CALCULATION OF METHANE PRODUCTION FROM ENTERIC FERMENTATION IN DAIRY COWS

Authors:
W. Smink
K.W. van der Hoek
A. Bannink
J. Dijkstra

October 2005

Project number SenterNovem:
0377-05-02-02-003

CALCULATION OF METHANE PRODUCTION FROM ENTERIC FERMENTATION IN DAIRY COWS

October 2005

Authors:
W. Smink [a]
K.W. van der Hoek [b]
A. Bannink [c]
J. Dijkstra [d]

a: Feed Innovation Services (FIS)
Generaal Foulkesweg 72
6703 BW Wageningen

b: RIVM
PO Box 1
3720 BA Bilthoven

c: WUR (Wageningen University and Research Centre)
Animal Sciences Group, Animal Husbandry
Edelhertweg 15, PO Box 65 8200 AB Lelystad

d: WUR (Wageningen University and Research Centre)
Wageningen University, Animal Nutrition Group
Marijkeweg 40
6709 PG Wageningen

Project number SenterNovem: 0377-05-02-02-003

Principal:
SenterNovem, Utrecht
The Netherlands

CONTENTS

1 INTRODUCTION

In a recent report (Smink et al., 2004) methane production in The Netherlands from 1990 to 2002 onwards via the IPCC-GPG Tier 2 was calculated. Methane production was calculated for different kinds of ruminants. About two third of the total methane production via enteric fermentation is produced by dairy cows. Until 2004, the data used were those calculated by Van Amstel et al. (1993) which originate from the formulas of IPCC-OECD from a 1991 workshop. These formulas are now sometimes referred to as the precursors of the present IPCC-GPG Tier 2 method. The IPCC-GPG Tier 2 method provides no mechanistic approach for the calculation of methane. The only nutritional factor affecting methane production is the energy digestibility.

The calculated dry matter intake by the IPCC-GPG Tier 2 method leads to similar results to calculations based on the Dutch Net Energy system. This is true for most ruminant species, except dairy cows.
The aim of this study is to calculate methane production by dairy cows during the period 1990 till present. A dynamic mechanistic model of rumen fermentation and digestion will be used which represents the effect of detailed dietary characteristics on methane production.

In order to achieve continuity calculation with inclusion of the dietary effect on methane production is included. First, the methodology used is motivated in Chapter 2. In Chapter 3, the activity data are presented. In Chapter 4 the results of the calculations are presented and finally the results are discussed in Chapter 5.

2 METHOD OF METHANE CALCULATION

2.1 Method used for calculation of methane from enteric fermentation

The IPCC-GPG Tier 2 method starts with calculation of the net energy required by the animal for maintenance, activity, growth, gestation and lactation. Subsequently, the gross energy intake and methane production are calculated from calculated net energy intake. In this way, only the digestibility is included as a nutritional factor affecting methane production, and no further details are included. Because important details are missing in the approach of IPCC-GPG Tier 2, in the present study the choice was made to carry out calculations of methane production with a dynamic mechanistic model. More information about the model is presented in chapter 2.4.

Principally, the dry matter intake of dairy cows is the most important factor in the calculation of methane production. The dry matter intake can be estimated from the energy requirement system that is used in The Netherlands. The basic data for the calculation of the intake of roughages, wet byproducts and concentrates are collected by the Working Group on Uniform calculations of Manure and Mineral Figures [Werkgroep Uniformering berekening Mest- en Mineralencijfers; WUM] (1994). Since 1990 mineral excretion will be calculated on basis of the feed intake of dairy cows. For this purpose, the intake of grass silage, maize silage, wet byproducts and concentrates will be estimated from national statistics. Based on the requirement of energy (i.e. VEM or feed unit of lactation), the other part of the ration is estimated to be meadow grass. This means that the calculated intake of feed is suitable to cover the need for VEM. More background information about the VEM method is presented in chapter 2.3.

The advantages of the method used is that (1) a mechanistic dynamic approach is used and that (2) the basis of the ration intake is originated from Dutch databases.

2.2 Scheme of calculation

Since 1990 mineral excretion is calculated by the WUM on basis of the feed intake of dairy cows. For this purpose, the intake of grass silage, maize silage, wet byproducts and concentrates will be estimated from national statistics. Based on the requirement of energy (i.e. VEM or feed unit of lactation), the remaining part of the ration is estimated to be grass consumed in the meadow. This means that the calculated intake of feed is suitable to cover the total need for VEM. More background information about the VEM method is presented in Chapter 2.3.

