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Estimation of the methane emission factor for the Italian Mediterranean buffalo

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In order to contribute to the improvement of the national greenhouse gas emission inventory, this work aimed at estimating a country-specific enteric methane (CH_4) emission factor for the Italian Mediterranean buffalo. For this purpose, national agriculture statistics, and information on animal production and farming conditions were analysed, and the emission factor was estimated using the Tier 2 model of the Intergovernmental Panel on Climate Change. Country-specific CH_4 emission factors for buffalo cows (630 kg body weight, BW) and other buffalo (313 kg BW) categories were estimated for the period 1990–2004. In 2004, the estimated enteric CH_4 emission factor for the buffalo cows was 73 kg/head per year, whereas that for other buffalo categories it was 56 kg/head per year. Research in order to determine specific CH_4 conversion rates at the predominant production system is suggested.

Keywords: Mediterranean buffalo, emission factor, methane

Introduction

Methane (CH_4) is a powerful greenhouse gas (GHG) and globally enteric CH_4 production in ruminant livestock is the single most important source of CH_4 emission. Clearly, there is a need for more accurate emission inventory from this source. In accordance with Articles 4 and 12 of the United Nations Framework Convention on Climate Change (UNFCCC), countries submit national GHG inventories following the scientific guidance provided by the Intergovernmental Panel on Climate Change (IPCC). The IPCC has developed comprehensive guidelines for national GHG inventories and for livestock CH_4 has suggested different levels (tiers) of estimations. A good practice method of estimation of emissions disaggregating both spatially and by sub-sources to the furthest extend possible and taking into consideration specific country characteristics has been advocated (IPCC, 2002).

Dairy water buffalo (*Bubalus bubalis*) farming is a traditional Italian enterprise, which has been conducted for centuries in the central-southern lowland swampy areas of the country. However, economic interest in this animal species, driven by the utilisation of its milk in the making of Mozzarella cheese, has lead to intensified farming practices and increase in population. In fact, according to the National Institute of Statistic (ISTAT, 2007) the Italian buffalo cow population has increased from 62 000 heads in 1990 to 137 000 heads in 2005.

In Italy, to date, only CH_4 emissions from cattle have been estimated using country-specific emission factors, while for other livestock species the default emission factors (IPCC, 2000) are used.

This manuscript, following the Tier 2 method in accordance with the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000) and as requested by the UNFCCC (2006), describes the estimation of the country-specific enteric CH_4 emission factor for the Italian Mediterranean buffalo and discusses the reliability of it. Furthermore, recommendations from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories has been considered (IPCC, 2006).

Materials and methods

Models for estimating the methane emission factor

The IPCC (2006) guidelines have proposed three levels of approach (Tier 1, Tier 2 and Tier 3) for estimating enteric CH_4 emissions from livestock. Tier 1 is a simplified initial estimation method and is recommended when enteric fermentation is not a 'key category' and the animal species is not significant in the country, whereas Tiers 2 and 3 are

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more advanced approaches requiring country-specific data and more detailed characterisation of livestock population and farming situations. Tier 3 applies when a country-specific methodology for enteric CH_4 emission estimation has been developed. The present study followed the Tier 2 approach for estimating the enteric CH_4 emission factor for the Italian Mediterranean buffalo. According to IPCC (2006), a good practice to estimate a CH_4 emission factor involves: (a) collection of data that describe typical diet and performance and feeding conditions (diet quality) of the sub-categories of animal species in question, and (b) estimation of feed intake for each sub-category based on energy metabolism algorithms.

In this study, the annual statistical reports on the buffalo population produced by the ISTAT were the main source of information used for the emission factor estimation. Greco and Martino (2001) and Cóndor *et al*. (2005) have indicated that ISTAT statistical reports collate information both from specific agricultural surveys and from agricultural census (1990 and 2000). For convenience, the period 1990–2004 was chosen. In addition, close networking with staff of the Agriculture Service Section of ISTAT allowed the authors of this study to obtain relevant information on unpublished topics.

The ISTAT divides the buffalo population into two categories: buffalo cows and other buffaloes (0 to 3 years old). Unfortunately, the data concerning the latter category are presented in an aggregated way. Therefore, we have assumed a proportion of distribution of 1/3 for calves (<1 year old) and 2/3 for sub-adult buffaloes (1 to 3 years old).

