vTI
Johann Heinrich
von Thünen-Institut

Vol.62 No. 1/2 06.2012

Landbauforschung
vTI Agriculture and Forestry Research

Bundesministerium für
Ernährung, Landwirtschaft
und Verbraucherschutz

Landbauforschung

Landbauforschung (vTI Agriculture and Forestry Research) ist ein wissenschaftliches Publikationsorgan des Johann Heinrich von Thünen-Instituts (vTI), Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei. Die Zeitschrift wird vom vTI herausgegeben und erscheint vierteljährlich. Die Sprache der Beiträge ist deutsch und englisch. Sonderhefte erscheinen nach Bedarf.

In der Zeitschrift werden Forschungsergebnisse aus der Ressortforschung des BMELV mit Bezug zur Land- und Forstwirtschaft und den ländlichen Räumen veröffentlicht, einschließlich Forschungsergebnissen aus Kooperationsprojekten, an denen das vTI beteiligt ist.

Die Landbauforschung ist eine multidisziplinär ausgerichtete Zeitschrift, die die verschiedenen Facetten der Agrar- und Forstwissenschaften einschließt und besonderes Augenmerk auf deren interdisziplinäre Verknüpfung legt.

Englischsprachige Beiträge sind erwünscht, damit die Forschungsergebnisse einem möglichst breiten wissenschaftlichen Diskurs zugeführt werden können.

Für den Inhalt der Beiträge sind die Autoren verantwortlich. Eine Haftungsübernahme durch die Redaktion erfolgt nicht.

Mit der Einsendung von Manuskripten geben die Verfasser ihre Einwilligung zur Veröffentlichung. Die von den Autoren zu beachtenden Richtlinien zur Einreichung der Beiträge sind unter www.vti.bund.de oder bei der Geschäftsführung erhältlich.

Indexiert in:
CAB International, Science Citation Index Expanded, Current Contents - Agriculture, Biology & Environmental Sciences

Herausgeber
Johann Heinrich von Thünen-Institut (vTI)

Gutachtergremium
Siehe 3. Umschlagseite

Schriftleitung
Prof. Dr. Folkhard Isermeyer

Geschäftsführung
Dr. Matthias Rütze
Tel. 040 · 739 62 - 247
Leuschnerstraße 91
21031 Hamburg, Germany

landbauforschung@vti.bund.de
www.vti.bund.de

ISSN 0458-6859

vTI Agriculture and Forestry Research

Landbauforschung (vTI Agriculture and Forestry Research) is a scientific journal of the Johann Heinrich von Thünen Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries. The journal is published quarterly by the vTI. The articles appear in either German or English. Special issues are published as required.

The journal publishes research results under the auspices of the German Ministry of Food, Agriculture and Consumer Protection (BMELV). Articles bear relevance to agriculture and forestry, as well as to rural areas, and include research results from cooperative projects involving the vTI.

vTI Agriculture and Forestry Research is a multidisciplinary journal, encompassing the various facets of this field of research and placing a particular emphasis on interdisciplinary linkages.

English language contributions are desired so that the research results can achieve as broad a scientific discourse as possible.

The authors are responsible for the content of their papers. The publishers cannot assume responsibility for the accuracy of articles published.

With the submission of a manuscript, the author grants his or her permission for publication. Authors are requested to follow the guidelines for submission found at www.vti.bund.de or available from the management.

Indexed in:
CAB International, Science Citation Index Expanded, Current Contents - Agriculture, Biology & Environmental Sciences

Publisher
Johann Heinrich von Thünen Institute (vTI)

Editorial Board
Directors of vTI-Institutes

Editor in Chief
Prof. Dr. Folkhard Isermeyer

Managing Editor
Dr. Matthias Rütze
Phone + 49 - 40 · 739 62 - 247
Leuschnerstraße 91
21031 Hamburg, Germany

landbauforschung@vti.bund.de
www.vti.bund.de

ISSN 0458 – 6859

Landbauforschung
vTI Agriculture and Forestry Research

Vol. 62 No. 1/2 06.2012

Data sets to assess methane emissions from untreated cattle and pig slurry and solid manure storage systems in the German and Austrian emission inventories

Ulrich Dämmgen*, Barbara Amon**, Nicholas J. Hutchings***, Hans-Dieter Haenel*, and Claus Rösemann*

Abstract

Methane emissions have to be reported within the Framework Convention on Climate Change. They are assessed according to the guidelines provided by IPCC. However, the methane conversion factors provided in the guidance documents published in 1996, 2000 and 2006 differ considerably. The literature available was inspected in order to establish those parameters that allow for the most adequate description of the situation in Germany and Austria. Matching pairs for maximum methane producing capacities (B_o) and methane conversion factors (MCF) were deduced for cattle and pig slurry and farmyard manure.

Keywords: methane, emission, model, manure management, cattle, pigs

Zusammenfassung

Datensätze zur Berechnung von Methan-Emissionen aus Lagern von unbehandeltem Flüssig- und Festmist für Rinder und Schweine im deutschen und österreichischen Emissionsinventar

Methan-Emissionen aus dem Wirtschaftsdünger müssen im Rahmen des Klimarahmenabkommens berichtet werden. Die Quantifizierung erfolgt nach Richtlinien, die IPCC vorgibt. Die in den Jahren 1996, 2000 und 2006 veröffentlichten Richtlinien enthalten jedoch stark voneinander abweichende Methan-Umwandlungsfaktoren. Die vorhandene Literatur wurde mit dem Ziel gesichtet, die für die Situation in Deutschland und Österreich am ehesten geeigneten Parameter zu ermitteln. Für Rinder- und Schweinegülle und -festmist wurden Wertepaare für die maximale Methan-Bildungskapazitäten (B_o) und die Methan-Umwandlungsfaktoren (MCF) ermittelt.

Schlüsselwörter: Methan, Emission, Modell, Wirtschaftsdüngerlager, Rinder, Schweine

* Johann Heinrich von Thünen-Institut (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute for Agricultural Climate Research, Bundesallee 50, 38116 Braunschweig, Germany

** University of Natural Resources and Life Sciences, Department of Sustainable Agricultural Systems, Division of Agricultural Engineering, Konrad-Lorenz-Strasse 24, A-3430 Tulln, Austria

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

1 Introduction

Methane (CH_4) emissions in animal husbandry originate from enteric fermentation (in particular from ruminants), from storage of animal slurries and manures and from subsequent application. The latter are very low (Chadwick et al., 2000) and are usually ignored in emission inventories. Emissions from enteric fermentation exceed those from storage of slurry and manure and are regarded a key source in greenhouse gas emission reporting. However, emissions from storage are also a key category in many states, including Germany and Austria. The assessment of emissions from stored manures is difficult due to lack of experimental data. So it is customary to model them. Mechanistic models are still being developed (e.g. Huang et al., 2010), and at present not utilizable for inventory purposes. It is customary to use the methodology provided by the Intergovernmental Panel on Climate Change (IPCC). The three IPCC Guidelines (IPCC 1996, 2000a, 2006) propose a general pathway and default values. However, these default values differ considerably.

The goal of this paper is the derivation of an instrument to describe methane emissions from manure management (cattle and pigs) in Germany and Austria that allows either for the establishment of national data sets or for a decision concerning the best IPCC default value to use.

2 Reporting of emission rates and emission explaining variables

In this section, we consider the origins and basis for the IPCC approach for calculating CH_4 emissions. We then consider the extent to which the constants used are indeed constants and to what extent default values are adequate.

2.1 The IPCC methodology

IPCC uses the calculation procedure proposed by Safley et al. (1992) that relates CH_4 emission factors EF to the amount of total volatile solids excreted (VS), their maximum methane producing capacity (B_o) and methane conversion factors (MCF). Emission rates have to be reported as mass flows in kg a^{-1} CH_4 for single animal categories together with the B_o and MCF used for their assessment. Many categories (e.g. other cattle, pigs) consist of subcategories whose emissions have to be calculated separately. Here, the entity used for comparison is the implied emission factor IEF which is the weighted mean of the subcategory emission factors taking into account the various manure management systems:

$$IEF_{\mathrm{CH4,\,MM,\,i}} = \frac{1}{\sum_{\mathrm{k}} n_{\mathrm{k}}} \sum_{\mathrm{k}} \left(n_{\mathrm{k}} \cdot VS_{\mathrm{k}} \cdot \alpha \cdot B_{\mathrm{o,k}} \cdot \rho_{\mathrm{CH4}} \cdot \sum_{\mathrm{j}} MCF_{\mathrm{j}} \cdot X_{\mathrm{k,j}} \right) \qquad (1)$$

with

$$\sum_{\mathrm{j}} X_{\mathrm{k,j}} = 1$$

for any k and

$$\sum_{\mathrm{k}} n_{\mathrm{k}} = n_{\mathrm{i}}$$

where

$IEF_{\mathrm{CH4,\,MM,\,i}}$ implied emission factor for methane from manure management for animal category i composed of k subcategories with j manure management systems each (in kg place^{-1} a^{-1} CH_4)
n_{k} number of animal places in subcategory k (in place)
VS_{k} volatile solid excretion of animal subcategory k (in kg place^{-1} d^{-1})
α time units conversion factor (365 d a^{-1})
$B_{\mathrm{o,\,k}}$ maximum methane producing capacity of animal subcategory k (in m^3 kg^{-1} CH_4)
ρ_{CH4} density of methane (ρ_{CH4} = 0.67 kg m^{-3})
MCF_{j} methane conversion factor for manure management system j (in m^3 m^{-3})
$X_{\mathrm{k,\,j}}$ fraction of VS excreted by animal subcategory k in manure management system j (in kg kg^{-1})
n_{i} number of animal places in animal category i (in place)

For a single livestock category i and a single manure management system j the relevant entities can be combined to describe the emission factor:

$$EF_{\mathrm{CH4,\,MM,\,i}} = VS_{\mathrm{i}} \cdot \alpha \cdot B_{\mathrm{o,\,i}} \cdot \rho_{\mathrm{CH4}} \cdot MCF_{\mathrm{j}} \qquad (2)$$

where

$EF_{\mathrm{CH4,\,MM,\,i}}$ emission factor for methane from manure management for animal category i (in kg place^{-1} a^{-1} CH_4) [1]

[1] The term "animal place" (unit: place) is used here to describe the number of animals counted at a certain date. The term "animal place" does not describe the number of places in animal houses potentially used for animal production. The number of places thus defined is equal to the IPCC term "annual average population". Places are the elements of the population.

VS_i daily volatile solid excretion of animal category i (in kg place^{-1} d^{-1})
α time units conversion factor (365 d a^{-1})
$B_{o,i}$ maximum methane producing capacity for animal category i (in m^3 kg^{-1} CH_4)
ρ_{CH4} density of methane (ρ_{CH4} = 0.67 kg m^{-3})
MCF_j methane conversion factor for manure management system j, temperature dependent (in m^3 m^{-3})

The theoretical background of the IPCC methodology is to relate CH_4 emissions to the mass or mass flow of degradable organic matter from which they originate (volatile solids, VS). A general approach makes use of a maximum formation rate, a practice-oriented reduction factor and a term that considers losses in the storage system, e.g. by oxidation within the natural crust, resulting in a relation as in Equation (3):

$$EF_{\mathrm{CH4, MM, i, j, T}} = VS_{\mathrm{i}} \cdot \alpha \cdot X_{\mathrm{BD, i}} \cdot X_{\mathrm{MS, i, j, T}} \cdot (1 - X_{\mathrm{ox, j}}) \quad (3)$$

where

$EF_{CH4, MM, i, j, T}$ annual emission factor for CH_4 from manure management for animal category i, manure management system j, and a storage temperature T (in kg place^{-1} a^{-1} CH_4)
VS_i daily input rate of VS into the manure management system of animal category i (in kg place^{-1} d^{-1})
α time units conversion factor (365 d a^{-1})
$X_{BD, i}$ amount of CH_4 that can be obtained from biological degradation of VS under optimal conditions (in kg kg^{-1})
$X_{MS, i, j, T}$ fraction of CH_4 that can be obtained from biological degradation under practical conditions, in relation to degradation under optimal conditions, for animal category i, manure management system j, and storage temperature T (in kg kg^{-1})
$X_{ox, j}$ fraction of CH_4 formed that is oxidized in the storage system j

As the volumes of gas collected are measured rather than the masses, the amount of CH_4 from biological degradation of VS entering the storage system may be rewritten as:

$$X_{\mathrm{BD, i}} = \frac{v_{\mathrm{CH4, opt, i}} \cdot \rho_{\mathrm{CH4}}}{VS_{\mathrm{i}}} \quad (4)$$

where

$X_{BD, i}$ amount of CH_4 that can be obtained from biological degradation of VS under optimal conditions (in kg kg^{-1})
$v_{CH4, opt, i}$ volume[2] of CH_4 emitted daily under optimal conditions, as a function of animal category i (in m^3 kg^{-1} d^{-1} CH_4)
ρ_{CH4} density[2] of CH_4 (in kg m^{-3})
VS_i daily input rate of degradable matter into the manure management system of animal category i (in kg place^{-1} d^{-1})

In the IPCC terminology, the maximum methane producing capacity describes a specific volume rather than a specific mass. Hence, the term $X_{BD,i}$ corresponds to the maximum methane producing capacity for an animal category i ($B_{o,i}$, in m^3 kg^{-1} CH_4) times the density of methane ρ_{CH4} (in kg m^{-3}) c.f. Equation (2), whereas $X_{MS, i, j, T}$ and $X_{ox, i}$ are elements of the methane conversion factor MCF.
MCF cannot be measured as such. It should be assessed by emission measurements and back-calculated using VS_i and $B_{o,i}$, i.e. by solving Equation (2) for MCF_j.

2.2 Constants and variables in the IPCC methodology

The method given by IPCC (1996) and (2006) relates emissions to VS excreted, B_o and MCF (see Equation (2)). The assessment of VS excretion rates was described in detail in Dämmgen et al. (2011a, b).

B_o and B_u

B_o is the maximum cumulative methane yield that can be gained from the biological degradation of the organic material. B_o falls below the theoretical methane yield B_u that would result from the complete degradation of all the organic compounds. This is because not all the organic material is biologically degradable under the anaerobic conditions pertaining in manure storage. In particular, lignin-containing compounds are decomposed incompletely (Ianotti et al., 1979; Møller et al., 2004a).

[2] Volumes of gases (v) have to be reported in combination with the relevant temperature and pressure. It is customary to "reduce" them to standard conditions. However, these vary between nations and regions. The US National Institute of Standards and Technology (NIST) recommended the use of a standard temperature $T_{n, NIST}$ = 293.15 K and a standard pressure $p_{n, NIST}$ = 1013 hPa, whereas German standard DIN1343 uses a standard temperature $T_{n, DIN}$ = 273.15 K. Standard pressures are identical: $p_{n, NIST} = p_{n, DIN}$. Gas densities (ρ) can then be adjusted using the relation $T_{n,1}/T_{n,2} = \rho_2/\rho_1$.

Within the IPCC methodology, B_o is provided as a single default value for each animal category (or subcategory). In principle and in practice, B_o for a given livestock category is not a constant entity, but a variable that depends on feed composition (e.g. Buswell and Mueller, 1952; Külling et al., 2001; Velthof et al., 2005; Amon et al., 2006; Massè et al., 2008; Klevenhusen et al., 2010). Hence, it should be related to national feeding data and reflect typical feeding practices.

B_o default values for pigs supplied by IPCC (1996) and IPCC (2006) have for some time been criticized as being too high (see IPCC, 2000b).

Buswell and Mueller (1952) and Ianotti et al. (1979) provide methodologies that allow calculating methane yields from fermentation of "practically any sort or kind of organic matter … used as a substrate". However, their calculation procedure only describes the fate of organic matter that is completely converted into CH_4 and CO_2, and also presupposes knowledge of the chemical analysis of the substrate that is decomposed (expressed as $C_nH_aO_b$). In practice, some of the organic matter (particularly lignin) is resistant to decomposition, so B_o is only a fraction of B_u. The ratio of the two is termed the biodegradability, and a range of values is given in Møller et al. (2004a). B_o can also be modelled using the chemical composition of the feed and the degradability (see Sommer et al., 2002a).

ρ_{CH4}

As B_o is to be reported as volume per unit of VS (m³ kg⁻¹), the density of CH_4 has to be taken into account. The IPCC guidelines use a density of 0.67 kg m^{-3} without further information on temperature and pressure. However, at German and Austrian standard temperature and pressure (273.17 K and 1013 hPa), a density of 0.72 kg m^{-3} should be used. Nevertheless, for sake of consistency with the IPCC guidelines, we will continue to use the value of 0.67 kg m^{-3}.

MCF

The IPCC methodology assumes that values of MCF are typical for each storage system (and independent of the type of manure stored). IPCC (1996, 2006) clearly state that MCF are temperature dependent.

For reasons of practicality, the IPCC methodology does not take storage times or the kinetics of the fermentation process into account (e.g. Chen et al., 1980; Linke, 1997) which results in an additional uncertainty of the values provided. Nor does it reflect the influence of the composition of excreta (e.g. their protein contents) and the viscosity of slurries. The latter may vary considerably (see e.g. Sommer et al., 2009; also data provided by Massè et al., 2003, in Table 16).

In principle, the incorporation of losses by oxidation (e.g. during penetration of a natural crust) into MCF contradicts the meaning of the term "methane conversion factor" describing the conversion of VS to CH_4.

Without giving an explanation, the MCF default value for liquid storage provided in IPCC (1996), IPCC (2000a) and IPCC (2006) varies by a factor of almost 4 (see Table 13). A temperature dependency is likely, see Chapter 5.2.

3 Empirical and modelled methane emission rates from manure management

Information about B_o and MCF is gained by measurements of specific CH_4 emissions. The IPCC methodology is based on measurements that are commonly related to VS available. In this work, these VS related emissions are called specific emissions, $\varepsilon_{CH4,}$.

$$\varepsilon_{CH4} = \frac{E_{CH4}}{VS} = B_o \cdot MCF \quad (5)$$

where

$\varepsilon_{CH4,}$	specific emission of methane (in m³ kg⁻¹ CH_4)
E_{CH4}	CH_4 emission rate (in m³ d⁻¹ CH_4)
VS	volatile solids input into the system (in kg d⁻¹ VS)
B_o	maximum methane producing capacity (in m³ kg⁻¹ CH_4)
MCF	methane conversion factor (in m³ m⁻³)

Such specific emissions have been reported for cattle and to a lesser extent for pig slurry. For solid manures data are very rare (see also Webb et al., 2012). ε_{CH4} calculated from measured data is collated in Tables 1 and 2 (cattle) and 6 and 7 (pigs), a comparison with emission rates back-calculated using IPCC default values is made with Tables 4 and 5 (cattle) and 8 and 9 (pigs). Table 3 contains modelled values for cattle for low temperatures.

All tables report volumes using a density ρ_{CH4} of 0.67 kg m^{-3}.

Tables 1 and 2 as well as 5 and 6 show a considerable variability of experimentally-derived specific emissions of CH_4 from cattle and pig slurry and solid manure. They also indicate a temperature dependence (see Chapter 5.2). No conclusion can be drawn yet which of the default values provided by IPCC (1996, 2000a, 2006) are most adequate. Hence an investigation into the elements B_o and MCF that can be used to establish the specific emission is undertaken below.

Table 1:

Experimentally derived specific emissions for slurry. **Cattle**. Partly recalculated from original data. All values in $m^3\ kg^{-1}\ CH_4$. Temperatures mentioned are ambient air temperatures.

	ε_{CH4}		Reference
cattle	0.019	crust at times	Husted (1994)
	0.003	slurry, 10 °C and 9.2 % DM; crust not mentioned	Massé et al. (2003)
	0.008	slurry, 10 °C and 4.2 % DM; crust not mentioned	Massé et al. (2003)
	0.0129	May to September, partly covered with crust, no temperature provided	Rodhe et al (2009)
	0.0096	annual average, mean temperature 8.4 °C	Rodhe et al (2009)
	0.0023	slurry, cold season, crusted[A]	Amon and Hörtenhuber (2010), summary of measurements in Amon et al. (2002)
	0.0893	slurry, warm season, crusted[A]	Amon and Hörtenhuber (2010), summary of measurements in Amon et al. (2002)
dairy cows	0.0012	slurry, cold season, crusted[A]	Amon et al. (2002), pg. 110
	0.0821	slurry, warm season, crusted[A]	Amon et al. (2002), pg. 109
	0.146	March to June, mean temperature 14.9 °C[A]	Amon et al. (2004)
	0.107	slurry without straw cover, summer, no temperature provided	Amon et al. (2002, 2006c)
	0.115	slurry with straw cover, summer , no temperature provided	Amon et al. (2006c)
	0.026	no temperature provided; crust not mentioned, but unlikely	Klevenhusen et al. (2010)

[A] Crust not mentioned in the report. In Austria, the formation of a crust is observed almost without exception.

Table 2:

Experimentally derived specific emissions for farmyard manure. **Cattle**. Value in $m^3\ kg^{-1}\ CH_4$.

	ε_{CH4}		Reference
cattle	0.005	farmyard manure	Husted (1994)

Table 3:

Modelled specific emissions for slurry. **Cattle**. Values in $m^3\ kg^{-1}\ CH_4$. Temperatures mentioned are ambient air temperatures.

	ε_{CH4}		Reference
cattle	0.020	slurry, 3.9 °C annual mean	Sommer et al. (2004)
	0.027	slurry, 7.3 °C annual mean	Sommer et al. (2004)

Table 4:

IPCC specific emissions for slurry for comparison. **Cattle**. Recalculated from B_o and MCF provided. Temperatures mentioned are ambient air temperatures.

	B_o	MCF	ε_{CH4}		Reference
	$m^3\ kg^{-1}$	$m^3\ m^{-3}$	$m^3\ kg^{-1}$		
dairy cows	0.24	0.10	0.024	slurry, cool climate	IPCC (1996), Table B-3
dairy cows	0.24	0.39	0.094	slurry, cool climate	IPCC (2000a), Table 4.10
dairy cows	0.24	0.10	0.024	slurry with natural crust, annual temperature ≤ 10 °C	IPCC (2006), Tables 10A-4 and 10.17
	0.24	0.17	0.041	slurry without natural crust, annual temperature ≤ 10 °C	
	0.24	0.17	0.041	slurry below animal confinements, > 1 month, annual temperature ≤ 10 °C	
other cattle[A]	0.17	0.10	0.017	slurry, cool climate	IPCC (1996), Table B-4
other cattle	0.17	0.39	0.066	slurry, cool climate	IPCC (2000a), Table 4.10
other cattle	0.18	0.10	0.018	slurry with natural crust, annual temperature ≤ 10 °C	IPCC (2006), Tables 10A-5 and 10.17
	0.18	0.17	0.031	slurry without natural crust, annual temperature ≤ 10 °C	
	0.18	0.17	0.031	slurry below animal confinements, > 1 month, annual temperature ≤ 10 °C	

[A] The term “other cattle” is used in IPCC to describe all cattle apart from dairy cattle.

Table 5:

IPCC specific emissions for farmyard manure for comparison. **Cattle**. Recalculated from B_o and MCF provided. Temperatures mentioned are ambient air temperatures.

	B_o m³ kg⁻¹	MCF m³ m⁻³	ε_{CH4} m³ kg⁻¹		Reference
dairy cows	0.24	0.01	0.0024	solid storage, cool climate	IPCC (1996), Table B-3
	0.24	0.01	0.0024	solid storage, cool climate	IPCC (2000a), Table 4.10
	0.24	0.02	0.0048	solid storage, cool climate	IPCC (2006), Tables 10A-4 and 10.17
other cattle	0.17	0.01	0.0017	solid storage, cool climate	IPCC (1996)
other cattle	0.17	0.01	0.0017	solid storage, cool climate	IPCC (2000a), Table 4-10
	0.17	0.39	0.066	deep litter, cool climate	
other cattle	0.18	0.02	0.0036	solid storage, cool climate	IPCC (2006), Tables 10A-5 and 10.17

Table 6:

Experimentally derived specific emissions for slurry. **Pigs**. Partly recalculated from original data. Temperatures mentioned are ambient air temperatures.

	ε_{CH4} m³ kg⁻¹		Reference
pigs	0.148	slurry, cold climate[A]	Husted (1994)
	0.041	slurry, summer[B]	Amon et al. (2002), pg. 183
	0.01	slurry, winter[B]	Amon et al. (2002), pg. 182
	0.034	slurry, 10 °C and 11 % dry matter[C]	Massé et al. (2003)
	0.026	slurry, 10 °C and 4.9 % dry matter[C]	Massé et al. (2003)
	0.063	slurry, 15 °C and 11 % dry matter[C]	Massé et al. (2003)
	0.128	slurry, 15 °C and 4.9 % dry matter[C]	Massé et al. (2003)
	0.146	March to June[B]	Amon et al. (2004)
	0.092	slurry lagoon, American diet	DeSutter & Ham (2005)
	0.036	slurry, winter 10 °C, maize based diets[C]	Massé et al. (2008)
	0.077	slurry, summer 20 °C, maize based diets[C]	Massé et al. (2008)
	0.030	October to April[D]	Rodhe et al. (2010)
	0.076	May to September	Rodhe et al. (2010)
	0.0147	slurry, cold season[B]	Amon and Hörtenhuber (2010)
	0.0174	slurry, warm season[B]	Amon and Hörtenhuber (2010)

[A] Crust reported.
[B] Crust not mentioned in the report. In Austria, the formation of a crust is observed almost without exception.
[C] Obviously no crust.
[D] Crust not mentioned, but likely.

Table 7:

Experimentally derived specific emissions for farmyard manure. **Pigs**.

	ε_{CH4} m³ kg⁻¹		Reference
pigs	0.064	farmyard manure	Husted (1994)
	0.00	"no emission", composted farmyard manure	Sommer and Møller (2000)

Table 8:

Modelled specific emissions for slurry. **Pigs**. Temperatures mentioned are ambient air temperatures.

	ε_{CH4} m³ kg⁻¹		Reference
pigs	0.036	slurry, 3.9 °C annual mean	Sommer et al. (2004)
	0.058	slurry, 7.3 °C annual mean	Sommer et al. (2004)

Table 9:

IPCC specific emissions for slurry for comparison. **Pigs**. Recalculated from B_o and MCF provided. Temperatures mentioned are ambient air temperatures.

	B_o m³ kg⁻¹	MCF m³ m⁻³	ε_{CH4} m³ kg⁻¹		Reference
pigs	0.45	0.10	0.045	slurry, cool climate	IPCC (1996), Table B-6
pigs	0.45	0.39	0.176	slurry, cool climate	IPCC (2000a), Table 4.10
pigs	0.45	0.10	0.045	slurry with natural crust, annual temperature ≤ 10 °C	IPCC (2006), Table 10.17
	0.45	0.17	0.077	slurry without natural crust, annual temperature ≤ 10 °C	
	0.45	0.17	0.077	slurry below animal confinements, > 1 month, annual temperature ≤ 10 °C	

Table 10:

IPCC specific emissions for farmyard manure for comparison. **Pigs**. Recalculated from B_o and MCF provided.

	B_o m³ kg⁻¹	MCF m³ m⁻³	ε_{CH4} m³ kg⁻¹		Reference
pigs	0.45	0.01	0.0045	solid storage, cool climate	IPCC (1996), Table B-6
pigs	0.45	0.01	0.0045	solid storage, cool climate	IPCC (2000a), Table 4.10
pigs	0.45	0.02	0.0090	solid storage, cool climate	IPCC (2006), Table 10.17
	0.45	0.03	0.014	deep bedding, < 1 month, cool climate	
	0.45	0.17	0.077	deep bedding, < 1 month, cool climate	

4 Maximum methane-producing potentials

The maximum methane-producing potential B_o is a function of the composition of slurry and solid manure. It may be derived from modelling or measurements.

4.1 Measured maximum methane-producing potentials

The knowledge of "methane yields" is a prerequisite for planning and operation of biogas plants. Hence, such yields have been measured and can be used to derive B_o values. German Guideline VDI 4630 was used to derive a German national guidance document for methane yields (KTBL, 2010).

The accuracy of these measurements is described in Heuwinkel et al. (2009). If inoculation is sufficient, a coefficient of variation of about 10 % can be assumed.

Tables 11 and 12 collate experimental B_o values and compare them to IPCC default values.

It is assumed that these values are related to VS excreted rather than VS entering storage, as CH_4 emissions can also originate from temporary storage in slurry channels (Møller et al., 2004a).

All B_o values are calculated using a density of 0.67 kg m^{-3} as used by IPCC in order to maintain comparability.

The IPCC methodology provides VS inputs from faeces only (see Dämmgen et al., 2011a). However, solid manure systems have an additional VS input from bedding material that should be treated accordingly. However, it has to be taken into account that additional straw increases the oxygen availability and leads to a considerable reduction of net CH_4 emission rates (see also Equation (3)). The fraction X_{ox} of CH_4 that is oxidized is likely to increase with the amount of VS imported into the system with straw. For experimental data covering cattle and pig farmyard manures (FYM) see Yamulki (2006). The specific emissions $\varepsilon_{CH4,\ faeces}$ and $\varepsilon_{CH4,\ straw}$ are also depending on the share of VS added with straw.

Table 11:
Experimentally derived B_o values and IPCC default values. **Cattle**. All values in m^3 kg^{-1} CH_4. IPCC default values are given for comparison.

	B_o	Reference	
dairy cows	0.24	Morris (1976)	
	0.17	Bryant et al. (1976)[A]	
	0.14	Hill (1984)	
	0.10	Chen et al. (1988)	
	0.154	Kryvoruchko et al. (2004)	
	0.148	Wood Venture (undated)	
cattle	0.380	Hashimoto (1983)	
	0.285	Hansen et al. (1998)	
	0.220	Sommer et al. (2001)	
	0.159	Møller et al. (2004a)	7 experiments, SD 0.044[B]
	0.248	Vedrenne et al. (2005)	
	0.316	Rodhe et al. (2009)	
	0.226	KTBL (2010)	data recommended for biogas plants
bulls (beef)	0.33	Chen et al. (1980)	
	0.29	Hashimoto et al. (1981)	7 % corn silage, 87.6 corn
	0.33	Hashimoto et al. (1981)	corn-based high energy
	0.17	Hashimoto et al. (1981)	91.5 % corn silage, 0 % corn
	0.23	Hill (1984)	
	0.231	Wood Venture (undated)	
calves	0.239	Wood Venture (undated)	
other cattle	0.139	Kryvoruchko et al. (2004)	
dairy cows	0.24	IPCC (1996)	highest value out of 4 in Safley et al. (1992)
	0.24	IPCC (2006)	based on Safley et al. (1992)
other cattle	0.17	IPCC (1996)	lowest value out of 4 in Safley et al. (1992)
	0.18	IPCC (2006)	based on Safley et al. (1992)

[A] as cited in Safley et al. (1992)
[B] SD: standard deviation

Table 12:
Experimentally derived B_o values and IPCC default values. **Pigs**. All values in m^3 kg^{-1} CH_4. IPCC default values are given for comparison.

	B_o	Reference	
pigs	0.47	Chen (1983)	"corn-based high energy"[A]
	0.45	Fischer et al. (1975)	"corn-based high energy"
	0.48	Stevens and Schulte (1979)	"corn-based high energy"
	0.44	Ianotti et al. (1979)	"corn-based high energy"
	0.36	Summers and Bousfield (1980)	"barley-based ration"
	0.48	Hashimoto (1984)	"corn-based high energy"
	0.32	Hill (1984)	
	0.52	Kroeker et al. (1984)	"corn-based high energy"
	0.300	Hansen et al. (1998)	
	0.35	Møller et al. (2004b)	
	0.230 to 0.373	Vedrenne et al. (2005)	
	0.27	KTBL (2010)	data recommended for biogas plants
	0.286	Wood Venture (undated)	
fatteners	0.383	Møller et al. (2004a)	7 experiments, SD 0.030[B]
sows	0.296	Møller et al. (2004a)	3 experiments, SD 0.039
pigs	0.45	IPCC (1996)	
	0.45	IPCC (2006)	

[A] explanations in quotation marks as provided in Safley et al. (1992), pg. 27;
"high energy" denotes an intake of 45 MJ animal^{-1} d^{-1}, no energy content of the feed is provided.
[B] SD standard deviation

$$E_{\text{CH4}} = \left(\varepsilon_{\text{CH4, faeces}} \cdot VS_{\text{faeces}} + \varepsilon_{\text{CH4, straw}} \cdot VS_{\text{straw}}\right) \cdot \left(1 - X_{\text{ox}}\right) \qquad (6)$$

where

E_{CH4}	CH_4 emission (in m^3 CH_4)
$\varepsilon_{CH4, faeces}$	specific emission of methane from faeces (in m^3 kg^{-1} CH_4)
VS_{faeces}	*VS* available in faeces (in kg VS)
$\varepsilon_{CH4, straw}$	specific emission of methane from straw (in m^3 kg^{-1} CH_4)
VS_{straw}	*VS* available in straw (in kg VS)
X_{ox}	fraction of CH_4 formed that is oxidized in the storage system

Table 13:

Experimentally derived B_o values and IPCC default values. **Straw**. All values in m^3 kg^{-1} CH_4

	B_o	Reference	
straw	0.260	Hashimoto (1983)	
	0.210	Møller et al. (2004a)	standard deviation 0.006
	0.226	KTBL (2010)	data recommended for biogas plants
	---	IPCC	

Hence it is assumed that the IPCC (1996) and (2006) emission factors relating CH_4 emissions from solid manure systems to the amounts of *VS* excreted include typical amounts of straw and typical FYM storage conditions.

4.2 Modelling maximum methane-producing potentials

Buswell and Mueller (1952) and Ianotti et al. (1979), see Chapter 2.3, developed equations that allow the assessment of B_u from the constituents of faeces and urine. Similarly, B_o can be derived from faeces composition and the biological degradability of its constituents (Table 14).

Table 14:

Modelled B_o values and IPCC default values. Values in m^3 kg^{-1} CH_4

	B_o	Reference	
cattle	0.23	Sommer et al. (2002b)	recalculated using IPCC density of CH_4
pigs	0.34	Sommer et al. (2002b)	
cattle	0.189	Boxer (undated)	
pigs	0.322	Boxer (undated)	
cattle	0.25	IPCC (2000b), pg. 343	
pigs	0.34	IPCC (2000b), pg. 343	

However, Dustan (2002) concludes that "the significant spread in the estimate of B_o … is likely to be a result of the dependence on diet and straw content, which vary from farm to farm and from country to country". Khan et al. (1997) explain the different B_o contents of pig and cattle manures with their different shares in easily degradable constituents; straw has a high share of slowly degradable constituents.

5 Methane conversion factors

5.1 Measured and calculated methane conversion factors

Methane conversion factors *MCF* are determined from emission rate measurements, *VS* and B_o using the following equation:

$$MCF = \frac{E_{\text{CH4}}}{VS \cdot B_{\text{o}}} \qquad (7)$$

where

MCF	methane conversion factor for a given storage system (in m^3 m^{-3})
E_{CH4}	methane emitted from the storage system (in m^3 d^{-1} CH_4)
VS	volatile solid input into the storage system (in kg d^{-1} VS)
B_o	maximum methane producing capacity (in m^3 kg^{-1} CH_4)

Data for cattle and pig slurry and farmyard manure are collated in Table 15. The results scatter considerably. For slurry, they are obviously temperature dependent and sensitive to crust formation. Both effects have to be studied in detail.

5.2 Temperature dependency of methane conversion factors

As indicated by some results shown in Table 15 and obvious from IPCC (2006), Tables 10A-4 to 10A-9, the temperature dependency of *MCF* definitely requires attention. Hence an attempt is made to identify potential explanations and descriptions.