The proposed methodology of the methane calculation due to enteric fermentation by dairy cows is as follow:

1. The VEM requirement per cow is annually determined on basis of milk production and milk composition.

2. From statistical databases the average intake of roughage, byproducts and concentrates are determined (in DM per cow per year) and the corresponding VEM intake is calculated.

3. Calculated intake of meadow grass based on remaining VEM requirements of the cow (in DM per cow per year)

4. Calculated GE intake in MJ per cow per year by the dynamic simulation model

5. Calculation of the methane production in kg per cow per year by the dynamic simulation model

6. Calculation of the methane conversion factor (MCF)
MCF = methane production (MJ) / GE intake (MJ)

The annual average ration used for the calculation of the methane production is based on the activity data presented in Chapter 3.

2.3 Energy requirement of dairy cows

A brief description of the Dutch net energy and the Dutch intestinal digestible protein system is presented by Dijkstra (2000). The characterization of the energy system below has been taken from the relevant part of the Dijkstra (2000) paper.

In the Netherlands, feed evaluation for ruminants is based on net energy (VEM and VEVI system) and on metabolizable protein (DVE system). The VEM and VEVI system are based on the same principles, with the VEM system used for dairy cattle and the VEVI system for beef cattle. This introduction will not consider the VEVI system. A detailed description of the system is given by Van Es (1978).

VEM system

The VEM system (feed unit of lactation system) is a net energy system, based upon digestion and calorimetry studies with cattle and sheep. The system was introduced in 1977 and is used in the Netherlands and Belgium. Within the system, VEM values are attributed to each single feed, and dietary VEM requirements are calculated for an animal. VEM values are expressed in an arbitrary unit (feed unit of lactation); one feed unit of lactation corresponds to 6.9 kJ. This feeding value is close to the average net energy for lactation value of 1 g barley. The choice of an arbitrary feed unit, rather than net energy Joules, was considered appropriate for better understanding by the farmer.

VEM feed values

The VEM value of a feed is calculated from regression equations that represent the relationships between GE (gross energy), ME (metabolizable energy) and NE (net energy). The GE content of feeds is calculated using the equation:

$$\text{GE (kJ/kg)} = 24.14\ \text{CP} + 36.57\ \text{EE} + 20.92\ \text{CF} + 16.99\ \text{NFE} - 0.63\ \text{SU}^{*}$$

where CP, EE, CF, NFE and SU denote the concentrations (g/kg) of crude protein, ether extract (fat), crude fibre, nitrogen-free extract and soluble sugars, respectively. The sugar correction (*) is to be applied only when sugar content exceeds 80 g/kg and its background is that mono- and disaccharides (‘sugars’) have a lower energy content than other components of NFE fraction.

The ME content of feeds is calculated based on the digestible nutrients (DCP, DEE, DCF, DNFE and SU, assuming that all SU are digested) and depends on the actual feedstuff. For concentrate ingredients, it is:

$$\text{ME (kJ/kg)} = 15.90\ \text{DCP} + 37.66\ \text{DEE} + 13.81\ \text{DCF} + 14.64\ \text{DNFE} - 0.63\ \text{SU}^{*}$$

For maize and maize products, the equation simplifies to:

$$\text{ME (kJ/kg)} = 15.48\ \text{DOM}$$

where DOM (g/kg) represents digestible organic matter. For other roughages, the ME content depends on the ratio of DOM and DCP:

$$\text{ME (kJ/kg)} = 14.23\ \text{DOM} + 5.86\ \text{DCP} \qquad \text{DOM/DCP} \leq 7$$

$$\text{ME (kJ/kg)} = 15.06\ \text{DOM} \qquad \text{DOM/DCP} > 7$$

For all feedstuffs, the metabolizability (q) is calculated as:

$$q = 100\ \text{ME} / \text{GE}$$

The partial efficiency of ME to NE depends on the composition of the feed, the production form and the feed intake level. The efficiency is higher for maintenance than for lactation, in turn higher than that for growth. The efficiency is always higher when q is higher, but the slope of the regression that denotes the partial efficiency change with q for growth is clearly different from those for maintenance and lactation. The main reason is that q is related to the profile of nutrients (amino acids, long chain fatty acids, volatile fatty acids, glucose etc.) available for absorption, and that each of these nutrients is used with a different efficiency. The NE for lactation is calculated using the equation:

$$\text{NE (kJ/kg)} = 0.6\ [1 + 0.004\ (q - 57)]\ 0.9752\ \text{ME}$$

This function assumes that each unit of change of q results in a 0.4% unit change in partial efficiency. Also, digestion coefficients were determined at maintenance level. It is estimated that each increase in feeding level results in a 1.8% unit decrease in partial efficiency. For practical reasons, it was assumed to have only one NE value for each feedstuff. This value applies to the average feeding level of lactating cows in the Netherlands at the time of introduction of the system. The level is 2.38 times maintenance, assuming a dairy cow of 550 kg live weight (W) and a 15 kg fat corrected milk (FCM) production per day. In other words, the factor 0.9752 is calculated as 1 - (2.38 - 1) * 0.018. As mentioned previously, the NE value is divided by 6.9 to obtain the VEM value of a feed:

