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Methane conversion factors from cattle manure in México

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RESUMEN

Los factores de emisión de metano de diferentes sistemas de manejo de excretas, incluyendo la simulación de la fermentación en un sistema de lechada, fueron determinados experimentalmente en este trabajo y en otro anterior (González-Avalos y Ruiz-Suárez, 2001). Al combinar ambos, se obtuvieron valores para la producción máxima de metano (B_0) provenientes de excretas producidas por ganado bovino de diferentes sistemas de producción y climas, lo cual implica diversas calidades de alimento y factores de conversión de metano (MCF) dependiendo de los sistemas de manejo de excretas. Este conjunto de datos tiene la misma funcionalidad que los de la metodología actual del IPCC, pero ofrece un conjunto de parámetros más amplio para estimar las emisiones de metano por excretas, lo cual puede ser de interés en otros países. En este trabajo se reporta que los MCF pueden ser hasta 17.3 veces más pequeños que los sugeridos en las Directrices de la Metodología Revisada del IPCC de 1996 (IPCC, 1997) y en la Guía de Buenas Prácticas (IPCC, 2000).

ABSTRACT

Methane emission factors from different cattle manure management systems including simulated slurry system fermentation were experimentally determined in this and a previous study (González-Avalos and Ruiz-Suárez, 2001). Combining results from both studies, we report values for maximum CH_4 yield, called B_0, for manure produced by cattle under different production systems and climates, which also implies different quality of feeds and associated methane conversion factors (MCF) for distinct manure management systems. This set of data has the same functionality than that of the current IPCC methodology, but offer a wider set of key parameters to estimate methane emissions from manure, which may be of interest in other countries. In this work, we report MCF can be up to 17.3 times smaller than those suggested in the 1996 Revised IPCC Methodology Guidelines (IPCC, 1997) and Good Practice Guidance (IPCC, 2000).

Keywords: Methane, methane emissions, methane conversion factors, cattle manure, manure fermentation, México.

1. Introduction

Methane emissions from cattle manure management systems are often found as a key source in many national greenhouse gas (GHG) emissions inventories (UNFCCC, 2000). To reduce uncertainty on such estimates it is advisable to use locally determined emission factors (IPCC, 2000). Current default values in the 1996 IPCC Methodology Guidelines (IPCC, 1997) are based in a much reduced set of experiments under conditions very different to those found in tropical and subtropical regions (Steed and Hashimoto, 1994). In addition, feed rations and feeding conditions were very different to those found in many other countries, particularly in developing ones. To reduce the uncertainty in the Mexican National Greenhouse Emissions Inventory (González and Ruiz, 1995), methane emission factors (MEF) were experimentally determined under a wide variety of conditions (González-Avalos and Ruiz-Suárez, 2001). Those experiments simulated drying and fermentation conditions of manure in three climates (cool, temperate and warm), from animals in intensive, semi-intensive and extensive production systems. Manure was obtained under actual management practices from dairy, beef and dual purpose cattle, from three manure management systems (MMS): storage, consisting of piles outside the stable for spreading later in agricultural fields as fertilizer; corral, handling of manure associated to beef cattle production systems where the manure stands in the corral until is dried; and grazing system, where animal manure stands on grassland where livestock is grazing. Samples were collected from sixty production units within a radius of 250 km around México City. Because of the complex terrain in the central part of México, samples were collected from a wide range of sites in cool, temperate and warm climates. For example, some samples were collected at 3000 m above sea level, in the Angangueo region, in the state of Michoacán, México. This region has a semi-humid season and an average temperature of 10 °C during winter. Other manure samples were collected from places down to 1000 m of altitude, in the humid region of Puente de Ixtla, in the state of Morelos, with temperatures up to 40 °C during the spring and summer seasons.