5.2.1 Theoretical background

The formation of methane is temperature dependent. In physical chemistry, temperature dependent equilibria are described with the van't Hoff Arrhenius equation:

Table 15:

Experimentally derived *MCF* values and IPCC default values for cool climates. B_o values are provided whenever they are mentioned. Temperatures mentioned are ambient air temperatures.

	animal category	*MCF*	B_o	further details	Reference
		m^3 m^{-3}	m^3 kg^{-1}		
slurry	any	0.002		10 °C, B_o measured	Steed and Hashimoto (1994)
	any	0.553		20 °C, B_o measured	Steed and Hashimoto (1994)
	any	0.33		15 °C, from Figure 3, B_o measured	Steed and Hashimoto (1994)
	cattle	0.091	0.213	crusted at times, B_o from literature	Husted (1994)
	cattle	0.11			Sommer et al. (2002b)
	cattle	0.0097	0.24	cold season, crusted, B_o from IPCC (1996)	Amon and Hörtenhuber (2010)
	cattle	0.3722	0.24	warm season, crusted, B_o from IPCC (1996)	Amon and Hörtenhuber (2010)
	pigs	0.091	0.45	winter, crust not mentioned	Amon et al., (2002)
	pigs	0.0327	0.45	cold season, crusted, B_o from IPCC (1996)	Amon and Hörtenhuber (2010)
	pigs	0.0387	0.45	warm season, crusted, B_o from IPCC (1996)	Amon and Hörtenhuber (2010)
	any	0.10	0.24 0.17 0.45	dairy cattle other cattle pigs	IPCC (1996), taken over from Safley et al. (1992)[A]
		0.39		B_o identical with IPCC (1996)	IPCC (2000b), see discussion below[B]
	any	0.17	0.24 0.18 0.45	dairy cattle other cattle pigs	IPCC (2006), without natural crust
	any	0.10	0.24 0.18 0.45	dairy cattle other cattle pigs	IPCC (2006), with natural crust
FYM	cattle	0.05			Dustan (2002), based on Amon et al. (1998)
	cattle	0.016		winter	Dustan (2002), based on Amon et al. (1998)
	cattle	0.04		summer	Dustan (2002), based on Amon et al. (1998)
	pigs	0.142			Husted (1994)
	any	0.002		10 °C, B_o measured	Steed and Hashimoto (1994)
	any	0.457		20 °C, B_o measured	Steed and Hashimoto (1994)
	any	0.25		15 °C, from figure 3, B_o measured	Steed and Hashimoto (1994)
	any	0.01	 0.24 0.17 0.45	cold climate dairy cattle other cattle pigs	IPCC (1996), Tables B-3, B-4 and B-6
	any	0.01		cold climate B_o identical with IPCC (1996)	IPCC (2000b), Table 4.10
	any	0.02	 0.24 0.17 0.45	cold climate dairy cattle other cattle pigs	IPCC (2006), Table 10.17
	any	0.03		deep bedding, cold climate, < 1 month	IPCC (2006), Table 10.17
	any	0.17		deep bedding, cold climate, > 1 month	IPCC (2006), Table 10.17

[A] The *MCF* for slurry, deep pit and litter in IPCC (1996) are taken from Safley et al. (1992) where they are labelled "author's estimate; no data available in the literature."

[B] *MCF* for slurry and pigs of 39 % was presented in IPCC (2000b) with a reference to Zeeman (1994). In there, this value is listed as valid for 15 °C (which is the upper boundary condition of "cool climate"). For a temperature of 10 °C, a value of 0.27 is given by the same authors. Zeeman (1994) lists this *MCF* under "manure". It seems clear from the context that slurry is meant.

$$\frac{\mathrm{d}\ln k_{\mathrm{p}}}{\mathrm{d}T}=\frac{\Delta E_{\mathrm{A}}}{RT^{2}} \tag{8}$$

where

k_p reaction velocity constant for a reaction under constant pressure (unit depending on order of reaction)
T absolute temperature (in K)
ΔE_A energy of activation (in J mol^{-1})
R gas constant (R = 8.3143 J K^{-1} mol^{-1})

For any two temperatures T_1 and T_2 with $T_2 > T_1$ the integration yields:

$$\ln\frac{k_{\mathrm{p},2}}{k_{\mathrm{p},1}}=\frac{\Delta E_{\mathrm{A}}}{R}\cdot\frac{T_2-T_1}{T_1\cdot T_2} \tag{9}$$

If one replaces the ratio of reaction velocity constants by the ratio of emission (production) rates P_1 and P_2 or methane conversion factors MCF_1 and MCF_2 at temperatures T_1 and T_2 (this is allowed for identical substrates only, as the fraction of reaction velocity constants then equals the fraction of products E formed and hence MCF), and if one considers the changes of the product $T_1 \cdot T_2$ within the range of temperature differences insignificant the equation reads:

$$\frac{\ln\frac{P_2}{P_1}}{T_2-T_1}=\frac{\ln\frac{MCF_2}{MCF_1}}{T_2-T_1}=a \tag{10}$$

where a (in K^{-1}) is an increment specific for the system under consideration and describes the increase rate of CH_4 release per temperature unit.

Equation (9) also shows that the increment a can be derived from a known energy of activation[3]:

$$a=\frac{\Delta E_{\mathrm{A}}}{R\cdot T_1\cdot T_2} \tag{11}$$

It is obvious that this increment is *a* function of the temperatures T_1 and T_2. E_A is also temperature dependent.

The van't Hoff Arrhenius equation (or its integrated form) may be a useful instrument that can be applied in practice to estimate or evaluate the temperature dependence of CH_4 emission rates.

However, there are limitations: The original Equation (8) describes equilibria of chemical reactions where the reaction enthalpy does not change significantly with temperature. The processes governing CH_4 emissions from storage cannot be regarded in equlibria. The temperature considered is that of the (very dilute) solution where nevertheless the reaction velocity is not hampered by diffusion processes.

In practice, slurry is not a dilute solution. Experiments with different dry matter contents reveal that the reaction velocity is higher in diluted slurries with a lower viscosity (Massé et al., 2003).

In the manure storage systems described in this paper the composition of the microbial community is likely to be different at different temperatures. Hence the activation energy may change.

As the processes inside the storage system are exothermic the temperature of ambient air cannot be used to describe the temperature in the storage system in principle.[4]

Even with these restrictions, it might still be possible to find practice-oriented values of the increase rate a (similar to the evident increase rate in IPCC, 2006, Table 10.17). An attempt is made in the following section.

5.2.2 Establishing the increase rate a

A small number of measurements were performed under different temperature regimes and may allow for a determination of a. The results are listed in Table 16.

The increase rates a listed above scatter to an extent that prohibits their use in principle. This may be due to the fact that emission rates at low temperatures are difficult to quantify. Khan et al. (1997) state that the specific emission rates are highly correlated with slurry temperature. They could not identify a relation between air temperature and specific emission rates. Against that, Husted (1993) points out that in his experiments "slurry and air temperature were highly correlated for pig slurry and cattle slurry".

For the purpose of inventories, only air temperature can be taken into account because slurry temperatures are not routinely available. IPCC (2006) relates MCF to air temperatures.

---

[3] Care should be taken, as normally the experimental assessment of the energy of activation makes use of the inverted Equation (9) to derive E_A from measurements of reaction velocities at two different temperatures.

[4] Slurry temperatures inside the storage vary with depth (e.g. Patni and Jui, 1987; Rodhe et al., 2009). Citing just one slurry temperature may be misleading. Reactions in slurry and solid manure are exothermic. With a reaction velocity positively correlated to temperature, temperatures inside the storage facility are likely to exceed those of ambient air. Husted (1994) showed that major differences between the temperatures of ambient air and the contents of a slurry tank occur during winter. The variability of temperatures inside the tank exceeds the difference between outside and inside temperatures.

Table 16:
Increments a derived from emission measurements at different temperatures t (in °C)

Source	t_1	t_2	a	comment
Husted (1993)	9.2	19.3	0.082	cattle slurry, LE[A], ST[B]
Husted (1994)			0.27	cattle slurry, annual mean of monthly data; ST
Steed and Hashimoto (1994)	10	20	0.562	slurry type, not specified
Linke (1997)	24	35	0.120	pig slurry (laboratory scale)
Linke (1997)	24	35	0.094	cattle slurry (laboratory scale)
Massé et al. (2003)	10	15	0.033	cattle slurry, 9.2 % DM; AT[C]
Massé et al. (2003)	10	15	0.074	cattle slurry, 4.2 % DM; AT
Massé et al. (2003)	10	15	0.121	pig slurry, 11.3 % DM; AT
Massé et al. (2003)	10	15	0.317	pig slurry, 4.9 % DM; AT
Sommer et al. (2004)	10	20	0.068	calculation based on assumed activation energy[1]
Mangino (undated)	5	30	0.092	calculation based on assumed activation energy[2]
IPCC (2006)	10	20	0.092	slurry without natural crust, Table 10.17, results taken over from Mangino et al. (undated)
Massé et al. (2008)			0.076	pig slurry, maize based diet; ST
Klevenhusen et al. (2010)	14	27	0.152	cattle, hay based diet; LE, AT
Klevenhusen et al. (2010)	14	27	0.223	cattle, barley based diet; LE, AT

[A] LE: laboratory experiment;
[B] ST: slurry temperature;
[C] AT: air temperature
[1] using an energy of activation of 112.7 J mol^{-1}
[2] energy of activation of 63.5 J mol^{-1} as in Safley and Westerman (1990). It is likely that the chemical compounds to which the activation energies are related, are different.

5.3 Effects of crust and cover

The natural crust in slurry stores acts as a "biosphere" where methanotrophic microorganisms oxidize CH_4 to CO_2 (Petersen et al., 2005). About three quarters of the methane released from a tank can be converted (Ambus and Petersen, 2005). The crust should be 15 to 20 cm thick to act as an effective biofilter (Petersen and Ambus, 2006). Experimental results are compiled in Table 17.

Crust formation is a periodical process going along with changes in the populations of methanotrophic microorganisms and hence changing methane oxidation potentials (Petersen, 2011).

CH_4 emission and oxidation rates are moisture dependent. The natural crust must stay dry in order to allow for optimal aerobic conditions inside the crust. A crust that is subjected to rainfall gets wet and anaerobic. As a result, the rate of CH_4 oxidation will strongly be reduced.

Hence we assume that the data listed in Husted (1994) describe ideal conditions whereas the other authors give results for real (i.e. partly wet) conditions.

"Inorganic crusts" (such as formed by LECA[5] additions) are ineffective (Petersen and Ambus, 2006).

Table 17:
Reduction of CH_4 emissions due to the **formation of a crust**

Source	reduction
Petersen et al. (2005)	20 %
Petersen and Ambus (2006)	yes, but no data
Clemens et al. (2006)	15 - 30 %
Husted (1994)	97 %

Covering the tank with solid roofs or tent structures results in a decreased air exchange rate and longer retention time in the aerobic layer of the slurry (see also Petersen and Miller, 2006). Laboratory experiments with varied air flows above the slurry surface resulted in up to 90 % reduction of CH_4 emissions (Williams and Nigro, 1997). Rodhe et al. (2010) covered their tanks with plastic sheet and obtained reduced emissions, see Table 18. However, Husted (1993) reports that the emissions from covered pig slurry are independent of the air flow rate above the surface.

Covering the slurry tank prevents precipitation entering the crust and the drier conditions permit a good oxygen supply within the crust, which is a prerequisite for CH_4 oxidation.

[5] LECA: light expanded clay aggregates

Table 18:

Reduction of specific CH_4-C emissions (weight by weight) due to **covering** with plastic sheeting

Source	specific emissions without cover	specific emissions with cover	reduction	comment
Rodhe et al. (2010)	2.7 g (kg VS)$^{-1}$ CH_4-C	1.8 g (kg VS)$^{-1}$ CH_4-C	33 %	cattle slurry, annual mean
Rodhe et al. (2010)	2.6 g (kg VS)$^{-1}$ CH_4-C	1.5 g (kg VS)$^{-1}$ CH_4-C	43 %	pig slurry, annual mean

6 Conclusions and derivation of German and Austrian national values to describe methane formation from animal manures

National data describing CH_4 emissions from storage have to fit Equation (5). Calculations should provide specific emissions ε_{CH4} from measured VS inputs and measured volumes of CH_4 released (E_{CH4}). Another entity that can be measured is the maximum methane producing capacity B_o. Methane conversion factors MCF can then be derived from Equation (7).

Whereas the Austrian inventory is backed by national experimental data, the German approach has to rely on international measurements and data sets that might be "extrapolated" to describe the German situation. The derivation of German national data sets uses the experimental background provided in the Tables in Chapters 3 to 5 and compares them to default values provided by IPCC.

6.1 Maximum methane-producing potentials B_o

6.1.1 Applicability of B_o values provided by IPCC

In the 1996 IPCC Guidelines, "the B_o values as adapted for the US are also used in the IPCC Guidelines for developed countries as it is assumed that the typical diets are similar." (IPCC, 2000b, pg. 341). However, this assumption is invalid for pigs, as pig feed composition in Central Europe differs significantly from the US feeds used to derive B_o. Hence, the same source IPCC (2000b, pg. 343) states: "a re-estimation of the default B_o values should be considered."

6.1.2 German approach

Biogas plants convert VS using optimal conditions. Hence measured biogas yields, i.e. the biogas production rates as related to VS input rates can be used as adequate B_o. National data sets were generated for and collated by KTBL and reviewed by a team of German and Austrian experts. The results were published in KTBL (2010).

For dairy cows and other cattle, KTBL (2010) recommends[6] the use of 0.23 m^3 (kg VS)$^{-1}$ CH_4. This value is supported by measurements in Central Europe (see Table 11: Hansen, Kryvoruchko, Møller, Rodhe, Sommer, Vedrenne). The experimental data available for Europe is insufficient for a differentiation to be made between dairy cows and other cattle.

Given the uncertainties in both the national recommendations (KTBL, 2010) and the IPCC default values, the agreement between national and IPCC data is sufficient for cattle.

Table 12 indicates that the assumption on the use of US B_o data (indicated by "corn-based high energy") is not met for ***pigs*** in Germany. Here, pig diets are based on grain (wheat and barley, see Dämmgen et al., 2011b) and not on maize as in the United States. KTBL (2010) recommends[7] the use of 0.27 m^3 (kg VS)$^{-1}$. However, European data in Table 12 (Hansen, Møller, Sommer, Vedrenne) suggests a B_o of about 0.30 m^3 (kg VS)$^{-1}$. For pigs, Northwest European B_o values deviate considerably from IPCC default values.

We propose the use of German national B_o values in future inventories of 0.23 m^3 kg^{-1} CH_4 for cattle (dairy cows and other cattle), and 0.30 m^3 kg^{-1} CH_4 for pigs.

6.1.3 Austrian solution

Austria has no country-specific B_o values for cattle and pigs available.

The Austrian inventory uses IPCC (1996) default B_o values for all animal categories: 0.24 m^3 kg^{-1} CH_4 for dairy cattle, 0.17 m^3 kg^{-1} CH_4 for other cattle, 0.45 m^3 kg^{-1} CH_4 for breeding sows and fattening pigs.

---

6 calculated from 0.210 m^3 (kg VS)$^{-1}$, a standard density of 0.72 kg m^{-3} and an IPCC density of 0.67 kg m^{-3}.

7 calculated from 0.250 m^3 (kg VS)$^{-1}$, a standard density of 0.72 kg m^{-3} and an IPCC density of 0.67 kg m^{-3}.

6.2 Methane conversion factors *MCF* for slurry

6.2.1 Applicability of *MCF* values provided by IPCC

From Equation (7) follows that *MCF* and B_o form matching pairs. Hence, *MCF* have to be adjusted to the B_o described above.

The IPCC assumption that *MCF* values are independent of the source of *VS* (i.e. cattle or pigs, see IPCC, 1996, Table 4-8; IPCC, 2006, Tables 10A4 to 10A-8) is not maintained, "because the amount of slowly degradable carbohydrates is much higher in cattle slurry than in pig slurry" (Sommer et al., 2002a) (see also IPCC, 2000b; Dustan, 2004). Furthermore, *MCF* values depend on temperature and dry matter content of the slurries, on the formation of aerobic zones (crusts) and the air exchange rate above the containment. This is reflected in the IPCC (2006) approach and ignored in the IPCC (1996) methodology.

The following discussion deals with those systems in the first instance that are likely to be described best in the literature or used most often, i.e. systems with crust for cattle and systems without crust for pigs.

6.2.2 Experimental data – the problem of crust formation

The experimental data collated in Tables 1 and 6 can be used as guidance only, as reliable information about crust formation is sparse. Hence, the assumption that many of the slurry stores can be treated as always or temporarily crusted is considered adequate. However, the depth will vary, also the water content of the crust and the composition of its microcrobial populations.

6.2.3 Methane conversion factors for cattle slurries with crust

6.2.3.1 German approach

In 2010, about three quarters of uncovered cattle slurry stores were reported to have a natural crust. As *MCF* are depending on storage temperatures, climate has to be taken into account. In accordance with the IPCC (1996) and (2006) methodologies, air temperatures can serve as auxiliary entities (see above).

There is a wide consensus that CH_4 emissions from stored slurry at air temperatures below 10 °C are small in comparison to those at higher temperatures (e.g. Steed and Hashimoto, 1994; Husted, 1994; Massé et al., 2003; Sommer et al., 2007; Rodhe et al., 2009; Klevenhusen et al., 2010). In Germany this applies to the period from October to April, whereas monthly mean air temperatures are above 10 °C between May and September, as shown in Figure 1.

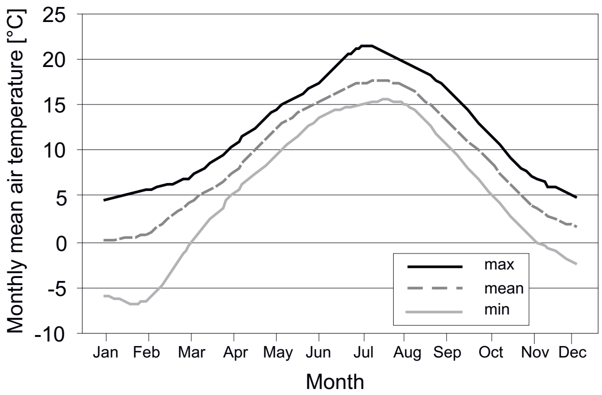

Figure 1:

Monthly mean air temperatures in Germany (Data for 1970 to 2000, courtesy of German Weather Service)

However, the relation between *MCF* and temperature is not linear (see Chapter 5.2). Hence, mean temperatures below 10 °C do not necessarily result in negligible overall emission rates; the overall temperature profile has to be taken into account. As no use can be made of the increase rate *a* (see Chapter 5.2), annual means of *MCF* have to be established using winter and summer measurements.

Comparisons of *MCF* between different countries presuppose similar annual temperature profiles.

Emissions were measured during the summer months in Austria by Amon et al. (2004) and in Sweden by Rodhe et al. (2009) in regions with annual mean air temperatures of 9.8 and 9.7 °C, respectively. This compares with a mean German temperatures of 9.8 °C (see Rösemann et al., 2011).

Hence, The *MCF* of 0.10 $m^3\ m^{-3}$ was obtained for similar annual mean temperatures and is regarded applicable for the German inventory.

It is also clear that the present IPCC (2000a) default value (0.39 $m^3\ m^{-3}$ [8]) is to be considered a "pure" summer value and is not adequate for the use as annual mean (see Austrian "summer" value for cattle and Steed and Hashimoto, 1994, in Table 15). Zeeman's model results that formed the basis for the *MCF* provided in IPCC (2000a) have been declared irrelevant (see review by Dustan, 2002, and DeSutter and Ham, 2005).

---

[8] calculated for pig manure using a process (i.e. slurry) temperature of 15 °C and a storage time of 180 d. Zeeman's *MCF* for cattle manure with process temperatures of 15 and 20 °C are 0.27 and 0.41 $m^3\ m^{-3}$, respectively. All measurements relate to conditions in a continuously stirred reactor (CSTR) and are not hampered by diffusion processes.

However, it is accepted that the importance of crusts under practical conditions "remains uncertain" (Petersen, 2011).

Keeping in mind that the methane oxidizing properties of crusts vary with depth and water content, a "provisional" mean *MCF* can be deduced from the data provided in Table 1. The arithmetic mean of the specific emissions reported by Husted (1994), Rhode et al. (2009, annual mean) and Amon and Hörtenhuber (2010, weighted mean for 7 winter and 5 summer months) and a B_o of 0.23 $m^3\ kg^{-1}$ yields 0.10 $m^3\ m^{-3}$ which is identical in practice with the IPCC (2006) default *MCF* of 0.10 $m^3\ m^{-3}$ for cattle slurry with crust for cool climates.

We propose the use of an *MCF* for cattle slurry with natural crust of 0.10 $m^3\ m^{-3}$ in association with a national B_o of 0.23 m^3 (kg VS)$^{-1}$ for dairy cows and other cattle in the German emission inventory. This *MCF* equals the value proposed in IPCC (2006).

No attempts should be made to further disaggregate with respect to regional climates, as information about the temporal variation of the amounts of slurry stored is not available.

6.2.3.2 Austrian solution

In Austria, *MCF* assessed for cattle and pig slurries are considered to represent a situation with a natural crust. However, owing to a lack of activity data, it is unknown how many stores with natural crusts in Austria are really covered.

IPCC encourages measurements of emissions from manure management under field conditions in order to improve the basis of emission estimates. In Austria, a three-year measurement campaign on emissions from manure stores financed by the Federal Ministry of Agriculture, Forestry, Environment, and Water Management and the Federal Ministry for Education, Science, and Culture was carried out. Measurements were performed under field scale conditions. Campaigns covered emissions from stored cattle and pig slurry under cool (winter, spring, autumn) and under warm (summer) conditions. Emission rates were published in peer reviewed publications. They can therefore be used for calculating *MCF* values for liquid manure stores.

In Austria, a recent update of the national greenhouse gas inventory used national *MCF* values and distinguished between slurry storage in the warm and in the cold season (Amon and Hörtenhuber 2010).[9] The updated inventories have successfully passed an external review process. The results were accepted within the UNFCCC expert review process.

Four seasons are distinguished for the application of *MCF* in Austria: spring, summer, autumn, winter. The extensive emission measurements under field conditions showed that a substantial increase in CH_4 emissions during slurry storage was only observed during the summer season. The low air temperatures in all other seasons in Austria hindered CH_4 formation during slurry storage. Emission measurements were carried out in one of the warmest Austrian regions and therefore may tend to overestimate *MCF* values.

From the data of all emission measurements during slurry storage the following country-specific *MCF* values for stored cattle slurry were deduced:

- cattle, cold seasons: *MCF* = 0.097 $m^3\ m^{-3}$
- cattle, warm season: *MCF* = 0.3722 $m^3\ m^{-3}$

A weighted annual mean *MCF* of 0.17 m m^{-3} results for 9 winter and 3 summer months, which equals the respective default MCF for slurry *without* natural crust in IPCC (2006). However, the Austrian inventory does not distinguish *MCF* for stores with or without cover or crust.

6.2.4 Methane conversion factors for cattle slurries without crust for Central European climates

6.2.4.1 German approach

Data describing slurry stores without crust are considered insufficient. *MCF* could be deduced from the data for storage with a crust, if the fraction X_{ox} of CH_4 that is oxidized (see Equation (3)) was known.

IPCC (2006) assume a reduction of the *MCF* as result of crust formation of 40 %. This is within the range that might be deduced from Table 17. IPCC (1996), Table 4-8, does not differentiate between storage without and with

[9] The detailed description of the experiments can be found in Amon et al. (2002). Pages 35 to 47 of that report describe the measurement technologies. The time table of the emission measurement is shown in Tables 11 and 12. Chapters 3 and 4 show the results of the emission measurement including air and slurry temperatures. Results have been published in the following peer reviewed publications (Amon et al., 2005, 2006, 2006a, 2006b and 2007). Chapter 3.2.6 in Amon et al. (2002) shows the results on *MCF* from stored cattle slurry. CH_4 emissions from untreated cattle slurry under summer conditions amounted to 0.342 $m^3\ m^{-3}$ of (IPCC standard) B_o. During the other seasons, only 0.005 $m^3\ m^{-3}$ of B_o were emitted as CH_4. The cool conditions in winter, spring and autumn in Austria drastically reduced CH_4 emissions.

a natural crust. This is felt to be inadequate (see Chapter 6.2.3).

An increase of 40 % is equivalent to an *MCF* for storage without crust of 0.17 $m^3\ m^{-3}$.

The few measured data indicate that the IPCC (1996) default value of 0.10 $m^3\ m^{-3}$ is too low for Central Europe (see Table 15: Husted, 1994; Amon and Hörtenhuber, 2010).

As neither IPCC (1996) nor IPCC (2000a) can provide satisfactory *MCF*, and experimental data do not allow for a well-founded *MCF* for uncrusted systems, the default data of IPCC (2006) is selected as the only alternative.

We recommend that an increased *MCF* for slurries without a natural crust by 40 % in agreement with IPCC (2006), i.e. 0.17 $m^3\ m^{-3}$ be applied to cattle.

6.2.4.2 Austrian solution

As described above, the Austrian *MCF* reflect the national situation and are considered to represent a situation with a natural crust.

6.2.5 Methane conversion factors for pig slurries without and with crust

6.2.5.1 German approach

Table 6 contains several emission data for summer and winter conditions. For the derivation of a German data set, these *MCF* have to be re-calculated for summer and winter conditions using a B_o of 0.30 $m^3\ kg^{-1}$. Data clearly reflecting feeding not used in Germany were omitted. Of these, only data with no or almost no effective crust were used. Massé et al. (2003) provide two data sets for each temperature of which the set with the lower DM content is used. (KTBL, 2010, assumes a DM content of 6 % for German pig slurries.) These data are collated in Table 19.

If one calculates the weighted mean of the summer data (5 months) obtained from Amon et al. (2004) and Massé et al. (2003) of 0.49 and 0.43 $m^3\ m^{-3}$, respectively, and the winter data (7 months) obtained from Rodhe et al. (2010) and Massé et al. (2003) of 0.10 and 0.09 $m^3\ m^{-3}$, respectively, one obtains a mean *MCF* of about 0.25 $m^3\ m^{-3}$ for pig slurry without crust.

This *MCF* is equivalent to the 17 % proposed in IPCC (2006) for any slurry without natural crust if one takes the ratio of German national B_o to the IPCC B_o (2/3) into account.

Table 19:
CH_4 emissions rates and *MCF* for **pig slurry without natural crust**

ε_{CH4} $m^3\ kg^{-1}$	B_o $m^3\ kg^{-1}$	*MCF* $m^3\ m^{-3}$	restriction	source
0.128	0.30	0.427	15 °C, 4,9 % DM	Massé et al. (2003)
0.146	0.30	0.487	summer	Amon et al. (2004)
0.030	0.30	0.100	winter	Rodhe et al. (2010)
0.026	0.30	0.087	10 C°, 4,9 % DM	Massé et al. (2003)

In a considerable share of German storage systems for pig slurry, a natural crust is not formed. With no data available, the IPCC (2006) approach is used that assumes a 40 % decrease of *MCF* for systems with crust. However, we maintain that this reasoning is unsatisfactory.

We propose to apply a national *MCF* for pig slurry without natural crust of 0.25 $m^3\ m^{-3}$ and of 0.15 $m^3\ m^{-3}$ for pig slurry with a natural crust in combination with a national B_o of 0.30 $m^3\ kg^{-1}$ CH_4.[10]

6.2.5.2 Austrian solution

Amon et al. (2002) give data on *MCF* from pig slurry storage based on measurements. Here, CH_4 emissions were considerably lower than those derived with the default IPCC *MCF* during the warm summer season and during the cooler seasons. Summer includes the months June, July and August.
In the Austrian inventory, measured *MCF* are used: For pigs in the cold and warm seasons *MCF* values of 0.0327 $m^3\ m^{-3}$ and 0.0387 $m^3\ m^{-3}$ are used, respectively, in combination with the IPCC (1996, 2006) default B_o of 0.45 $m^3\ kg^{-1}$ CH_4.

6.2.6 Methane conversion factors for cattle and pig slurries with cover

Solid covers or plastic sheets are used mainly in pig production to reduce odour. There is evidence that these covers result in oxidation of CH_4 at the surface of the slurries (see Table 18).

Within the MIDAIR project (Clemens et al. 2006) pilot scale measurements in Austria proved that a cover on cattle slurry that formed a natural crust was able to reduce methane emissions due to methane oxidation in the crust.

[10] The national pair of B_o = 0.30 $m^3\ kg^{-1}$ and *MCF* = 0.25 $m^3\ m^{-3}$ is equivalent to the IPCC (2006) pair of B_o = 0.45 $m^3\ kg^{-1}$ and *MCF* = 0.17 $m^3\ m^{-3}$. German data: ε_{CH4} = 0.075 $m^3\ (kg\ VS)^{-1}$; IPCC (2006) data: ε_{CH4} = 0.0765 $m^3\ (kg\ VS)^{-1}$.

This was confirmed by a study of Petersen et al. (2005) who took samples of the crusts and could identify the presence of methane oxidising bacteria.

However, the data are at present considered insufficient to propose separate values for covered storages.

6.2.6.1 German approach

In order to avoid underestimation of emissions, a worst case assumption is the use of the higher MCF for cattle and pig slurries.

We propose that an MCF of 0.17 m^3 m^{-3} be used for covered cattle slurry storage and of 0.25 m^3 m^{-3} for covered pig slurry storage systems.

6.2.6.2 Austrian solution

The Austrian inventory does not differentiate between covered and uncovered storage systems.

6.3 Methane conversion factors for pit storage below animal confinements (underneath slatted floor)

In principle, the temperature inside slurry underneath slatted floor will exceed that of outside storage. This should be taken into account. However, only one reference is available for emissions from slurry stored underneath slatted floors without providing a temperature or temperature difference (Sommer et al., 2002a) (see Table 6). Sommer et al. (2009) contribute model assumptions for indoor and outdoor storage. At present, the knowledge is limited to an extent (Petersen, 2011) that the data provided do not justify any other conclusion than to treat emissions from pit storage below animal confinements in the same way as emissions from outdoor storage of slurry without crust.

6.3.1 German approach

We propose that the German inventory use an MCF for cattle slurry underneath slatted floors of 0.17 m^3 m^{-3} and for pig slurry the value of 0.25 m^3 m^{-3} that was derived for slurry stores without a crust. This is likely to avoid underestimation of emissions.

6.3.2 Austrian solution

In Austria, the GHG inventory only covers outside stores for cattle and pig slurry. No specific MCF is applied for pit storage below animal confinements.

6.4 Methane conversion factors MCF for farmyard manure stored in heaps

6.4.1 Experimental and IPCC data

Few measurements report CH_4 emissions from ***cattle*** farmyard manure. Table 15 collates the results as MCF related to IPCC default B_o values.

No measurements are available for ***pig*** manure that can be used as comparison to IPCC data.

In principle, the treatment of farmyard manure requires calculations according to Equation (6). For this purpose the amounts of bedding material added as well as the respective B_o, MCF and X_{ox} have to be known. With the exception of B_o these values cannot be provided. However, it is common practice within the IPCC process not to quantify emissions from bedding.

IPCC (1996) and IPCC (2006) do not differentiate between cattle and pig farmyard manures with respect to MCF. However, cattle and pig solid manures differ with respect to their properties and storage conditions. Pig manures contain comparatively much bedding giving it a higher porosity that facilitates oxygen transport. Cattle manure exhibits a greasy consistency and is more compact. Under comparable conditions, pig manure heaps tend to generate more heat than cattle manure heaps and should hence be treated with different MCF (Husted, 1994).

6.4.2 German approach

The application of Equation (6) that relates emissions to the amounts of VS from faeces and bedding with their respective specific emissions and the availability of oxygen in the storage system is not feasible. No detailed information on input data can be found yet.

The experimental data base for specific emissions ε_{CH4} is very poor, see Tables 2 and 7. The reasoning leading to an MCF of 2 % provided in IPCC (2006), Table 10.17, indicates that an MCF of 2 % is likely to underestimate emissions[11]: In contrast to the practice applied above that derived an annual mean from winter and summer MCF (see Chapters 6.2.3.1 and 6.2.4.1), the winter MCF of 2 % is chosen to represent the cool climate MCF of the entire year (in agreement with IPCC (2006). Hence, the MCF of 1 % as proposed in IPCC (1996) and IPCC (2000a) is definitively too low. This is underlined by the following comparison:

If European data (Dustan, 2002, based on Amon et al., 2001) are back calculated with the IPCC default B_o for *dairy cows* (0.24 m^3 (kg VS)$^{-1}$), specific emissions of 0.0038 m^3

[11] Expert judgement for MCF describing solid storage: … "shows emissions of approximately 2 % in winter and 4 % in summer." (IPCC, 2006, Table 10.17)

$(kg\ VS)^{-1}$ are observed for winter months and 0.0096 m^3 $(kg\ VS)^{-1}$ for summer months. The weighted mean of 5 summer months and 7 winter months is 0.0062 m^3 $(kg\ VS)^{-1}$. For *other cattle*, using the IPCC (2006) default B_o (0.18 m^3 $(kg\ VS)^{-1}$), the weighted mean of annual specific emissions is 0.0047 m^3 $(kg\ VS)^{-1}$.

Considering the ratio between dairy cow places and other cattle places which is about 1 to 2 in Germany (see Rösemann et al., 2011)) one obtains a weighted mean specific emission for cattle of 0,0052 m^3 $(kg\ VS)^{-1}$. Using the German B_o value for cattle (0.23 m^3 $(kg\ VS)^{-1}$), this leads to a national mean MCF of 0.023 $m^3\ m^{-3}$ or about 2 % for cattle.

Due to lack of data, the approach applied to cattle is also used for pigs by analogy. However, the MCF of 2 % provided in IPCC (2006) relates to a B_o of 0.45 $m^3\ kg^{-1}$ CH_4. If the specific emissions resulting from IPCC (2006) MCF and B_o are considered correct then the national MCF is to be related to the national B_o of 0.30 $m^3\ kg^{-1}$ CH_4. A national MCF of 0.030 $m^3\ m^{-3}$ results.

We propose that the German inventory use an MCF of 0.02 $m^3\ m^{-3}$ for cattle farmyard manure and of 0.03 $m^3\ m^{-3}$ for pig farmyard manure stacked in heaps in combination with national B_o of 0.23 $m^3\ kg^{-1}$ CH_4 for cattle and 0.30 $m^3\ kg^{-1}$ CH_4 for pigs.

6.4.3 Austrian solution

In Austria, the following MCF are applied to FYM:

- 'solid storage composted' (MCF from IPCC, 2006: 0.005 $m^3\ m^{-3}$),
- 'solid storage untreated' (MCF from IPCC, 1996: 0.01 $m^3\ m^{-3}$),
- 'deep litter composted' and 'deep litter untreated' with the MCF for deep litter applied in each case according to IPCC (2006) (MCF = 0.17 $m^3\ m^{-3}$).

The Austrian emission inventory does not distinguish summer and winter storage.

6.5 Methane conversion factors MCF for deep bedding systems

No experimental data can be provided for deep bedding systems. Both IPCC (2000a) and IPCC (2006) treat deep bedding stored for more than a month in the same way as slurry without crust.

Deep bedding systems are not mentioned in IPCC (1996). Hence, we recommend the use of the IPCC (2006) approach to equate these emissions with those of slurry without natural crust (see Chapters 6.2.4.1 and 6.2.5.1), as the storage times of the bedding material exceed 1 month.

7 Conclusions

Whereas Austria is able to provide an almost comprehensive experimental data set describing CH_4 emissions from manure management, German data on CH_4 emissions from storage are scarce. Here, data from neighbouring countries with similar meteorological conditions and similar types of animal production were used to derive data sets for specific CH_4 emission rates. Experimental findings are very variable. However, where data sets could be established they tended to support the IPCC (2006) guidelines, rather than earlier versions (see sections on MCF for cattle and pig slurries). The IPCC (1996) and (2000a) approaches were here found to be inadequate for pigs in particular, because the application of North American pig feed composition data to Northwest European conditions is not justified. Hence, wherever missing national data had to be replaced by default values, the values proposed in IPCC (2006) were preferred and the reasoning provided.

The lack of experimental data relevant to the German animal husbandry is striking, and the almost complete absence of German data is considered a serious obstacle with respect to adequate reporting of CH_4 emissions from manure management.