$$\text{VEM}_{\text{feed}}\ (\text{/kg}) = \text{NE} / 6.9$$

VEM requirements

The maintenance requirement of cattle is estimated from calorimetric balance trials. The NE for maintenance value is 292 kJ / $W^{0.75}$ /d or (in VEM) 42.4 $W^{0.75}$ /d. Also, these studies show that 1 kg of FCM contains 3054 kJ or 442 VEM. These requirements are only correct for the average cow (550 kg W and 15 kg FCM). For higher and lower levels, the factor mentioned before (1.8% unit change for each unit change in feeding level) has to be applied. Hence the VEM requirement is calculated using the equation:

$$VEM_{req}\ (/d) = (42.4\ W^{0.75} + 442\ FCM)\ [1 + (FCM - 15)\ 0.00165]$$

Additional requirements during lactation for growth (during first lactation) or for improving body condition, and foetal requirements are given by Van Es (1978).

2.4 Modelling enteric fermentation

Modelling enteric fermentation in cattle requires a description of degradation of feed in the rumen and hindgut, subsequent formation of VFA, CO_2 and CH_4, and microbial metabolism. A number of mechanistic models have been developed that predict these processes. In the present study, the model of Mills et al. (2001) was used. This model is fully described and a brief summary is given below.

The model of Mills et al. (2001) is based on the Dijkstra et al. (1992) rumen model. Dijkstra et al. (1992) developed this model with particular emphasis on the various roles of distinct microbial groups in the rumen. The model considers three types of carbohydrate (neutral detergent fibre (NDF), starch and sugars), protein and fat sources and predicts the degradation of nutrients in the rumen, production of VFA, methane, carbon dioxide and the microbial metabolism. The microbial groups considered were fibrolytic bacteria (degrading fibre), amylolytic bacteria (degrading starch and soluble sugars) and protozoa (degrading mostly starch and sugars and predating on bacteria). An evaluation against rumen and duodenal flow data indicated good predictive power for nutrient degradation, but the type of VFA formed was not predicted well (Neal et al. 1992). As the VFA molar proportions are important determinants of methane formation, proper prediction is essential for methane evaluations. Bannink et al. (2000) addressed the topic of incorrect VFA molar proportions and derived stoichiometric coefficients of the major VFA related to type of substrate fermented (cellulose, hemicellulose, starch, sugars, protein) based on a large dataset in dairy cattle. These coefficients are at present used in the Dijkstra model.

Mills et al. (2001) extended the Dijkstra et al. (1992) model, including the new representation of the VFA coefficients of Bannink et al. (2000), and added a postruminal fermentation part to it. Also, they included a prediction of methane formation based on hydrogen sources and sinks in the rumen and hindgut. In the model, excess hydrogen produced during fermentation of carbohydrates and protein (in the production of the lipogenic VFA acetate and butyrate) is partitioned between use for microbial growth, biohydrogenation of unsaturated fatty acids, and production of glucogenic volatile fatty acids (VFA). The assumption is made that remaining hydrogen is used solely and completely for methanogenesis. In this representation, a shift in VFA production from acetate or butyrate towards propionate will lead to a reduced methane production.

Application of the model indicated that the mean simulated contribution of large intestinal fermentation to total enteric methane emissions was 9.1% ± 2.6. This is included in the enteric fermentation (rumen plus hindgut). On a range of typical dairy cattle diets, methane was the major hydrogen sink (78.2% ± 1.3). The production of glucogenic VFA was the next largest sink (18.5% ± 1.3). However, long chain fatty acid hydrogenation (2.6% ± 0.5) and microbial growth (0.6% ± 0.0) were considerably smaller hydrogen sinks. From various other evaluations, Mills et al. (2001) concluded that the mechanistic model is a valuable tool for predicting methane emissions from dairy cows.

Recently, Bannink & Dijkstra (2005) developed a new representation with a pH-dependent stoichiometry of VFA formation in the rumen. Some initial results of the consequences of introducing this pH-dependency have been published by Bannink et al., (2005). The model of Mills et al. (2001) updated with the new pH-dependent stoichiometry of Bannink & Dijkstra (2005) has been applied in the present study.

3 ACTIVITY DATA

The input for modelling and calculation of the total methane production in The Netherlands is presented in Chapter 3.3 and 3.4:
- intake of dry matter for roughage and concentrates, including the calculated intake of meadow grass.
- quality characteristics of the diet.