Methane emission factor for buffalo cow

Methane is derived from feed energy and therefore the CH_4 emission factor is considered proportional to the gross energy (GE) intake in feed (IPCC, 2000 and 2006). The GE intake is the amount of energy consumed by an animal in order to meet maintenance, activity, growth, lactation, pregnancy and other (e.g. thermoregulation) requirements. Equation (1) (see Annex I) shows the general equation and relationships to estimate GE intake by the buffalo cow, whereas Equation (2) (see Annex I) describes the formula for calculating the CH_4 emission factor (EF). Table 1 shows the specific parameters used in the process of calculation of both GE intake (Equation (1)) and EF (Equation (2)) for the buffalo cow. In turn, Figure 1 presents a flow chart of the process of estimation.

It is obvious that GE intake and therefore EF by the buffalo cow depend on BW and milk yield. On the basis of expert judgement, we used a mean BW of 630 kg. This assumes that about 80% of the buffalo cow population constitutes mature animals weighing 650 kg and 20% of the cows are still growing with an average BW of 550 kg. The maintenance net energy requirement (NE_m) was calculated by multiplying the maintenance energy required per unit of metabolic weight (i.e. Cf_i) by the metabolic size. In this study, a value of 0.335 MJ for Cf_i was used as suggested by IPCC (2000).

The net energy for activity (NE_a) is the energy that the animal needs to obtain feed, water and shelter, and as such it is a function of NE_m. IPCC (2000 and 2006) suggest that NE_a may account for 17% and 36% of the NE_m, depending on whether the cow is stall fed, pastured or grazing large areas. In this study we considered the relative proportion of grazing animals and stall-fed animals for calculating a country-specific NE_a. Literature (e.g. Zicarelli, 2001) and expert consultation indicated that in the Caserta and Frosinone provinces, about 5% of the buffalo cow population is grazed; hence, a 3% grazing population has been estimated.

The net energy required for growth (NE_g) was estimated as a function of the BW of the animal and the rate of weight gain. For this, it was assumed that mature animals have no net weight gain (Gibbs and Johnson, 1993; IPCC, 2006). However, for the buffalo cow category we estimated a weight gain of 0.06 kg/day under the assumption that 80% of buffalo cows are mature with no net weight gain, whereas 20% of them have a weight gain of 0.27 kg/day (i.e. an increase from 550 to 650 kg BW over a year).

The net energy for lactation (NE_l) was calculated as a function of milk yield and the fat content (%) of milk. For this, the national average milk production was reconstructed based on the annual data reported by ISTAT and other national

Table 1 *Calculation of enteric methane emission factor for buffalo cows*

Parameter	Values	Reference
Animal body weight (kg)	630	Infascelli, 2003; Consorzio per la tutela del formaggio mozarella di bufala campana, 2002
Maintenance coefficient (Cf_i)	0.335	IPCC, 2000
Activity coefficient (C_a)	0.17	IPCC, 2000
Pregnancy coefficient (C_p)	0.10	IPCC, 2000
Weight gain (kg/day)	0.055	Our estimation
Milk fat content (%)	7.7 to 8.1	ISTAT, 2007
Hours of work per day	0	Our estimation
Proportion of cows giving birth	0.85 to 0.89	De Rosa and Trabalzi, 2004; Barile, 2005
Average daily milk yield (kg/head)	3.4 to 4.0	e.g. ISTAT, 2007; OSSLATTE, 2001; OSSLATTE/ISMEA, 2003
Feed digestibility (%)	65	Masucci *et al*., 1997, 1999; Infascelli, 2003
Methane conversion rate (%)	6	IPCC, 2000
MJ/kg methane	55.65	IPCC, 2000