References

Ambus P, Petersen SO (2005) Oxidation of ^{13}C-labelled methane in surface crusts of pig and cattle slurry. Isotopes Environ Health Studies 41:125-133

Amon B, Amon T, Boxberger J, Alt C (2001) Emissions of NH_3, N_2O and CH_4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading). Nutr Cycl Agroecosystems 60:103-113

Amon B, Amon T, Boxberger J, Pöllinger J (1998) Emissions of NH_3, N_2O and CH_4 from composted and anaerobically stored farmyard manure [online]. To be found at <http://www.ramiran.net/doc98/FIN-POST/AMON-BAR.pdf> [quoted 08.12.2011]

Amon B, Hörtenhuber S (2010) Revision der österreichischen Luftschadstoffinventur (OLI) für NH_3, NMVOC und NO_X, Sektor 4, Landwirtschaft. Wien : Umweltbundesamt, 62 p

Amon B, Kryvoruchko V, Amon T, Boxberger J (2005) Lagerung von Milchviehflüssigmist : Wirkung der Abdeckung auf NH_3-, N_2O- und CH_4-Emissionen. Agrartechn Forsch 11(4):64–80

Amon B, Kryvoruchko V, Amon T, Moitzi G (2004) Ammonia, methane and nitrous oxide emission during storage of cattle and pig slurry and influence of slurry additive "Effective Micro-Organisms (EM)" : final report on behalf of Multikraft GmbH, Haiding. Vienna : Univ Natural Resour Appl Life Sci, Dept Sustain Agric Syst, 33 p

Amon B, Kryvoruchko V, Amon T, Zechmeister-Boltenstern S (2006c) Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agric Ecosyst Environ 112:153-162

Amon B, Kryvoruchko V, Fröhlich M, Amon T, Pöllinger A, Mösenbacher I, Hausleitner A (2007) Ammonia and greenhouse gas emissions from a straw flow system for fattening pigs : housing and manure storage. Livestock Sci 112:199–207

Amon B, Kryvoruchko V, Moitzi G, Amon T (2006a) Greenhouse gas and ammonia emission abatement by slurry treatment. Internat Congress Ser 1293:295-298

Amon B, Moitzi G, Schimpl M, Kryvoruchko V, Wagner-Alt C (2002) Methane, nitrous oxide and ammonia emissions from management of liquid manures : final report for the Federal Ministry of Agriculture, Forestry, Environmental and Water Management and the Federal Ministry of Education, Science and Culture. Vienna : Univ Natural Resour Life Sci, Dept Sustain Agric Syst, Div Agric Eng

Amon, B, Kryvoruchko V, Amon T (2006b) Influence of different levels of covering on greenhouse gas and ammonia emissions from slurry stores [online]. To be found at <http:///www.ramiran.net/doc04/Proceedings%2004/B_Amon4.pdf> [quoted 20.12.2011]

Boxer-Infodienst (2010) Biogas – Biogaspotentiale [online]. To be found at <http://www.boxer99.de/default.asp?Menue=106> [quoted 07.12.2011]

Bryant MP, Varel VH, Frobish RA, Isaacson HR (1976) Biological potential of thermophilic methanogenesis from cattle wastes. In: Schlegel HG (ed) Seminar on microbial energy conversion. Göttingen : Goltz, pp 347-360

Buswell AM, Mueller HF (1952) Mechanism of methane formation. Ind Eng Chem 44:550-552

Chadwick DR, Pain BF, Brookman SKE (2000) Nitrous oxide and methane emissions following application of animal manures to grassland. J Environ Quality 29:277-287

Chen TH (1983) Kinetic analysis of anaerobic digestion of pig manure and its implications. Biol Wastes 8:65-81

Chen TH, Day DL, Steinberg MP (1988) Methane production from fresh versus dry dairy manure. Biol Wastes 24:297-306

Chen YR, Varel VH, Hashimoto AG (1980) Effect of temperature on methane fermentation kinetics of beef-cattle manure. Biotechnol Bioeng Symp 10:325-339

Clemens J, Trimborn M, Weiland P, Amon B (2006) Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry. Agric Ecosyst Environ 112(2-3):171-177

Dämmgen U, Amon B, Gyldenkærne S, Hutchings NJ, Kleine Klausing H, Haenel H-D, Rösemann C (2011a) 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):115-126

Dämmgen U, Brade W, Schulz J, Kleine Klausing H, Hutchings NJ, Haenel HD, Rösemann C (2011b) The effect of feed composition and feeding strategies on excretion rates in German pig production. Landbauforsch 61(4):327-342

DeSutter TM, Ham JM (2005) Lagoon-biogas emissions and carbon balance estimates of swine production facility. J Environ Quality 29:1356-1365

Dustan H (2002) Review of methane and nitrous oxide emission factors for manure management in cold climates. JTI-Rapport Lantbruk Industri 299

Fischer JR, Seivers DM, Fulhage DC (1975) Anaerobic digestion in swine wastes. In: Jewell WJ (ed) Energy, agriculture, and waste management : proceedings of the 1975 Cornell Agricultural Waste Management Conference. Ann Arbor : Ann Arbor Science Publ, pp 307-316

German Guideline VDI 4630 (2006) Fermentation of organic materials : characterisation of the substrate, sampling, collection of material data, fermentation tests. Düsseldorf : VDI, 93 p

Hansen KH, Agelidaki I, Ahring BK (1998) Anaerobic digestion of swine manure : inhibition by ammonia. Water Res 32:5-12

Hashimoto AC (1983) Conversion of straw-manure mixtures to methane at mesophilic and thermophilic temperatures. Biotechnol Bioeng 25:185-200

Hashimoto AC (1984) Methane from swine manure : effect of temperature and influent substrate composition on kinetic parameter (K)*. Agric Wastes 9:299-308

Hashimoto AC, Varel VH, Chen YR (1981) Ultimate methane yield from beef cattle manure : effect of temperature, ration constituents, antibiotics and manure age. Agric Wastes 3:241-256

Heuwinkel H, Aschmann A, Gerlach R, Gronauer A (2009) Die Genauigkeit der Messung des Gasertrags von Substraten mit der Batchmethode. SchrR Bayer Landesanst Landwirtsch 15:95-103

Hill DT (1984) Methane productivity of the major animal types Transactions ASAE 27:530-540

Huang Q, Wohlgemut O, Cicek N, France J, Kebreab E (2010) A mechanistic model for simulating methane emissions from unstirred liquid manure stores. Can J Soil Sci 90:507-515

Husted S (1993) An open chamber technique for determination of methane emission from stored life stock manure. Atmos Environ A 27:1635–1642

Husted S (1994) Seasonal variation in methane emission from stored slurry and solid manures. J Environ Quality 23:585-592

Ianotti EL, Porter JH, Fischer JR, Sievers DM (1979) Changes in swine manure during anaerobic digestion. Dev Ind Microbiol 20:519-520

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 08.12.2011]

IPCC – Intergovernmental Panel on Climate Change (2000a) Good practice guidance and uncertainty measurement in national greenhouse gas inventories : CH_4 emissions from animal manure [online]. To be found at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/4_Agriculture.pdf> [quoted 20.12.2011]

IPCC – Intergovernmental Panel on Climate Change (2000b) Background papers : IPCC expert meetings on good practice guidance and uncertainty management in national greenhouse gas inventories [online]. To be found at <http://www.ipcc-nggip.iges.or.jp/public/gp/gpg-bgp.html> [quoted 01.02.2012]

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 08.12.2011]

Khan RZ, Müller C, Sommer SG (1997) Micrometeorological mass balance technique for measuring CH_4 emission from stored cattle slurry. Biol Fertil Soils 24:442-444

Klevenhusen F, Bernasconi SM, Kreuzer M, Soliva CR (2010) Experimental validation of the Intergovernmental Panel on Climate Change default values for ruminant-derived methane and its carbon-isotope signature. Anim Production Sci 50:159-167

Kroeker EJ, Schulte DD, Sparling AB, Lapp HM (1984) Anaerobic treatment process stability. J Water Pollut Control Fed 51:718-727

Kryvoruchko V, Amon T, Amon B, Gruber L, Schreiner M, Zolitsch W (2004) Influence of nutrient composition on methane production from animal manures and co-digestion with maize and glycerine [online]. To be found at <http:// www.prairieswine.com/pdf/3596.pdf> [quoted 20.12.2011]

KTBL (2010) Gasausbeute in landwirtschaftlichen Biogasanlagen. Darmstadt : KTBL, 36 p, KTBL-Heft 88

Külling DR, Menzi H, Kröber TF, Neftel A, Sutter F, Lischer P, Kreuzer M (2001) Emissions of ammonia, nitrous oxide and methane from different types of dairy manure during storage as affected by dietary protein content. J Agric Sci 137:235-250

Linke B (1997) A model for anaerobic digestion of animal waste slurries. Environ Technol 18:849-854

Mangino J, Bartram D, Brazy A (undated) Development of a methane conversion factor to estimate emissions from animal waste lagoons [online]. To be found at <http://www.epa.gov/ttnchie1/conference/ei11/ammonia/mangino.pdf> [quoted 06.12.2011]

Massé DI, Croteau F, Patni NK, Masse L (2003) Methane emissions from dairy cow and swine manure slurries stored at 10 °C and 15 °C. Can Biosyst Eng 45:6.1-6.6

Massé DI, Masse L, Claveau S, Benchaar C, Thomas O (2008) Methane emission from manure storages. Transactions ASABE 51:1775-1781

Møller HB, Sommer SG, Ahring BK (2004a) Methane productivity of manure, straw and solid fractions of manure. Biomass Bioenergy 26:485-495

Møller HB, Sommer SG, Ahring BK (2004b) Biological degradation and greenhouse gas emissions during pre-storage of liquid manure. J Environ Quality 33:27-36

Morris GR (1976) Anaerobic fermentation of animal wastes : a kinetic and empirical design evaluation. Ithaca : Cornell Univ

Park K-H, Thompson AG, Marinier M, Clark K, Wagner-Riddle C (2006) Greenhouse gases from stored liquid swine manure in a cold climate. Atmos Environ 40:618-627

Patni NK, Jui PY (1987) Changes in solids and carbon content of dairy-cattle slurry in farm tanks. Biol Wastes 20:11-34

Petersen SO (2011) Methane and nitrous oxide emissions from livestock manure : the scientific basis. KTBL-Schrift 491:122-133

Petersen SO, Ambus P (2006) Methane oxidation in pig and cattle slurry storages, and effects of surface crust moisture and methane availability, Nutr Cycl Agroecosystems 74:1-11

Petersen SO, Amon B, Gattinger A (2005) Methane oxidation in slurry storage crusts. J Environ Quality 34:455-461

Petersen SO, Miller DN (2006) Greenhouse gas mitigation by covers on livestock slurry tanks and lagoons? J Sci Food Agric 86:1407-1411

Rodhe L, Ascue J, Nordberg Å (2009) Emissions of greenhouse gases (methane and nitrous oxide) from cattle slurry storage in Northern Europe [online]. To be found at <http://iopscience.iop.org/1755-1315/8/1/012019/pdf/1755-1315_8_1_012019.pdf> [quoted 23.11.2011]

Rodhe L, Ascue J, Nordberg Å (2010) Greenhouse gas emissions from stored slurry with and without different covers [online]. To be found at <http://www.ramiran.net/ramiran2010/docs/Ramiran2010_0194_final.pdf> [quoted 23.11.2011]

Rösemann C, Haenel H-D, Poddey E, Dämmgen U, Döhler H, Eurich-Menden B, Laubach P, Dieterle M, Osterburg B (2011) Calculations of gaseous and particulate emissions from German agriculture 1990-2009. Braunschweig : vTI, 389 p, Landbauforsch SH 342

Safley LM, Westerman PW (1990) Psychrophilic anaerobic digestion of animal manure : proposed design methodology. Biol Wastes 34:133-148

Safley LM, Casada ME, Woodbury JW, Roos KF (1992) Global methane emissions from livestock and poultry manure. Washington DC : US Environmental Protection Agency, 68, 145 p, EPA 400/1 ; 91/048

Sommer DG, Møller HB (2000) Emission of greenhouse gases during composting of deep litter from pig production : effect of straw content. J Agric Sci 134:327-335

Sommer DG, Petersen S, Møller HB (2002a) A new model for calculating the reduction in greenhouse gas emissons through anaerobic co-digestion of manure and organic waste. DIAS Rep Plant Prod 81:54-63

Sommer SG, Møller HB, Petersen SO (2002b) Reduction in methane and nitrous oxide emission of animal slurry through anaerobic digestion. In: van Ham J (ed) Non-CO_2 greenhouse gases : scientific understanding, control options and policy aspects ; proceedings of the third international symposium, Maastricht, the Netherlands, 21-23 January 2002. Rotterdam : Millpress, pp 475-480

Sommer SG, Petersen SO, Møller HB (2004) Algorithms for calculating methane and nitrous oxide emissions from manure management. Nutr Cycl Agroecosystems 69:143-154

Sommer SG, Petersen SO, Søgaard (2000) Atmospheric pollutants and trace gases : greenhouse gas emissions from stored livestock slurry. J Environ Qual 29:744-751

Sommer SG, Petersen SO, Sorensen P, Poulsen HD, Møller HB (2007) Methane and carbon dioxide emissions and nitrogen turnover during liquid manure storage. Nutr Cycl Agroecosystems 78:27-36

Sommer, SG, Olesen JE, Petersen SO, Weibjerg MR, Valli L, Rodhe L, Béline F (2009) Region-specific assessment of greenhouse gas mitigation with different manure management strategies in four agroecological zones. Global Change Biol 15:2825-2837

Steed J Jr, Hashimoto AG (1994) Methane emissions from typical manure management systems. Biores Technol 50:123-130

Stevens MA, Schulte DD (1979) Low temperature digestion of swine manure. J Environ Eng Div, ASCE 105(EE1):33-42

Summers R, Bousfield S (1980) A detailed study of piggery-waste anaerobic digestion. Agric Wastes 2:61-78

Vedrenne F, Beline F, Bernet N (2005) Evaluation of the methane production of livestock wastes : ultimate productivity and organic matter characterisation [online]. To be found at <http:// static.blog4ever.com/2006/02/126682/artfichier_126682_24254_201004120338758.pdf> [quoted 23.11.2011]

Velthof GL, Nelemans JA, Oenema O, Kuikman PJ (2005) Gaseous nitrogen and carbon losses from pig manure derived from different diets. J Environ Quality 34:698-706

Webb J, Sommer SG, Kupper Th, Groenestein K, Hutchings NJ, Eurich-Menden B, Rodhe L, Misselbrook TH, Amon B (2012) Emissions of ammonia, nitrous oxide and methane during the management of solid manures. Sustain Agric Rev 8:67-107

Williams AG, Nigro E (1997) Covering slurry stores and effects of emissions of ammonia and methane. In: Voermans AM, Monteny GJ (eds) Ammonia and odour emissions from animal production facilities : proceedings ; 6-10 October 1997, Vinkeloord, The Netherlands. Rosmalen : NVTL, pp 421-428

Woodventure (ed) Rinder-Gülle [online]. To be found at <http://www.woodventure.de/bioenergie/rohstoffe/guelle/rinderguelle/> [quoted 23.11.2011]

Yamulki S (2006) Effect of straw addition on nitrous oxide and methane emssions from stored farmyard manures. Agric Ecosyst Environ 112:140-145

Zeeman G (1994) Methane production/emission in storages for animal manure. Fert Res 37:207-211

Enteric methane emissions from German dairy cows

Ulrich Dämmgen*, Claus Rösemann*, Hans-Dieter Haenel*, and Nicholas J. Hutchings**

Abstract

Up to now, the German agricultural emission inventory used a model for the assessment of methane emissions from enteric fermentation that combined an estimate of the energy and feed requirements as a function of performance parameters and diet composition, with the constant methane conversion rate provided in the IPCC guidelines. The two existing guidelines propose two different constant rates (IPCC, 1996: 6.0 % or 60 kJ MJ^{-1}, and IPCC, 2006: 6.5 % or 65 kJ MJ^{-1}, of the gross energy intake, respectively). Both constants do not reflect that the rates should be dependent on feed properties, as stated by IPCC. A methane emission model was selected here that is based on German feed data. It was combined with the hitherto applied model describing energy requirements.

The emission rates thus calculated deviate from those previously obtained. In the new model, the methane conversion rate is back-calculated from emission rates and gross energy intake rates. For German conditions of animal performance and diet composition, the national means of methane conversion rates range between 71 kJ MJ^{-1} and 61 kJ MJ^{-1} for low and high performances (4700 kg animal^{-1} a^{-1} in 1990 to 7200 kg animal^{-1} a^{-1} in 2010), respectively.

Keywords: methane, emission, model, enteric fermentation, dairy cows

Zusammenfassung

Methan-Emissionen aus der Verdauung bei deutschen Milchkühen

Im Emissionsinventar für die deutsche Landwirtschaft erfolgte die Berechnung der Methan-Emissionen aus der Verdauung bei Milchkühen bisher mit Hilfe eines Modells, das Energie- und Futterbedarf anhand von Leistungsparametern und Futtereigenschaften beschreibt, und einer in den IPCC-Richtlinien vorgegebenen Methan-Umwandlungsrate. Die beiden zur Verfügung stehenden Richtlinien schlagen zwei unterschiedliche (konstante) Raten vor (IPCC, 1996: 6,0 % bzw. 60 kJ MJ^{-1}, und IPCC, 2006, 6,5 % bzw. 65 kJ MJ^{-1} von eingesetzter Bruttoenergie), die allerdings nicht die von IPCC ebenfalls erwähnte Abhängigkeit von den Futtereigenschaften aufweisen. Daher wurde ein geeignetes, auf nationalen Futterdaten beruhendes Methan-Emissionsmodell identifiziert und mit dem bisher im Inventar verwendeten Energiebedarfsmodell kombiniert.

Die so berechneten Emissionsraten weichen von den bisher erhaltenen ab. Im neuen Emissionsmodell wird die zu berichtende Methan-Umwandlungsrate aus Emissionen und Bruttoenergie-Aufnahme zurückgerechnet. Für das deutsche Spektrum an Leistung und Fütterung ergeben sich im nationalen Mittel Umwandlungsraten zwischen 71 kJ MJ^{-1}bei geringen Leistungen und 61 kJ MJ^{-1} bei hohen Leistungen (4700 kg animal^{-1} a^{-1} in 1990 bis 7200 kg animal^{-1} a^{-1} in 2010).

Schlüsselwörter: Methan, Emission, Modell, Verdauung, Milchkühe

* Johann Heinrich von Thünen-Institut (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute for Agricultural Climate Research, Bundesallee 50, 38116 Braunschweig, Germany

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

1 Introduction

Emissions of methane (CH_4) from domestic animals contribute to global warming and to regional air pollution (e.g. Möller, 2011). Any measures to reduce the adverse effects presuppose a satisfactory description of the processes leading to emissions and the adequate assessment of these emissions. In 2009, about 50 Gg a^{-1} CO_2-eq were calculated to have been emitted as CH_4 in Germany, more than half of which originate from agriculture. Within agriculture, the most prominent source category is enteric fermentation of dairy cows, contributing more than 50 % of the overall agricultural CH_4 emissions (Freibauer et al., 2011). At present, the assessment of these emissions makes use of a detailed calculation of energy requirements, but uses the default IPCC methane conversion rate (MCR) of 60 kJ MJ^{-1} of the gross energy (GE) intake (IPCC, 1996) instead of the IPCC (2006) default MCR of 65 kJ MJ^{-1}. These default values do not take feed properties into account. However, animal performance has changed over the two decades covered by emission reporting to UNFCCC. Increased animal weights, increased milk yields and changes in milk protein and fat contents have required different diets. The share of grain in diets has increased since 1990. Hence the MCR should have decreased.

The aim of this work is to establish national emission factors and methane conversion rates for CH_4 from enteric fermentation of dairy cows as a function of animal performance and diet composition.

2 Formation of methane in the rumen and its description in models

In the rumen of cattle, the organic matter in feed is subject to microbial degradation that forms volatile fatty acids (VFA), gases (carbon dioxide, CO_2, and CH_4) and microbial biomass and releases adenosine triphosphate (ATP) as source of energy. The CH_4 formation rate is dependent on diet composition. Lowest emissions per unit of dry matter (DM) intake originate from cereal rich diets, highest from diets rich in fibre and with a low digestibility. For a detailed description of these processes see e.g. Jouany (2008).

Numerous models have been published that allow the prediction of CH_4 emissions from dairy cows as a function of performance and diet composition (for reviews see Jouany, 2008, or Ellis et al., 2007). The quality of the resulting predictions is to a large extent dependent on the number of input parameters available. A very detailed model (Dijkstra et al., 1992; modified by Mills et al., 2001) makes use of the input rates of neutral detergent fibre (NDF: cellulose, hemicellulose, lignin), protein, ammonia, water soluble carbohydrates, starch, lipids, lactate and VFA. Such a model predicts emissions that can be in good agreement with experimental data (Benchaar et al., 1998) or can contradict them (Hinrichs et al., 2004). However, the required (very) detailed data on diet composition is not routinely collected in Germany.

German data sets obtained in respiration chambers are available. Linear regression models based on these measurements were published in Kirchgeßner et al. (1994a) as well as in Jentsch et al. (2007) and Piatkowski et al. (2010). The equations provided in Jentsch et al. (2007) and used in Piatkowski et al. (2010) differ, even though they were derived from the same experimental data set. In these three publications, a number of equations for emissions factors are provided. In the following, those with the highest coefficient of correlation are selected (in chronological order).

2.1 Detailed regression model of Kirchgeßner et al. (1994a)

Kirchgeßner et al. (1994a) reported on their experiments with lactating dairy cows and their approach to relate CH_4 emissions to the crude nutrient intake.

Model 2 in Kirchgeßner et al. (1994a) relates emission factors to the following parameters for lactating dairy cows:

$$EF_{CH4,1} = a_1 \cdot M_{XFi} + b_1 \cdot M_{NFE} + c_1 \cdot M_{XP} + d_1 \cdot M_{XF} + e_1 \qquad (1)$$

where

$EF_{CH4,1}$ methane emission rate (factor) (in kg $animal^{-1}$ a^{-1}) according to Kirchgeßner et al. (1994a)
a_1 coefficient (a_1 = 0.079 kg kg^{-1})
M_{XFi} intake rate of crude fibre (in kg $animal^{-1}$ a^{-1})
b_1 coefficient (b_1 = 0.010 kg kg^{-1})
M_{NFE} intake rate of N-free extracts (in kg $animal^{-1}$ a^{-1})
c_1 coefficient (c_1 = 0.026 kg kg^{-1})
M_{XP} intake rate of crude protein (in kg $animal^{-1}$ a^{-1})
d_1 coefficient (d_1 = – 0.212 kg kg^{-1})
M_{XFa} intake rate of ether extract (fat) (in kg $animal^{-1}$ a^{-1})
e_1 constant (e_1 = 365 · 0.063 kg $animal^{-1}$ a^{-1})

Kirchgeßner et al. (1995) applied the same equation successfully to other cattle. They provide a comparison between observed and predicted emissions (Figure 1).

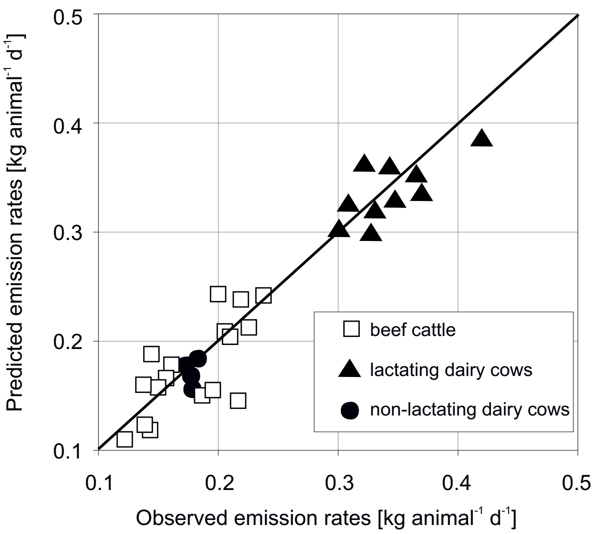

Figure 1:

Comparison of observed and predicted emission rates, as published in Kirchgeßner et al. (1995), based on additional data from Beyer et al. (1993) and Kirchgeßner et al. (1980, 1994b) (redrawn). Slope: 0.99; R^2 = 0.92)

2.2 Simple regression model approach of Kirchgeßner et al. (1994a)

Kirchgeßner et al. (1994a) also interpreted the experimental data set using dry matter as sole explaining entity (see Equation (2) below). This is equivalent to the IPCC methodology in principle as the GE content of dry matter, η_{GE}, is almost constant (IPCC default η_{GE} = 18.45 MJ kg^{-1}, see also Dämmgen et al., 2011). The following equation resulted:

$$EF_{CH4,2} = a_2 \cdot m_{DM} + b_2 \tag{2}$$

where

$EF_{CH4,2}$ CH_4 emission rate (in g animal^{-1} d^{-1})
a_2 coefficient (a_2 = 12 g kg^{-1})
m_{DM} dry matter intake rate (in kg animal^{-1} a^{-1})
b_2 constant (b_2 = 134 g animal^{-1} a^{-1})

with a coefficient of regression of R^2 = 0.19.

The IPCC methodology describes a direct relation without an intercept (constant b_2 = 0).

2.3 Detailed regression model of Jentsch et al. (2007)

Respiration experiments with oxen, young bulls, heifers, lactating and non-lactating dairy cows of Black Pied cattle covering a wide range of body weights yielded a number of regression equations relating CH_4 formation with diet properties. Of these, the following relation offered the best description (Equation 6 in Jentsch et al., 2007, transformed):

$$EF_{CH4,3} = \frac{1}{\eta_{CH4}} \cdot \left(a_3 \cdot m_{DP} + b_3 \cdot m_{DF} + c_3 \cdot m_{DST} + d_3 \cdot m_{DSU} + e_3 \cdot m_{DNFR} + f_3\right) \tag{3}$$

where

$EF_{CH4,3}$ CH_4 emission rate (in kg animal^{-1} a^{-1}) according to Jentsch et al. (2007)
η_{CH4} energy content of methane (η_{CH4} = 55.65 MJ (kg CH_4)$^{-1}$)
a_3 coefficient (a_3 = 1.28 MJ kg^{-1})
m_{DP} intake rate of digestible crude protein (in kg animal^{-1} a^{-1})
b_3 coefficient (b_3 = -0.31 MJ kg^{-1})
m_{DF} intake rate of digestible crude fat (in kg animal^{-1} a^{-1})
c_3 coefficient (c_3 = 1.31 MJ kg^{-1})
m_{DST} intake rate of digestible starch (in kg animal^{-1} a^{-1})
d_3 coefficient (d_3 = 1.16 MJ^{-1})
m_{DSU} intake rate of digestible sugar (in kg animal^{-1} a^{-1})
e_3 coefficient (e_3 = 2.40 MJ kg^{-1})
m_{DNFR} digestible N-free extracts (in kg animal^{-1} a^{-1})
f_3 constant (f_3 = 1.835 MJ animal^{-1} d^{-1} · 365 d a^{-1})

The coefficient of regression was R^2 = 0.889.

2.4 Simple regression model of Jentsch et al. (2007) as used by Piatkowski et al. (2010)

Piatkowski et al. (2010) used the simple approach developed by Jentsch et al. (2007) (Equation (4)) requiring just two variables, the DM intake and the live weight of the animals:

$$EF_{CH4,4}{}^* = a_4 \cdot \frac{m_{DM}}{w} + b_4 \tag{4}$$

where

$EF_{CH4,4}$* specific CH_4 emission related to feed intake (in g (kg DM)$^{-1}$ d^{-1} CH_4)
a_4 coefficient (a_4 = 0.384 kg kg^{-1})
m_{DM} dry matter intake rate (in g d^{-1})
w live weight (in kg)
b_4 constant (b_4 = 32.76 g (kg DM)$^{-1}$ d^{-1} CH_4)

The coefficient of regression was R^2 = 0.224.

2.5 Selecting the adequate model

2.5.1 Input data

All regression models proposed by Kirchgeßner et al. (1994) and by Jentsch et al. (2007) were derived from different German data sets reflecting different animal performances and feed constituents.

The models described in Kirchgeßner et al. (1994a) were originally based on 153 records from respiration trials using lactating cows with milk yields from 10 to 30 kg animal^{-1} d^{-1} and weights between 450 and 700 kg animal^{-1}. The performance data used within the emission inventory are well covered by these data. The results were described and discussed in great detail in the paper and in preceding publications (in particular Kirchgeßner et al., 1991).

The models established by Jentsch et al. (2007) are based on a re-evaluation of experimental data obtained between 1957 and 1989 in 337 experiments with Black Pied cattle, including 42 dairy cows. The live weights of the cows varied between 420 and 672 kg animal^{-1} with a mean of 547 kg animal^{-1}. Milk yields are not reported. A graph is provided showing the methane emissions in energy equivalents as a function of DM intake related to body weight.

2.5.2 Comparing the models using a national set of animal performance, feed intake, diet composition and properties of diet constituents

In order to assess the results obtained with the equations (1) to (4) listed above independent of energy requirement calculations, a standard data set published as an example for nutrient excretion modelling in DLG (2005) was applied to them. The only animal performance entity varied is ECM (energy corrected milk yield). The amounts of the different diet constituents proposed are shown in Table 1, the relevant feed properties in Table 2.

The relevant properties of the diet constituents grass silage, maize silage, hay, straw, soya bean extraction meal and wheat were extracted from Beyer et al. (2004). Standard concentrates (MLF) contents of water, crude ash, crude protein, crude fat, starch and sugar and organic matter were obtained from measurements performed at Riswick experimental station (LWK-NRW, 2004 to 2011). All in all, 132 analyses were taken into consideration.

The calculation of the concentration of nitrogen free extracts (NfE) is a standard operation in the Weender feed analysis (see e.g. Kirchgeßner et al., 2008). It is obtained as residue as follows:

$$x_{\mathrm{NfE}} = x_{\mathrm{OM}} - \left(x_{\mathrm{XP}} + x_{\mathrm{XFa}} + x_{\mathrm{XFi}}\right) \tag{5}$$

where

- x_{NfE} concentration of nitrogen free extracts in a feed constituent (in kg kg^{-1})
- x_{OM} organic matter content in a feed constituent (in kg kg^{-1})
- x_{XP} crude protein content in a feed constituent (in kg kg^{-1})
- x_{XFa} crude fat content in a feed constituent (in kg kg^{-1})
- x_{XFi} crude fibre content in a feed constituent (in kg kg^{-1})

Table 1:
Composition of diets proposed for dairy cows in DLG (2005). Amounts in kg animal^{-1} a^{-1}.

feed variant *	G1	G2	G3	A1	A2	A3	GH1	GH2	GH3	AH1	AH2	AH3
milk yield (ECM)	6000	8000	10000	6000	8000	10000	6000	8000	10000	6000	8000	10000
grass	1900	1600	1300	1000	1000	1000	0	0	0	800	800	800
grass silage	1900	2200	2500	1100	1300	1500	3300	3300	3250	900	1100	1300
maize silage	400	700	1000	2000	2200	2400	400	700	1000	2000	2200	2400
hay	0	0	0	0	0	0	500	500	500	500	500	500
straw	200	200	200	300	200	200	200	200	200	200	100	100
soya bean extraction meal	0	100	250	200	300	450	0	100	250	200	300	450
wheat	200	200	250	100	200	250	200	200	250	100	200	2050
standard concentrate**	1300	1700	2200	1200	1500	1900	1400	1800	2300	1200	1500	1900
mineral feed	10	15	20	20	25	30	10	15	20	20	25	30
total	5910	6715	7720	5920	6725	7730	6010	6815	7770	5920	6725	7730

* feed variants: G: grassland farms, no hay fed; A: mixed farms, predominantly arable land, no hay fed; GH: grassland farms, hay fed; AH: mixed farms, predominantly arable land, hay fed
** standard concentrate MLF 18/3[1], in variant G1 MLF 16/3. For our calculations MLF 16/3 was replaced by MLF 18/3

[1] MLF: Milchleistungsfutter, concentrate for dairy cows

Table 2:

Properties of relevant diet constituents (for sources see text)

contents related to DM	gross energy	digestible crude protein	digestible crude fat	digestible starch	digestible sugars	digestible N free residues	crude fibre	N-free extracts	crude protein	crude fat
	η_{GE}	η_{DP}	η_{DF}	η_{DST}	η_{DSU}	η_{DNFR}	η_{Fi}	η_{NFE}	η_{XP}	η_{XF}
unit	MJ kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}	kg kg^{-1}
feed constituent										
grass silage	18.5	0.112	0.024	0.029	0.049	0.426	0.245	0.452	0.162	0.042
maize silage	17.9	0.038	0.020	0.146	0.061	0.406	0.228	0.582	0.080	0.028
hay	18.0	0.066	0.014	0.029	0.058	0.439	0.280	0.485	0.115	0.025
straw	18.1	0.008	0.007	0.010	0.010	0.402	0.450	0.425	0.038	0.017
rape seed extraction meal	23.6	0.311	0.060	0.046	0.078	0.212	0.130	0.350	0.370	0.070
soya bean extraction meal	20.0	0.446	0.010	0.048	0.092	0.239	0.080	0.345	0.495	0.015
wheat	18.5	0.110	0.014	0.631	0.032	0.072	0.030	0.785	0.145	0.020
standard concentrate *	18.7	0.169	0.029	0.212	0.083	0.095	0.115	0.554	0.216	0.042
mineral feed	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

* standard concentrate MLF 18/3

Inverting Equation 10.21 in IPCC (2006) yields the definition of the MCR which is obtained from the GE intake rate and the amount of CH_4 emitted:

$$MCR = \frac{EE_{CH4}}{GE} = \eta_{CH4} \cdot \frac{EF_{CH4}}{GE} \tag{6}$$

where

MCR methane conversion rate (in MJ MJ^{-1})
EE_{CH4} energy equivalent of methane excreted (in MJ animal^{-1} a^{-1})
GE gross energy intake rate (in MJ animal^{-1} a^{-1})
η_{CH4} energy content of CH_4 (η_{CH4} = 55.65 MJ kg^{-1})
EF_{CH4} methane emission factor (in kg animal^{-1} a^{-1} CH_4)

As a consequence, the MCR can be considered a measure of energy loss by CH_4 emission from enteric fermentation.

The results obtained from the application of Equations (1) to (4) are collated in Figure 2.

As shown in Figure 2, all MCR values decrease with increasing GE intake rates. The values obtained with Equation (3) are highest and exceed the results obtained with both IPCC approaches. The application of Equation (4) yields results above the IPCC (2006) value for GE intake rates below 120 GJ animal^{-1} a^{-1}, and values in the same range as the IPCC (2006) default value for a GE intake rates above 120 GJ animal^{-1} a^{-1}. The estimates using the procedures published by Kirchgeßner et al. (1995) fall below the IPCC (2006) estimates and below the IPCC (1996) in many cases.

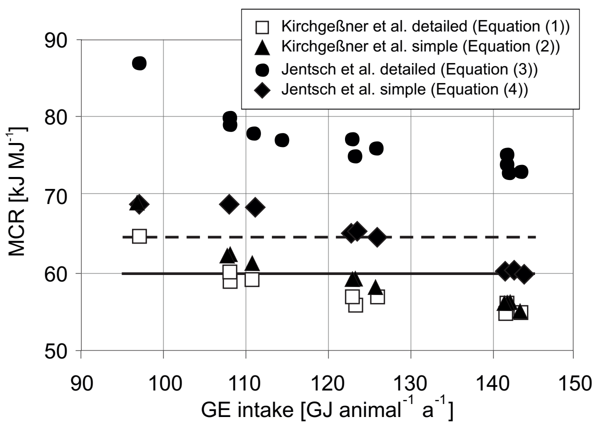

Figure 2.

Methane conversion rates predicted by the models of Kirchgeßner et al. (1994a) (Equations (1) and (2)) and Jentsch et al. (2007) (Equations (3) and (4)) as well as the IPCC (1996) (solid line) and IPCC (2006) dotted line) default values as a function of the gross energy intake.

None of the models agree with the results predicted by the IPCC (1996) and (2006) default values. This may be due to the method to assess the energy requirements and/or the method assessing the CH_4 emission rates.

Hence, the structures of the models calculating these entities have to be investigated and comparisons reported in the literature have to be used as an instrument for selection of the methodology to be applied in the German emission inventory.

2.5.3 The adequate model

Both simple regression models (Equations (2) and (4)) do not provide a mechanistic tool to reflect feed properties as key variables governing *MCR* appropriately. Piatkowski et al. (2010) claim this to be necessary. Hence it is not unexpected that both simple models yield rather low coefficients of regression when compared to the other two models (Equations (1) und (3)). As a consequence, both simple models cannot be considered adequate models.[2]

In an intercomparison using a New Zealand data set, the more detailed model by Kirchgeßner et al. (1994a) [3] (Equation (1)) was found to predict emissions falling below measured data (Palliser and Woodward, 2002).

Bannink et al. (2011) modelled rumen chemistry and published results of CH_4 emissions from Dutch dairy cattle derived from feed properties only. The values for the back-calculated *MCR* are very close to the IPCC (1996) default *MCR*. However, no comparison with measured data is provided. Nevertheless it underpins the likelihood that *MCR* close to 60 kJ MJ^{-1} reflect the reality for cows with a milk yield of about 7000 kg $animal^{-1}$ a^{-1}.

Equation (1) was included in a comparison of observed and predicted emissions together with the IPCC (1996) Tier 2 methodology in Ellis et al. (2010). In comparison with the so-called individual data base (of emissions) both approaches yielded modelled data that exceeded the observed data by about 8 % (Ellis et al., 2010, Table 3). The evaluation states that "Kirchgeßner et al. [1995, Eq. 1] performed better than most other equations on the TRT [4] database". For whole farm models, the equation is clearly more appropriate than the other models in the comparison, in particular IPCC (1996) Tier 2 (see Ellis et al., 2010, Figure 2).

Other than the more detailed model by Kirchgeßner et al. (1994a) [5] (Equation (1)) the recently published results by Jentsch et al. (2007) (Equation 3) were not yet involved in international model intercomparisons.

For the following reasons we conclude that the model defined by Equation (1) represents the best choice out of the four models available:

- it was derived from experimental data covering German dairy cow husbandry which are well documented,
- it is based on mechanistic considerations,
- it requires input data that are available for all German diet constituents,
- it is the only German model which has performed satisfactorily in international comparisons.

3 Combining the module predicting energy requirements and the detailed Kirchgeßner et al. (1994a) module

The German agricultural emission inventory model GAS-EM uses a module to assess energy requirements and dry matter intake for dairy cows based on experimental data obtained in Austria, Germany and Switzerland. The approach is derived from GfE (2001) and DLG (2006) and is described in detail in Dämmgen et al. (2009). Recent changes are documented in Haenel et al. (2012). The establishment of the data base can be found in Dämmgen et al. (2010). This module was combined with the procedure proposed in the Tier 2 methodologies in IPCC (1996) and (2006) to calculate CH_4 emissions from enteric fermentation.

3.1 The IPCC methodology

Both the IPCC (1996) and (2006) guidelines provide the same Tier 2 methodology to assess CH_4 emissions from dairy cows. The major steps are

- the identification of the performance data
- the assessment of the net energy requirements
- the derivation of GE intake rates
- the application of an *MCR* to quantify CH_4 emission rates.