In order to calculate the total methane production and the methane production per kg of milk, the number (and kind) of animals and milk production of the animals are presented in Chapter 3.1 and 3.2, respectively.

3.1 Numbers of animals

In the following table the number of animals per cattle category, including cows in milk and in calf, are presented. Only the data of the dairy cows or cows in milk and in calf are relevant for the calculation. For a numeric impression of the other categories of cattle for breeding and cattle for fattening, the numbers of these categories are added.

Table 3.1 Number of animals per animal category, per year

Year	1990	1991	1992	1993	1994	1995	1996
Cattle for breeding							
Female young cattle < 1 yr	752,658	760,636	720,342	687,326	687,442	696,063	703,237
Male young cattle < 1 yr	53,229	59,044	53,905	49,573	47,841	44,163	57,182
Female young cattle 1 yr – calving	879,726	907,854	892,867	836,109	802,884	807,858	804,949
Male young cattle 1-2 yrs	34,635	37,628	39,297	31,957	33,034	33,118	37,203
Cows in milk and in calf	1,877,684	1,852,165	1,775,259	1,746,733	1,697,868	1,707,875	1,664,648
Bulls for service > 2 yrs	8,762	9,899	8,547	8,551	7,975	8,674	9,229
Cattle for fattening							
Meat calves, rosé veal*	28,876	39,784	51,018	62,996	77,226	85,803	100,394
Meat calves, white veal	572,709	581,834	586,713	593,214	612,290	583,516	577,196
Female young cattle < 1 yr	53,021	65,551	61,436	63,009	63,144	57,218	55,575
Male young cattle + young bullocks < 1 yr	255,375	275,383	244,178	233,479	226,539	188,193	147,553
Female young cattle 1-2 yrs and over	99,489	121,882	127,823	128,765	121,131	115,018	97,145
Male young cattle + young bullocks > 1 yr	190,330	211,036	212,514	198,417	191,875	180,515	150,622
Suckling, fattening and grazing cows > 2yrs	119,529	139,375	145,978	156,459	146,462	146,181	146,384
Total The Netherlands	4,926,023	5,062,071	4,919,877	4,796,588	4,715,711	4,654,195	4,551,317

Year	1997	1998	1999	2000	2001	2002	2003
Cattle for breeding							
Female young cattle < 1 yr	651,019	615,834	596,635	562,563	552,595	529,127	503,703
Male young cattle < 1 yr	46,785	41,830	37,653	37,440	88,001	44,692	31,213
Female young cattle 1 yr – calving	821,891	756,995	714,018	698,733	665,997	648,497	617,295
Male young cattle 1-2 yrs	31,632	27,586	25,331	26,328	26,819	31,543	19,650
Cows in milk and in calf	1,590,571	1,610,630	1,588,489	1,504,097	1,539,180	1,485,531	1,477,766
Bulls for service > 2 yrs	8,198	8,141	10,278	10,410	10,982	14,132	11,755
Cattle for fattening							
Meat calves, rosé veal	100,948	101,267	118,397	145,828	150,950	152,033	171,501
Meat calves, white veal	603,171	609,724	634,257	636,907	556,780	561,300	560,027
Female young cattle < 1 yr	47,669	42,362	45,977	41,300	42,911	38,887	38,016
Male young cattle + young bullocks < 1 yr	137,053	115,106	97,465	83,447	76,861	62,988	59,682
Female young cattle 1-2 yrs and over	76,482	70,377	63,990	61,724	61,047	58,565	60,676
Male young cattle + young bullocks > 1 yr	150,714	137,870	120,619	98,066	94,902	80,127	63,905
Suckling, fattening and grazing cows > 2yrs	144,502	145,362	152,581	163,397	160,802	150,972	144,004
Total The Netherlands	4,410,635	4,283,084	4,205,690	4,070,40	4,027,827	3,858,394	3,759,193

* The Agricultural Census provides the numbers of rosé veal calves from 1995. The rosé veal breeding farming started in the second half of the 80-ies. In 1995 the share of rosé veal calves was 12.8% of the total number of veal calves. It is assumed that over the period from 1987 to 1995 the share of rosé veal calves annually increased by 1.6%. Therefore, the share for 1990 was calculated to be 4.8%.

3.2 Milk production

The national average values are indicated in Table 3.2. The milk production per day has been calculated by dividing the total milk production (source: Marketing Board for Dairy Products [Productschap Zuivel; PZ]) by the number of cows in milk and in calf and by dividing this again by 365 days. The WUM did use years from May to May and therefore differs somewhat with the figures of the milk production presented in Table 3.2.