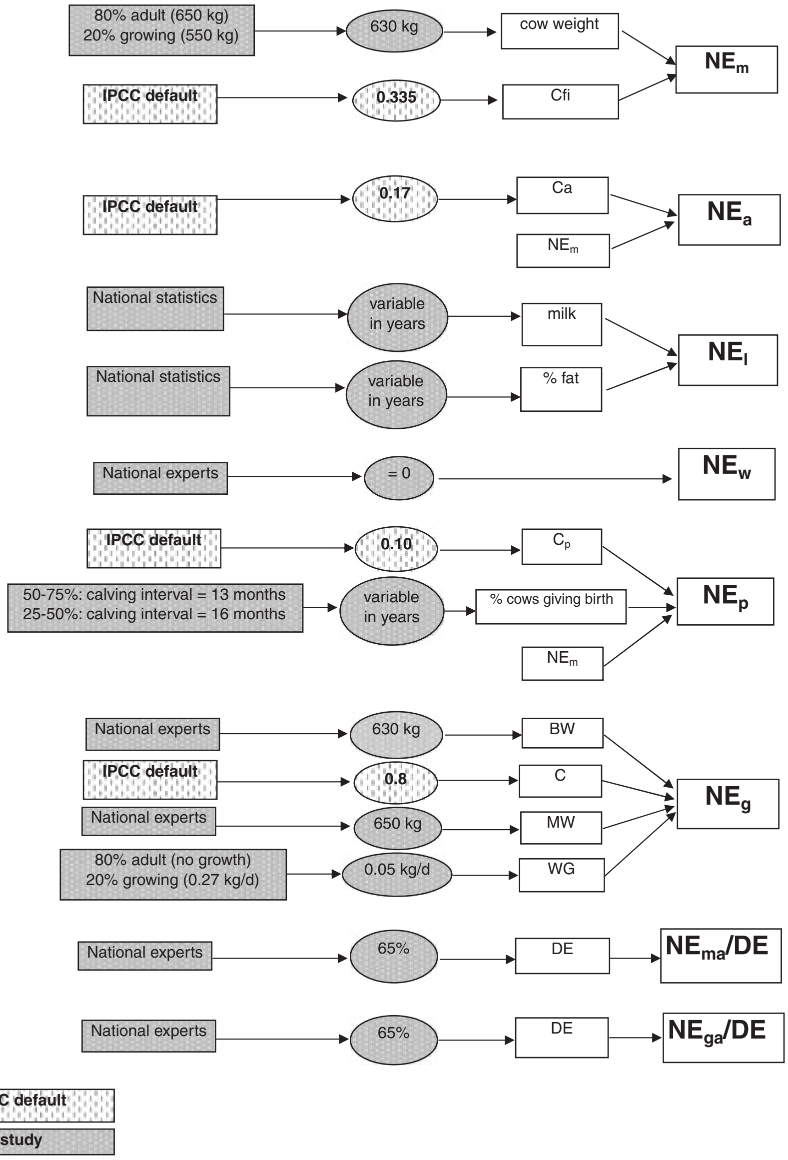

Figure 1 Flow chart used for the calculation of the gross energy intake by buffalo cows.

publications (OSSLATTE, 2001; OSSLATTE/ISMEA, 2003). When these national data were cross-checked with statistical databases of Food and Agricultural Organization (FAO, 2007) and Statistical Office of the European Commission (EUROSTAT, 2007), it was found that these international databases accounted for the collected milk only (85 to 92% of the total milk production). Hence, the total milk production (including collected milk, directly sold, direct consumed, fed to animals and transformed at farm) was calculated. Subsequently, the average daily milk production was calculated by dividing the total milk production by the number of animals and 365 days (IPCC, 2000 and 2006). We assumed that in Italy buffalo cows have no requirements of energy for work.

The net energy required for pregnancy (NE_p) was calculated as a 10% of the NE_m (IPCC, 2000 and 2006). When the NE_p component of energy requirements was applied in the process of GE intake calculation, this component was weighted by the proportion of mature females that give birth in any year. Also, in this process, we took into account the changes in the reproductive management of the buffalo cow. In fact, during the last 20 years, farmers have introduced the 'out of season' mating with the aim to maximise the market opportunity of buffalo milk in the season of high demand for mozzarella production (Zicarelli, 1997; De Rosa and Trabalzi, 2004; Barile, 2005). However, it has been reported (Zicarelli, 1997) that as a consequence of the out-of-season mating, the calving interval has increased from 12–13 months (natural calving season) to 15–16 months. For purposes of this study, we estimated that the number of farms using out-of-season mating has increased from 25% in 1990 to 50% in recent years.