The data flow within this module is shown in Figure 3.

IPCC (2006), Table 10.12, provides default values for *MCR* of 65 (± 10) kJ MJ^{-1} of the GE intake rate. However, Johnson and Johnson (1995) illustrate that observed *MCR* can vary between 20 and 110 kJ MJ^{-1}, also that the *MCR* modelled according to Blaxter and Clapperton (1965) exceeds 60 kJ MJ^{-1} in any case. This is also true for the *MCR* measured by Lassey (2007) – the other source cited in IPCC (2006). However, it remains unclear whether the data sets can reflect the situation of lactating cows in Germany, as diet composition and performance differ.

---

[2] It is confusing that IPCC (2006) refer to Johnson and Johnson (1995) as a source for *MCR* whose evaluation of a data set relating GE intake and the *MCR*.results with a coefficient of correlation of 0.05.

[3] Kirchgeßner et al. (1995) quote Kirchgeßner et al. (1994a) as origin of the equation used.

[4] " … a literature derived treatment average database (37 data points from seven studies)…." (Ellis et al., 2010)

[5] see footnote 3

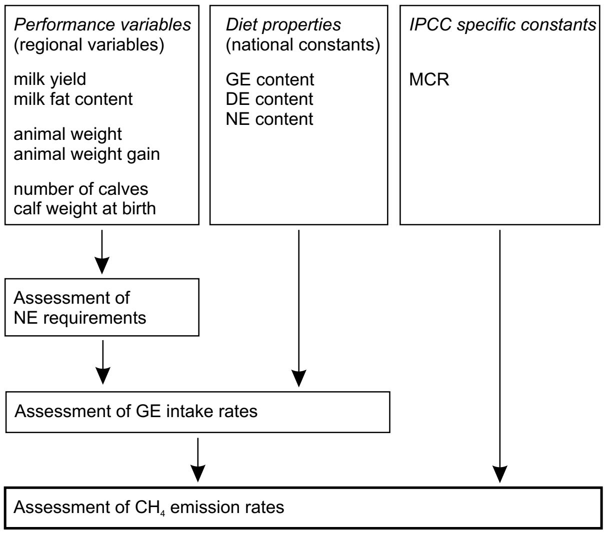

Figure 3:

Flow of data within the IPCC module to assess methane emissions from dairy cows

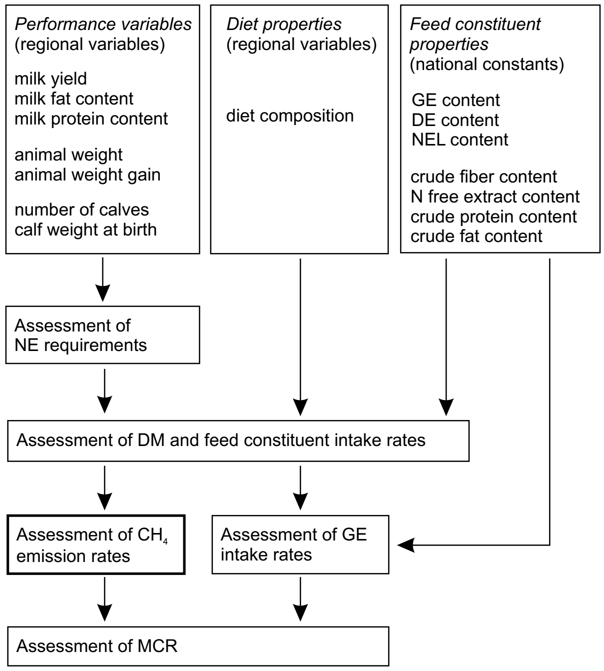

Figure 4:

Flow of data within the combined modules to assess methane emissions from dairy cows

3.2 The combination of the energy and feed intake and the Kirchgeßner modules

The module describing energy requirements and feed intake rates in GAS-EM makes use of the NEL [6] requirements to assess the feed intake as a function of milk yield, milk protein and fat contents, body weight and weight gain, the development of conception products as well as the grazing time to cover the requirements to obtain feed and the energy contents of roughage and concentrates.

For each German district, a grass based diet (constituents: pasture grass, grass silage, wheat, MLF, ratios depending on performance) and a mixed diet typical for farms with arable land (constituents: pasture grass, grass silage, maize silage, rape seed expeller, MLF, ratios depending on performance) are considered. The shares of the two types vary between districts and between years, as does the duration of grazing and hence the share of pasture grass in the diets.

This module is combined with the Kirchgeßner module as defined by Equation (1) to derive CH_4 emission rates. The data flow is illustrated in Figure 4. Note that the role of MCR differs in the IPCC and the combined approach used here, as the latter calculate MCR as a diagnostic entity. The calculation procedure needs the GE intake rate as an auxiliary entity.

4 Sensitivity analysis of the combined modules

The combined energy, feed intake and the Kirchgeßner modules as described above yield CH_4 emission rates. International reporting of CH_4 emissions from enteric fermentation delivers MCR as an entity to characterize the emission process. Hence, our sensitivity analysis concentrates on this entity. It was performed changing one input parameter at a time, *ceteris paribus*. The range of variation of those parameters reflects those of the potential input data.

A dimensionless sensitivity indicator S is defined by

$$S = \frac{\frac{\Delta MCR}{MCR_{st}}}{\frac{\Delta P}{P_{st}}} \tag{7}$$

where

S	sensitivity indicator (dimensionless)
ΔMCR	variation of MCR (in kJ MJ^{-1})
MCR_{st}	MCR at standard conditions (in kJ MJ^{-1})
ΔP	variation of the input parameter P
P_{st}	value of the input parameter P at standard conditions

[6] NEL: net energy for lactation

Table 4:
Entities varied in the sensitivity analysis

	feed type	range	range	standard value	variation	unit
Entitiy varied		from (min)	to (max)	P_{st}	ΔP	
milk yield	mixed	4600	8100	6000	600	kg animal^{-1} a^{-1}
milk yield	grass	4600	8100	6000	600	kg animal^{-1} a^{-1}
milk fat	mixed	0.040	0.043	0.041	0.0041	kg kg^{-1}
milk fat	grass	0.040	0.043	0.041	0.0041	kg kg^{-1}
milk protein	mixed	0.033	0.036	0.034	0.0034	kg kg^{-1}
milk protein	grass	0.033	0.036	0.034	0.0034	kg kg^{-1}
live weight	mixed	580	670	620	62	kg animal^{-1}
live weight	grass	580	670	620	62	kg animal-1
weight gain	mixed	10	20	13.3	1,33	kg animal^{-1} a^{-1}
grazing time	grass	0.00	0.39	0	1	h d^{-1}

Table 5:
Sensitivity of MCR towards varied input parameters (MCR in kJ MJ^{-1})

	feed type	MCR	MCR	MCR_{st}	S_1	S_{graz}
Entity varied		from	to		%	%
milk yield	mixed	73.4	62.2	68.1	-0.30	
milk yield	grass	69.4	60.4	65.5	-0.24	
milk fat	mixed	68.4	67.6	68.1	-0.15	
milk fat	grass	65.7	65.2	65.5	-0.11	
milk protein	mixed	68.3	67.8	68.1	-0.07	
milk protein	grass	65.6	65.3	65.5	-0.05	
live weight	mixed	68.8	67.8	68.1	-0.10	
live weight	grass	66.1	65.3	65.5	-0.09	
weight gain	mixed	68.2	68.0	68.1	-0.04	
grazing time	grass	65.5	64.2	65.5		-0.1

The sensitivity indicator S_1 used reflects changes in MCR (in %) as result of a variation of P of 1 %. For grazing, the indicator S_{graz} shows the effect of 1 h additional grazing per day.

A negative S indicates that an increase in P results in a decrease in MCR.

For a given performance, diets richer in grass or grass silage result in reduced MCR.

Extended grazing also leads to reduced MCR.

It should be kept in mind that decreasing MCR do not necessarily result in decreased CH_4 emission rates, but that increased performance will result in increased CH_4 emission rates per animal.

5 Application of the combined modules to German dairy cows

5.1 Case study reflecting regional peculiarities

Dairy cows representing three different regions and performance classes were selected for an example calculation. Their respective properties are collated in Table 6.

Variants 6M and 6G were selected representing cows in Bayern (Bavaria) with 6000 kg animal^{-1} a^{-1}. They differ with respect to their feeding: M denotes mixed feeding (diet contains pasture grass, grass silage, maize silage, rape seed expeller, MLF, ratios depending on performance), G refers

Table 6:

Animal performance data and grazing regimes used in the example calculations (for symbols see text)

Variant	6M	6G	7Mv	7Gv	7Mc	7Gc	8Mv	8Gv	8Mc	8Gc	
milk yield	6000	6000	7200	7200	7200	7200	8400	8400	8400	8400	kg animal^{-1} a^{-1}
final weight	675	675	650	650	675	675	620	620	675	675	kg animal^{-1}
initial weight	650	650	620	620	650	650	580	580	650	650	kg animal-1
lifespan	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	a
milk fat content	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	kg kg^{-1}
milk protein content	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	kg kg^{-1}
share on mixed feed	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	animal animal^{-1}

Table 7:

Methane emission rates and methane conversion rates obtained in the example calculations (for symbols see text)

Variant	6M	6G	7Mv	7Gv	7Mc	7Gc	8Mv	8Gv	8Mc	8Gc	
CH_4 emission rate	130.0	125.6	133.3	128.8	134.5	130.0	136.3	131.9	139.0	134.3	kg animal^{-1} a^{-1}
MCR	67.5	65.1	64.2	62.4	64.0	62.2	61.4	59.9	59.9	59.6	kJ MJ^{-1}

to a grass based diet (pasture grass, grass silage, wheat, MLF, ratios depending on performance). Dairy cows with a milk yield of 7200 kg animal^{-1} a^{-1} (7M and 7G) are likely to be found in Niedersachsen (Lower Saxony). These animals are lighter than those in Bavaria. In order to eliminate potential effects of different live weights, one additional variant keeps weights and weight gains constant (7Mc and 7Gc), whereas 7Mv and 7Gv use the varied weights. The same applies to the high performance cows 8M and 8G with a milk yield of 8400 kg animal^{-1} a^{-1} which may be located in present Mecklenburg-Vorpommern.

Grazing time was kept constant for all variants, i.e. the share of animals housed permanently was 85 %, that of animals grazing part time 15 %. The latter were grazed 12 hours per day and 170 days per year.

The resulting CH_4 emission rates and *MCR* are listed in Table 7.

Table 7 illustrates the ranges of CH_4 emission rates and *MCR* to be considered, indicating that *MCR* will fall below the IPCC (1996) default value of 60 kJ MJ^{-1} on a national scale if milk yields continue to increase. It also shows that the low milk yields as in the early 1990s will result in *MCR* well above the IPCC (2006) default value of 65 kJ MJ^{-1}.

5.2 Application to the time series of German dairy cow performance and grazing data used in the national inventory

In order to illustrate the effect of the application of the combined modules to the German national inventory, a data set containing national weighted means of all parameters described above (milk yield, milk fat and protein contents, weight, weight gain, diet composition and feed properties as well as grazing times) was used to establish a time series of national *MCR* (Figure 5).

MCR decrease almost steadily primarily as a result of increasing milk yields (4700 kg animal^{-1} a^{-1} in 1990 to 7200 kg animal^{-1} a^{-1} in 2010). Projections expect mean milk yields of 7800 kg animal^{-1} a^{-1} in 2020, which are likely to result in *MCR* of about 61 kJ MJ^{-1}. Again, animals kept on mixed farms emit more CH_4 per MJ GE than those receiving a grass based diet.

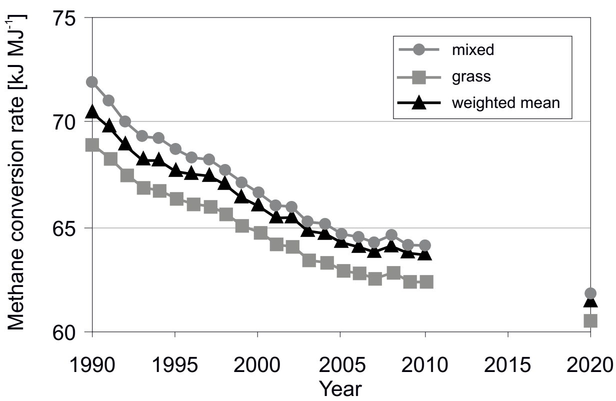

Figure 5:

Time series of mean methane conversion rates obtained from German inventory data

6 Discussion

CH_4 emission rates from enteric fermentation depend on performance data such as weight and weight gain, milk yield, concentrations of milk fat and protein. They are also governed by feed properties and the rumen microflora.

The IPCC approach (IPCC, 1996; IPCC, 2006) describes CH_4 emission rates from enteric fermentation as proportional to the GE intake rates (divided by the energy content of CH_4) where the constant of proportionality is the so called methane conversion rate MCR. The gross energy can be calculated as function of the energy requirements which in turn are a function of the animal performance. The only feed property considered is the digestibility of energy.

It is striking that – given the importance of CH_4 emissions from enteric fermentation – the experimental data base is sparse.

The data sets that are the base of the IPCC's MCR fixing suffer from this inadequacy. The data used in Johnson and Johnson (1995) obviously originate from North American measurements. They illustrate however that the approach to derive CH_4 emission rates from GE intake rates may be inadequate. In addition, they state that an approach that takes feed properties into account (such as in Moe and Tyrrell, 1979) yields better results and should be preferred. The data set provided by Lassey (2007), based on tracer techniques, illustrates the variability of MCR but does not allow for a direct comparison. The five French cows used in the measurements were obviously dry and of a heavy breed.

The investigations made for the present paper clearly indicate that the use of a constant MCR is inadequate. Any approach to derive MCR has to reflect at least feed composition and feed properties. It should also reflect a typical rumen microflora (see Dijkstra and France, 1996; Ellis et al., 2008; Hook et al., 2010). Both aspects require national solutions, i.e. national feed property data and national data on diet composition as a function of animal performance data (American and European conditions differ substantially with respect to diet composition data, see Table 2 in Mills et al., 2003). Assuming a "mean national microflora", the emissions from the various feed constituents have to be obtained from experiments. Germany is fortunate in having both data sets at hand. In the combined GAS-EM and Kirchgeßner modules they can be used as parameters to derive energy requirements, CH_4 emissions and non-constant MCR.

Even if the experimental results used in this work are now two decades old and have not been checked or updated since, they are not contradiced by more modern data (such as those reported in Lassey, 2007, Hindrichsen et al., 2004, Jouany, 2008, and Ellis et al., 2009).

Hence, it is recommended that the updated GAS-EM module reflecting diet composition and feed properties leading to variable methane conversion rates for dairy cows according to Kirchgeßner et al. (1994a) be applied in future German agricultural emission inventories.

References

Bannink A, van Schijndel MW, Dijkstra J (2011) A model of enteric fermentation in dairy cows to estimate methane emission for the Dutch National Inventory Report using the IPCC Tier 3 approach. Anim Feed Sci Technol 166-167:603-618

Benchaar C, Rivest J, Pomar C, Chiquette J (1998) Prediction of methane production from dairy cows using existing mechanistic models and regression equations. J Anim Sci 76:617-627

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 : Forschungsinstitut für die Biologie landwirtschaftlicher Nutztiere. 392 pp

Beyer M, Jentsch W, Hoffmann L (1993) Einfluss der Stärkeherkünfte Gerste, Mais und Kartoffeln und ihrer Rationsanteile auf die Nährstoffverdaulichkeiten und die Energieverwertung bei Wiederkäuern. Arch Anim Nutr 44:265-281

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, Brade W, Müller-Lindenlauf M, Eurich-Menden B, Döhler H, Hutchings NJ (2010) An improved data base for the description of dairy cows in the German agricultural emission model GAS-EM. Landbauforsch 60(2):87-100

Dämmgen U, Haenel H-D, Rösemann C, Hutchings NJ, 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

Dijkstra J, France J (1996) A comparative evaluation of models of whole ru men function. Ann Zootech 45(Suppl):175-192

Dijkstra J, Neal HD, Beever DE, France J (1992) Simulation of nutrient digestion, absorption and outflow in the rumen : model description. J Nutr 122(11):2239-2256

Deutsche Landwirtschaftsgesellschaft (2006) Schätzung der Futteraufnahme bei der Milchkuh [online]. To be found at <http://statictypo3.dlg.org/fileadmin/downloads/fachinfos/futtermittel/futteraufnahme_milchkuh06.pdf> [quoted 07.05.2012]

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

Ellis JL, Bannink A, France J, Kebreab E, Dijkstra J (2010) Evaluation of enteric methane prediction equations for dairy cows used in whole farm models. Global Change Biol 16:3246-3256

Ellis JL, Dijkstra J, Kebreab E, Bannink A, Odongo NE, McBride BW, France J (2008) Aspects of rumen microbiology central to mechanistic modelling of methane production in cattle. J Agric Sci 146:213-233

Ellis JL, Kebreab E, Odongo NE, Beauchemin K, McGinn S, Nkrumah JD, Moore SS, Christopherson R, Murdoch GK, McBride, BW, Okine EK, France J (2009) Modeling methane production from beef cattle using linear and nonlinear approaches. J Anim Sci 87:1334-1345

Ellis JL, Kebreab E, Odongo NE, McBride BW, Okine EK, France J (2007) Prediction of methane production from dairy and beef cattle. J Dairy Sci 90:3456-3467

Gesellschaft für Ernährungsphysiologie (2001) Empfehlungen zur Energie- und Nährstoffversorgung der Milchkühe und Aufzuchtrinder 2001. Frankfurt a M : DLG-Verl, 136 p, Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere 8

Haenel H-D, Rösemann C, Dämmgen U, Poddey E, Freibauer A, Döhler H, Eurich-Menden B, Wulf S, Dieterle M, Osterburg B (2012) Calculations of gaseous and particulate emissions from German agriculture 1990–2010 : report on methods and data (RMD) Submission 2012. Braunschweig : vTI, 394 p, Landbauforsch SH 356

Hindrichsen IK, Mills JAN, Madsen J, Kreuzer M, Dijkstra J (2004) Results of mechanistic model estimating methane in relation to methane emissions measured in dairy cows. J Anim Feed Sci 13(Suppl 1):99-102

Hook SE, Wright A-DG, McBride BW (2010) Methanogens : methane producers of the rumen and mitigation strategies [online]. To be found at <http://www.hindawi.com/journals/arch/2010/945785/> [quoted 04.05.2012]

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.htm> [quoted 07.05.2012]

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.htm> [quoted 07.05.2012]

Jentsch W, Schweigel M, Weissbach F, Scholze H, Pitroff W, Derno M (2007) Methane production in cattle calculated by the nutrient composition of the diet. Arch Anim Nutr 61:10-19

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483-2492

Jouany J-P (2008) Enteric methane production by ruminants and its control. In: Andrieu S, Wilde D (eds) Gut efficiency : the key ingredient in ruminant production ; elevating animal performance and health. Wageningen : Wageningen Acad Publ, pp 35-59

Kirchgeßner M, Roth FX, Schwarz FJ, Stangl G (2008) Tierernährung : Leitfaden für Studium, Beratung und Praxis. Frankfurt a M : DLG-Verl, 635 p

Kirchgeßner M, Müller HL, Birkenmaier F, Schwarz FJ (1994b) Energetische Verwertung von Saccharose durch laktierende Milchkühe und Konsequenzen für die Energiebewertung von Zucker. J Anim Physiol Anim Nutr 71:247-260

Kirchgeßner M, Müller HL, Sax J (1980) Energieumsatz und Energieverwertung nichtlaktierender und laktierender Kühe bei unterschiedlicher Fütterungsfrequenz. Z Tierphysiol Tierernähr Futtermittelkd 44:279-289

Kirchgeßner M, Windisch W, Müller HL (1994a) Methane release from dairy cows and pigs. EAAP Publ 76:399-402

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

Kirchgeßner M, Windisch W, Müller HL, Kreuzer M (1991) Release of methane and carbon dioxide by dairy cattle. Agrobiol Res 44:91-102

Lassey KR (2007) Livestock methane emission : from the individual grazing animal through national inventories to the global methane cycle. Agric Forest Meteorol 142:120-132

Landwirtschaftskammer Nordrhein-Westfalen (2004 to 2011). Milchleistungsfutter im Test. Energetische Futterwertprüfungen [online]. To be found at<http://www.riswick.de/versuche/tierhaltung/futterwertpruefung/index.htm> [quoted 04.05.2012]

Mills JAN, Dijkstra J, Bannink A, Cammell SB, Kebreab E, France J (2001) A mechanistic model of whole-tract digestion and methanogenesis in the lactating dairy cow : model development, evaluation and application. J Anim Sci 79:1584-1597

Mills JAN, Kebreab E, Yates CM, Crompton LA, Cammell SB, Dhanoa MS, Agnew RE, France J (2003) Alternative approaches to predicting methane emissions from dairy cows. J Anim Sci 81:3141-3150

Moe PW, Tyrrell HF (1979) Methane production in dairy cows. J Dairy Sci 62:1583-1586

Möller D (2011) Chemistry of the climate system. Berlin : De Gruyter, 722 pp

Palliser CC, Woodward SL (2002) Using models to predict methane reduction in pasture-fed dairy cows [online]. To be found at <http://www.iemss.org/iemss2002/proceedings/pdf/volume%20uno/209_palliser.pdf> [quoted 04.05.2012]

Piatkowski B, Jentsch W, Derno M (2010) Neue Ergebnisse zur Methanproduktion und zu deren quantitativer Vorhersage beim Rind. Züchtungskunde 82:400-407

Fütterung und Haltung von Hochleistungskühen 7. Die Futteraufnahme und ihre Schätzer

Klaus Walter*

Zusammenfassung

Hohe Milchleistungen erfordern entsprechend hohe Futteraufnahmen, wenn die Kuh nicht abmagern und gefährlichen Energie- und Nährstoffdefiziten ausgesetzt sein soll. Milchviehhalter und Beratung nutzen Schätzer für die Bestimmung der Futteraufnahme, um die bestmögliche Fütterung zu erzielen. Die Schätzer von NRC (2001) und Meinhold et al. (1976) basieren allein auf tierspezifischen Daten. Obwohl die Schätzer von Robinson (2006) und Gruber et al. (2004) zusätzlich Kennzahlen des Futters und der Ration umfassen, liegen die errechneten Futteraufnahmen auf vergleichbarem Niveau.

Mit dem Gewicht der Kuh steigt die Futteraufnahme und damit auch die maximal erzielbare Milchleistung. Die Futteraufnahme weist jedoch erhebliche tierspezifische Niveauunterschiede auf, die die maximal erzielbare Leistung ebenso stark beeinflusst wie die Gewichtsdifferenzen.

Alle Schätzer stellen eine enge Beziehung zwischen Milchleistung und Futteraufnahme her. Diese positive Relation bewirkt, dass die Schätzer des NRC (2001) und von Meinhold et al. (1976) auch ohne direkte Beziehung zur Futterqualität ein ähnliches Niveau der Futteraufnahme aufweisen wie die Schätzer von Robinson (2006) und Gruber et al. (2004), die eine positive Beziehung zur Futterqualität berücksichtigen.

Gegen Ende der Laktation übersteigt bei den höchsten Futterqualitäten die von allen Schätzern ermittelte Futteraufnahme das für eine bedarfsgerechte Versorgung erforderliche Niveau.

Milchvieh haltende Betriebe sorgen in der Regel für eine stets ausreichende Versorgung mit (aufgewertetem) Grundfutter und verabreichen entsprechend der Milchleistung zusätzlich Kraftfutter. Diese am Durchschnitt orientierte Versorgung berücksichtigt weder das tierspezifische Niveau des Futteraufnahmevermögens noch deren tägliche Schwankung.

Bei der erforderlichen Weiterentwicklung der Schätzer sollten tierspezifische Unterschiede, Energie- und Nährstoffbilanz, Kondition, Krankheit, Klima und betriebliche Charakteristika größere Bedeutung erlangen.

Schlüsselworte: Futteraufnahme, Schätzer der Futteraufnahmekapazität, Futterqualität, Milchleistung, Energie- und Nährstoffbilanz

Abstract

The feeding und husbandry of high performance cows Part 7. Dry matter intake and its estimators

High milk yield requires an appropriate level of feed intake in order to avoid excessive loss of weight and dangerous energy and nutrient deficiencies. Thus, estimators are used by dairy farmers and consultants to determine feed intake, aiming at the best possible feeding. The estimators of the NRC (2001) and Meinhold et al. (1976) are based solely on animal specific data. Although the estimators of Robinson (2006) and Gruber et al. (2004)) include additional statistics on feed and rations, the calculated feed intake is at a comparable level.

Feed intake increases with the weight of the cow and thus also the maximally targetable milk yield. Feed intakes show significant animal-specific level differences that impact the maximal targetable performance just as strongly as weight differences.

All estimators presume a strong cohesion between yield and feed intake. That is why the estimators of the NRC (2001) and Meinhold et al. (1976), even without a direct correlation to feed quality, show a similar level of feed intake as do the estimators of Robinson (2006) and Gruber et al. (2004), which take a positive correlation between feed quality and intake into account.

Towards the end of lactation, assuming constantly highest quality feed, all estimators present feed intakes higher than needed.

Dairy cows are generally provided a constantly adequate supply of (enriched) basic rations, as well as additional concentrates according to each cow's individual level of milk yield. The supply based on the average yield considers neither the animal-specific level of feed intake nor the amount of day to day shifts in milk yield.

In the course of a necessary further development of the estimators of feed intake, variables like animal-specific differences, energy and nutrient balances, body condition, disease, climate and farm characteristics should be awarded a greater attention and meaning.

Keywords: Feed intake, estimators for dry matter intake, quality of feed, milk yield, energy and nutrient balance

* Johann Heinrich von Thünen-Institut (vTI), Institut für Agrartechnologie und Biosystemtechnik, Bundesallee 50, 38116 Braunschweig, klaus.walter@vti.bund.de

Einleitung

Die Variation der tier- und futterspezifischen Daten lenkt die Aufmerksamkeit auf die Unsicherheiten, die bei Verwendung der aus Versuchen gewonnenen Mittelwerte, Relationen und Funktionen auftreten, weil sie die monetären und naturalen Erfolgskriterien beeinflussen. Die Milchviehhaltung ist geprägt von einer nichtlinearen Beziehung zwischen Aufwand und Ertrag, die zu spürbar negativen Veränderungen der Erfolgskennzahlen führen, wenn die täglichen Milchleistungen sowie Futteraufnahmen variieren und sich die Individuen der Herde hinsichtlich Alter, Gewicht, Leistungsvermögen, Fruchtbarkeit, Verlauf der Laktation etc. unterscheiden. Die Bedeutung der Futteraufnahme und die Ansätze für ihre Bestimmung für die Input-Outputrelationen ist Gegenstand dieser Analyse.

1 Ausgangssituation und Fragestellung

Die Milchviehhalter legen ihren Kühen jeden Tag ausreichend Grundfutter oder Grund- und Kraftfuttermischungen (TMR) vor. Aus den Gesamtmengen lassen sich nach Abzug der Futterreste zwar Informationen über den Gesamtverzehr der Gruppe bzw. der Herde gewinnen, aber keine tierspezifischen Futteraufnahmen ableiten. Die genaue Erfassung der aufgenommenen Nährstoff- und Energiemengen ist eine elementare Voraussetzung für die anzustrebende bedarfsgerechte Versorgung. Viele Experimente offenbaren erhebliche Unterschiede der tierspezifischen Futteraufnahmemengen zwischen den Individuen. Trotz der damit korrespondierenden Unterschiede der aufgenommenen Energie- und Nährstoffmengen wird nur eine leistungsabhängige Kraftfutterversorgung empfohlen, die mittels Kraftfutterautomaten realisiert wird. Bei Weidegang lassen sich die abgeweideten Mengen extrem schwer erfassen, zudem verfügen die Milchviehhalter nicht wie beim konservierten Grundfutter über Nährstoffanalysen.

Der Landwirt kann daher nur an Hand des Erscheinungsbildes der Kühe feststellen, ob seine Rationsbemessung bzw. sein Fütterungsregime erfolgreich ist. Weil die Kuh Körpersubstanz abbaut, um Milch zu produzieren, manifestiert sich eine Unterversorgung im Gewichtsverlust. Dieser ist ebenso wie die Verfettung bei Überversorgung nicht zeitnah und eindeutig identifizierbar, weil die Haltungsverfahren keine Wägung vorsehen. Wissenschaft und Beratung empfehlen die regelmäßige Bestimmung des „body condition score" (bcs), um eine Über- und Unterversorgung zu erkennen und entsprechend zu reagieren. Zusätzlich sind eine Vielzahl von Ansätzen zur Berechnung der tierspezifischen Tagesaufnahmen entwickelt worden, die eine leistungsgerechte Versorgung ermöglichen sollen.

2 Ansätze zur Bestimmung der Futteraufnahme

Den Milchviehhaltern sind die täglichen Verzehrsmengen der einzelnen Kühe nicht bekannt, daher verwenden sie bzw. ihre Fütterungsberater durchweg Rationsberechnungsprogramme der Wissenschaft, der Zucht- und Beratungsverbände etc. Aus der Vielzahl der in diesen Programmen implementierten Ansätzen zur Bestimmung der Futteraufnahme werden die von Gruber et al. (2004), Meinhold et al. (1976), NRC (2001) und Robinson (2006) vorgelegten Schätzformeln für die Ermittlung der täglichen Futteraufnahme in den Vergleich einbezogen. Diese Schätzer wurden ausgewählt, weil der von Gruber et al. (2004) in der deutschsprachigen Fachpresse einen hohen Stellenwert erreicht, ähnliches gilt für den vom NRC (2001) vorgelegten Ansatz in der amerikanischen Fachliteratur. Der Ansatz von Robinson (2006) ist integraler Bestandteil eines umfassenden Analyse- und Beratungskonzeptes und basiert auf allen Informationen, die den Betrieben zur Verfügung stehen. Der von Meinhold et al. (1976) vorgelegte Schätzer ist der erste Ansatz, der für rechnergestützte Verfahren mit optimierten tierspezifischen Rationen entwickelt wurde.

Tabelle 1 nennt die von den Schätzern verwendeten Variablen und Kennzahlen. Dabei nutzen die Ansätze von Meinhold et al. (1976) und NRC (2001) nur tierspezifische Informationen, die von Gruber et al. (2004) und Robinson (2006) dagegen zusätzliche Angaben aus der zu verabreichenden Ration. Robinson (2006) bestimmt die durch „body locomotion score" (bls) und Klima verursachte Minderung der Futteraufnahme. Nur Robinson (2006) setzt den „body condition score" (bcs), also ein Maß für die augenblickliche Energie- und Nährstoffbilanz, für die Berechnung der Futteraufnahme ein.

Um die Futteraufnahme mittels der von Gruber et al. (2004) und Robinson (2006) entwickelten Berechnungsansätze bestimmen zu können, sind die in Tabelle 1 genannten rationsspezifischen Kennzahlen von Nöten. Das für diese Analyse eingesetzte Simulationsprogramm (Walter 2008) bestimmt zunächst eine Ration nach dem Ansatz von Meinhold et al. (1976) als Basislösung und nutzt dann die Ansätze von Gruber et al. (2004) oder Robinson (2006), um sich iterativ der Futteraufnahme zu nähern, die den von den Autoren vorgegebenen Funktionen entspricht. Nach wenigen Iterationen unterscheiden sich die Schätzungen der täglichen Futteraufnahme i. d. R. nur noch um wenige Prozente, weil die Lösungen der Schätzsysteme konvergieren.

Eine Bewertung der vorgelegten Ansätze mittels Funktionsanalyse ist wegen der vielen Variablen wenig aufschlussreich. Zudem ist die Beurteilung der Milchproduktion allein an Hand des Futterinputs unzureichend, denn die dynamischen Aspekte wie Körpersubstanzabbau und

Tabelle 1:
Benötigte Variablen für die Berechnung der täglichen Futteraufnahme

Autor	Gruber et al. (2004)	Meinhold et al. (1976)	NRC (2001)	Robinson (2006)
Tierspezifische Variablen				
Rasse	+	nur HF [1)]	nur HF	nur HF
Metabolisches Lebendgewicht	+	+	+	+
bcs [2)]				+
bls [3)]				+
Tagesleistung (kg Milch)	+	+	+	+
Tag der Laktation	+	+	+	+
Trächtig ab Tag …		190	190	
Alter (Anzahl Laktationen)	1, 2, 3, 4++	1, 2, 3++	1, 2, 3++	1, 2, 3, 4, 5 …
Rationsspezifische Variablen				
Trockensubstanzgehalt	+			+
Kraftfutteranteil	+			+
Kraftfuttermenge	+			+
Heuanteil	+			
Maisanteil	+			
Grünfutteranteil	+			
Energiegehalt	+			+
Rohproteingehalt	+			+
Energie- zu Rohproteingehalt	+			+
Fettgehalt				+
Stärkegehalt				+
Aschegehalt				+
Rohfasergehalt	+			
NDF [4)]				+
NDF [4)] rumen				+
Betriebsspezifische Kennzahlen				
Management	+			
Klima				+
Abgleich mit tier- und gruppenspezifischer Futteraufnahme				erforderlich

[1)] HF = Holstein Frisian
[2)] bcs = body condition score
[3)] bls = body locomotion score
[4)] NDF = nutrient detergent fiber (NRC 2001)

-wiederaufbau, Leistungsminderung durch unzureichende Nährstoffzufuhr bei zu geringer Futteraufnahme etc. bestimmen die Input- Outputrelationen.

Daher geht es weniger um Tageswerte, sondern vor allem um die naturalen und ökonomischen Erfolgsdaten der gesamten Laktationsperiode.

Weil in der Trockenstehzeit die Kuh knapp gefüttert werden soll, um eine Überversorgung und Verfettung zu vermeiden, wird das Futteraufnahmevermögen nicht ausgeschöpft. Diese Phase der Zwischenkalbezeit wird daher im Folgenden ausgespart.

Die Schätzer von Meinhold et al. (1976) und NRC (2001) sind einfach zu kalkulierende Funktionen, deren Variablen in Tabelle 1 aufgelistet sind.

Der von Robinson (2006) entwickelte Ansatz errechnet zunächst eine auf das Gewicht bezogene „base maximal dry matter intake". Für die in Tabelle 1 genannten Größen werden Faktoren bestimmt, die dann zum „predicted maximal dry matter intake" führen. Die tatsächlich im Betrieb[1] erzielte Futteraufnahme „actual dry matter intake" ist zu ermitteln, um den für weitere Kalkulationen erforderlichen Faktor „predicted / actual" errechnen zu können.

Der von Gruber et al. (2004) geschaffene Schätzer unterscheidet vier verschiedene Grundfutterregime[2], für die jeweils ein eigener Ansatz mit den in Tabelle 1 genannten Variablen zu nutzen ist.

2.1 Gewicht und Futteraufnahme

In Abbildung 1 wird das Ergebnis der Simulation mit Erstkalbinnen von alternativ 450, 500, 550 und 600 kg Lebendgewicht sowie vier Schätzern der Futteraufnahme dargestellt. Diese beträgt alternativ 80, 85, 90, 95, 100, 105, 110, 115 und 120 Prozent des Schätzwertes, um die in vielen Versuchen und von Milchviehhaltern bestätigten Unterschiede der tierspezifischen Futteraufnahmekapazität bewerten zu können. Die Laktationsperiode beträgt 300 Tage. Die Trockenstehzeit dauert 60 Tage und bleibt ausgespart. Das Wachstum der Erstkalbin wird mit 50 kg und das Geburtsgewicht des zweiten Kalbes mit 38 kg vorgegeben.