Table 3.2 Milk production per cow and fat content (source: Marketing Board for Dairy Products).

Year	Milk production per cow (kg / year)	Milk production in kg per day (calculated)	Fat content (%)	Fat Corrected Milk (FCM) production (calculated) **)
1990	6050	16.58	4.38	17.53
1991	6090	16.68	4.43	17.76
1992	6140	16.82	4.41	17.85
1993	6270	17.18	4.46	18.37
1994	6405	17.55	4.43	18.68
1995	6580	18.03	4.40	19.11
1996	6626	18.15	4.43	19.32
1997	6803	18.64	4.41	19.79
1998	6827	18.70	4.40	19.82
1999	7034	19.27	4.34	20.25
2000	7416	20.32	4.38	21.48
2001 *)	7336	20.10	4.44	21.43
2001	7127	19.53	4.44	20.82
2002	7187	19.69	4.43	20.96
2003	7494	20.53	4.43	22.74

*): Number of dairy cows adjusted for fmd (utilized for the calculations)
**): Fat corrected milk production is milk production corrected to standard fat percentage of 4.00%

3.3 Intake of raw materials and concentrates

The intake of roughage and concentrates for dairy cows is presented in Table 3.3.

Table 3.3 Ration classification numbers from 1990 -2003 in the housing and grazing periods (WUM).

	1990	1991	1992	1993	1994	1995	1996	1997
housing period								
Grass silage / hay (kg DM)	1054	1211	896	1074	1052	895	887	843
Maize silage (kg DM)	531	472	686	683	678	646	685	699
Wet byproducts (kg DM)	100	74	57	47	74	127	81	179
Concentrate standard (kg)	759	751	861	784	807	847	846	844
High protein concentrate (kg)	317	321	280	304	341	429	451	404
grazing period								
Meadow grass (kg DM)	1484	1637	1843	1671	1396	1480	1462	1485
Grass silage / hay (kg DM)	198	132	63	203	228	144	250	129
Maize silage (kg DM)	371	269	132	252	504	380	309	437
Wet byproducts (kg DM)	66	49	38	32	50	84	54	119
Concentrate standard (kg)	718	715	761	725	765	850	865	832
High protein concentrate (kg)	0	0	0	0	0	0	0	0

Table 3.3 continued.

	1998	1999	2000	2001	2002	2003
housing period						
Grass silage / hay (kg DM)	1055	1086	1254	1299	1297	1367
Maize silage (kg DM)	753	775	786	823	771	790
Wet byproducts (kg DM)	157	138	163	152	157	177
Concentrate standard (kg)	863	783	959	1007	1045	1036
High protein concentrate (kg)	436	429	336	290	239	269
grazing period						
Meadow grass (kg DM)	999	1266	994	1244	1045	732
Grass silage / hay (kg DM)	468	412	416	340	409	804
Maize silage (kg DM)	595	508	657	531	649	804
Wet byproducts (kg DM)	84	74	75	70	72	81
Concentrate standard (kg)	699	652	594	594	589	598
High protein concentrate (kg)	0	0	0	0	0	0

3.4 Nutrient composition of raw materials and concentrates

In order to calculate the methane production via modelling, quality characteristics of the raw materials are needed. The nutrient composition of maize silage, grass and grassilage is based on the values presented by the Laboratory for Soil and Crop Testing [Bedrijfslaboratorium voor Grond- en Gewasonderzoek (BLGG)] in Oosterbeek. The nutrient content of NDF (Neutral Detergent Fibre) and sugar in grass en grass silage is relatively new and not available in 1990. There is a trend of a decreased crude protein content in grass and grass silage. For this reason, a year-specific value has been presented. The rest value (Organic Matter – CP – sugar – NDF – crude fat – starch – fermentation products or FP) has been subdivided into 50% sugar and 50% NDF. The composition of grass and grass silage is presented in Table 3.5 en 3.4. The composition of maize silage and concentrates is presented in Table 3.6. A constant value for maize silage was used because there was no trend in nutrient contents of maize silage is and the composition was less variable in comparison with grass products.

Table 3.4 Composition of grass silage (source: BLGG; WUM, Den Boer and Bakker, 2005). Values are in units or gram/kg dry matter. Average nutrient contents were used for missing values in the table.

	VEM	Ash	Crude protein	Crude fat	NDF	Sugar	FP
1989	911	109	182				
1990	868	119	189				
1991	838	125	177				
1992	857	121	184				
1993	861						
1994	863						
1995	839	115	179			90	
1996	874	134	209			58	
1997	845	125	183			64	
1998	868	123	176		479	63	
1999	879	111	179		463	101	
2000	877	120	178		493	65	
2001	893	106	174		486	108	
2002	863	116	167		510	74	
2003	847	112	159		530	82	
2004		111	173		489	78	
Average				40*	493	78	50*

* Estimated average content.