Finally, to calculate the ratios of net energy for maintenance available in diet to digestible energy consumed (NE_{ma}/DE) and energy available for growth in diet to digestible energy consumed (NE_{ga}/DE) (IPCC, 2000 and 2006), data from digestion trials have been collected from the literature (Masucci *et al.*, 1997 and 1999; Infascelli, 2003) and a single digestibility of energy of 65% was considered. The latter could be questioned because intensification in buffalo farming over the last 15 years likely resulted in changed feed digestibility and CH_4 yields as the diet moved from forage-based diets to more concentrate ingredients. However, this is the best available information for estimations.

Once the GE intake by the buffalo cow was estimated, Equation (2) (see Annex I) was used to calculate the EF (kg CH_4/head per year). For this, we adopted the IPCC (2000) suggestion that 6% of the GE intake is lost in CH_4 energy.

Methane emission factor for other buffaloes
Parameters used to estimate the enteric CH_4 emission factor for this buffalo category are shown in Table 2. Daily dry matter (DM) intake (kg/head) was calculated as a percentage of BW following the methodology described in APAT (2006), which was for non-dairy cattle. The other buffalo categories were subdivided into calves (3 to 12 months old) and sub-adult animals (1 to 3 years old). It was assumed that calves (40 kg birth BW) grow at 0.6/day during their first year (Cutrignelli *et al.*, 2003); hence, a 130 kg average BW was estimated for this sub-category (calves). Similarly, for the sub-adult sub-category a 0.6 kg/day BW gain reaching 550 kg at the 3rd year of age was estimated, with an average BW of 405 kg for the sub-category. Dry matter intake by calves and sub-adult buffaloes were calculated as a proportion of their BW (3.0 and 2.5%, respectively), as suggested by Infascelli (2003). Then, the DM intakes were converted to GE intake (MJ/head) using the default conversion factor of 18.45 MJ/kg DM (IPCC, 2000 and 2006). The enteric CH_4 emission factor for this buffalo category was calculated using Equation (2) as for the buffalo cows.

Finally, the enteric CH_4 emission factor for the Italian Mediterranean buffalo was calculated as a weighted average considering population percentage and specific emission factors for buffalo cows and other buffalo categories.

Results and discussion

Table 3 presents the time series (1990–2004) for buffalo cow population and average values for milk yield, GE intake and enteric CH_4 emission factor. In 2004, the mean daily milk yield and GE intake per cow were 3.4 kg and 185 MJ, respectively, with an enteric CH_4 emission factor of 73 kg/head per year. As expected, the latter value was much lower than that estimated for dairy cows for the same year (111 kg CH_4/head per year) (APAT, 2006) as dairy cows had much higher milk yield (16.8 kg/day) and therefore higher GE intake (283 MJ/day) than buffalo cows.

In the present study, the estimated annual average of milk production per buffalo cow for the year 2004 was 1897 kg (3.37 kg/head per day), this value being lower than that

Table 2 *Estimation of enteric methane emission factors for other buffaloes*

Parameter	Calves (3 months to 1 year)	Sub-adult buffaloes (1 to 3 years)
Body weight (BW, kg)	130	405
Feed intake		
% of BW	3.0	2.5
DM (kg/day)	3.9	10.1
GE intake (MJ/day)	71.68	186.58
CH_4 conversion rate (%)	6	6
CH_4 emission factor (kg/head per year)	21.16	73.42

DM = dry matter; GE = gross energy.

(2184 kg) reported by the Italian Animal Breeders Association (AIA, 2006) for the same year. Nevertheless, the average milk production reported by AIA (2006) applies only to elite herds on milk recording scheme (17% of the national population), whereas our estimates are for the entire national herd.

In this study the mean daily feed intake by buffalo cow, including both the lactation and non-lactation periods, was 10 kg DM (185 MJ). Bartocci *et al.* (2002) reported DM intakes of 10.1 and 16.8 kg/head for dry and lactating buffalo cows, respectively. However, the latter herd exhibited higher milk yield than the national average (2417 *v.* 1896 kg/year).

The GE intake for calves and sub-adults buffaloes was estimated to be 71.68 MJ/head per day and 186.58 MJ/head per day, respectively, and the CH_4 emission factors were 21.16 kg CH_4/head per year and 73.42 kg CH_4/head per year, respectively (see Annex I, Equation (2)). In particular, we have considered that calves between 0 and 3 months do not emit CH_4, as they are milk fed; therefore, we have applied a correction factor of 9/12 to the CH_4 emission factor (28.21 kg CH_4/head per year), which considered only the time between 3 months and 1 year. A weighted CH_4 emission factor for the other buffalo categories has been estimated with emission factors from calves and sub-adult buffaloes and the number of animals. The CH_4 emission factor for other buffaloes was estimated to be 56 kg CH_4/head per year, corresponding to an average weight of 313 kg.