Die Schätzer des NRC (2001) und Meinhold et al. (1976) errechnen die tägliche Futteraufnahme u. a. aus dem Gewicht, der Zahl der Laktationen, der Tagesmilchleistung,

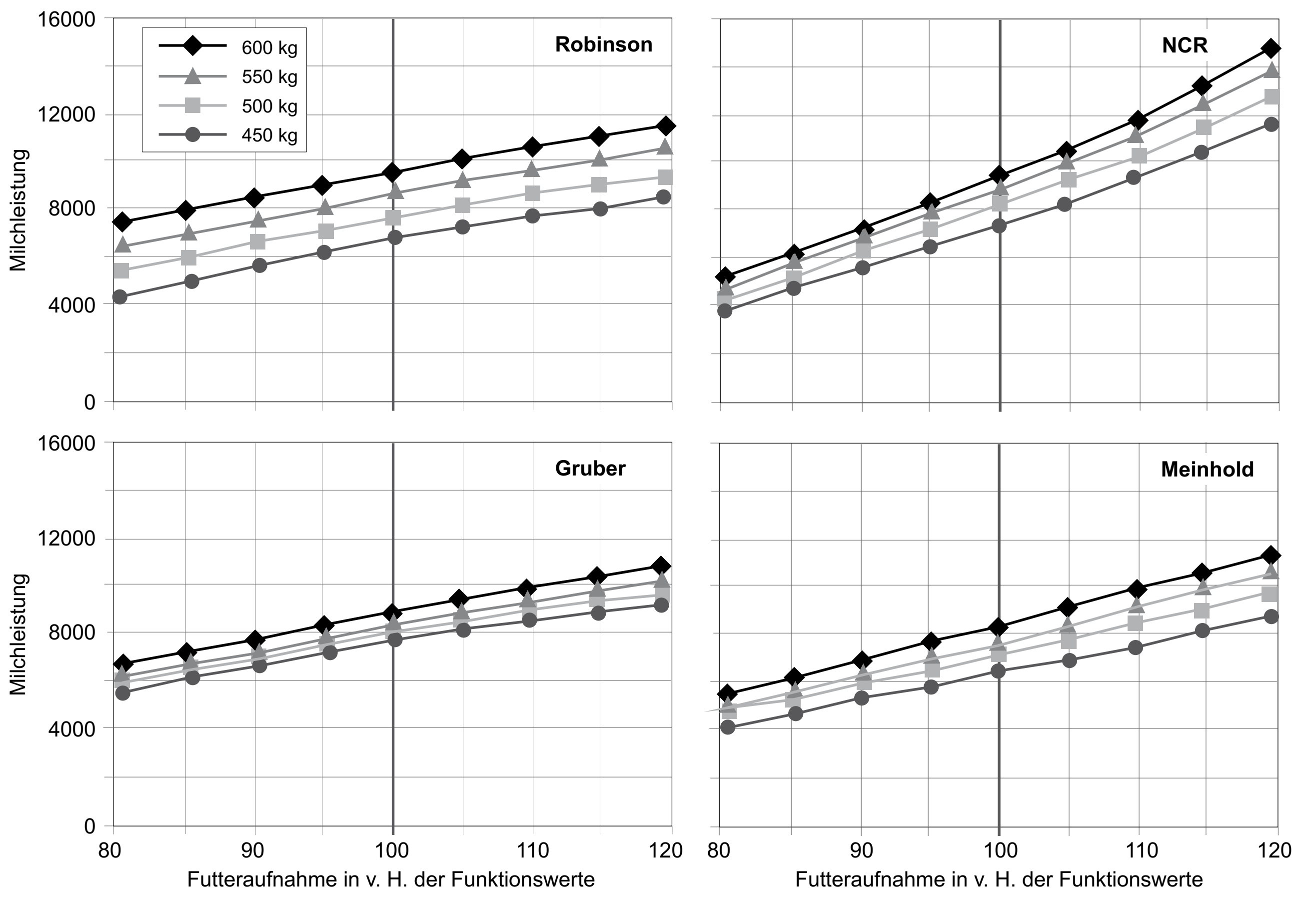

Abbildung 1:
Maximal erzielbare Leistung einer Kuh in 1. Laktation, mit einer Laktationsperiode von 300 Tagen, für unterschiedliche Schätzer der Futteraufnahme, die wiederum 80, 85 … bis 120 Prozent der Funktionswerte betragen

[1] Erneut wird mittels des Schätzers von Meinhold et al. (1976) die als tatsächliche im Betrieb erzielte Futteraufnahme bestimmt und als Einstieg in den o. g. Berechnungszyklus genutzt. Wird stattdessen der Ansatz des NRC (2001) oder von Gruber et al. (2004) gewählt, so unterscheiden sich die Ergebnisse nur im Bereich weniger Prozente.

[2] Im Einzelnen werden vier Ansätze entwickelt: getrennte Vorlage-Standard, getrennte Vorlage-Heu, TMR-Standard und TMR-Heu.

dem Laktationstag und der Dauer der Zwischenkalbezeit, siehe Tabelle 1. Die Ansätze von Robinson (2006) und Gruber et al. (2004) berücksichtigen zusätzlich die Kennzahlen der Ration, wie Qualitäten und Anteile der eingesetzten Futtermittel.

Allen Schätzern ist gemein, dass von den Lebendgewichten ein geringerer Einfluss auf die maximal erzielbare Leistung[3] ausgeht als von der Futteraufnahme. Die Schätzer von Gruber et al. (2004), NRC (2001) und Meinhold et al. (1976) bewerten die Differenz der kalkulierten Lebendgewichte von 450, 500, 550 und 600 kg mit einem Zuwachs von knapp 1.000 kg Milch und zwar weitgehend unabhängig von der o. g. prozentualen Abweichung des Niveaus der Futteraufnahme. Wird der Schätzer von Robinson (2006) eingesetzt, dann führen die unterschiedlichen Lebendgewichte zu rd. 3.500 kg Leistungszuwachs.

Der Anstieg der maximal erzielbaren Leistung bei Zunahme der Futteraufnahme beträgt bei allen Ansätzen zur Bestimmung der Futteraufnahme mehr als 4.000 kg Milch, wenn die Aufnahme alternativ auf 80, 85 … bis 120 Prozent des Schätzwertes festgelegt wird. Da das NRC (2001) dem Leistungsniveau einen starken Effekt auf das Aufnahmevermögen zuordnet, steigt die erzielbare Leistung stärker als bei den übrigen Ansätzen zur Ermittlung der Futteraufnahme.

Auf den ersten Blick wird sichtbar, dass die in den Betrieben übliche Selektion der Erstkalbinnen nach Leistung nicht ohne Rückwirkung auf die Verteilung des Futteraufnahmevermögens und des Gewichts bleiben kann, denn hohe Milchleistungen sind ohne hohe Futteraufnahmen nicht zu erzielen.

Die Erklärung für diese überragende Bedeutung des Futteraufnahmeniveaus resultiert aus folgenden Sachverhalten:

- Höhere Lebendgewichte führen bei allen Ansätzen zu höheren Futteraufnahmen, bedeuten aber gleichzeitig auch entsprechend größere Erhaltungsansprüche, so dass ein Teil des Aufnahmezuwachses durch den notwendigen Mehraufwand für Erhaltung aufgezehrt wird.
- Werden bei gleichem Gewicht höhere Futteraufnahmen erreicht, stehen die damit verbundenen zusätzlichen Nährstoffaufnahmen ohne Abzug für entsprechende Leistungssteigerungen[4] zur Verfügung, bzw. geringere Futteraufnahmen münzen sich direkt in geringere Leistungen um

Für die Verteilung der Leistungsmerkmale in den Herden hat das eine Reihe von Konsequenzen:

- Milchviehhalter selektieren die Erstlaktierenden vorrangig nach Leistung. Abbildung 1 zeigt, dass bei allen Schätzern hauptsächlich Kühe mit unterdurchschnittlicher Futteraufnahme aus der Herde genommen werden. Denn Leistungen von mehr als 8.000 kg Milch erreichen nur Erstlaktierende mit mittlerer und überdurchschnittlicher Futteraufnahme.
- Abbildung 1 zeigt aber auch, dass eine Selektion nach Lebendgewicht geringe Effizienz erreicht, wenn es gilt, hohe Futteraufnahmen als Voraussetzung für entsprechende Leistungen zu erzielen.

Die in Abbildung 1 dargestellten Ergebnisse machen deutlich, dass mit der Entscheidung für einen der Ansätze zur Bestimmung der Futteraufnahme eine spezifische Struktur der Input-Outputrelationen die Folge ist. Diese Unterschiede werden größer, wenn das Alter der Kühe einbezogen wird.

2.2 Alter und Futteraufnahme

Alle Schätzer unterstellen, dass mit zunehmendem Alter die Futteraufnahme steigt. Bei den heute üblichen Konzepten der Milchviehhaltung kalben die Kühe bereits vor Erreichen des Endgewichts, so dass in der ersten und auch zweiten Laktation die Tiere noch wachsen. Somit enthalten die Schätzer zwei Komponenten, zum einen wachsen die Kühe in den ersten Laktationen, was steigende Futteraufnahmen zeitigt und zum anderen erhöhen sich die Aufnahmen altersbedingt. Dieser Effekt lässt sich quantifizieren, wenn die „unnatürliche Konstellation“ unterstellt wird, dass allein das Alter, nicht aber die anderen Variablen variieren. Abbildung 2 zeigt die zugehörigen Ergebnisse.

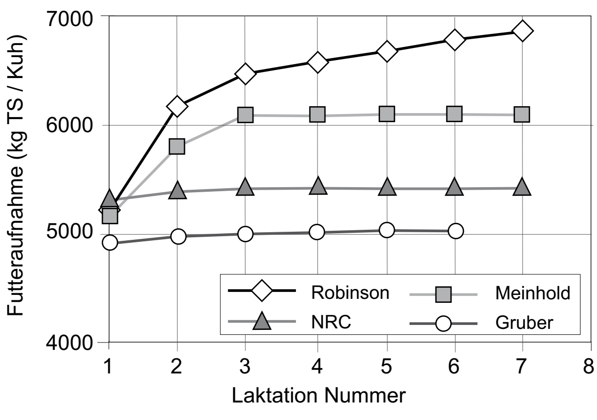

Abbildung 2:

Die Beziehung zwischen Futteraufnahme und Zahl der Laktationen für unterschiedliche Schätzer der Futteraufnahme, für eine Kuh mit einem Lebendgewicht von 550 kg, ohne Wachstum, mit einer Laktationsperiode von 300 Tagen, einer Jahresleistung von 6.000 kg Milch

[3] Mit zunehmender Milchleistung sinkt der bcs. Die maximal erzielbare Leistung ist erreicht, wenn der bcs den Wert 1 erreicht hat.

[4] Es wird ein ausreichendes Milchleistungspotential unterstellt.

Die Schätzer von Gruber et al. (2004) und vom NRC (2001) weisen nur geringe Zuwächse der Futteraufnahme mit zunehmender Zahl an Laktationen, die von Meinhold et al. (1976) und Robinson (2006) dagegen deutlichere Anstiege in der ersten und auch noch in der zweiten Laktation auf. Nur Robinson (2006) unterstellt auch über die dritte bzw. vierte Laktation hinaus weiter zunehmende Futteraufnahmekapazitäten.

2.3 Milchleistung und Futteraufnahme

Alle Schätzer weisen eine positive Beziehung zwischen Tagesleistung und täglicher Futteraufnahme auf. Abbildung 3 zeigt die Entwicklung der Futteraufnahme für eine Laktationsleistung zwischen 5.000 bis 9.000 kg Milch, wenn alle übrigen Variablen wie Gewicht, Alter etc. konstant gehalten werden.

Die Milchleistung besitzt bei allen Schätzern einen klaren positiven Effekt auf die Futteraufnahmekapazität. Wie bei den Kalkulationen für Abbildungen 1 und 2 wird auch für Abbildung 3 ein Lebendgewicht von 550 kg unterstellt, um die Ansätze zur Berechnung der Futteraufnahme besser vergleichen zu können.

Die von Robinson (2006) und Meinhold et al. (1976) entwickelten Beziehungen zwischen Futteraufnahme und Milchleistung ergeben eine geringfügig höhere Futteraufnahme, die Leistungen bis 9.000 kg Milch zulässt, ohne dass der bcs unter den kritischen Wert von Eins abfällt. Die maximal erzielbare Milchleistung erreichen bei Gruber et al. (2004) und beim NRC (2001) bei vergleichbarer Futteraufnahme nur 8.000 kg.

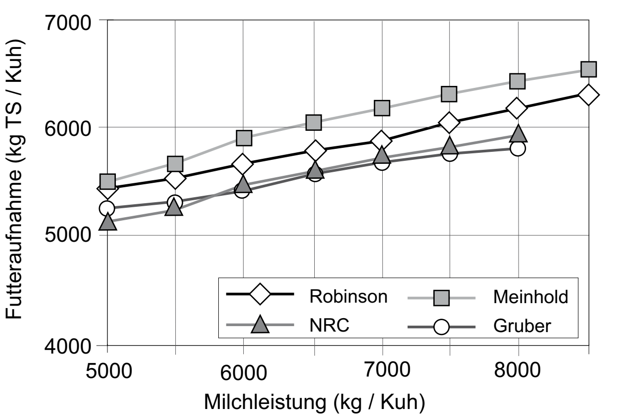

Abbildung 3:

Die Beziehung zwischen Futteraufnahme und Milchleistung für unterschiedliche Schätzer der Futteraufnahme, für eine Kuh in 2. Laktation, mit einem Lebendgewicht von 550 kg, ohne Wachstum, einer Laktationsperiode von 300 Tagen

2.4 Futterqualität und Futteraufnahme

Nur die Schätzer von Gruber et al. (2004) und Robinson (2006) stellen eine Beziehung zwischen Futterqualität und -aufnahme her. In Abbildung 4 werden die maximal erzielbaren Milchleistungen ausgewiesen, wenn die Energie- und Rohproteingehalte alternativ 80, 85, 90, 95, 100, 105, 110, 115 und 120 Prozent der von Meyer (2008) ermittelten mittleren Gras- und Maissilagequalitäten betragen. Unverändert bleiben dagegen die Qualitäten des Getreides, des Rapsextraktionsschrotes und des Milchviehmischfutters.

Abbildung 4 (obere Teilgrafik) zeigt, dass unabhängig vom Schätzer die Futterqualität die maximal erzielbare Milchleistung entscheidend mitbestimmen kann, wenn die Kühe über das erforderliche genetische Potential verfügen.

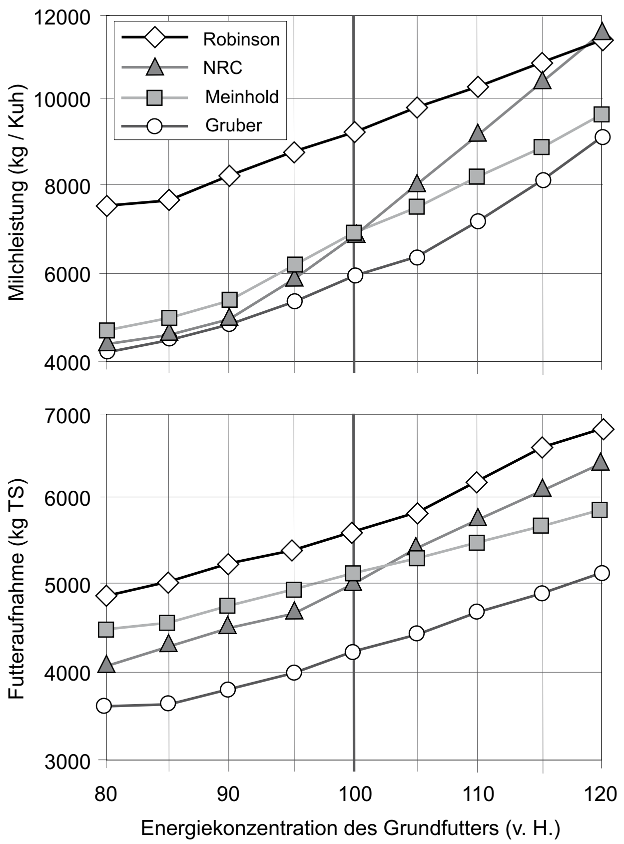

Abbildung 4:

Die Beziehung zwischen Futterqualität und Milchleistung sowie Futteraufnahme für unterschiedliche Schätzer der Futteraufnahme, für eine Kuh in 2. Laktation, einem Lebendgewicht von 550 kg, einer Laktationsperiode von 300 Tagen

Der vom NRC (2001) entwickelte Schätzer reagiert auf zunehmende Energiekonzentration mit dem höchsten Leistungsanstieg. Die alternativen Schätzer zeigen einen schwächeren Anstieg und weisen bei ähnlichem Verlauf ein unterschiedliches Niveau auf. Die Ansätze des NRC (2001) und von Meinhold et al. (1976) haben zwar keinen direkten Bezug zur Futterqualität, vermögen diese jedoch indirekt zu reflektieren, weil die maximale erzielbare Leistung mit der Grundfutterqualität wächst und über diesen „Umweg" die Futteraufnahmen positiv beeinflussen, vergleiche Walter (2010).

Die untere Teilgrafik der Abbildung 4 stellt die Verzehrsmengen für die in der oberen Teilgrafik abgebildeten Leistungen dar. Die Unterschiede bei den Futteraufnahmen fallen geringer aus als bei den maximal erzielbaren Leistungen, das lässt sich wie folgt erklären:

- Der Schätzer von Robinson (2006) weist im Bereich geringer Milcherträge erhebliche Abweichungen auf (Abbildung 4), denn er ist für die deutlich höheren Milchleistungen in den USA konzipiert.
- Der Schätzer von Gruber et al. (2004) führt zu niedrigeren Futteraufnahmen und zu rechnerisch geringeren maximal erzielbaren Milcherträgen.
- In den ersten Monaten der Laktation fällt die Futteraufnahme in der Realität und so auch bei allen Schätzern zu gering aus, um den Nährstoffbedarf zu decken, sodass die Kuh Körpersubstanz mobilisiert.
- Danach folgt eine Phase des Wiederaufbaus der Körpersubstanz, weil die Milchleistung sinkt und die Futteraufnahme dagegen gleich bleibt oder noch weiter steigt.
- Im letzten Drittel der Laktation, nach dem Ausgleich der Energie- und Nährstoffbilanz, übertrifft die von den hier analysierten Schätzern ausgewiesene Futteraufnahme die für die leistungsgerechte Ernährung erforderliche Menge.
- Dieser Aufnahmeüberhang führt bei steigenden Futteraufnahmevermögen zu wachsenden Unterschieden zwischen errechnetem Aufnahmevermögen und erforderlichem Bedarf.

In Abbildung 4 fallen die Schätzungen der täglichen Futteraufnahmen speziell in den ersten Tagen der Laktation in Kombination mit geringen Energiekonzentrationen vergleichsweise gering aus, sodass schnell hohe Defizite entstehen, die sich in der Folgezeit nur schwer wieder ausgleichen lassen.

Bei höheren Energiekonzentrationen ergeben zusätzliche Kalkulationen, dass im letzten Drittel der Laktation die täglichen Energie- und Nährstoffüberschüsse nochmals höher ausfallen. Den Milchviehhaltern ist diese Konstellation bekannt, deshalb versorgen sie ihre Kühe mit geringeren Futterqualitäten oder rationieren die Futtermengen.

2.5 Konsequenzen geringerer und höherer Futteraufnahme

Abbildung 5 stellt die Ergebnisse der Simulationen mit unterschiedlichen Futteraufnahmekapazitäten in Kombination mit maximal erzielbarer (linke Spalte der Abb. 5) und auf 7.000 kg Milch (rechte Spalte) begrenzter Leistung dar. Die beiden oberen Teilgrafiken zeigen die Laktationsleistungen.

Das Simulationsprogramm kalkuliert eine Vielzahl von Kennzahlen, die für die Effizienz der Milchviehhaltung von erheblicher Bedeutung sind, auch wenn ihnen bisher zu wenig Aufmerksamkeit zukam. Berechnet werden:

- Der Termin, an dem letztmalig Energie durch Körpersubstanzabbau aktiviert werden muss, also dem Zeitpunkt bis zu dem das aufsummierte Energiedefizit ansteigt (Abbildung 5, Teilgrafiken der 2. Reihe).
- Der Tag, an dem die eingesetzte Körpersubstanz wieder aufgebaut ist, an dem das Energiedefizit endet, die Energiebilanz der Laktationsperiode erstmals ausgeglichen ist (Abbildung 5, Teilgrafiken der 2. Reihe).
- Die gesamte Futteraufnahme während der Laktation.
- Das Volumen der nicht benötigten, bei exakter Fütterung ungenutzten Futteraufnahmekapazität (Abbildung 5, Teilgrafiken der 3. Reihe).
- Die Erlöse aus Milch minus Futterkosten, ein monetärer Erfolgsmaßstab (untere Teilgrafiken der Abbildung 5).

Die beiden die Energiebilanz betreffenden Zeitpunkte sind entscheidende Wendepunkte für die Physiologie der laktierenden Hochleistungskuh und ihre Futteraufnahme. Das von Paul (1990) entwickelte Modell „Physiologie der Milchkuh" bestätigt diesen Sachverhalt, denn die Modellvariable „physiologischer Hunger" erfährt wie viele weitere Variablen einen Vorzeichenwechsel.

Es wird allein die Laktationsperiode in die Simulation einbezogen, weil im Zeitraum zwischen Laktationsende und Geburt des Kalbes die Futteraufnahme strikt begrenzt werden muss, um eine Verfettung mit den von Evans (2003) und Drackley (2005) nachgewiesenen negativen Auswirkungen auf die folgende Zwischenkalbezeit zu vermeiden. In der Phase des Trockenstehens entsteht dementsprechend eine erhebliche Differenz zwischen täglicher Aufnahmekapazität und Futterbedarf. Dieser Überhang der Futteraufnahme ist bei allen Schätzern anzutreffen. Bei Kühen mit überdurchschnittlichem Futteraufnahmevermögen setzt diese Überschusssituation früher ein und fällt höher aus.

In Abbildung 6 werden die beiden unteren Teilgrafiken der Abbildung 5 nochmals dargestellt, jedoch ergänzt um den Graphen, der die Differenz aus Erlös für Milch minus Futterkosten für eine unbegrenzte Versorgung mit Futter darstellt. Im letzten Drittel der Laktation entsteht ein „Aufnahmeüberhang", der bei freier Verfügbarkeit des Futters zu „Luxuskonsum" führt. Das verursacht nicht nur höhere

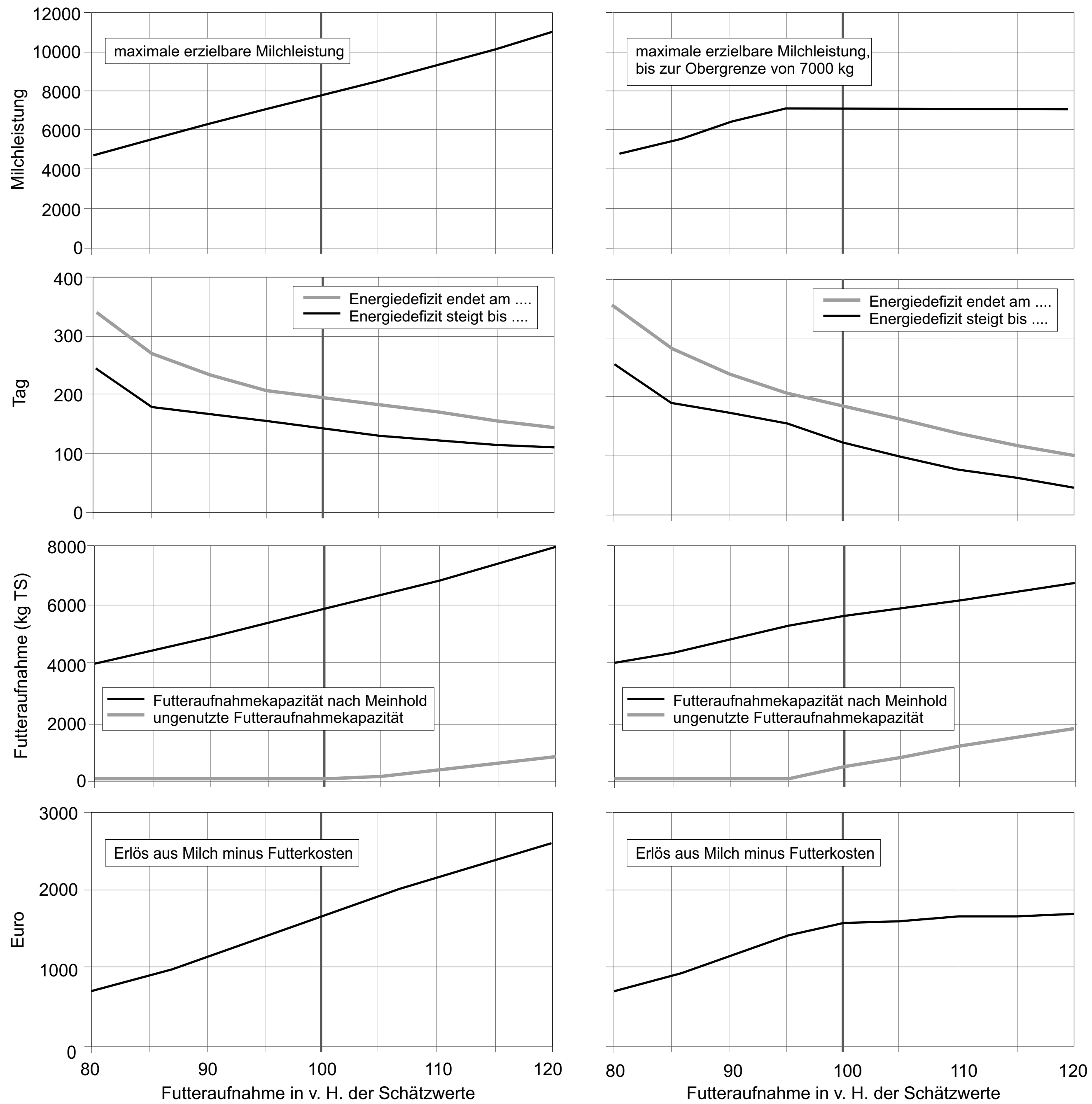

Abbildung 5:

Die Bedeutung geringerer und höherer Futteraufnahme für wichtige Kennzahlen der Milchproduktion, ermittelt für eine Kuh in 2. Laktation, mit einem Lebendgewicht von 650 kg, einer Laktationsperiode von 300 Tagen

Futterkosten, sondern bedeutet auch eine unerwünschte Verfettung der Kühe. Nach Evans (2003) und Drackley (2005) mindert das die Futteraufnahme in den ersten Wochen der Folgelaktation und erhöht die Anfälligkeit für Stoffwechselkrankheiten.

Die von Gruber et al. (2004), Meinhold et al. (1976), NRC (2001) und Robinson (2006) entwickelten Schätzer für die Futteraufnahme weisen bei den heutigen Milchleistungen alle einen Aufnahmeüberhang im letzten Drittel der Laktation auf, so dass in dieser Phase die Aufnahmekapazität eine nachrangige Position einnimmt. Für diesen Fütterungsabschnitt wird vielmehr eine knappe Versorgung empfohlen. Alternativ könnten Futtermittel geringerer Energie- und Nährstoffkonzentration eingesetzt werden,

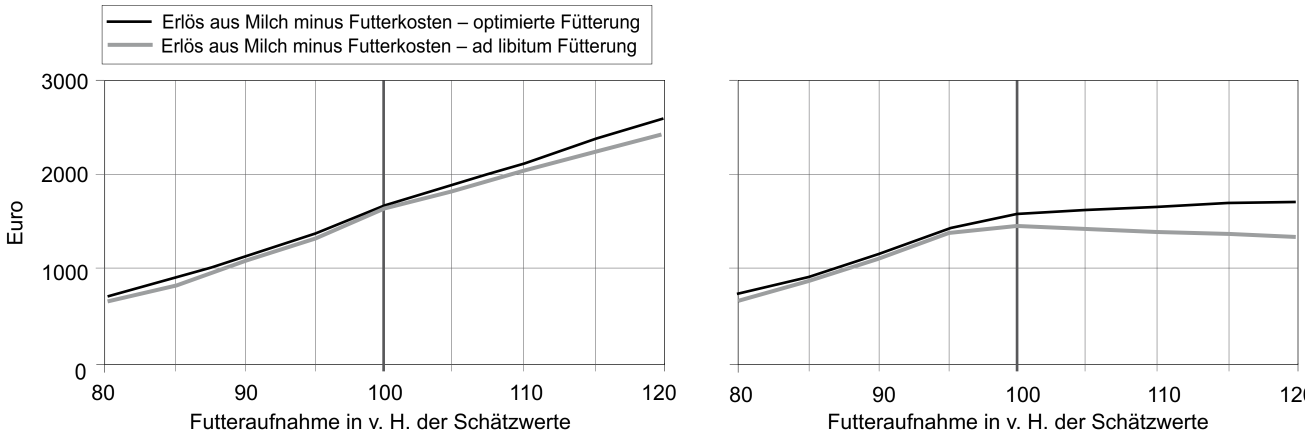

Abbildung 6:
Die Bedeutung der optimierten und ad libitum Fütterung für die Erlöse aus Milch minus Futterkosten, ermittelt für eine Kuh in 2. Laktation, mit einem Lebendgewicht von 650 kg, einer Laktationsperiode von 300 Tagen

wenn die Futterumstellung ohne Risiko in Kauf genommen werden kann und Kostenvorteile erzielbar sind.

Weil die Betriebe weder über eine Gewichtserfassung noch über ein Konzept zur Bestimmung der Energiebilanz verfügen, erweist sich die Bestimmung des Zeitpunkts mit erstmals ausgeglichener Energiebilanz als ein schwer lösbares Problem. Als Folge ergeben sich latent defizitäre Bilanzen bei Kühen mit unterdurchschnittlichem Futteraufnahmevermögen, ebenso anhaltende Überversorgung bei überdurchschnittlicher Aufnahmekapazität. Die empfohlene regelmäßige Erfassung des bcs kann keine Wägungen ersetzen, denn diese visuelle Beurteilung der körperlichen Kondition birgt erhebliche Ungenauigkeiten.

3 Bedeutung von Über- und Unterversorgung

Abbildung 1 macht deutlich, dass eine unterdurchschnittliche Futteraufnahmekapazität eine geringe maximal erzielbare Milchleistung zur Folge hat. Diese begrenzte Aufnahme behindert das Ausschöpfen eines möglicherweise hohen Milchleistungspotentials. Der Kuh ist ein entgangener Gewinn anzulasten, den eine Bessere erzielt hätte.

Eine überdurchschnittliche Futteraufnahmekapazität ist eine unerlässliche Voraussetzung für höchste Leistungen (Abbildung 1) und damit für das Erreichen der Gewinnzone. Wenn die Differenz zwischen Grund- und Kraftfutterpreisen hoch ausfällt, eröffnet der Ersatz von teurem Kraftfutter durch preiswerteres Grundfutter eine zusätzliche Möglichkeit den Gewinn zu steigern. Die Abbildungen 4 und 5 zeigen aber auch, dass der Vorteil der hohen Futteraufnahme sich zu einem Kostenfaktor wandeln kann, wenn im letzten Drittel der Laktation und während der zwei Monate des Trockenstehens keine Begrenzung der Futterversorgung vorgenommen wird, also eine Überfütterung mit zugehöriger Verfettung in Kauf genommen wird.

Meinhold et al. (1976, Abbildung 9, S. 180) diskutieren diese Zusammenhänge auf der Basis von Versuchsergebnissen. Meinhold et al. (1976, Abbildung 1, S. 145) zeigen die Einzelergebnisse der Tiere mit optimierter und bedarfsgerechter Versorgung unter Berücksichtigung des tierspezifischen Futteraufnahmevermögens. Dieses Konzept führt zu den geringsten Futterkosten (Meinhold et al., 1976, Abbildung 9, S. 180). Die Futterkosten der alternativen Versuchsgruppen fallen umso höher aus, je weniger Informationen für eine bedarfsgerechte Versorgung zur Verfügung stehen.

4 Vergleich der Schätzer

Die hier eingesetzten und einander gegenübergestellten vier Schätzer der Futteraufnahme für Milchkühe unterscheiden sich nicht nur hinsichtlich der benötigten bzw. genutzten Kennzahlen, sondern erfordern auch eine unterschiedliche Vorgehensweise bei der Berechnung der täglichen Futteraufnahmekapazität.

Die Ansätze von Meinhold et al. (1976) und NRC (2001) führen direkt zum Ergebnis und eignen sich bei Fragestellungen, die keinen direkten Bezug zur Futterqualität herstellen.

Die Schätzer von Gruber et al. (2004) und Robinson (2006) nutzen tier- und futterspezifische Daten (Tabelle 1). Das Resultat, nämlich die täglich erzielbare Futteraufnahme, bildet eine Einheit mit der errechneten Ration.

Trotz der unterschiedlichen Datenbasis unterscheiden sich die ermittelten Futteraufnahmen erstaunlich wenig. Alle Schätzer liefern ein Resultat für die Durchschnittskuh, sie machen keine Angaben zur Streuung oder zur Spannweite.

Mittels Simulation lassen sich keine eindeutigen Prioritäten für einen der Schätzer herausarbeiten, das bleibt Versuchen vorbehalten. Allerdings lassen sich Hinweise für deren Weiterentwicklung ableiten:

- Die von Robinson (2006) konzipierten Beziehungen zwischen Futteraufnahme und bcs, bls und Klima gewinnen bei steigenden Leistungen an Bedeutung.
- Die von Gruber et al. (2004) abgeleiteten Einflüsse des Managements, der Rasse und der Futterbasis stellen eine notwendige Ergänzung dar.
- Die Rechenleistung wirkt in der Regel nicht begrenzend, daher sollten die Ergebnisse mehrerer Schätzer ermittelt und einbezogen werden.
- Die tierspezifischen Veranlagungen bleiben bei allen Ansätzen unberücksichtigt. Dieser Mangel ist an die derzeit üblichen Haltungsverfahren gebunden. Die jeweils errechneten Futteraufnahmen sollten durch Ausweisen von Vertrauensintervall, Häufigkeitsverteilung oder ähnlicher statistischer Kennzahlen ergänzt werden.
- Die Futteraufnahme der nächsten Wochen ist zu ermitteln, um die zu erwartende Entwicklung einbeziehen zu können.

Allen Schätzern ist gemein, dass Tageswerte ermittelt werden. Die Milchviehhaltung ist jedoch ein auf die Zwischenkalbezeit bezogener Produktionsprozess. Daher sollte die Zeitpunktbetrachtung durch ein dynamisches Konzept abgelöst werden, das dem Ab- und Wiederaufbau von Körpersubstanz Rechnung trägt, eine Bilanzierung der Energie und der einzelnen Nährstoffe umfasst und zusätzlich Haltungsbedingungen, Gesundheit, Klima usw. einbindet.

5 Bewertung und Ausblick

Der Einsatz von Schätzern ist ein heute übliches Hilfsmittel zur Bestimmung der täglichen Futteraufnahmekapazität. Sie werden benötigt, weil in den Betrieben Wägungen selten oder gar nicht vorgenommen werden. Die Streuung der täglichen Aufnahme und die tierspezifischen Unterschiede bei den Verzehrsmengen werden als gegeben hingenommen. Die Milchviehhalter sorgen für genügend Futter und gehen davon aus, dass die Futteraufnahme der Tiere dem Bedarf angepasst ist.

In größeren Herden wird Gruppenhaltung praktiziert, für die die Schätzer geeignete Mittelwerte liefern sollen. Die Gruppen werden nach Leistung zusammengestellt, an der sich die Grund- und Kraftfuttermischung (TMR) orientiert, die dann zur freien Verfügung vorgelegt wird. Dazu erhalten die Kühe eine an der aktuellen Milchleistung bemessene Kraftfuttergabe. Damit entsteht eine deutliche Distanz zur tierspezifischen Bemessung der Aufwands- und Ertragsrelationen, denn die Niveauunterschiede der individuellen Futteraufnahmekapazität, des Erhaltungsbedarfs etc. werden übergangen und bleiben unberücksichtigt. Die hier vorgelegten Kalkulationen offenbaren erhebliche Fehleinschätzungen der tatsächlichen Ertrags- und Aufwandsrelationen, wenn die Schätzwerte, die eigentlich Mittelwerte darstellen, in die tierspezifische Bewertung eingehen.

Es stellt sich die Frage, ob diese Normierung nicht Ursache für die vielen produktionstechnischen Schwierigkeiten ist, wie z. B. kurze Nutzungsdauer, große Belastungen und gesundheitliche Probleme etc..

Alle bisher vorgestellten Kalkulationen zeigen, dass die Genauigkeit nur dann entscheidend verbessert werden kann, wenn alle Daten täglich und tierspezifisch erfasst und berücksichtigt werden. Die dafür notwendige Technik wird bisher nur in wissenschaftlichen Einrichtungen eingesetzt. Allerdings ist der Aufwand für die tägliche Erfassung des Lebendgewichts und der Futteraufnahme beträchtlich und übersteigt auch bei optimistischen Annahmen die erzielbaren Gewinnzuwächse. Langfristig, insbesondere unter den Aspekten weiter steigender Leistungen und wachsender Qualitätsanforderungen, wird eine tierspezifische Datenerfassung und Versorgung unausweichlich.

Die Ergebnisse aller bisher durchgeführten Kalkulationen legen nahe, dass die heutigen Haltungs- und Fütterungskonzepte den tierindividuellen Ansprüchen nicht gerecht werden und dass der Weg zum Ziel „precision farming" noch lang ist.