Table 3.5 Composition of grass (source: BLGG; WUM). Values are in units or gram/kg dry matter. Average nutrient contents were used for missing values in the table.

	VEM	Ash	Crude protein	Crude fat	NDF	Sugar	FP
1989		99	246				
1990		106	268				
1991	995	110	263				
1992	1030	110	252				
1993	991		257				
1994	1003		259				
1995	1008	104	259				
1996	1033	107	273				
1997		108	253			86	
1998	1020	107	255			92	
1999	1012	105	230		524	105	
2000	1005	108	232		442	95	
2001	994	107	229			93	
2002	990	105	227		508	92	
2003	977	107	227		432	108	
2004		111	225		488	104	
Average				40*	479	97	0*

* Estimated average content.

Table 3.6 Composition of maize silage, standard concentrate and protein rich concentrate used in the simulated methane production. Values are in gram/kg dry matter.

	Ash	Crude protein	Crude fat	NDF	Sugar	Starch	FP
Maize silage	42	74	30	433	15	371	35
Standard concentrate	100	180	50	320	100	250	0
Protein rich concentrate	100	330	50	270	70	180	0

Availability of data

In order to calculate the methane production from enteric fermentation of dairy cows as is presented in this report, the following data should be available:

- Number of animals
- Figures of feed intake of ration components (WUM)
- Nutrient content of roughage (BLGG)

4 RESULTS CALCULATION OF METHANE PRODUCTION

The results of the simulated methane production are presented in Table 4.1.

Table 4.1 Results of methane production of dairy cows in the period 1990-2003.

Year	Dry matter intake (kg/cow/year) 1	Methane production (kg/cow/year) 2	Methane production (MJ/cow/year) 3	GE intake (MJ/cow/year) 2	MCF 4	Methane production (in g per kg FCM)
1990	5,365	107.7	5,994	98,733	0.061	16.8
1991	5,399	108.1	6,016	98,827	0.061	16.7
1992	5,370	108.4	6,032	98,554	0.061	16.6
1993	5,539	110.8	6,166	101,784	0.061	16.5
1994	5,646	112.4	6,255	103,941	0.060	16.5
1995	5,606	112.7	6,272	103,350	0.061	16.2
1996	5,609	110.7	6,160	103,273	0.060	15.7
1997	5,701	114.0	6,344	104,938	0.060	15.8
1998	5,849	115.4	6,422	107,478	0.060	16.0
1999	5,881	117.1	6,517	108,197	0.060	15.8
2000	5,988	117.9	6,561	109,876	0.060	15.0
2001	6,104	121.1	6,739	112,179	0.060	15.5
2002	6,030	118.8	6,611	110,624	0.060	15.6
2003	6,411	124.6	6,934	117,497	0.059	15.0

1: Based on Dutch Energy system (VEM system); values are derived from WUM
2: Based on modelling the input of the diet
3: Methane in MJ, calculated as 1 kg methane = 55.65 MJ
4: Calculated from the simulated gross energy intake and output via methane

The methane emission factor for cows in milk and in calf is increased with about 16 kg in the period 1990-2003. The produced energy by methane, the MCF factor was decreased by 0.2 percent point with means a decrease of 3-4 % per kg of feed. The methane production decreased from 16.8 to 15.0 g per kg fat corrected milk (FCM) in the period 1990-2003.

5 DISCUSSION

The used model

The dynamic simulation model used in the present study has been extensively evaluated. The basal elements (fermentation processes and microbial metabolism in the rumen) were evaluated against independent data by Neal et al. (1992) as described before, and it has been established that the model accurately predicts nutrient degradation in the rumen. Methane predictions by the Mills et al. (2001) model was further evaluated by Kebreab et al. (2005) in an evaluation of various empirical and mechanistic models to predict methane, including the IPCC Tier 1 and Tier 2 methods, using an independent database of 47 records comprising diets that had considerable variation in composition and intake level. Analysis was done on dry and lactating cows. The Mills et al. (2001) simulation model gave accurate and precise predictions for both dry and lactating cattle data, with bias correction factor close to unity. The two-point estimate of the Tier I model gave close agreement with the mean of observed methane production and in this evaluation, under predicted mean methane production by 4%. However, the Tier II method did not predict methane production as well as the other models. Kebreab et al. (2005) indicated that the assumption that a fixed proportion of GE is converted to methane regardless of DMI contributed significantly to the error. It is now well established that as intake increases, the percentage of gross energy lost as methane declines and hence the fixed value of 6% in IPCC should be revised to vary with GE intake. Moreover, type of carbohydrate in the feed which constitutes the bulk of GE also affects methane production. Both factors are included in the Mills et al. (2001) model and therefore (although the mean predictions were quite close in both models) is much more suitable to predict feed effects of dietary manipulations on methane production than the IPCC models.