Methane emission factor for the buffalo category
In this study, a weighted enteric CH_4 emission factor of 56 kg/head per year was estimated for the other buffalo category (Table 3). This value was considered to be constant throughout the period of study (1990–2004), which may not be entirely reliable as animals LW and feeding characteristics have likely increased over this period. Daily gross energy intakes of 71.7 and 186.6 MJ were estimated for calves and sub-adult sub-categories, respectively. These feed intakes resulted in enteric CH_4 factors of 21.2 and 73.4 kg/head per year for calves and sub-adult buffaloes, respectively. The emission factor for calves (21.2 kg) assumes that 0 to 3-month-old calves do not emit CH_4.

In this study, buffalo cows had an estimated mean enteric CH_4 emission factor of 73 kg/head per year (year 2004),

Table 3 *Population, production characteristics and estimated enteric methane emission factors for the Italian Mediterranean buffalo for the period 1990–2004*

	Buffalo cows				Other buffaloes*		All buffaloes
Year	Population (1000)	Milk production (kg/head per day)	GE intake (MJ/head per year)	CH_4 emission factor (kg CH_4/head per year)	Population (1000)	CH_4 emission factor (kg CH_4/head per year)	CH_4 emission factor (kg CH_4/head per year)
1990	61.80	1.91	164.49	64.73	32.70	56.00	61.71
1991	52.30	2.35	170.33	67.03	31.00	56.00	62.93
1992	65.80	2.15	167.92	66.08	37.40	56.00	62.43
1993	63.30	3.05	180.85	71.17	37.60	56.00	65.52
1994	67.60	3.20	181.23	71.32	40.70	56.00	65.56
1995	93.53	2.36	171.29	67.41	54.88	56.00	63.19
1996	107.43	2.16	168.33	66.24	64.12	56.00	62.41
1997	100.79	2.31	170.31	67.02	60.70	56.00	62.88
1998	119.68	2.01	165.84	65.26	66.60	56.00	61.95
1999	130.30	2.80	176.93	69.63	70.18	56.00	64.86
2000	116.00	3.19	183.04	72.03	76.00	56.00	65.69
2001	161.05	3.00	179.60	70.68	32.73	56.00	68.20
2002	160.96	2.50	172.70	67.96	24.48	56.00	66.38
2003	165.88	2.83	177.00	69.66	56.39	56.00	66.19
2004	154.17	3.37	184.95	72.78	56.02	56.00	68.31

GE = gross energy.
*Other buffaloes include two sub-categories (calves and sub-adult buffaloes).

whereas the corresponding value for the other buffalo categories was a constant estimate of 56 kg/head per year, hence resulting in the estimated weighted value of the CH_4 emission factor for the Italian Mediterranean buffalo of 68 kg/head per year (year 2004). The estimated CH_4 emission factor for the other buffalo categories obtained in this study is comparable with the default value (55 kg/head per year) suggested by IPCC (2006) for animals with an average BW of 300 kg.

Assuming a CH_4 yield of 7.5% of GE intake, Gibbs and Johnson (1993) reported enteric CH_4 emission factors of 54.9 to 77.1, 44.6 to 67.2 and 23.0 to 49.6 kg/year for adult male buffalo (350 to 550 kg BW), buffalo cow (250 to 450 kg BW) and young buffalo (100 to 300 kg BW), respectively. In turn, Crutzen *et al*. (1986), by assuming a CH_4 yield of 9% of GE intake by grazing buffaloes, reported a CH_4 emission factor of 50 kg/year.

The enteric CH_4 emission factor for buffalo based on research evidence is lacking. Hence, it is not possible to state how accurate the estimations of country-specific emission factors found in the present study are. Although our approach of considering constant BW and CH_4 energy yield over the study period (1990–2004) for the buffalo categories (cows and other buffaloes) seems simplified, the CH_4 emission factors for the recent years may prove reliable as recent data become more scrutinised and the default CH_4 yield (% GEI) is well supported by research findings with cattle fed on mixed diets (IPCC, 2006).