Literatur

Drackley JK (2005) Fütterung und Management der Milchkuh im peripartalen Zeitraum [online]. Zu finden in <http://www.dr-pieper.com/file/89.pdf> [zitiert am 23.05.2012]

Evans E (2003) Auswirkungen von Stoffwechselstörungen auf die Fruchtbarkeit [online]. Zu finden in <http://www.dr-pieper.com/file/66.pdf> [zitiert am 23.05.2012]

Gruber L, Schwarz FJ, Erdin DK , Fischer B, Spiekers H, Steingaß H, Meyer U, Chassot A, Jilg T, Obermaier A, Guggenberger T (2004) Vorhersage der Futteraufnahme von Milchkühen – Datenbasis von 10 Forschungs- und Universitätsinstituten Deutschlands, Österreichs und der Schweiz VDLUFA-Schriftenr 60:484–504

Meinhold K, Rosegger S, Schlünsen D, Walter K (1976) Die Futterkosten bei unterschiedlichen Methoden der Rationsermittlung und –bemessung für Milchkühe. Landbauforsch Völkenrode SH 35:131-190

Meyer A (2008) Ergebnisse der Grassilageuntersuchung 2008 [online]. Zu finden in <http://www.lwkNiedersachsen.de/index.cfm/portal/tier/naw/752/article/11042.html/> [zitiert am 11.06.2008]

National Research Council (NRC) (2001) Nutrition requirements of dairy cattle. Washington DC : Nat Acad Pr, 381 p

Robinson PH (2006) Excel Spreadsheet: PredDMI.xls, NRGREQ.xls [online]. Zu finden in <http://animalscience.ucdavis.edu/faculty/robinson/Excel/default.htm> [zitiert am 23.05.2012]

Paul W (1990) Physiologie der Milchkuh - eine mathematische Systemanalyse. Braunschweig : FAL, 290p, Landbauforsch Völkenrode SH 116

Walter K (2008) Das Simulationsprogramm „Milchproduktion der Zukunft" – methodischer Ansatz und Realisierung : Version 1.2. Braunschweig : FAL, 95 p, Ber Inst Agrartechnol Biosystemtechnik 398

Walter K (2010) Fütterung und Haltung von Hochleistungskühen 2. Grundfutterqualität und erzielbare Leistung. Landbauforsch 58(3):211-230

Effects of free air carbon dioxide enrichment and drought stress on the rumen in sacco degradability of corn silage harvested at various times

Malte Lohölter*, Ulrich Meyer*, Peter Lebzien*, Remy Manderscheid**, Hans-Joachim Weigel**, Martin Erbs**, Gerhard Flachowsky*, and Sven Dänicke*

Abstract

The present study investigated the effects of increased atmospheric CO_2 concentration, drought stress and harvest date on the rumen in sacco dry matter degradability of corn silage. A free air carbon dioxide enrichment facility (FACE) was operated in a field to generate a CO_2 concentration of 550 ppm in three treatment plots. Three plots served as control. All plots were divided into two semicircles to produce drought stress by the exclusion of precipitation in one half each. Corn plants were harvested at three dates (26 August, 12 September, 29 September 2008), chopped, ensiled, dried and ground. The in sacco degradability after 2, 4, 8, 16, 24, 48 and 96 h was evaluated using six non-lactating rumen cannuled Holstein cows. The potential dry matter degradability, the sum of water soluble and degradable unsoluble fraction, was not affected by CO_2 elevation. A low CO_2 effect below 1 % unit was found on the effective degradability, which is calculated in consideration of an assumed rate of passage from the rumen. Drought did not alter the potential degradability, but the kinetics of dry matter degradation and decreased the effective degradability by 2 % units. Harvest date affected all degradation parameters. Later harvest was related to an increased potential but reduced effective degradability. The potential degradability had close inverse relationships to neutral detergent fibre concentration ($r = -0.74$, $P < 0.01$) but was positively correlated to starch ($r = 0.80$, $P < 0.01$) and DM ($r = 0.80$, $P < 0.01$). The correlations between effective degradability and crude nutrients were generally not significant. Harvest date will remain an important factor influencing the feed value of corn silage, but the effects of elevated CO_2 concentration and drought stress did not indicate considerable impacts.

Keywords: CO_2 concentration, drought stress, in sacco degradability, corn silage, harvest date

Zusammenfassung

Einfluss von erhöhter CO_2-Konzentration, Trockenstress und Erntezeitpunkt auf die in sacco Abbaubarkeit von Maissilage

Die Effekte von erhöhter atmosphärischer CO_2-Konzentration, Trockenstress und Erntezeitpunkt auf die in sacco Abbaubarkeit der Trockensubstanz von Maissilage wurden untersucht. Unter Verwendung von Freiluft CO_2-Expositionstechnik wurde in einem Maisfeld an drei Stellen eine erhöhte CO_2-Konzentration von 550 ppm generiert. Drei weitere Flächen dienten als Kontrolle. In der Hälfte jeder Stelle erfolgte die Erzeugung von Trockenstress durch Niederschlagsausschluss. Maispflanzen wurden an drei Zeitpunkten geerntet, siliert und vermahlen. Zur Ermittlung der in sacco Abbaubarkeit der Trockensubstanz nach 2, 4, 8, 16, 24, 48 und 96 Stunden wurden sechs am Pansen fistulierte Kühe verwendet. Die potentielle Abbaubarkeit, die Summe aus wasserlöslicher und unlöslicher Fraktion, wurde nicht durch die CO_2-Konzentration beeinflusst. Allerdings konnte ein geringer CO_2 Effekt von unter 1 %-Punkt auf die effektive Abbaubarkeit, welche unter Berücksichtigung einer angenommenen Passagerate aus dem Pansen errechnet wird, festgestellt werden. Trockenstress veränderte die potentielle Abbaubarkeit nicht, beeinflusste jedoch die Kinetik des Abbaues und reduzierte die effektive Abbaubarkeit um 2 %-Punkte. Der Erntezeitpunkt beeinflusste alle untersuchten Abbauparameter. Spätere Ernte induzierte eine erhöhte potentielle, aber verminderte effektive Abbaubarkeit. Die potentielle Abbaubarkeit war negativ mit den Gehalten an neutraler Detergenzienfaser ($r = -0{,}74$, $P < 0{,}01$) sowie negativ mit den Gehalten an Stärke ($r = 0{,}80$, $P < 0{,}01$) und Trockensubstanz ($r = 0{,}80$, $P < 0{,}01$) korreliert. Der Erntezeitpunkt wird ein bestimmender Faktor für den Futterwert von Maissilage bleiben. Die Effekte von steigender atmosphärischer CO_2-Konzentration und Trockenstress lassen nicht auf nennenswerte Veränderungen schließen.

Schlüsselwörter: CO_2 Konzentration, Trockenstress, in sacco Abbaubarkeit, Maissilage, Erntezeitpunkt

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

** Johann Heinrich von Thünen-Institut (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Biodiversity, Bundesallee 50, 38116 Braunschweig, Germany

Correspondence to: Ulrich Meyer, ulrich.meyer@fli.bund.de

1 Introduction

Changing climatic conditions will likely affect both crop and livestock production with considerable regional differences. Since the beginning of human industrialisation, the atmospheric CO_2 concentration has risen from about 280 ppm to a current value of approximately 390 ppm and may exceed 700 ppm by the middle and 1000 ppm by the end of the century, depending on the prospective greenhouse emission scenario (IPCC, 2007). According to the same survey, many regions in different parts of the world may be affected by a higher incidence of drought.

Various effects of elevated atmospheric CO_2 concentrations on photosynthesis, yield and chemical composition of C_3 plants such as decreased forage and grain protein contents were reported (Schenk et al., 1997; Wu et al., 2004; Weigel and Manderscheid, 2005; Yang. et al., 2007; Manderscheid et al., 2009). In contrast, C_4 plants do not respond to increasing CO_2 concentrations with an increase of photosynthesis and biomass production due to their CO_2 concentration mechanism in the leaves which serves to saturate photosynthesis in ambient air (Ghannoum, 2009). However, in both C_3 and C_4 plants decreased stomatal water loss can be observed under elevated CO_2 concentrations. For example, decreased stomatal plant water loss of corn (*Zea mays L.*) was observed using free air carbon dioxide enrichment (FACE) technology (Leakey et al., 2006). Consequently, positive CO_2 effects on C_4 crops like corn may only be observed under water shortage potentially reducing the negative effects of drought. While the physiological mechanisms of CO_2 x drought interactions are basically known there is little evidence from field scale studies under true agronomic growth conditions testing the consequences of changes of these important climate change factors on crop growth and food quality (DaMatta et al., 2010).

More information about possible impacts of rising CO_2 and its interactions with water supply on corn are necessary as besides the immense importance for human food supply whole plant corn silage is used prevalently as a main component of dairy and beef cattle diets to meet the requirements of high-yielding animals. Both chemical composition and feed value of corn silage strongly depend on plant maturity. Later harvest date was reported to reduce the in sacco degradability of cob-free corn plants (Flachowsky et al., 1993; Akbar et al., 2002). Nevertheless, within the process of starch deposition in the cob later harvest results in a decreased cell wall but increased starch content in whole corn plants indicating an improved ruminal degradability, though the proportion of bypass-starch that is not degradable in the rumen may rise with advanced maturity (Johnson et al., 2003; Filya, I., 2004).

The aim of the present study was to investigate effects of elevated atmospheric CO_2 concentration and drought stress on the ruminal in sacco degradability of whole plant corn silage harvested at different harvest dates.

2 Materials and methods

2.1 FACE experiment and sampling

In 2008, the corn variety "Romario" (S 240, K 240) was planted on an experimental field of the Institute of Biodiversity, Johann Heinrich von Thünen-Institut, Federal Research Institute for Rural Areas, Forestry and Fisheries, Braunschweig, Germany (52°18′N, 10°26′E, 79 m a.s.l.), according to local farm practices. A FACE (Free air carbon dioxide enrichment) system was operated as described by Lewin et al. (1992). Treatments included three rings with blowers and CO_2 enrichment to meet a target CO_2 concentration of 550 ppm during daylight hours (FACE) and three control rings operated with blowers and ambient air of approximately 380 ppm (Control), respectively. The rings had an outer diameter of 20 m and were divided into 2 semicircles. A facility for the exclusion of precipitation in a rain-laden summer was designed to generate drought stress in one semicircle each (drought stress). Water was provided continuously via drip-irrigation in the other semicircles to exceed 50 % field capacity (well watered).

Five whole plants per semicircle were harvested manually within an inner diameter of 16 m at three sampling dates each (26 August (1), 12 September (2) and 29 September (3)). The corn plants were chopped and stored at -18 °C. After defrosting, the samples from all semicircles per treatment and harvest were pooled. Ensiling was performed for 28 consecutive days in airtight glass laboratory jars containing a volume of 2.5 l each. The jars were kept at a constant temperature of 25 °C. Afterwards, the samples were freeze dried for 48 h (Epsilon I/15, Martin Christ Gefriertrocknungsanlagen GmbH, Osterode, Germany) and ground to pass through a 3 mm sieve for further analyses (DR 100/15-40, Retsch GmbH, Haan, Germany).

2.2 In sacco degradability

The in sacco experiment was conducted at the experimental station of the Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig, Germany. Six non-lactating German Holstein cows with a mean initial bodyweight of 663 ± 69 kg equipped with large rubber cannulas in the dorsal rumen sac were used. The animals were kept in a tethered barn with individual troughs and free access to water. The cows were fed on 8.2 kg dry matter (DM) silage mixture, consisting of 60 % corn and 40 % grass silage, 2 kg concentrate mixture and 100 g mineral and vitamin premix per day. The diet was presented twice daily in equal portions at 5:30 h and 15:30 h. 4 ± 0.1 g of ground corn silage samples were weighed in nylon bags (100 x 200 mm, pore size 50 ± 15 µm, Ankom Technology, New York, USA). Two samples of every treatment were incubated in the rumen of each cow 30 minutes before morning feeding for 2, 4, 8, 16, 24, 48 and 96 hours. Immediately after removal from the rumen the bags were transferred into iced water to inhibit microbial activity followed by a cleaning in cold water using a washing machine. Subsequently the samples were oven-dried at 60 °C for 24 hours and weighed. For the determination of the water soluble fraction four bags of each treatment were subjected to the same procedure except the incubation in the rumen.

2.3 Chemical analyses

Water soluble carbohydrates (WSC) in fresh whole corn plants were determined via colorimetry using anthrone as described by Laws and Oldenburg (1993). Fermentation acids and ethanol in corn silages were measured following Canale et al. (1984) and Siegfried et al. (1984). The composition of the corn silages (DM, crude ash, crude protein, ether extract, starch, neutral detergent fibre (NDF) and acid detergent fibre (ADF)) was determined according to the methods of the Association of German Agricultural Analysis and Research Centres (VDLUFA, 1976). NDF and ADF were expressed without residual ash.

2.4 Calculations

The content of DM in the examined silages was corrected for potential substance losses during drying following the equation for corn silages given by Weissbach and Kuhla (1995).

The ruminal in sacco degradability was determined according to Ørskov and McDonald (1979). Dry matter degradability data were fitted to the non-linear degradation equation $p = a + b\,(1 - e^{-ct})$, where p is the DM degradation (%) at time t, a represents the intercept of the degradation curve at time zero or the water soluble fraction including small but insoluble particels, b is the insoluble, but degradable fraction, c is the rate of degradation of b (% h^{-1}) and a + b represents the potential degradability.

The effective degradability was calculated by the equation $P = a + bc / (c + k)$ (McDonald, 1981), where k is the assumed fractional rate of passage of 0.05 h^{-1} from the rumen following Tothi et al. (2003).

2.5 Statistical Analysis

Statistical analyses were performed using the software package SAS version 9.1. DM degradation parameters were analyzed by the GLM procedure. CO_2 concentration (CO_2), irrigation (I) and harvest date (H) were used as the class variables in the model. Pearson correlation coefficients were calculated using the procedure "CORR". The content of water soluble carbohydrates in fresh corn plants and the chemical composition of the generated corn silages could not be subjected to statistical analysis since the samples from all plots per treatment were pooled before ensiling. Differences were considered to be significant at $P < 0.05$. Trends were declared at $P < 0.1$.

3 Results

3.1 Chemical composition

The pH values and the concentration of fermentation acids and ethanol of the investigated corn silages are given in Table 1. pH was found to be generally below 4.0 and the contents of butyric acid were below 0.05 % of DM in all samples. Water soluble carbohydrates in fresh plants and the crude nutrient contents of the experimental corn silages are presented in Table 2. The nominal effects of both atmospheric CO_2 concentration and irrigation on the chemical composition were low or not existent. Later harvest was accompanied by a considerable decline of WSC in fresh samples. Furthermore, progressing maturity resulted in nominally increased silage DM and starch but decreased fibre content. However the CO_2 control sample grown under drought stress and harvested at 29 September showed a reduced starch concentration and an increase of WSC compared to all other treatments at the third harvest. Moreover, the increase of WSC was already visible at the first harvest date.

Table 1:

Fermentation acids, ethanol and pH in corn silages (% dry matter).

Treatment[a]			Parameter					
CO_2	I	H	Acetic acid	Propionic acid	Butyric acid	Lactic acid	Ethanol	pH
FACE	WW	1	0.3	0.02	0.00	7.6	0.5	3.6
		2	0.5	0.03	0.03	6.5	0.3	3.6
		3	0.4	0.14	0.02	5.9	0.4	3.7
	DS	1	0.3	0.05	0.00	7.7	1.0	3.6
		2	0.2	0.06	0.00	6.4	0.4	3.7
		3	0.5	0.05	0.00	5.6	0.3	3.8
Control	WW	1	0.4	0.02	0.00	7.9	0.3	3.5
		2	0.3	0.09	0.01	6.1	0.8	3.7
		3	0.3	0.09	0.01	5.6	0.4	3.7
	DS	1	0.3	0.04	0.00	7.9	1.5	3.6
		2	0.2	0.08	0.00	5.9	0.3	3.7
		3	0.6	0.00	0.00	6.3	0.4	3.8

[a] Treatments were CO2 concentration (CO2, FACE vs. Control), irrigation (I, Well Watered (WW) vs.
Drought Stress (DS)) and harvest date (H, 26 August (1), 12 September (2) and 29 September (3)).

Table 2:
Water soluble carbohydrates in fresh corn plants (% DM) as well as DM (% fresh matter) and crude nutrient content of corn silages (% DM).

Treatment[a]			Parameter[b]							
CO_2	I	H	WSC	DM	Ash	CP	EE	NDFom	ADFom	Starch
FACE	WW	1	15.2	27.3	4.5	5.8	1.8	51.3	26.7	21.7
		2	9.4	31.8	3.9	6.0	2.7	44.4	24.6	30.0
		3	8.1	35.5	4.2	5.1	2.5	42.9	22.8	32.6
	DS	1	16.8	28.1	4.3	5.8	2.0	51.3	26.2	17.4
		2	10.9	33.5	3.8	5.6	2.5	47.2	24.0	26.6
		3	6.5	41.2	3.7	5.1	2.5	45.3	23.3	31.9
Control	WW	1	15.7	26.3	4.1	5.9	1.9	49.4	25.8	18.6
		2	9.2	32.5	3.8	5.1	2.4	48.4	25.0	28.3
		3	8.5	37.1	3.9	5.0	2.4	40.9	20.9	35.7
	DS	1	21.1	28.9	4.1	6.3	1.8	52.1	26.1	15.2
		2	11.2	34.8	3.6	5.5	2.4	48.6	24.1	27.3
		3	9.8	39.7	4.1	6.3	2.1	47.3	24.3	26.7

[a] Treatments were CO_2 concentration (CO_2, FACE vs. Control), irrigation (I, Well Watered (WW) vs. Drought Stress (DS)) and harvest date (H, 26 August (1), 12 September (2) and 29 September (3)).
[b] WSC, water soluble carbohydrates; DM, dry matter; Ash, crude ash; CP, crude protein; EE, ether extract; NDFom, neutral detergent fibre expressed without residual ash; ADFom, acid detergent fibre expressed without residual ash.

Table 3:
Effects of atmospheric CO_2 concentration, irrigation and harvest date on degradation parameters (%) of corn silage DM (Means ± SD, n=6).

Treatment[a]			Parameter[b]				
CO_2	I	H	a	b	c	a + b	P
FACE	WW	1	35.9 ± 1.1	32.1 ± 1.0	0.035 ± 0.003	68.0 ± 1.0	49.1 ± 0.6
		2	35.0 ± 0.8	37.3 ± 2.1	0.032 ± 0.007	72.3 ± 2.2	49.5 ± 1.3
		3	34.2 ± 1.0	39.2 ± 1.7	0.032 ± 0.006	73.4 ± 1.2	49.4 ± 1.5
	DS	1	34.0 ± 0.4	33.3 ± 1.2	0.037 ± 0.006	67.3 ± 1.2	48.1 ± 1.1
		2	33.0 ± 1.4	39.4 ± 1.8	0.030 ± 0.005	72.3 ± 2.0	47.6 ± 1.0
		3	29.7 ± 0.7	46.6 ± 0.7	0.028 ± 0.002	76.3 ± 1.0	46.2 ± 1.0
Control	WW	1	36.4 ± 0.5	32.9 ± 1.3	0.033 ± 0.006	69.6 ± 1.3	49.7 ± 1.2
		2	32.4 ± 0.8	40.1 ± 2.2	0.030 ± 0.004	72.5 ± 2.0	47.5 ± 1.4
		3	33.9 ± 0.9	40.9 ± 1.3	0.030 ± 0.005	74.8 ± 1.9	49.0 ± 1.1
	DS	1	35.6 ± 0.8	32.7 ± 1.8	0.033 ± 0.007	68.3 ± 1.9	48.4 ± 1.3
		2	32.7 ± 0.7	39.7 ± 0.8	0.032 ± 0.005	72.4 ± 0.8	48.1 ± 1.3
		3	27.3 ± 1.1	45.7 ± 1.6	0.027 ± 0.004	73.0 ± 1.4	43.3 ± 1.1
P-value							
CO_2			0.020	0.072	0.251	0.647	0.027
I			<0.001	<0.001	0.461	0.610	<0.001
H			<0.001	<0.001	0.002	<0.001	<0.001
CO_2 × I			0.388	0.004	0.592	0.017	0.926
CO_2 × H			<0.001	0.226	0.592	0.050	0.011
I × H			<0.001	<0.001	0.306	0.223	<0.001
CO^2 × I × H			<0.001	0.765	0.560	0.027	0.003

[a] Treatments were CO_2 concentration (CO_2, FACE vs. Control), irrigation (I, Well Watered (WW) vs. Drought Stress (DS)) and harvest date (H, 26 August (1), 12 September (2) and 29 September (3)).
[b] a = water soluble fraction, b = insoluble, but degradable fraction, c = rate of degradation of b (% h^{-1}), a+b = potential degradability, P = effective degradability.

3.2 In sacco degradability

The potential ruminal DM degradability (a + b) of the investigated silages was found to be generally below 80 % (Table 3). Assuming a rate of passage of 0.05 h^{-1} from the rumen, the estimated effective DM degradability (P) did not exceed 50 %. The lowest values of both water soluble fraction (a) and effective degradability were observed for the CO_2 control sample grown under drought stress and harvested at 29 September which was characterized by a low starch but high fibre content, compared to the other treatments.

Though the atmospheric CO_2 concentration had significant effects on water soluble fraction and effective degradability, the nominal impacts on both parameters were below 1 % unit and the other degradation parameters were not influenced by CO_2 enrichment. Drought stress decreased the water soluble fraction and the effective degradability of the incubated samples by 2.5 and 2 % units, respectively. However the insoluble, but degradable fraction (b) was increased by 2.5 % units resulting in a lack of impacts of drought stress on the potential degradability of silage DM. Harvest date had a significant effect on all calculated degradation parameters and altered both DM degradation kinetics and degradability. Later harvest resulted in a decreased water soluble fraction and effective degradability as well as a slower rate of DM degradation. However, the rising insoluble, but degradable fraction overcompensated these effects and the potential degradability increased with later harvest. The pooled potential degradabilities were 71.6 ± 3.4 % for FACE and 71.8 ± 2.7 % for CO_2 Control treatment, 71.8 ± 2.9 % for well watered and 71.6 ± 3.3 % for drought stress treatment as well as 68.3 ± 1.5 %, 72.4 ± 1.7 % and 74.4 ± 1.9 % for harvest 1, 2 and 3, respectively.

Though various interactions were found to influence the kinetics of DM degradation significantly, the nominal differences were mostly low or undirected. Interestingly, CO_2 elevation resulted in a slightly higher potential degradability during drought stress (1 % unit) but lower a + b (0.7 % unit) during sufficient water supply (CO_2 x I. P = 0.017). Furthermore, the CO_2 x I x H interaction was found to be significant for the potential degradability (P = 0.027). For harvest 3, the CO_2 control samples showed a reduced a + b when grown under drought stress (3 % units).

WSC in fresh samples and the cell wall contents of the produced silages were found to have close inverse relationships to the insoluble, but degradable fraction and the potential degradability, respectively, however ADFom was closer negatively correlated to the fraction b than NDFom (Table 4). Furthermore, positive relationships of WSC and ADFom to both water soluble fraction and rate of DM degradation were observed. Both silage DM and starch content were positively correlated to the insoluble, but degradable fraction and the potential degradability, respectively, but had negative relationships to the other degradation parameters. Except for DM, the correlations between the examined nutrients and the effective degradability were generally not significant.

Table 4:

Correlation coefficients between degradation parameters and water soluble carbohydrates in fresh corn plants (% DM), silage DM (% fresh matter) as well as silage crude nutrient contents (% DM).

Parameter[a]	Fraction[b]				
	WSC	DM	ADFom	NDFom	Starch
a	0.54**	-0.79**	0.43**	0.22	-0.39**
b	-0.79**	0.93**	-0.71**	-0.58**	0.71**
c	0.35**	-0.43**	0.35**	0.28**	-0.32**
a + b	-0.81**	0.80**	-0.77**	-0.74**	0.80**
P	0.23	-0.53**	0.17	-0.04	-0.08

[a] a = water soluble fraction, b = insoluble, but degradable fraction, c = rate of degradation of b (% h^{-1}), a + b = potential degradability, P = effective degradability.

[b] WSC, water soluble carbohydrates; DM, dry matter; Ash, crude ash; NDFom, neutral detergent fibre expressed without residual ash; ADFom, acid detergent fibre expressed without residual ash.

*: P < 0.05, ** P < 0.01.

4 Discussion

In a recent study, Porteaus et al. (2009) investigated the responses of the nutritive value of wheat (*Triticum aestivum L.*) straw and grain to an increased atmospheric CO_2 concentration of 550 ppm and reported the quality to be altered in a potentially adverse fashion. Though the composition of wheat straw was generally not affected by CO_2 enrichment, significant reductions of crude protein and NDF in grain DM were reported to be accompanied by increased starch concentrations. In C_4 plants, CO_2 is concentrated in the leaves {Ghannoum, 2009) and the effect of elevated atmospheric CO_2 will therefore likely be limited. Leakey et al. (2006) demonstrated in a FACE experiment that increased atmospheric CO_2 did not stimulate corn photosynthesis, yield, the activity of key photosynthetic enzymes or metabolic markers of carbon and nitrogen status in the absence of drought. In a recent FACE trial CO_2 enrichment did not increase corn growth and yield under sufficient water supply but under drought stress (Manderscheid et al., 2011). Accordingly, the effects of increased CO_2 on both water soluble fraction and effective ruminal degradability of the investigated corn silages did not indicate relevant alterations of the feed value in the present experiment as for both parameters the nominal differences between the CO_2 treatments were below 1 % unit.

Drought stress can decrease biomass and grain yield of corn (Bolanos and Edmeades, 1993; Azeez et al., 2005;

Efeoglu et al., 2009), kernel number per ear (Otegui et al., 1995; Zinselmeier et al., 1999; Boyer and Westgate, 2004) as well as thousand kernel weight (Weerathaworn et al., 1992) and hence potentially impact the feed value of corn silage since starch as a major constituent is primarily located in the grains. However, restricted irrigation did not affect the potential DM degradability of the incubated samples and, though significant, only low nominal effects on the kinetics of DM degradation and the estimated effective degradability were found. Furthermore, a slightly decreased effective ruminal DM degradability of corn silage, a feedstuff containing relatively slowly rumen degradable starch (Tothi et al., 2003; Matthe et al., 2003), does not necessarily indicate a reduced feed value. A potentially increased flooding of starch into the small intestine may result in a more efficient use of starch for milk synthesis than that digested in the rumen (Nocek and Tamminga, 1991). However, within the limits of the conducted analyses it is unknown which compounds contributed to the decreased effective degradability of the investigated silages grown under drought stress.

In corn, atmospheric CO_2 enrichment was reported to result in decreased plant water loss via stomatal conductance (Leakey et al., 2006) and an increase of the water use efficiency of biomass production (Manderscheid et al., 2011). That may lead to the hypothesis that atmospheric CO_2 elevation may reduce the negative effects of drought stress on corn growth and composition and hence indirectly improve the feed value of corn silage during periods of drought. However, this was not reflected in the examined parameters of DM degradation in the present experiment. No significant CO_2 x I interaction was observed for the effective degradability of silage DM and though significance was calculated for the potential degradability, the nominal effects were below 1 % unit. However, due to elevated CO_2 a slightly higher potential degradability was found during drought stress but it decreased if the plants were grown well watered. For harvest 3, the CO_2 control sample grown under drought stress was characterized by an unexplainable low starch but high fibre content in comparison to the other treatments and the previous harvest. These differences were not clearly explainable within the performed analyses and therefore incorrect sampling may have contributed to this effect.

Advancing maturity is accompanied by substantial changes in the chemical composition of corn since WSC levels in fresh whole plants were reported to decrease (Johnson et al., 2003; Filya et al., 2006), whereas starch concentration and DM percentage increase up to a certain limit (Browne et al., 2004; Browne et al., 2005; Mc Geough et al., 2010). In the present experiment, these alterations were reflected in significant effects on both kinetics and extent of ruminal degradability. Insoluble, but degradable fraction and potential degradability increased gradually with later harvest. Both parameters were found to have close positive relationships to DM and starch content and were negatively correlated to silage fibre concentration, which is known to decrease with later harvest (Filya, 2004). These observations were consistent because increasing starch, but decreasing fibre contents will likely enhance the ruminal DM degradability of corn silage since ground corn grain was reported to be highly degradable exceeding 90 % after longer periods of incubation in the ovine forestomach (Flachowsky et al., 1992). Though the ruminal DM degradability of cobs does not necessarily increase with later harvest, their percentage of the whole plants rises and they are generally faster and to a greater extent degradable than stover (Akbar et al., 2002), which were shown to contain more fibre and to become less degradable with later harvest (Flachowsky et al., 1993). Nevertheless, these processes do not imperatively lead to an improved DM degradability of ensiled corn. Jochmann et al. (1999) compared both in sacco DM degradability and effective degradability of corn silages harvested at different maturity stages and did not observe significant differences between the incubated samples.

5 Conclusion

In the present experiment, the low effects of rising atmospheric CO_2 concentration and drought stress on the calculated parameters of in sacco DM degradation of corn silage did not indicate considerable alterations of the future feed value of ensiled whole corn plants grown under changed cultivation conditions. In contrast, harvest date influenced all evaluated degradation parameters and will likely remain an important factor determining feed value and ruminal degradability of corn silage.

Acknowledgements

The study was supported by the Ministry for Science and Culture of Lower Saxony within the network KLIFF – climate impact and adaptation research in Lower Saxony and the German Ministery of Education and Research. Furthermore, the assistance of the co-workers of the Institute of Animal Nutrition and the Experimental Station of the Friedrich-Loeffler-Institute in performing experiment and analysis, the provision of FACE corn samples by the staff of the Institute of Biodiversity, Johann Heinrich von Thünen-Institut, Federal Research Institute for Rural Areas, Forestry and Fisheries in Braunschweig, Germany and Dr. G. Pahlow and staff from the Julius Kühn-Institute, Federal Research Centre for Cultivated Plants in Braunschweig, Germany, for their analyses and advices is gratefully acknowledged.

References

Akbar MA, Lebzien P, Flachowsky G (2002) Measurement of yield and in situ dry matter degradability of maize varieties harvested at two stages of maturity in sheep. Anim Feed Sci Tech 100(1-2):53-70

Azeez JO, Chikoye D, Kamara AY, Menkir A, Adetunji MT (2005) Effect of drought and weed management on maize genotypes and the tensiometric soil water content of an eutric nitisol in South Western Nigeria. Plant Soil 276:61-68

Bolanos J, Edmeades GO (1993) 8 cycles of selection for drought tolerance in lowland tropical maize : 1. Responses in grain-yield, biomass, and radiation utilization. Field Crop Res 31:233-252

Boyer JS, Westgate ME (2004) Grain yields with limited water. J Exp Bot 55:2385-2394

Browne EM, Juniper DT, Bryant MJ, Beever DE (2005) Apparent digestibility and nitrogen utilization of diets based on maize silage harvested at three stages of maturity and fed to steers. Grass Forage Sci 60:274-282

Browne EM, Juniper DT, Bryant MJ, Beever DE, Fisher AV (2004) Intake, live-weight gain and carcass characteristics of beef cattle given diets based on forage maize silage harvested at different stages of maturity. Anim Sci 79:405-413

Canale A, Valente ME, Ciotti A (1984) Determination of volatile carbolic-acids (C1-C51) and lactic-acid in aqueous acid-extracts of silage by high-performance-liquid-chromatography. J Sci Food Agr 35:1178-1182

DaMatta FM, Grandis A, Arenque BA, Buckeridge MS (2009) Impacts of climate changes on crop physiology and food quality. Food Res Int 43:1814-1823

Efeoglu B, Ekmekci Y, Cicek N (2009) Physiological responses of three maize cultivars to drought stress and recovery. S Afr J Bot 75:34-42

Filya I (2004) Nutritive value and aerobic stability of whole crop maize silage harvested at four stages of maturity. Anim Feed Sci Tech 116:141-150

Filya I, Sucu E, Karabulut A (2006) The effect of Lactobacillus buchneri on the fermentation, aerobic stability and ruminal degradability of maize silage. J Appl Microbiol 101:1216-1223

Flachowsky G, Baldeweg P, Schein G (1992) A note on the in sacco dry-matter degradability of variously processed maize grains and of different maize varieties in sheep. Anim Feed Sci Tech 39:173-181

Flachowsky G, Peyker W, Schneider A, Henkel K (1993) Fiber analyses and in sacco degradability of plant fractions of 2 corn varieties harvested at various times. Anim Feed Sci Tech 43:41-50

Ghannoum O (2009) C4 photosynthesis and water stress. Ann Bot 103:635-644

Forster PV, Ramaswamy P, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC, Myhre G, Nganga J, Prinn R (2007) Changes in atmospheric constituents and in radiative forcing. In: Solomon S, Qin D, Mannin M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007 : the physical science basis : contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge : Cambridge Univ Pr, pp 131-217

Jochmann K, Lebzien P, Dänicke R, Flachowsky G (1999) Zum Einfluß des Reifestadiums von Maispflanzen und des Einsatzes von Milchsäurebakterien bei ihrer Einsilierung auf die Nährstoffumsetzungen im Verdauungstrakt von Milchkühen. J Anim Physiol Anim Nutr 82:178-192

Johnson LM, Harrison JH, Davidson D, Mahanna WC, Shinners K (2003) Corn silage management : effects of hybrid, maturity, inoculation, and mechanical processing on fermentation characteristics. J Dairy Sci 86:287-308

Laws W, Oldenburg E (1993) Zuckergehalte von Wintergerste und Mais : 2. Methodenvergleich HPLC/Anthron. Landbauforsch Völkenrode 43(2/3):60-63

Leakey ADB, Uribelarrea M, Ainsworth E, Naidu SL, Rogers A, Ort DR, Long SP (2006) Photosynthesis, productivity, and yield of maize are not affected by open-air elevation of CO_2 concentration in the absence of drought. Plant Physiol 140:779-790

Lewin KF, Hendrey GR, Kolber Z (1992) Brookhaven National Laboratory free-air carbon-dioxide enrichment facility. Crit Rev Plant Sci 11:135-141

Manderscheid R, Erbs M, Weigel H-J (2012) Interactive effects of free-air CO_2 enrichment and drought stress on maize growth. Eur J Agron [online]. To be found at <http://dx.doi.org/10.1016/j.eja.2011.12.007> [quoted 29.05.2012]

Manderscheid R, Pacholski A, Frühauf C, Weigel H-J (2009) Effects of free air carbon dioxide enrichment and nitrogen supply on growth and yield of winter barley cultivated in a crop rotation. Field Crop Res 110(3):185-196

Matthe A, Lebzien P, Hric I, Flachowsky G (2003) Influence of prolonged adaptation periods on starch degradation in the digestive tract of dairy cows. Anim Feed Sci Technol 103(1):15-27

McGeough EJ, O'Kiely P, Foley PA, Hart KJ, Boland TM, Kenny DA (2010) Methane emissions, feed intake, and performance of finishing beef cattle offered maize silages harvested at 4 different stages of maturity. J Anim Sci 88:1479-1491

McDonald I (1981) A revised model for the estimation of protein degradability in the rumen. J Agr Sci 96:251-252

Nocek JE, Tamminga S (1991) Site of digestion of starch in the gastrointestinal tract of dairy cows and its effect on milk yield and composition. J Dairy Sci 74:3598-3629

Orskov ER, McDonald I (1979) Estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J Agr Sci 92:499-503

Otegui ME, Andrade FH, Suero EE (1995) Growth, water-use and kernel abortion of maize subjected to drought at silking. Field Crop Res 40:87-94

Porteaus F, Hill J, Ball AS, Pinter PJ, Kimball BA, Wall GW, Adamsen FJ, Hunsaker DJ, LaMorte RL, Leavitt SW, Thompson TL, Matthias AD, Brooks TJ, Morris CF (2009) Effect of Free Air Carbon dioxide Enrichment (FACE) on the chemical composition and nutritive value of wheat grain and straw. Anim Feed Sci Technol 149:322-332

Schenk U, Jäger H-J, Weigel H-J (1997) The response of perennial ryegrass/white clover swards to elevated atmospheric CO_2 concentrations : II. Effects on yield, fodder quality and water use. Grass Forage Sci 52:232-241

Siegfried R, Rückemann H, Stumpf G (1984) Eine HPLC-Methode zur Bestimmung organischer Säuren in Silagen. Landwirt Forsch 37:298-304

Tothi R, Lund P, Weisbjerg MR, Hvelplund T (2003) Effect of expander processing on fractional rate of maize and barley starch degradation in the rumen of dairy cows estimated using rumen evacuation and in situ techniques. Anim Feed Sci Technol 104:71-94

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 74:3583-3597

VDLUFA (1976) Die chemische Untersuchung von Futtermitteln. Darmstadt: VDLUFA-Verl

Weerathaworn P, Thiraporn R, Soldati A, Stamp P (1992) Yield and agronomic characters of tropical maize (Zea Mays L.) cultivars under different irrigation regimes. J Agron Crop Sci 168:326-336

Weigel H-J, Manderscheid R (2005) CO_2 enrichment effects on forage and grain nitrogen content of pasture and cereal plants. J Crop Impr 13(1-2):73-89

Weissbach F, Kuhla S (1995) Substance losses in determining the dry matter content of silage and green fodder: arising errors and possibilities of correction. Übers Tierernährg 23:189-214

Wu DX, Wang GX, Bai YF, Liao JX (2004) Effects of elevated CO_2 concentration on growth, water use, yield and grain quality of wheat under two soil water levels. Agric Ecosyst Environ 104:493-507

Yang LX, Wang YL, Dong GC, Gu H, Huang JY, Zhu JG, Yang HJ, Liu G, Han Y (2007) The impact of free-air CO_2 enrichment (FACE) and nitrogen supply on grain quality of rice. Field Crop Res 102:128-140

Zinselmeier C, Jeong BR, Boyer JS (1999) Starch and the control of kernel number in maize at low water potentials. Plant Physiol 121:25-35

Herzfrequenzen von Färsen und Kühen im Melkstand unter Berücksichtigung der Gewöhnung an die Melkroutine und des Schallpegels

Anja Schwalm*, Frank Brandes**, Heiko Georg*, Hans-Jürgen Helke**, Torsten Hinz** und Gracia Ude*

Zusammenfassung

Im Melkstand der Versuchsstation Braunschweig der ehemaligen FAL (jetzt FLI) wurde bei 10 Fokustieren (8 Färsen, 2 Kühe) die Herzfrequenz am 1. und 9. Laktationstag mit Polar® heart rate Monitoren erfasst und zeitgleich die Schallereignisse mit einem Noisy-Messsystem der Firma Wölfel aufgenommen. Vier der Färsen wurden vor der Kalbung an drei aufeinander folgenden Tagen in die Melkstandroutine integriert. Die vier übrigen Färsen und die Kühe betraten den Melkstand routinemäßig nach der Kalbung.