Results

The methane production as a percentage of GE decreased from 1990 till 2003. The main reason for this decrease is the higher use of maize silage in dairy cattle diets, at the expense of fresh grass in particular, in the period 1990 - 2003. Maize silage increases the molar proportion of propionic acid resulting in a shift of the site of degradation from the rumen to intestine and consequently decreases methane production per kg of feed. Maize silage was estimated to produce only 80 to 85% of the methane produced with grass silage with a similar VEM content. Hence the replacement of grass products by maize silage will decrease methane production per kg feed by some 1% (from ±6 to 5%).

Recently, Van Zijderveld and Van Straalen (2004) estimated a MCF factor of 6% for the Dutch situation in 2002. This was an estimation based on respiration experiments presented in the literature. The MCF factor was in agreement with the value presented for 2002 in this report.

The DM intake increased by some 19% in the period 1990 – 2003. An increase in DMI will reduce the methane production per unit GE, since in general the retention time in the rumen is reduced and relatively more of the energy consumed is digested in the intestine rather than fermented in the rumen. This increased DM intake will contribute to the decline in methane conversion factor. For example, Mills et al. (2001) calculated on a 50% roughage, 50% concentrate diet that the methane production decreased from 6.6% to 6.0% of GE as intake increased from 10 to 25 kg DM per day. Although such a decline depends on the diet fed, extrapolation to the 1990 – 2003 data indicate a possible decline in methane production due to increased DMI of 0.1% of GE.

The methane production per kg FCM decreased some 8% in the period 1990 - 2003. The main reasons are the reduced methane production per unit GE consumed as discussed before, and the increased milk production per cow in this period. An increase in milk production per cow will decrease the maintenance requirements for energy per kg milk produced. Maintenance requirements are related to processes to maintain the body (the basal processes including respiration, replacement of body components, etc). In most feed evaluation systems, these maintenance requirements are independent of the milk production level. In the Dutch system, energy requirements for maintenance are roughly 1/3 of the total energy requirements of the animal producing 20 kg FCM/day. Thus, the increased FCM production reduces the GE inputs required per kg FCM and therefore reduces methane production per kg FCM.

The present simulations assume that the quality characteristics of individual components remains are largely unchanged in the period 1990 – 2003. However, in recent years farmers tend to use silage of higher quality than in 1990 and this may additional lower the methane production. In particular, the tendency to use maize silage with a higher proportion of rumen resistant starch will have an impact. Starch resistant to rumen fermentation will not give rise to methane production in the rumen, whilst a large part of this starch is still available through small intestinal digestion without production of methane. Exact values are not yet quantifiable.

The calculated enteric methane production per cow in the period 1990 until 2002 is increased with 10% (and 15% for the year 2003). This is comparable with an increase of 11% that has been calculated with the IPCC-GPG Tier 2 method for the period 1990-2002. However, dietary effects did decrease the calculated methane production via modelling by 3-4%, while the same dietary change did increase the calculated methane production via the IPCC method. The total enteric methane production calculated by modelling was 5% higher than with the IPCC method. This is understandable whereas the DM intake per cow is in the Dutch VEM system about 5% higher in comparison with the IPCC calculations (Smink et al., 2004).

The simulation of methane production by modelling includes a large number of feed characteristics. From recent studies it is clear that feed additives will decrease (or increase) the production of methane in the rumen (Smink et al., 2003). However in this study the effects of additives are not included in the simulation of the methane production.

6 CONCLUSIONS

The main conclusions of the calculations are:

- The methane production by enteric fermentation in 1990 has been calculated to be 108 kg /cow/ year and did increase into ±120 kg after 2000 and even 125 kg in 2003.

- The calculated methane conversion factor for dairy cows decreased from 6.1 into 5.9% in the period 1990-2003.

- The methane production per kg of FCM decreased by approximately 10% in the period 1990-2003.

REFERENCES

Met opmaak: Nederlands (standaard)

Bannink, A., J. Kogut, J. Dijkstra, J. France, S. Tamminga and A.M. Van Vuuren (2000). Modelling production and portal appearance of volatile fatty acids in dairy cows. In: McNamara, J.P., J. France and D.E. Beever,(eds) *Modelling Nutrient Utilization in Farm Animals*, pp. 87-102. CAB International, Wallingford.