Conclusions

This paper represents a first attempt to estimate a country-specific enteric CH_4 emission factor for the Italian Mediterranean buffalo. Following, the Tier 2 approach of the IPCC (2000) guidelines, we have estimated emission factors for buffalo cows (73 kg CH_4/head per year) and other buffalo (56 kg CH_4/head per year) categories, which may be useful in preparing national emission inventories.

Specific research-based CH_4 conversion factors at the predominant buffalo production system are needed in order to increase the accuracy of the emission factors.

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Annex I Equations used for estimating the Gross Energy Intake for buffalo cow (IPCC, 2000)

Equation (1):

$$\mathrm{GE} = \left[\frac{\mathrm{NE}_m + \mathrm{NE}_a + \mathrm{NE}_l + \mathrm{NE}_w + \mathrm{NE}_p}{\mathrm{NE}_{ma}/\mathrm{DE}} + \frac{\mathrm{NE}_g}{\mathrm{NE}_{ga}/\mathrm{DE}}\right] \Big/ (\mathrm{DE}/100), \tag{1}$$

where

GE = gross energy intake (MJ/day)
NE_m = net energy required by the animal for maintenance (MJ/day)
NE_a = net energy for animal activity (MJ/day)
NE_l = net energy for lactation (MJ/day)
NE_w = net energy for work (MJ/day)
NE_p = net energy required for pregnancy (MJ/day)
NE_g = net energy needed for growth (MJ/day)
$\mathrm{NE}_{ma}/\mathrm{DE}$ = ratio of net energy available in a diet for maintenance to digestible energy consumed
$\mathrm{NE}_{ga}/\mathrm{DE}$ = ratio of net energy available for growth to digestible energy consumed
DE = digestible energy expressed as a percentage of gross energy.

Net energy required by the animal for maintenance (MJ/day):

$$\mathrm{NE}_m = Cf_i \cdot (\mathrm{Weight})^{0.75},$$

Cf_i = is the maintenance requirement per unit of metabolic size.

Net energy for animal activity (MJ/day):

$$\mathrm{NE}_a = C_a \times \mathrm{NE}_m,$$

C_a = maintenance requirement for activity depending on the animal situation (grazing, stall, pasture).

Net energy needed for growth (MJ/day):

$$\mathrm{NE}_g = 4.18 \cdot \{0.0635 \cdot [0.891 \cdot (\mathrm{BW} \cdot 0.96) \cdot (478/(C \cdot \mathrm{MW}))]^{0.75} \cdot (\mathrm{WG} \cdot 0.92)^{1.097}\},$$

BW = the live body weight (BW) of the animal (kg)
C = a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls
MW = the mature body weight of an adult animal (kg)
WG = the daily weight gain (kg/day).

Net energy for lactation (MJ/day):

NE_l = kg of milk per day (1.47 + 0.40 · % fat content of milk).

Net energy for work (MJ/day):

$$\mathrm{NE}_w = 0.10 \cdot \mathrm{NE}_m \cdot \text{hours of work per day}.$$

Net energy required for pregnancy (MJ/day):

$$\mathrm{NE}_p = C_\mathrm{p} \cdot \mathrm{NE}_m$$

C_p = maintenance requirement for pregnancy based on the energy required for the gestation.

Ratio of net energy available in a diet for maintenance to digestible energy consumed:

$$NE_{ma}/DE = 1.123 - (4.092 \cdot 10^{-3} \cdot DE) + (1.126 \cdot 10^{-5} \cdot (DE)^2) - (25.4/DE).$$

Ratio of net energy available for growth in a diet digestible energy consumed:

$$NE_{ga}/DE = 1.164 - (5.160 \cdot 10^{-3} \cdot DE) + (1.308 \cdot 10^{-5} \cdot (DE)^2) - (37.4/DE).$$

Equation (2):

$$EF = \left[\frac{GE \cdot (Y_m/100) \cdot 365\ \text{days/year}}{55.65\ \text{MJ/kg}\ CH_4}\right], \quad (2)$$

where
EF = CH_4 emission factor (kg CH_4/head per year)
Y_m = CH_4 conversion rate, which is the fraction of gross energy in feed converted to CH_4 (CH_4 yield).