Die Färsen zeigten am ersten Laktationstag deutlich höhere Herzfrequenzen (HF) mit großen Schwankungen, während am neunten Laktationstag (LT) eine deutliche Reduktion der Herzfrequenz zu erkennen war. Auch zeigten Färsen, die vor der Geburt den Melkstand kennen lernen konnten, eine niedrigere Herzfrequenz am 1. LT als die Vergleichsgruppe. Dieser Unterschied war am 9. Laktationstag nicht mehr vorhanden. Den Kühen waren der Melkstand und die Melkung von der vorherigen Laktation bereits bekannt, so dass hier keine Unterschiede in den HF zwischen dem 1. und 9. LT festgestellt werden konnten.

Der durchschnittliche Leq (Long-term equivalent continuous sound level) bei den Melkungen der Fokustiere lag zwischen 73,7 und 79,0 dB(A). Diese Lärmbelastung im Melkstand wird in der Literatur als „mäßig" (71 bis 75 dB(A)) bis ungenügend (>75 dB(A)) eingestuft (Baumgarten, 2006). Am ersten Laktationstag stehen Färsen durch die neue Umgebung, den unbekannten Melkvorgang und die ungewohnte Geräuschkulisse unter Stress. Hierbei scheint die Gesamtsituation die größte Rolle zu spielen. Es tritt relativ rasch eine Gewöhnung an die Melksituation als Ganzes und somit auch an die auftretenden Geräusche im Melkstand ein, so dass bei den Färsen am 9. Laktationstag deutlich niedrigere und ruhigere Herzfrequenzverläufe zu erkennen sind.

Schlüsselworte: Milchkühe, Melkstand, Herzfrequenz, Tierverhalten, Schallpegel

Abstract

Heart rates of heifers and cows in the milking parlour considering the habituation of heifers to the milking routine prior to calving and the noise level

In the milking parlour of the FAL (now FLI) the heart rates of 10 focus animals (8 heifers, 2 cows) during the milking procedure were evaluated with a POLAR® heart rate monitor on days one and nine of lactation. Simultaneously the acoustic noise was recorded with a Noisy Monitor (Wölfel).

Four heifers were exposed to the full milking parlour routine once daily on three subsequent days about one week prior to calving. The other four heifers and the cows routinely entered the milking parlour after calving.

On the first day of lactation these heifers displayed higher heart rates with considerable fluctuations compared with day nine of lactation, where a clear decline of the heart rates could be observed. The heifers that were allowed to get familiar with the milking parlour before calving had lower heart rates on the first day of lactation than the heifers that had not been familiarized with the new surroundings. This difference was no longer apparent on day nine of lactation. The heart rates of the cows were similar on day one and nine of lactation.

The Leq (Long-term equivalent continuous sound level) during the milking of the focus cows was between 73,7 and 79 dB(A). This noise exposure is identified in literature as "moderate" (71 to 75 dB(A)) to "unsatisfactory" (>75 dB(A)) (Baumgarten, 2006).

Primiparous cows, that were brought to the milking area the first time after calving were stressed due to the new environment, the milking and the unfamiliar noise surrounding. The overall situation seemed to constitute the most important factor concerning heart rates. The heifers habituated quickly to the milking situation including the noise in the milking parlour. On day nine lower and uneventful heart rate curves were observed.

Keywords: dairy cows, milking parlour, heart rate, animal behaviour, noise level

* Johann Heinrich von Thünen-Institut (vTI), Institut für Ökologischen Landbau, Trenthorst 32, 23847 Westerau, E-mail: anja.schwalm@vti.bund.de

** Johann Heinrich von Thünen-Institut (vTI), Institut für Agrartechnologie und Biosystemtechnik, Bundesallee 50, 38116 Braunschweig

Einleitung

Insbesondere Färsen stehen bei der ersten Melkung durch die neue Umgebung, die ungewohnte Geräuschkulisse, den engen Mensch-Tier-Kontakt am Euter und durch den erstmaligen Milchentzug unter Stress. Manche Tiere reagieren nervös und/oder gewalttätig, so dass eine Melkung schwierig und unter Umständen gefährlich für Mensch und Tier ist (Das und Das, 2004).

Es ist bekannt, dass Färsen, die sich vor der Kalbung an den Melkstand und die Melkroutine gewöhnen konnten, besser mit dem Stress in den ersten Wochen der Laktation zurecht kommen (Heinrichs, 1996). Die Tiere zeigen weniger Angstreaktionen, sind ruhiger und haben höhere Milchleistungen und längere Melkzeiten als ungewöhnte Tiere (Wicks et al., 2004; Bremner 1997). Zudem sind der Stress und die Gefahr für Tier und Melker durch Abwehrreaktionen reduziert (Bremner 1997). Die Herzfrequenz kann zur Beurteilung einer Stressreaktion bei Kühen auch im Melkstand verwendet werden (Troxler, 2009; Rushen et al., 1999, 2001; Hopster et al., 1998).

Der Melkstand ist ein Umfeld, in dem die Kuh ihr Leistungspotential voll ausschöpfen kann, wenn sie sich wohl fühlt. (Nosal und Bilgery, 2004). Der Melkstand ist jedoch auch der Ort, an dem Kühe am häufigsten Lärm ausgesetzt sind (Unrath, 2004).

Kühe sollen beim Melken ruhig und entspannt stehen, bei zuviel Lärm sind die Voraussetzungen dafür jedoch nicht gegeben. Bei einem zu hohen Lärmpegel im Melkstand verkrampfen sich die Tiere, werden unruhiger und lassen sich nicht vollständig ausmelken, da sie oftmals die Melkgeschirre abschlagen, was die Entstehung von Euterentzündungen fördern kann (Nosal und Bilgery, 2002).

Dabei sind die Montage von Vakuumpumpe, Leitungssystem und Regelventil sowie die Bauart und Befestigung der Pulsatoren die Verursacher von Lärm, Vibrationen und Rauschen im Vakuumsystem (Nosal und Rutishauser, 2004).

Auch für den Melker bedeutet Lärm am Arbeitsplatz eine nicht zu unterschätzende Belastung. Spezielle Vorgaben bzw. Grenzwerte für einen Lärmpegel im Nutztierbereich gibt es bislang nicht (Nosal und Bilgery, 2002; Behrend, 2003).

In Deutschland gibt es verschiedene Vorschriften zum Lärmschutz an Arbeitsstätten, wobei hier vor allem die Arbeitsstättenverordnung (12. August 2004, letzte Änderung 19. Juli 2010) und die Lärm- und Vibrations-Arbeitsschutzverordnung (06. März 2007, zuletzt geändert 23. März 2010) in Verbindung mit den Technischen Regeln zur Lärm- und Vibrations-Arbeitsschutzverordnung (23. März 2010) zu nennen sind (IFA, 2011). Demnach sind Auslösewerte für vorbeugende Maßnahmen zur Minderung des Lärmexpositionspegels $L_{EX,8h}$ = 80 dB(A) und/oder Spitzenschalldruckpegel $L_{pC,peak}$ = 135 dB(C) (untere Auslösewerte). Vorgeschriebene Präventionsmaßnahmen sind hier: Pflicht der Unterweisung, Bereitstellung von Gehörschutz und Angebot einer allgemeinen Arbeitsmedizinischen Beratung. Bei $L_{EX,8h}$ = 85 dB(A) und/oder Spitzenschalldruckpegel $L_{pC,peak}$ = 137 dB(C) (obere Auslösewerte) sind weitere Präventionsmaßnahmen vorgeschrieben: Tragen von Gehörschutz, Arbeitsmedizinische Untersuchung, Lärmbereiche müssen gekennzeichnet und abgegrenzt werden und ein Lärmminderungsprogramm muss ausgearbeitet und durchgeführt werden. Der Lärmexpositionspegel $L_{EX,8h}$ ist ein Leq (energie-äquivalenter Dauerschallpegel) der alle Geräusche am Arbeitsplatz über 8 h berücksichtigt.

Beim Melken sollte jedoch ein Geräuschpegel von 65 bis 70 dB dauerhaft nicht überschritten werden, da dadurch mittelfristig Gesundheitsstörungen bei Mensch und Tier auftreten können (Nosal und Bilgery, 2002; Behrend, 2003).

Ziel der Untersuchung war daher die Bewertung der Gewöhnung von Rindern (Färsen) an die Melkroutine inklusive der Geräuschkulisse im Melkstand in den ersten Laktationstagen sowie die Einschätzung der Lärmpegel allgemein mittels Herzfrequenz- und Schallpegelmessungen.

Material und Methode

Die praktischen Untersuchungen wurden im Melkstand der Versuchsstation Braunschweig der ehemaligen FAL (jetzt FLI) durchgeführt. In einem Versuch mit zehn Färsen und fünf Kühen der Rasse deutsche Holstein wurden die Herzfrequenzen in den ersten zehn Laktationstagen während der Nachmittags-Melkung erfasst.

Fünf der Färsen (Trainingsgruppe/TF) wurden ca. eine Woche vor dem errechneten Kalbungstermin an drei aufeinander folgenden Tagen in die Melkstandroutine der Nachmittagsmelkung integriert. Die fünf übrigen Färsen (Vergleichsgruppe/F) und die Kühe betraten den Melkstand (Abbildung 1, Doppel-Fünfer-Auto-Tandem-Melkstand, Firma Lemmer Fullwood) routinemäßig das erste Mal bei der ersten Nachmittagsmelkung nach der Kalbung. Alle Tiere hatten zum Zeitpunkt der Kalbung sehr engen Kontakt zum Menschen.

Die Herzfrequenz wurde mit dem POLAR® heart rate monitor erfasst und im beat-to-beat-Modus abgespeichert, so dass jeder Herzschlag aufgezeichnet wurde. Anhand von Videoaufzeichnungen konnten die gewonnenen Herzfrequenzdaten den Ereignissen im Melkstand (Eintritt in Melkstand und Melkbox, Vormelken und Euterreinigung, Ansetzen und Abnahme des Melkgeschirrs, Austritt aus der Melkbox, Austritt Melkstand) zugeordnet werden. Der Melkvorgang wurde in der Regel automatisch beendet und das Melkgeschirr automatisch abgenommen. Bei frisch gekalbten Tieren wurde der Melkvorgang manuell

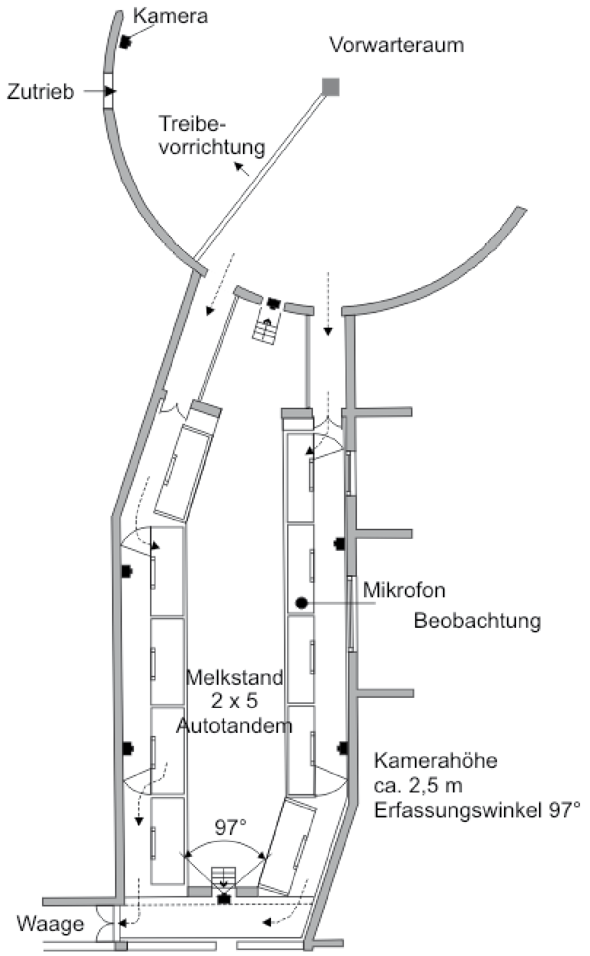

Abbildung 1:

Schematische Darstellung des Melkstandes mit Kamera- und Mikrofonpositionen

durch den Melker beendet. Die Datenerfassung erfolgte an den ersten neun Nachmittagsmelkungen, wobei der erste Melkstandbesuch immer nachmittags stattfand

Es konnten die Daten von vier Trainingsfärsen, vier Färsen und zwei Kühen in die Auswertung einbezogen werden.

Zur Schallaufzeichnung wurde ein Noisy-Messsystem der Firma Wölfel verwendet. Es besteht aus einem hochwertigen Mikrofon (GRAS 41CN), das mit den aggressiven Umgebungsbedingungen in Ställen gut zurecht kommt, einem Larson Davis LD824S Schallpegelmesser und einem Kalibriersystem AC0001 für die Ansteuerung des elektronischen Kalibrators im Mikrofon (modifiziert für LD824S). Die aufgenommenen Daten wurden mit dem im Messsystem ebenfalls enthaltenen Mini-PC aufgezeichnet. Der Schallpegelmesser, das Kalibriersystem und der Mini-PC waren in einem staubdichten Koffer (Marke Pelikan) untergebracht. Der Koffer befand sich in einem geschützten Beobachtungsraum. Das Mikrofon war im Melkstand installiert. Der Computer lief mit Windows XP. Die Aufzeichnungen und Auswertungen erfolgten mit der Noisy-Software (Firma Wölfel).

Die Daten wurden alle 30 min automatisch als Datei abgespeichert. Diese Datenspeicherung dauerte ca. 20 s in denen keine Daten vom Noisy-Monitor aufgezeichnet werden konnten.

Ergebnisse

Die Herzfrequenzen der Färsen sind am 1. LT höher und deutlich unruhiger als am 9. LT. Beispielhaft sind in Abbildung 2 und Abbildung 3 die Herzfrequenzen von Färse Nr. 409 am 1. und 9. LT dargestellt. Die Schallpegel zum Melkzeitpunkt am 1. und 9. LT waren relativ ähnlich. Inwieweit Herzfrequenzerhöhungen unmittelbar mit dem Schallpegel in Verbindung stehen ist insbesondere am 1. LT nicht eindeutig zu klären. Am 9. LT sind die Ausschläge der Herzfrequenz deutlich geringer und die Herzfrequenz ist insgesamt niedriger (Abbildung 3). Auch starke Ausschläge des Schallpegels (über 90 dB(A)) zeigen keinen Einfluss auf die Herzfrequenz.

Am ersten Laktationstag (LT) zeigten die beiden Färsengruppen deutlich höhere Herzfrequenzen während des Melkstandaufenthaltes als die Kühe (K), wobei die Färsen (F) ohne vorherige Gewöhnung an den Melkstand wiederum deutlich höhere Herzfrequenzen aufwiesen, als die Trainingsgruppe (TF). Am neunten LT zeigten sich kaum mehr Unterschiede zwischen F und TF, wobei die beiden Färsengruppen noch etwas höhere Herzfrequenzen aufwiesen als K (Abbildung 4).

Die Leqs während der Melkzeiten waren am 1. LT (zwischen 73,7 und 76,1 bzw. 79,0 dB(A)) und am 9. LT (zwischen 73,8 und 75,5 dB(A)) relativ ähnlich mit nur einigen wenigen Spitzenwerten über 90 dB(A). Eine Melkzeit war mit 79,0 dB(A) lauter als die übrigen. Dieser hohe Leq wurde durch das Brüllen einer Kuh im Melkstand erreicht und kann nicht primär auf den Melkstand zurückgeführt werden.

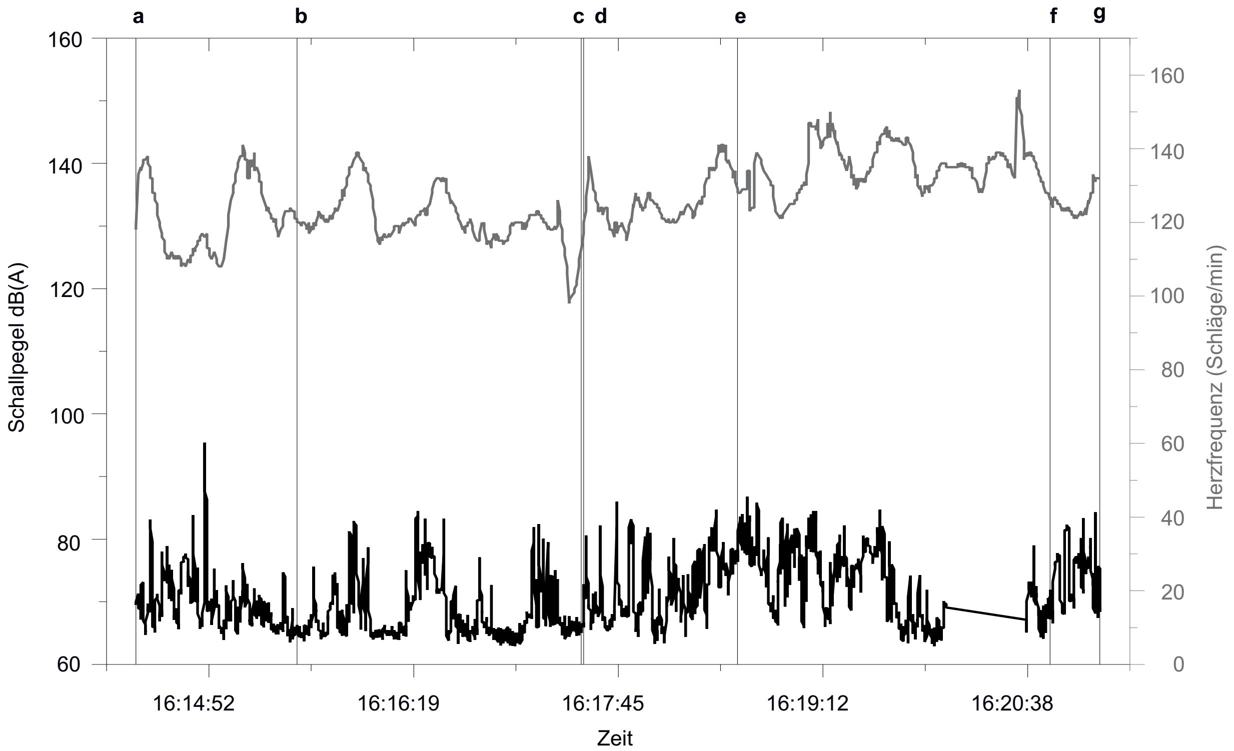

Abbildung 2:

Schallpegel und Herzfrequenz der Färse 409 am 1. Laktationstag (a: Eintritt Melkstand, b: Eintritt Melkbox, c: Vormelken, d: Euterreinigung, e: Ansetzen Melkzeug, f: Abnahme Melkzeug, g: Austritt Melkbox)

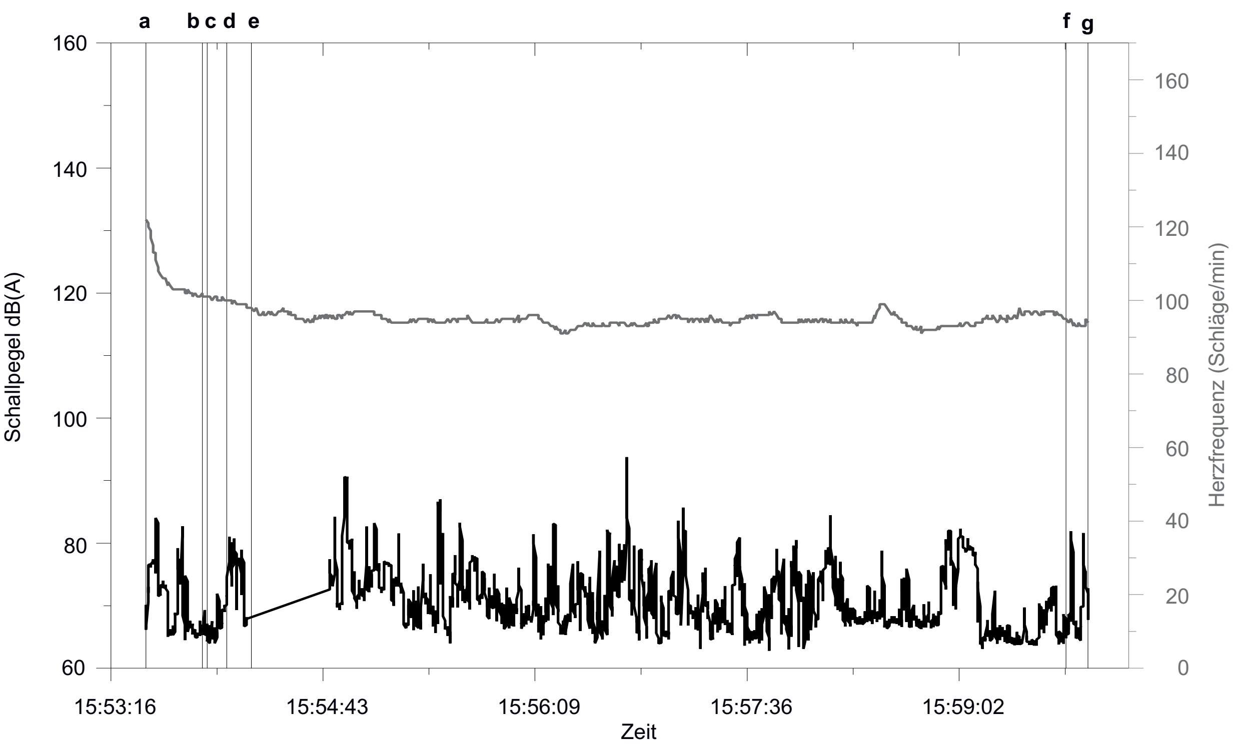

Abbildung 3:

Schallpegel und Herzfrequenz der Färse 409 am 9. Laktationstag (a: Eintritt Melkstand, b: Eintritt Melkbox, c: Vormelken, d: Euterreinigung, e: Ansetzen Melkzeug, f: Abnahme Melkzeug, g: Austritt Melkbox)

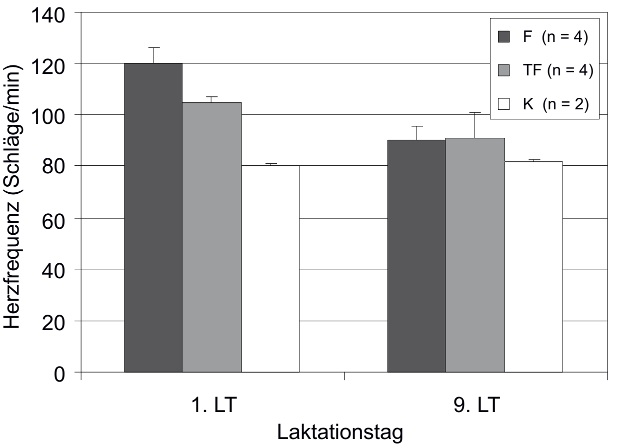

Abbildung 4:

Gruppenmittelwerte (F, TF, K) der Herzfrequenzen während des Melkstandaufenthaltes am 1. und 9. Laktationstag

Diskussion

Die Herzfrequenz ändert sich in Situationen, in denen Tiere Belastungen ausgesetzt sind, wie z. B. beim Melken, Füttern oder der Geburt. So reicht schon das Gemolken-Werden auf der „falschen" (anderen) Seite des Melkstands aus, um die Herzfrequenz zu erhöhen (Hopster et al., 1998). Auch ist die Herzfrequenz vom Umgang der Melker mit den Tieren abhängig (Knierim und Waran, 1993).

Situationen beim Melken, die für die Tiere Stress bedeuten, führen unter anderem zu einer Erhöhung der Herzfrequenz. Als Beispiel werden Melken in unbekannter Umgebung (Rushen et al., 2001), Melken auf der ungewohnten Seite des Melkstandes (Hopster et al., 1998), Lärm und Vibrationen beim Melken (Nosal und Rutishauser, 2004) genannt. Eine Erhöhung der Herzfrequenz von Kühen beim Melken kann als Indikator für die Stressbelastung herangezogen werden (Troxler, 2009).

Am ersten LT können möglicherweise ansteigende Herzfrequenzen als Reaktion auf laute plötzlich auftretende Geräusche erkannt werden. Diese Anstiege können jedoch nicht sicher auf den Lärmpegel zurückgeführt werden. Die meisten Erhöhungen der Herzfrequenzen sind direkt auf den Melkvorgang und den Kontakt mit den Melkern zurückzuführen. Am 9. LT ist bei allen Färsen eine Gewöhnung an den Melkstand, den Melkvorgang und die Geräuschkulisse eingetreten, hier sind insgesamt deutlich niedrigere und gleichmäßige Herzfrequenzen zu erkennen, wobei der Schallpegel bei allen Melkzeiten relativ gleich war.

Auch Kauke et al., 2008 konnten in ihren Untersuchungen keine Erhöhung der Herzfrequenz der Kühe bei einem Schallpegel von 80 dB(A) im Melkstand erkennen. Die in unserem Versuch erreichten Werte von Leq liegen deutlich unter 80 dB(A), so dass eine Beeinträchtigung des Wohlbefindens der Tiere durch den im Melkstand vorkommenden Geräuschpegel hier nicht zu erwarten ist.

Bei der Kombination von Lärm und Vibrationen wurde bereits 15 min vor dem Betreten des Melkstandes ein Anstieg der Herzfrequenz festgestellt, was auf eine negative Erwartungshaltung der Tiere schließen lässt (Kauke et al., 2008; Kauke und Savary, 2010). Die Unterschiede waren jedoch mit durchschnittlich 6,2 Schlägen/min nicht sehr hoch.

Arnold et al. (2007) stellten zwar eine erhöhte Herzfrequenz bei einem Lärmpegel einer Melkanlage von 85 dB(A) fest, allerdings nur am ersten Tag der Versuchsphase – danach stellte sich ein Gewöhnungseffekt ein.

Wolf und Marten (2002) (zitiert in Unrath, 2004) gehen ebenfalls von einem Gewöhnungseffekt bei Rindern an große Lärmbelastungen aus. Sie konnten bei Höchstwerten von 100 dB(A), die während der Futtervorlage durch den Mischwagen hervorgerufen wurden, keine negativen Auswirkungen auf das Tierverhalten beobachten.

Rinder gewöhnen sich schnell an die Geräusche der Umgebung. Sie können die täglichen Geräusche im Stall identifizieren und damit umgehen. Es führen nur noch unbekannte oder unerwartete Geräusche zu Angstreaktionen, insbesondere hochfrequente Geräusche (Arave, 1996). Auch bei der Geräuschkulisse im Melkstand scheint es relativ schnell zu einer Gewöhnung der Tiere zu kommen (Arnold et al., 2007), wie auch in unserem Versuch zu beobachten war.

Einen weiteren Hinweis auf die Gewöhnung stellen die Trainingsfärsen dar. Diese konnten sich schon vor der ersten Melkung an den Melkstand mitsamt der Geräuschkulisse gewöhnen und zeigen erwartungsgemäß niedrigere Herzfrequenzen am 1. LT als die Färsen ohne Gewöhnung. Auch dies ist konform mit der verfügbaren Literatur:

Bremner (1997) berichtete, dass eine Gewöhnung an den Melkstand vor der Kalbung bei konventionell aufgezogenen Färsen die Abwehrbewegungen beim Melken reduzieren kann. Es wird empfohlen, Färsen ab ca. 4 Wochen vor der Kalbung in die bestehende Milchviehherde zu integrieren, so dass sich diese an die neue Umgebung und den Melkstand gewöhnen können. Dadurch kommen die Tiere leichter mit den Stressfaktoren zurecht, denen sie in den ersten Wochen der Laktation ausgesetzt werden (Heinrichs, 1996).

Bei unseren Untersuchungen konnten wir feststellen, dass ein dreimaliges Durchlaufen der Melkroutine vor der Kalbung schon einen deutlichen Einfluss auf die Herzfrequenz der Färsen hat. Es ist daher anzunehmen, dass schon diese zeitlich sehr begrenzte Erfahrung mit der Melkroutine einen Gewöhnungseffekt bei den Färsen erzielt. Den Trainingsfärsen ist im Vergleich zu untrainierten Färsen die

Umgebung und die Situation inklusive der Geräuschkulisse im Melkstand schon bekannt, so dass nur der eigentliche Milchentzug (inkl. Euterreinigung und Vormelken) eine neue Situation für die Tiere darstellt. Die Tiere sind ruhiger, so dass der Umgang zwischen Melker und Tier vereinfacht und das Verletzungsrisiko reduziert wird.

Auch bei den „nichttrainierten" Färsen kommt es zu einer Gewöhnung an die Melkroutine, so dass im Verlauf der ersten zehn Tage der Laktation die Unterschiede in den Herzfrequenzen zwischen den Trainingsfärsen und den untrainierten Färsen verschwinden.

Der Leq der Melkzeiten der Fokustiere lag zwischen 73,7 und 79,0 dB(A). Laut der Definition von Baumgarten (2006) ist dieser Lärmpegel im Melkstand knapp noch mit „mäßig" (71 bis 75 dB(A)) zu bewerten. Ab einem Lärmpegel von 75 dB(A) spricht der Autor von „ungenügend". Bei diesen Melkständen ist in der Regel eine Lärmreduzierung durch technische Veränderungen möglich.

Zu bedenken ist, dass die in unseren Messungen doch recht hohen Lärmpegel nur Ausschnitte der jeweiligen Melkzeit darstellen. D. h. es wurden nur die Zeiträume gemessen, in denen sich die Fokustiere auch tatsächlich im Melkstand aufhielten. Möglicherweise würde der Leq über die gesamte Melkzeit etwas anders ausfallen. Zudem bewertet der Leq Lärmspitzen relativ stark. In der Literatur ist nicht angegeben, ob es sich bei den diskutierten Schallpegeln um einfache Mittelwerte, Leq oder ein andere Angabe handelt. Somit ist ein Vergleich unserer Werte mit der Literatur schwierig.

In Untersuchungen von Nosal und Rutishauser (2004) wurden auf Betrieben, die hinsichtlich der Eutergesundheit als gut eingestuft wurden, Lärm bis 70 dB(A) und Vibrationen zwischen 0,1 und 0,2 m/s^2 gemessen. Problembetriebe wiesen hingegen Lärmwerte von mehr als 70 dB(A) und Vibrationen von über 0,3 m/s^2 auf.

Nach Nosal und Rutishauser (2004) beobachten Tierhalter nach der Umstellung auf neue Melkstände mit hohen Lärm- und Vibrationsintensitäten häufig deutliche Veränderungen im Tierverhalten sowie eine Verbesserung der Eutergesundheit. Diese Beobachtungen konnten im standardisierten Versuch mit künstlich erzeugtem Lärm bzw. künstlich erzeugten Vibrationen bei unveränderter Melkanlage jedoch nicht bestätigt werden (Kauke et al., 2008; Kauke und Savary, 2010). Dies lässt darauf schließen, dass nicht Lärm und Vibrationen das Melkverhalten, das Wohlbefinden und die Eutergesundheit negativ beeinflussen, sondern deren Ursachen (z. B. Installations- und Montagefehler) (Kauke und Savary, 2010).

Beim Melken geht es nicht nur um den Komfort für die Kuh sondern auch für den Melker (Baumgarten, 2006). Auch wenn die erreichten Werte unter den laut Arbeitsstättenverordnung relevanten Werten liegen, ist davon auszugehen, dass das Verhalten, die innere Ruhe und die Zufriedenheit des Melkers den Melkprozess und damit das Wohlbefinden, die Leistungsbereitschaft der Kühe und die Milchqualität im entscheidenden Maße beeinflusst. Die positiven Veränderungen des Melkers bei einer niedrigeren Lärm- und Vibrationsbelastung im Melkstand werden auch durch arbeitswirtschaftliche Untersuchungen belegt. Die angenehmeren Bedingungen für Mensch und Tier äußerten sich in signifikant reduziertem Arbeitszeitbedarf (Nosal und Bilgery, 2002).

Unser Melkstand liegt zwar unter den geforderten Werten des Arbeitsschutzes, dennoch sind laute Geräuschkulissen schlecht für das Wohlbefinden und die Motivation der Melker, die wiederum einen negativen Einfluss auf die Tiere haben können. Eine mögliche Lärmreduzierung im Melkstand wäre zu überdenken.

Schlussfolgerungen

Eine Gewöhnung von Färsen an die Melkroutine vor der ersten Melkung ist sinnvoll, nicht nur im Bezug auf die Geräuschkulisse sondern insbesondere auf die Gesamtsituation im Melkstand und den Mensch-Tier-Kontakt. Schon ein dreimaliges Durchlaufen der Melkroutine vor der Kalbung reduziert die Herzfrequenz am ersten Laktationstag.

Eine Gewöhnung an den Melkvorgang, den Melkstand und somit auch an die Geräuschkulisse ist nach 9 Tagen Laktation nahezu abgeschlossen.

Kühe scheinen sich aus der vorherigen Laktation noch an den Melkstand mit seinen Gegebenheiten zu „erinnern", so dass es am 1. Laktationstag zu keinem Anstieg der Herzfrequenz kommt. Die Lärmbelastung im Melkstand war im Vergleich zu den Arbeitsplatzrichtlinien für den Menschen im Normbereich. Diese Grenzwerte können aber nicht auf Tiere übertragen werden. Lärmpegel für die Belastung von Tieren (Kühen) gibt es bislang nicht. Weitere Untersuchungen, insbesondere auch im hörbaren Frequenzbereich der Tiere, sind nötig, um die Lärmpegelbegrenzung für die Tierhaltung aus Sicht der Tiere besser einschätzen zu können

Danksagung

Unser besonderer Dank gilt Merle Gronau für die teilweise Auswertung der Videoaufnahmen im Melkstand, sowie Silke Beintmann, Ina Baumann und Hartmut Schwarze für die tatkräftige Unterstützung der praktischen Versuche.

