size and milk potential. Animal Sci 66:657-666

Steinwidder A, Häusler J (2004) Anforderungen an die Fütterung im Mutterkuhbetrieb. In: Bericht / 31. Viehwirtschaftliche Fachtagung zum Thema Kälberaufzucht, Mutterkuhhaltung, Milchviehfütterung : 27. und 28. April 2004 an der BAL Gumpenstein. Irdning : BAL, pp 5-20

Steinwidder A, Häusler J, Schauer A, Maierhofer G, Gruber L, Gasteiner J, Podstatzky L Einfluss des Absetztermins auf die Milchleistung und Körpermasse von Mutterkühen sowie die Zuwachsleitung von Mutterkuh-Jungrindern [online]. To be found at <http://www.raumberg-gumpenstein.at/c/index.php?option=com_fodok&Itemid=199&task=detail&filter_publnr[]=2154> [quoted 21.01.2014]

Waßmuth R, Bialek R, Schöne F, Löhnert H-J, Berger W, Hochberger H, Beyersdorfer G, Kästner B (2006) Leitlinie zur effizienten und umweltverträglichen Mutterkuhhaltung [online]. To be found at <http://www.tll.de/ainfo/pdf/muku0206.pdf> [quoted 11.12.2013]

Weiher O (1994) Zuchtziele und Marketing bei Fleischrindern. Züchtungs-kunde 66:471-483

Weiß J, Pabst W, Strack KE, Granz S (2005) Tierproduktion. Stuttgart : Parey. 579 p