Bannink, A., J. Dijkstra, J.A.N. Mills, E. Kebreab & J. France. 2005. Nutritional strategies to reduce enteric methane formation in dairy cows. pp. 367-376. In: Emissions from European Agriculture. Eds. T. Kuczyński, U. Dämmgen, J. Webb & A. Myczko. Wageningen Academic Publishers, Wageningen, The Netherlands.

Bannink, A. & J. Dijkstra. 2005. Schatting van de vorming van vluchtige vetzuren uit gefermenteerd substraat in de pens van melkvee. ASG rapport, in druk.

Benchaar, C., J. Rivest, C. Pomar & J. Chiquette 1998. Prediction of methane production from dairy cows using existing mechanistic models and regression equations. *Journal of Animal Science* 76, 617-627.

Den Boer, D.J. and R.F. Bakker (2005). Bemesting en kwaliteit graskuil. Koeien & Kansen, 1997-2003. Koeien & Kansen Rapport 25, Nutriënten Management Instituut, Wageningen.

Dijkstra, J., H.D.St.C. Neal, , D.E. Beever & J. France (1992). Simulation of nutrient digestion, absorption and outflow in the rumen: model description. *Journal of Nutrition* 122, 2239-2256.

Dijkstra, J. (2000). Introduction to the Dutch VEM and DVE system for dairy cattle. In: Postgraduate Course Development and Application of Mechanistic Simulation Models in Feed Evaluation, August 15-17, 2000. Wageningen University, Wageningen.

IPCC (2000). Good Practise Guidance.

Kebreab, E., J. France, B.W. McBride, N. Odongo, A. Bannink, J.A.N. Mills & J. Dijkstra (2005). Evaluation of models to predict methane emissions from enteric fermentation in north american dairy cattle. In: Kebreab, E., J. Dijkstra, A. Bannink, W.J.J. Gerrits. and J. France (eds) *Nutrient Digestion and Utilization in Farm Animals: Modelling Approaches*. CAB International, Wallingford, in press.

Mills, J.A.N., J. Dijkstra, A. Bannink, S.B. Cammell, E. Kebreab and J. France (2001). A mechanistic model of whole-tract digestion and methanogenesis in the lactating dairy cow: Model development, evaluation and application. *Journal of Animal Science* 79, 1584-1597.

Neal, H.D.St.C., J. Dijkstra and M. Gill (1992). Simulation of nutrient digestion, absorption and outflow in the rumen: model evaluation. *Journal of Nutrition* 122, 2257-2272.

Smink, W., K.D. Bos, A.F. Fitié, L.J. van der Kolk, W.K.J. Rijm, G. Roelofs & G.A.M. van den Broek (2003). *Methane reduction dairy cattle. A research project as to the estimation of the methane production from feed and as to the possibilities of reduction through the feed of dairy cows.* FIS report in the framework of ROB programme Novem, Utrecht, The Netherlands. *[Methaanreductie melkvee. Een onderzoeksproject naar inschatting van de methaanproductie vanuit de voeding en naar de reductiemogelijkheden via de voeding van melkkoeien.* FIS rapport in het kader van ROB programma Novem, Utrecht, Nederland.]

Smink, W., W.F. Pelikaan, L.J. van der Kolk & K.W. van der Hoek (2004). Methane production as a result from rumen fermentation in cattle calculated bij using IPCC Tier 2 method. Report FIS FS 04-12 EN.

Van Amstel, A.R., R.J. Swart, M.S. Krol, J.P. Beck, A.F. Bouwman & K.W. van der Hoek (1993). *Methane, the other greenhouse gas. Research and policy in the Netherlands.* RIVM report 481507-001.

Van Es, A.J.H. (1978). Feed evaluation for ruminants. 1. The systems in use from May 1977 onwards in the Netherlands. *Livestock Production Science* 5, 331-345.

Van Zijderveld, S.& W.M. van Straalen (2004). *Validation of the IPCC-methane conversion factor for circumstances under which Dutch dairy cattle is raised.* Report BET. 2004-28. Schothorst Feed Research BV, Lelystad. *[Validatie van de IPCC-methaanconversiefactor voor omstandigheden waaronder Nederlands melkvee gehouden wordt.* Proefverslag BET. 2004-28. Schothorst Feed Research BV, Lelystad.]

Working Group on the Uniform calculations of Manure and Mineral Figures (Ed.M.M. van Eerdt) [Werkgroep Uniformering Berekening Mest- en Mineralencijfers (Redactie M.M. van Eerdt)], (1994). *Standard figures cattle, sheep and goats, 1990-1992. [Standaardcijfers rundvee, schapen en geiten, 1990 t/m 1992.]*