Literaturverzeichnis

Arave CW (1996) Assessing sensory capacity of animals using operant technology. J Anim Sci 74(8):1996-2009

ArbStättV (2010) Arbeitsstättenverordnung vom 12. August 2004 (BGBl. I S. 2179), die zuletzt durch Artikel 4 der Verordnung vom 19.Juli 2010 (BGBl. I S. 960) geändert worden ist [online]. Zu finden in <http://bundesrecht.juris.de/bundesrecht/arbst_ttv_2004/gesamt.pdf> [zitiert am 14.11.2011]

Arnold NA, Ng KT, Jongmann EC, Hemsworth PH (2007) The behavioural and physiological responses of dairy heifers to tape recorded milking facility noise with and without a pre-treatment adaptation phase. Appl Anim Behav Sci 106:13-25

Baumgarten W (2006) Unnötige Mängel bei Lärm, Licht und Klima in Melkständen [online]. Zu finden in <http://www.dlr.rlp.de/Internet/global/themen.nsf/30921dbc5de96592c12573d1005132f8/67fcd2f36b13e6e4c12571ce0039d286?OpenDocument> [zitiert am 14.11.2011]

Behrend S (2003) Jede dritte Melkzeit ist zu laut! Top agrar 9/2003:R8-R11

Bremner KJ (1997) Behaviour of dairy heifers during adaptation to milking, Proc NZ Soc Anim Prod 57:105-108

Das KS, Das N (2004) Pre-udder massaging as a means for reduction of fear in primiparous cows at milking, Appl Anim Behav Sci 89:17-26

Heinrichs AJ (1996) Nutrition and management of replacement cattle, Anim Feed Sci Technol 59:155-166

Hopster H, Joop TN, van der Werft JTN, Blokhuis HJ (1998) Side preference of dairy cows in the milking parlour and its effects on behaviour and heart rate during milking. Appl Anim Behav Sci 55:213-229

IFA (2001) Rechtliche Vorgaben zu Lärm und Arbeitsplatz : Lärm- und Vibrations-Arbeitsschutzverordnung [online]. Zu finden in <http://www.dguv.de/ifa/de/fac/laerm/rechtliche_vorgaben/index.jsp> [zitiert am 14.11.2011]

Kauke M, Savary P (2010) Lärm und Vibrationen beim Melken : Auswirkungen auf Tier und Mensch. Ettenhausen : ART, 7 p, ART-Berichte 720

Kauke M, Savary P, Nosal D, Schick M (2008) Lärm und Vibrationen im Melkstand : Auswirkungen auf das Tier. KTBL-Schrift 471:89-96

Knierim U, Waran NK (1993) The influence of the human-animal interaction in the milking parlour on the behaviour, heart rate and milk yield of dairy cows. In: Nichelmann M, Wierenga HK, Braun S (eds) Proceedings of the International Congress on Applied Ethology, Berlin 1993. Darmstadt : KTBL, pp 169-173

LärmVibrationsArbSchV (2007) Lärm- und Vibrations-Arbeitsschutzverordnung vom 06.März 2007 (BGBl. I S 261), die zuletzt durch Artikel 3 der Verordnung vom 19. Juli 2010 (BGBl I S. 960) geändert worden ist [online]. Zu finden in <http://bundesrecht.juris.de/bundesrecht/l_rmvibrationsarbschv/gesamt.pdf> [zitiert am 14.11.2011]

Nosal D, Bilgery E (2004) Airborne noise, structure-borne sound (vibration) and vacuum stability of milking systems. Czech J Anim Sci 49(5):226-230

Nosal D, Bilgery E (2002) Welchen Einfluss hat der Lärm von Melkmaschinen? [online]. Zu finden in <http://www.bitec-melktechnik.ch/_downloads/Ufa_Revue_02_Melkmaschinen_ok.pdf> [zitiert am 14.11.2011]

Nosal D, Rutishauser R (2004) Lärm und Vibrationen als Stressfaktoren beim Melken : Verursacher, Auswirkungen und Lösungsmöglichkeiten. Ettenhausen : Agroscope, 12 p, FAT-Ber 625

Rushen J, de Passillé AM, Munksgaard L (1999) Fear of people by cows and effects on milk yield, behaviour and heart rate at milking. Appl J Dairy Sci 82:720-727

Rushen J, Munksgaard L, Marnet PG, DePasillé AM (2001) Human contact and the effect of acute stress on cows at milking. Appl Anim Behav Sci 73:1-14

Technische Regeln zur Lärm- und Vibrations-Arbeitsschutzverordung (TRLV Lärm) vom 23. März 2010 [online]. Zu finden in <http://www.baua.de/de/Themen-von-A-Z/Anlagen-und-Betriebssicherheit/TRLV/TRLV-Laerm.html> [zitiert am 14.11.2011]

Troxler J (2009) Die Kuh beim Melken : Einfluss der Haltungsumwelt und des Menschen. ART-Schriftenr 9:31-36

Unrath J (2004) Analyse und Bewertung von Parametern der Produktionsumwelt bei der Milchgewinnung mit automatischen Melksystemen (AMS). Berlin : Humboldt-Univ, 128 p

Wicks HCF, Carson AF, McCoy MA, Mayne CS (2004) Effects of habituation to the milking parlour on the milk production and reproductive performance of first calving Holstein-Friesian and Norwegian dairy herd replacements. Anim Sci 78:345-354

Wolf J, Marten F (2002) Untersuchungen zum Stallwetter in Außenklimaställen für Milchkühe unter besonderer Berücksichtigung des Tierverhaltens. Dummerstorf : LFA/IFT, 30 p

The phosphorus fertilizer value of bone char for potatoes, wheat, and onions: first results

Nina Siebers*, Frauke Godlinski**, and Peter Leinweber*

Abstract

Bone char (BC), being rich in phosphorus (P), calcium (Ca) and magnesium (Mg), was tested for its P fertilizing potential for potato, wheat, and onion growth. The effects of different rates of crude BC and BC inoculated with *Trichoderma harzianum* to increase the P solubilization were compared to P fertilization with pure $Ca(H_2PO_4)_2$ in a pot experiment. While $Ca(H_2PO_4)_2$ increased the dry matter yield and P concentration of plants compared to the non-fertilized control, the results for the BC treatments were inconsistent. An increase in dry matter yield was only observed for potatoes after application of BC (1000 mg P kg^{-1}), whereas wheat plants showed no response to all BC application levels, and dry matter yield of onions decreased. An increase in the plant's P concentration after BC application was observed for wheat, while plant's P was unaffected in onions and decreased in potatoes. The inconsistency of the dry matter yield and P concentration of plants after BC application is most likely caused by an insufficient incubation time of the BC added to the substrate, the application of lime carbonate, and the slightly acidic pH of the substrate all leading to a reduction in P dissolution from BC. However, initial results of the P utilization for potatoes of this pot experiment demonstrate that BC might be a potential P fertilizer, but further experiments are necessary to study the effect of incubation time, type of soil, and the mode of application.

Keywords: P fertilizer, nutrient utilization, Trichoderma harzianum

Zusammenfassung

Knochenkohle als Phosphordünger für Kartoffeln, Weizen und Zwiebeln: erste Ergebnisse

In einem Gefäßversuch wurde Knochenkohle (KK), welche reich an Phosphor (P), Magnesium (Mg) und Kalzium (Ca) ist, hinsichtlich ihrer Düngeeigenschaften für Kartoffeln, Weizen und Zwiebeln getestet. Die Auswirkungen von verschiedenen Konzentrationen an KK, KK inokuliert mit *Trichoderma harzianum* zur Erhöhung der P-Löslichkeit aus KK, und $Ca(H_2PO_4)_2$ (p.a.) wurden hierzu getestet. Die Zugabe von $Ca(H_2PO_4)_2$ hatte eine Erhöhung des Trockengewichtes und der P-Konzentration in den Pflanzen zur Folge, wohingegen die Ergebnisse nach KK Zugabe uneinheitlich waren. Eine signifikante Erhöhung der Trockenmasse konnte nur für Kartoffeln nach einer Zugabe von KK (1000 mg P kg^{-1}) beobachtet werden, wohingegen für Weizenpflanzen kein Effekt und für Zwiebeln sogar eine Verringerung der Trockenmasse beobachtet werden konnte. Ähnlich verhält es sich mit der Pflanzen P-Konzentration, die in Weizen nach KK Zugabe anstieg, in Zwiebeln unverändert blieb und in Kartoffeln verringert wurde. Die uneinheitlichen Resultate bezüglich Trockenmasse und P-Konzentration der Pflanzen wurde höchstwahrscheinlich durch eine unzureichende Inkubationszeit der KK, die Zugabe von kohlensaurem Kalk und den leicht sauren pH-Wert des Substrats verursacht, was eine Verminderung der P-Lösung aus der KK zur Folge hatte. Dennoch zeigen erste Ergebnisse aus diesem Gefäßversuch die potentielle Eignung von KK für Kartoffeln, aber es sind noch weitere Versuche nötig um den Einfluss der Inkubationszeit, des Versuchsbodens, und die Form der Zugabe zu untersuchen.

Schlüsselwörter: P-Düngung, Dünger Ausnutzungsgrad, Trichoderma harzianum

* University of Rostock, Soil Science, Justus-von-Liebig Weg 6, 18051 Rostock, Germany

** Julius Kühn-Institut (JKI), Institute for Crop and Soil Science, Bundesallee 50, 38116 Braunschweig, Germany

1 Introduction

Phosphorus (P) is a major element limiting plant growth (Beileski, 1973) and up to approximately 0.2 % of a plant's dry weight is made up of P. Plants are able to take up P from soil solution only and mainly in the form of phosphates. The soil P is not available to plants to great extent and only a few soils are capable of releasing enough plant available P to support high growth rates of crops (Schachtman et al., 1998). Thus, it is necessary to add P to soils in the form of organic and mineral P fertilizer in order to increase the concentration of plant available phosphate. Today's agriculture relies on P fertilizer mostly processed from mined phosphate rock (PR), which is a depleting non-renewable resource. Several studies estimate that the world's reserves will only last for about 50 to 125 years, and many reserves are laden with impurities, e.g., toxic heavy metals such as cadmium (Cd) and uranium (U) (Gilbert, 2009). Thus, alternative renewable P sources, which are free from contaminants, are urgently needed to meet the demands for sustainable food production worldwide. Bone char (BC) is one such renewable P source, since it contains about 10 to 15 % (w/w) (Warren et al., 2009) of P and is free from Cd and U. BC is produced from animal bone chips by pyrolysis at about 600 °C. Due to its porous structure BC can be successfully inoculated with microorganisms which strengthen the resistance of plants against pests and enhance P dissolution from BC if applied to soils (Postma et al., 2010).

Generally, only 10 to 25 % of the P applied by mineral and organic fertilizers is utilized by plants in the short term (Finck, 1992). P solubilizing microorganisms naturally residing in the rhizosphere of plants can be used to increase the P availability to plants (Abd-Alla, 1994; Illmer et al., 1995; El-Komy, 2005; Krey et al., 2011). Fungi, especially *Trichoderma spp.*, have been reported to possess a great ability to solubilize P from rock phosphate by synthesizing a number of organic acids that are necessary to scavenge phosphates from soils containing bound P (Rudresh et al., 2005, Kapri and Tewari, 2010). Thus, the application of *Trichoderma spp.* for assisting in P dissolution from BC in soils is promising. In the present study, BC was inoculated with *Trichoderma harzianum* strain DAR5 in order to increase P solubility of BC. This current work was primarily planned to investigate the value of BC as a renewable and high quality P fertilizer by conducting a first pot experiment with three different crops being important for human nutrition. Additionally, the performance of *Trichoderma harzianum* assisting in P dissolution from BC was tested.

2 Experimental

2.1 Substrate and amendment characteristics

For the pot experiment a fertilized and limed bog peat based substrate was used. This was characterized by a humification degree of H3-H4 (according to Bodenkundliche Kartieranleitung (Arbeitsgruppe Boden, 2005)) pH ($CaCl_2$) of 5.90 and total P, N, and K concentrations of 230 mg P kg^{-1}, 0.86 g N kg^{-1}, and 1.17 g K kg^{-1}, respectively. When conducting the pot experiment it was not known that the bog peat was limed and hence no adjustment of the incubation time of the soil amendment and the substrate was made. In the pot experiment three different P fertilizers were tested for their effects on crop yield and P transfer characteristics: $Ca(H_2PO_4)_2$ (p.a.), BC, and BC inoculated with *Trichoderma harzianum* strain DAR5 (BC+Tri). The $Ca(H_2PO_4)_2$ is the major compound of the highly soluble triple superphosphate fertilizer and the solutions used here were grade "p.a" (= pure for laboratory analyses) to compare the BC to a P source with highest solubility and purity. The BC used has been characterized previously in more detail by Warren et al. (2009), and it contained about 150 mg P kg^{-1}, 280 mg Ca kg^{-1}, and 6.5 mg Mg kg^{-1}. The bone char was in the form of granules < 5 mm (Ø 2 mm) and mixed into the peat in the upper half of the pots having a volume of 2.5 L.

2.2 Design of pot experiment

A three-factor pot experiment was carried out to investigate the effects of: 1) type of substrate amendment (BC, BC+Tri, and $Ca(H_2PO_4)_2$); 2) different fertilization levels: (Control (C = 0 g P kg^{-1}), BC at a level of 1 g P kg^{-1} (BC 1), BC at a level of 2 g P kg^{-1} (BC 2), BC+Tri at a level of 1 g P kg^{-1} (BC+Tri 1), BC+Tri at a level of 2 g P kg^{-1} (BC+Tri 1), and $Ca(H_2PO_4)_2$ at a level of 13.2 g P kg^{-1} (P), and 3) type of crop: (potato – Molli (G2) (*Solanum tuberosum* L.), spring wheat – Kadrili (*Triticum aestivum L.*) and onion – Ch: 108 (*Allium fistulosum*). The onions were grown from seeds, with six seeds per pot planted to a depth of 2 to 3 cm. The potatoes were grown from tubers, each of five potatoes being cut into six nearly equally sized pieces so that each piece contained one eye. For each fertilizer level the six pieces from the same potato were planted in a separate pot. Twenty seeds of wheat were planted to a depth of 1 to 2 cm. After planting the pots were placed on a fleece mat in a glasshouse, arranged in a randomized complete block design, and irrigated every day. The day/night temperature was set to be 18/10 °C. Five replicates were used for the control treatment for every crop and for each potato variant and four replicates for the wheat and onion variants. The wheat seedlings were thinned to ten plants per pot after 16 days of growth. Plants were not fertilized throughout the experiment, because the fertilizers were given to the substrate before seeding or planting. Soil and plant samples of wheat and onion were taken after 42 days of growth for chemical analyses. Wheat plants were separated into ears and straw. Potato plants were harvested after haulm senescence and separated into tubers and above-ground plant parts. After washing, the fresh weight of the plants was determined for each pot. Then, plants were dried to constant weight at 70 °C, and the dry weights were recorded. For further analyses the soil samples and plant materials were finely ground.

2.3 Chemical analyses of substrate and plants

Total P concentrations of the soil samples and total P of the BC sample were determined after microwave assisted digestion with HNO_3 and HCl (CEN, 2000) (for soil and BC) or 6 mL HNO_3 and 2 mL H_2O_2 (for plants) using an inductively coupled plasma-optical emission spectroscopy (JY 238, Jobin Yvon, France). The P utilization for each crop was then calculated by the difference of the nutrient uptake of fertilized and unfertilized plants and related to the amount of nutrients in the fertilizer according to the following equation (Finck, 1992):

$$P\ utilization\ (\%) = \frac{total\ uptake - uptake\ from\ soil\ storage}{amount\ of\ nutrients\ in\ the\ fertilizer} \cdot 100 \qquad (1)$$

2.4 Statistical analyses

One-way ANOVA was used to identify significant differences in P utilization between treatments (Tuckey test *$P < 0.05$* and **$P < 001$*).

3 Results and discussion

3.1 Substrate P concentration

The application of soil amendments increased total P concentrations in the substrate (Table 2), which was determined after crop harvest.

The total P concentration in the substrate after $Ca(H_2PO_4)_2$ application was lower for the wheat and onion variants compared to the total P concentration after BC application. This result is surprising as $Ca(H_2PO_4)_2$ was applied at a level of 13.2 g P kg^{-1}, whereas BC was applied only at a level between 1 to 2 g P kg^{-1}. This is a result of the high solubility of $Ca(H_2PO_4)_2$ and thus a loss of P with the irrigation water.

Table 1:
Total P concentration of substrate (mg kg^{-1})

Variant	Potato	Wheat	Onion
		mg kg^{-1}	
C	266 ± 35	244 ± 32	182 ± 80
P	800 ± 166**	462 ± 38**	639 ± 43**
BC 1	430 ± 74**	1915 ± 705**	3702 ± 633**
BC 2	539 ± 127**	4518 ± 1182**	6302 ± 1848**
BC+Tri 1	324 ± 26**	2820 ± 231**	3048 ± 791**
BC+Tri 2	397 ± 60**	4348 ± 1301**	5564 ± 790**

Significant at *$P < 0.05$ and **$P < 0.01$ (treatment vs. control).

3.2 Dry matter yield

The effects of the different soil amendments on plant dry matter yield are presented in Table 1. Application of $Ca(H_2PO_4)_2$ increased the dry matter yield for all crops

Table 2:
Dry matter yield of plant samples (g pot^{-1})

Variant	Potato		Wheat		Onion	
	shoots	tubers	straw	ears	shoots	bulbs
			g pot^{-1}			
C	11.13 ± 0.3	19.71 ± 7.6	24.45 ± 0.3	6.77 ± 0.3	8.18 ± 0.1	6.40 ± 0.2
P	12.83 ± 0.9**	38.90 ± 14.4*	28.81 ± 0.6**	13.0 ± 0.8**	12.9 ± 1.9**	7.36 ± 0.34**
BC 1	11.75 ± 0.1**	31.58 ± 6.4*	24.76 ± 0.4	6.65 ± 0.4	8.02 ± 0.1*	6.18 ± 0.4
BC 2	11.32 ± 0.5	20.20 ± 6.3	24.76 ± 0.4	7.26 ± 0.2*	8.04 ± 0.1*	6.26 ± 0.3
BC+Tri 1	10.75 ± 0.3	15.04 ± 5.7*	24.74 ± 0.4	6.89 ± 0.5	8.32 ± 0.4	5.99 ± 0.4
BC+Tri 2	11.21 ± 0.2	19.46 ± 1.3	24.67 ± 0.4	6.62 ± 0.35	8.12 ± 0.1	6.39 ± 0.9

Significant at *$P < 0.05$ and **$P < 0.01$ (treatment vs. control).

compared to the unfertilized controls. The results for the various BC applications were inconsistent. For a few treatments the dry matter yield increased after addition of BC, whereas dry matter yield of onion shoots decreased. The addition of BC+Tri had no effect on plant biomass compared to the control.

The P in $Ca(H_2PO_4)_2$ is highly water soluble and thus to a great extent available for plants, which explains the increase in dry matter yield after $Ca(H_2PO_4)_2$ application. In most of the samples the plant biomass was not altered after BC application, being a result of several factors. Firstly, the incubation time of the BC with the substrate was inadequate for significant P dissolution from BC into the substrate. Warren et al. (2009) studied P dissolution from BC and TSP and found that immediately after application a limited amount of plant available P was released, whereas the highly soluble triple superphosphate fertilizer increased the plant available P fraction to a much higher extent immediately after application. Thus, in this study the incubation time of BC seemed to not be adequate to release sufficient P available to plants. Secondly, the slightly acidic pH of the substrate may have caused a reduced P dissolution from BC. This can be concluded from Warren et al. (2009) who found that P was not released at a soil pH (water) above 6.14. In the present study the substrate had an initial pH ($CaCl_2$) of 5.90. Since the pH determined with the $CaCl_2$ method is generally lower compared to the water method (Minasny et al., 2011) the pH of the substrate used in present study might have exceeded the cut-off pH found by Warren et al. (2009) for a significant P dissolution. Thirdly, the form of lime that was applied to the substrate may also have inhibited the P dissolution from BC, as was shown by Rex and Kühn (2008). In their study, converter lime and lime carbonate were applied to BC amended soil but a fertilizing effect was observed for converter lime only. In that study lime carbonate applied to the soil might have reduced the P dissolution from BC. Thus, in order to definitely prove the plant growth enhancing effect of BC a new pot experiment was set-up to further study the factors of incubation time, soil pH, and application of other amendments.

3.3 Plant P concentration

The addition of $Ca(H_2PO_4)_2$ increased plant P concentration for all crops, whereas the BC 2 and BC+Tri 2 applications led to an increase in the P concentration of wheat (Figure 1). Furthermore, BC addition did not affect the P concentration in onions and reduced potato plant P for the BC 2, BC+Tri 1, and BC+Tri 2 treatments.

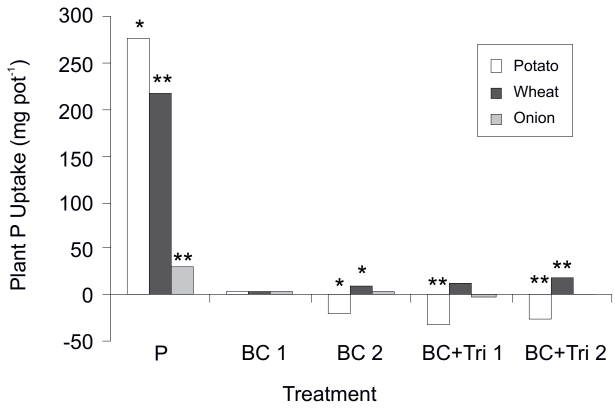

Figure 1:

Plant P uptake response to substrate amendment. Significant at $*P < 0.05$ and $**P < 0.01$ (treatment vs. control).

All crops with increased dry matter yield due to $Ca(H_2PO_4)_2$ application were also responsive to plant P concentration as a result of the high solubility and thus good P availability. Onion P concentration in the BC 1 and BC 2 treatments showed no treatment response even though the dry matter yield was reduced. Higher concentration of plant available P after biomass ash supply were also found in a study of Schiemenz and Eichler-Löbermann (2010). However, this increase did not always result in higher plant P uptake.

3.3 P utilization

The data for P utilization from $Ca(H_2PO_4)_2$ and BC for different fertilizer treatments and crops are presented in Table 3. In the present study, only the $Ca(H_2PO_4)_2$- and BC 1 treatments to potatoes reached a degree of P utilization of 9.42 and 15.96 %, respectively. For the other treatments the degree of P utilization was only in the range between -0.34 to 5.86 % and therefore lower than the general short term P utilization of mineral and organic P fertilizer (Finck, 1992). The low degree of P utilization for the highly soluble $Ca(H_2PO_4)_2$ can be explained by P leaching with the irrigation water, as equation (1) considers the amount of nutrients applied with the fertilizer but does not take leaching into account. Therefore, the P utilization from $Ca(H_2PO_4)_2$ might be underestimated. The application of $Ca(H_2PO_4)_2$ was equivalent to a highly soluble mineral P fertilizer and was used as control treatment to evaluate the P utilization from BC. The P utilization for potatoes and the BC 1 treatment was increased by 169.4 % relative to the P utilization from $Ca(H_2PO_4)_2$ serving as control treatment. This outstanding performance was not observed for the other treatments with a P utilization in the range of -3.6 to 26.8 % compared to the $Ca(H_2PO_4)_2$ treatment. However, more consistent results were obtained for wheat, with a

P utilization in the range between 15.2 to 42.7 % of the $Ca(H_2PO_4)_2$ treatment. BC inoculated with *Trichoderma harzianum* showed a slightly higher P utilization performance with 42.7 % (BC+Tri 1) and 40.4 % (BC+Tri 2) compared to the BC 1 and BC 2 treatments. This was different for the onion variants, for which P utilizations rates of 86.3 and 53.9 % for the treatments BC 1 and BC 2 were achieved, respectively, whereas the performances of BC+Tri 1 and BC+Tri 2 were -10.8 and 2.9 %, respectively.

Table 3:
P utilization (%) for different variants and crops

	P utilization (%)		
Variant	Potato	Wheat	Onion
P	9.42	5.86	1.02
BC 1	15.96**	0.91**	0.88**
BC 2	2.52**	1.53**	0.55**
BC+Tri 1	-0.34**	2.50**	-0.11**
BC+Tri 2	0.91**	2.37**	0.03**

Significant at $*P < 0.05$ and $**P < 0.01$ (BC amendments vs. P treatment).

The choice of the strain of *Trichoderma sp.* is of crucial importance for the P solubilizing performance. In a study conducted by Kapri and Tewari (2010), various *Trichoderma sp.* cultures were tested for their P solubilizing potential from tricalcium phosphate. After an incubation of 96 h the highest P solubilization was obtained for the isolate of *Trichoderma sp.* DRT-1 (352.8 µg P mL^{-1}), whereas the isolate ORT-4 solubilized only 251.9 µg P mL^{-1} above the baseline level of 51.3 µg P mL^{-1} for the control treatment. To the best of our knowledge, the strain used in this study has not been evaluated for its P solubilization capacity. In a previous study, no difference in acid phosphatase activity in soil was found between BC and BC inoculated with *Trichoderma harzianum* strain DAR5 (Baum et al., 2008). Thus, usage of BC inoculated with *Trichoderma harzianum* strain DAR5 combined with an insufficient incubation time might explain the inconsistent P utilization data for different crops.

4 Conclusions

The results of this study suggest that the P utilization from BC can be comparable to a highly soluble P source under some circumstances. Therefore, BC is potentially suitable as Cd- and U-free "ecological" P fertilizer. The attempt to enhance the P solubility by incorporating BC inoculated with *Trichoderma harzianum* into the substrate used for pot experiments was ineffective or counterproductive to increase the plant's P concentration and dry matter yield. In terms of environmental risks, especially water contamination, the application of BC compared to a highly soluble P compound is advantageous as P release is not that rapid and, thus, less prone to leaching. Another pot experiment was conducted to determine if the inconsistent performance of BC as P fertilizer for different crops was due to the experimental set-up of this pot experiment. Initial results suggest that changes in the experimental set-up with respect to lime addition to the substrate and mode of application influence the P fertilizing effect of BC.

Acknowledgements

The authors would like to thank Günther Langer, Institute for Plant Protection in Horticulture and Forest for maintaining the pot experiment and Melanie Schütt, Institute for Crop and Soil Science for sample preparation. N. Siebers also acknowledges a PhD-grant from the Federal State of Mecklenburg-Western Pomerania in Germany.

References

Abd-Alla MH (1994) Phosphates and the utilization of organic phosphorus by Rhizobium leguminosarum biovar. viceae. Lett Appl Microbiol 18:294-296

Arbeitsgruppe Boden (2005) Bodenkundliche Kartieranleitung. Stuttgart : Schweitzerbart, 438 p

Baum C, Leinweber P, Eckhardt K-U, Someus W, Halasz M (2008) Auswirkungen der Applikation von mit Trichoderma harzianum inoklierter Knochenkohle auf die mikrobielle Biomasse, Enzymaktivitäten und die Zusammensetzung der organischen Substanz des Bodens [online]. To be found at <https://docs.google.com/viewer?a=v&q=cache:frLA6kKVijkJ:eprints.dbges.de/27/1/Baum_et_al_Osnabrueck_2008_new.pdf+trichoderma+dar5&hl=de&gl=de&pid=bl&srcid=ADGEESj_LRzPBywgc_WiGTBczeMqiTCYpUKfcIfOUulIzI-Uis9na2JX2nCDsWu3jIEuYXRFubDVpQDSKh97eNE9NfVq0F5s7wRxrYT-tYyMvNrwCfV6RxsarLV0QwjQ7-LEavsywxVqJQ&sig=AHIEtbQp0stv1fjp7z-eZOolSAUf-Dsjy4A> [quoted 20.03.2012]

Beileski RL (1973) Phosphate pools, phosphate transport and phosphate availability. Annu Rev Plant Physiol 24:225-252

CEN (2000) EN 13346 : Characterization of sludges - determination of trace elements and phosphorus - aqua regia extraction methods, Brussels : CEN

El-Komy HMA (2005) Coimmobilization of Azospirillum lipoferum and Bacillus megaterium for successful phosphorus and nitrogen nutrition of wheat plants. Food Technol Biotechnol 43:19-27

Finck A (1992) Dünger und Düngung : Grundlagen und Anleitung zur Düngung der Kulturpflanzen. Weinheim : VCH, 288 p

Gilbert N (2009) The disappearing nutrient. Nature 461:716-718

Illmer P, Barbato A, Schinner F (1995) Solubilization of hardly-soluble AlPO4 with P-solubilizing microorganisms. Soil Biol Biochem 27(3):265-270

Kapri A, Tewari L (2010) Phosphate solubilization potential and phosphatase activity of rhizospheric Trichoderma spp. Braz J Microbiol 41(3):787-795

Krey T, Caus M, Baum C, Ruppel S, Eichler-Löbermann B (2011) Interactive effects of plant growth promoting rhizobacteria and manuring on the phosphorus supply of Zea mays L. and Brassica napus L. J Plant Nutr Soil Sci 174:602-613

Minasny B, McBratney AB, Brough DM, Jacquier D (2011) Models relating soil pH measurements in water and calcium chloride that incorporate electrolyte concentration. Eur J Soil Sci 62:728-732

Postma J, Nijhuis EH, Someus E (2010) Selection of phosphorus solubilizing bacteria with biocontrol potential for growth in phosphorus rich animal bone charcoal. Appl Soil Ecol 46(3):464-469

Rex M, Kühn M (2008) Phosphat-Düngewirkung von Tiermehlasche vor und nach thermischem Aufschluss in Konverterschlacke [online]. To be found at <http://www.jki.bund.de/fileadmin/dam_uploads/_koordinierend/bs_naehrstofftage/phosphor_landwirtschaft/Poster_Rex.pdf> [quoted 20.03.2012]
Rudresh DL, Shivaprakash MK, Prasad RD (2005) Tricalcium phosphate solubilizing abilities of Trochoderma spp. in relation ro P-uptake & growth yield parameters of chickpea (Cicer arietinum L.). Can J Microbiol 51:217-226
Schachtman DP, Reid RJ, Ayling SM (1998) Phosphate uptake by plants from soil to cell. Plant Physiol 116:447-453
Schiemenz K, Eichler-Löbermann B (2010) Biomass ashes and their phosphorus fertilizing effect on different crops. Nutr Cycl Agroecosystems 87:471-482
Warren GP, Robinson JS, Someus E (2009) Dissolution of phosphorus from animal bone char in 12 soils. Nutr Cycl Agroecosystems 84:167-178

Lieferbare Sonderhefte / Special issues available

328	Walter Dirksmeyer, Heinz Sourell (Hrsg.) *(2009)* **Wasser im Gartenbau –** Tagungsband zum Statusseminar am 9. und 10. Februar 2009 im Forum des vTI in Braunschweig. Organisiert im Auftrag des BMELV	8,00 €
329	Janine Pelikan, Martina Brockmeier, Werner Kleinhanß, Andreas Tietz, Peter Weingarten *(2009)* **Auswirkungen eines EU-Beitritts der Türkei**	8,00 €
330	Walter Dirksmeyer (Hrsg.) *(2009)* **Status quo und Perspektiven des deutschen Produktionsgartenbaus**	14,00 €
331	Frieder Jörg Schwarz, Ulrich Meyer *(2009)* **Optimierung des Futterwertes von Mais und Maisprodukten**	12,00 €
332	Gerold Rahmann und Ulrich Schumacher (Hrsg.) *(2009)* **Praxis trifft Forschung — Neues aus der Ökologischen Tierhaltung 2009**	8,00 €
333	Frank Offermann, Horst Gömann, Werner Kleinhanß, Peter Kreins, Oliver von Ledebur, Bernhard Osterburg, Janine Pelikan, Petra Salamon, Jürn Sanders *(2010)* **vTI-Baseline 2009 – 2019: Agrarökonomische Projektionen für Deutschland**	10,00 €
334	Hans-Dieter Haenel (Hrsg.) *(2010)* **Calculations of Emissions from German Agriculture - National Emission Inventory Report (NIR) 2010 for 2008** **Berechnung der Emissionen aus der deutschen Landwirtschaft - Nationaler Emissionsbericht (NIR) 2010 für 2008**	12,00 €
335	Gerold Rahmann (Hrsg.) *(2010)* **Ressortforschung für den Ökologischen Landbau 2009**	8,00 €
336	Peter Kreins, Horst Behrendt, Horst Gömann, Claudia Heidecke, Ulrike Hirt, Ralf Kunkel, Kirsten Seidel, Björn Tetzlaff, Frank Wendland *(2010)* **Analyse von Agrar- und Umweltmaßnahmen im Bereich des landwirtschaftlichen Gewässerschutzes vor dem Hintergrund der EG-Wasserrahmenrichtlinie in der Flussgebietseinheit Weser**	22,00 €
337	Ulrich Dämmgen, Lotti Thöni, Ralf Lumpp, Kerstin Gilke, Eva Seitler und Marion Bullinger *(2010)* **Feldexperiment zum Methodenvergleich von Ammoniak- und Ammonium-Konzentrationsmessungen in der Umgebungsluft, 2005 bis 2008 in Braunschweig**	8,00 €
338	Janine Pelikan, Folkhard Isermeyer, Frank Offermann, Jürn Sanders und Yelto Zimmer *(2010)* **Auswirkungen einer Handelsliberalisierung auf die deutsche und europäische Landwirtschaft**	10,00 €
339	Gerald Schwarz, Hiltrud Nieberg und Jürn Sanders *(2010)* **Organic Farming Support Payments in the EU**	14,00 €
340	Shrini K. Upadhyaya, D. K. Giles, Silvia Haneklaus, and Ewald Schnug (Editors) *(2010)* **Advanced Engineering Systems for Specialty Crops: A Review of Precision Agriculture for Water, Chemical, and Nutrient - Application, and Yield Monitoring**	8,00 €
341	Gerold Rahmann und Ulrich Schumacher (Hrsg.) *(2010)* **Praxis trifft Forschung — Neues aus der Ökologischen Tierhaltung 2010**	8,00 €
342	Claus Rösemann, Hans-Dieter Haenel, Eike Poddey, Ulrich Dämmgen, Helmut Döhler, Brigitte Eurich-Menden, Petra Laubach, Maria Dieterle, Bernhard Osterburg *(2011)* **Calculation of gaseous and particulate emissions from German agriculture 1990 - 2009** **Berechnung von gas- und partikelförmigen Emissionen aus der deutschen Landwirtschaft 1990 - 2009**	12,00 €
343	Katja Oehmichen, Burkhard Demant, Karsten Dunger, Erik Grüneberg, Petra Hennig, Franz Kroiher, Mirko Neubauer, Heino Polley, Thomas Riedel, Joachim Rock, Frank Schwitzgebel, Wolfgang Stümer, Nicole Wellbrock, Daniel Ziche, Andreas Bolte *(2011)* **Inventurstudie 2008 und Treibhausgasinventar Wald**	16,00 €

344	Dierk Kownatzki, Wolf-Ulrich Kriebitzsch, Andreas Bolte, Heike Liesebach, Uwe Schmitt, Peter Elsasser *(2011)* **Zum Douglasienanbau in Deutschland –** Ökologische, waldbauliche, genetische und holzbiologische Gesichtspunkte des Douglasienanbaus in Deutschland und den angrenzenden Staaten aus naturwissen-schaftlicher und gesellschaftspolitischer Sicht	10,00 €
345	Daniel Heinrich Brüggemann *(2011)* **Anpassungsmöglichkeiten der deutschen Rindermast an die Liberalisierung der Agrarmärkte**	14,00 €
346	Gerold Rahmann (Hrsg.) *(2011)* **Ressortforschung für den Ökologischen Landbau 2010**	8,00 €
347	Hiltrud Nieberg, Heike Kuhnert und Jürn Sanders *(2011)* **Förderung des ökologischen Landbaus in Deutschland – Stand, Entwicklung und internationale Perspektive – 2., überarbeitete und aktualisierte Auflage**	12,00 €
348	Herwart Böhm (Hrsg.) *(2011)* **Optimierung der ökologischen Kartoffelproduktion**	12,00 €
349	Klaus Nehring *(2011)* **Farm level implications of high commodity prices – An assessment of adaptation strategies and potentials in selected regions in Australia and Germany –**	18,00 €
350	Josef Frýdl, Petr Novotný, John Fennessy and Georg von Wühlisch (eds.) *(2011)* **COST Action E 52 Genetic resources of beech in Europe – current state**	18,00 €
351	Stefan Neumeier, Kim Pollermann, Ruth Jäger *(2011)* **Überprüfung der Nachhaltigkeit des Modellprojektes Einkommenssicherung durch Dorftourismus**	12,00 €
352	Bernhard Forstner , Andreas Tietz , Klaus Klare, Werner Kleinhanss, Peter Weingarten *(2011)* **Aktivitäten von nichtlandwirtschaftlichen und überregional ausgerichteten Investoren auf dem landwirtschaftlichen Bodenmarkt in Deutschland – Endbericht**	8,00 €
353	Wilfried Brade, Ottmar Distl, Harald Sieme und Annette Zeyner (Hrsg.) *(2011)* **Pferdezucht, -haltung und -fütterung – Empfehlungen für die Praxis**	10,00 €
354	Gerold Rahmann und Ulrich Schumacher (Hrsg.) *(2011)* **Praxis trifft Forschung — Neues aus dem Ökologischen Landbau und der Ökologischen Tierhaltung 2011**	8,00 €
355	Frank Offermann, Martin Banse, Markus Ehrmann, Alexander Gocht, Horst Gömann, Hans-Dieter Haenel, Werner Kleinhanß, Peter Kreins, Oliver von Ledebur, Bernhard Osterburg, Janine Pelikan, Claus Röse-mann, Petra Salamon, Jürn Sanders *(2012)* **vTI-Baseline 2011 – 2021: Agrarökonomische Projektionen für Deutschland**	10,00 €
356	Hans-Dieter Haenel, Claus Rösemann, Ulrich Dämmgen, Eike Poddey, Annette Freibauer, Helmut Döhler, Brigitte Eurich-Menden, Sebastian Wulf , Maria Dieterle, Bernhard Osterburg *(2012)* **Calculations of gaseous and particulate emissions from German agriculture 1990 - 2010** **Berechnung von gas- und partikelförmigen Emissionen aus der deutschen Landwirtschaft 1990 - 2010**	14,00 €
357	Stefan Schrader and Rüdiger M. Schmelz (Eds.) *(2012)* **Newsletter on Enchytraeidae No. 12** **Proceedings of the 9th International Symposium on Enchytraeidae, 14-16 July 2010, Braunschweig, Germany**	8,00 €
358	Frank Offermann, Martin Banse, Markus Ehrmann, Alexander Gocht, Horst Gömann, Hans-Dieter Haenel, Werner Kleinhanß, Peter Kreins, Oliver von Ledebur, Bernhard Osterburg, Janine Pelikan, Claus Röse-mann, Petra Salamon, Jürn Sanders *(2012)* **vTI-Baseline 2011 – 2021: Agri-economic projections for Germany**	10,00 €
359	Jürgen Gauer und Franz Kroiher (Hrsg.) *(2012)* **Waldökologische Naturräume Deutschlands – Forstliche Wuchsgebiete und Wuchsbezirke – Digitale Topographische Grundlagen – Neubearbeitung Stand 2011**	8,00 €

Johann Heinrich
von Thünen-Institut

Landbauforschung
vTI Agriculture and Forestry Research

Vol. 62 No. 1/2 06.2012

Preis / Price 16 €

ISSN 0458-6859