Results showed that for manure from the same production systems, having equal MMS, temperature was the most important factor driving methane production rate, whereas total methane production was determined by the moisture content of the manure. For animal manure from different production systems, type of cattle diet had the greatest effect on the amount of methane generated. The MEF obtained were smaller, on the average, by at least a factor of five than those proposed by the IPCC for Latin America. Those values were reported as part of the 2nd National Communication to the UNFCCC (INE, 2001), and were used in the 1994-1998 National Inventory of Greenhouse Gas (INE, 2002). However, because of the form they were published by González-Avalos and Ruiz-Suárez (2001) as MEF, they are of little use for the wide community of GHG inventories makers as in that form they were country specific. Methane conversion factors (MCF) and the maximum methane producing capacity (B_0) as given by equation (1) (Eq. 4.17 in IPCC, 2000) are more useful to those seeking data that can be applied to estimate emissions under similar conditions of climate regions, feeding practices, production systems and MMS.

$$EF_i = VS_i \cdot 365 \text{ days/year} \cdot B_{0i} \cdot 0.67 \text{ kh/m}^3 \cdot \Sigma_{jk}\, MCF_{jk} \cdot MS_{ijk} \quad (1)$$

where:

EF_i = annual emission factor for a defined livestock population *i*, in kg

VS_i = daily volatile solids excreted by an animal within a defined population *i*, in kg

B_{0i} = maximum CH_4 producing capacity for manure yielded by an animal within a defined population *i*, m^3/kg of VS

MCF_{jk} = CH_4 conversion factors for each manure management system *j* by climate region *k*

MS_{ijk} = fraction of animal species/category *i's* manure handled using manure system *j* in climate region *k*

However, the maximum methane production capacity B_{0i} is obtained in anaerobic lagoons, followed by slurry manure management systems (SMMS) (IPCC, 1997, 2000), and both management systems for cattle manure are almost non-existent in México (González-Avalos and Ruiz-Suárez, 2001). One reason for that is climate. The production system most likely able to benefit from SMMS is milk production under intensive systems. Such production systems are located in the central part of México, near the largest consumption centers of the country (México City and few other metropolitan areas). In consequence, cool and temperate climates driven by the high altitude of this region make it less suitable to get the best use of SMMS. This particular MMS was not investigated in our former paper (González-Avalos and Ruiz-Suárez, 2001). Nevertheless our experimental setup was also able to mimic such conditions. Therefore, to make our results more widely useful to other GHG emissions inventory practitioners, here we report some additional experiments conducted to simulate manure fermentation under SMMS conditions for the different types of manure found in the former study. With these data and those in the last cited paper, a set of B_0 and MCF that encompass a wide range of feeding practices were calculated.

2. Methods

In central México, regions with high livestock production have temperatures up to 35 °C. In relation to the aforesaid fact, in González-Avalos and Ruiz-Suárez, (2001) paper MEF from cattle manure dried and fermented at 35 °C were reported for MMS in corral, storage, and grazing, from intensive, semi-intensive, and extensive cattle production systems, except for SMMS. In such a case, results showed that the MEF had the highest values at 35 °C. Because of that, cattle manure must be fermented at 35 °C simulating SMMS, in order to compare with those MEF values obtained for the others MMS at the same temperature.

To complete the data set above mentioned and make it suitable to obtain B_0 and MCF, fresh manure samples were collected from cattle production systems in a given climate (temperate or warm regions), as shown in Table I. Samples were kept on ice during the trip to the laboratory. Manure samples from each production system and climate, were all mixed and homogenized in equal quantities, in order to minimize the effect of local agricultural production on methane emissions. To mimic SMMS, 100 g of fresh manure per sample, plus two replicates, were mixed with 100 ml of chlorine-free water and fermented at 35 °C. Samples fermentation was conducted using a system of nine cylindrical bioreactors, placed in a constant temperature bath. Each bioreactor was built with aluminum tubes of 6.4 mm thick, 10.16 cm inner diameter, and 25.0 cm height. Methane analysis was done by GC/FID (Pye Unicam series 204; Cambridge, UK). Details on experimental device for fermentation, gas production, and analyses procedures are described elsewhere (González-Avalos and Ruiz-Suárez, 2001).

Table I. Cattle feedstuffs from different production systems in temperate and warm climates.

System and climate	Feed composition
IBT	Milled corn, soya paste, citrus peels, milled sorghum, corn silage, molasses, oat forage, sorghum forage, barley roughage, sorghum silage, fresh alfalfa, and high rich pasture
IBT-SF	Milled corn, soya paste, citrus peels, milled sorghum, corn silage, and molasses. Diminished ratio of oat forage, sorghum forage, and barley roughage. Double ration of sorghum silage, fresh alfalfa and high rich pasture.
IBW	Husk of groundnut, milled corn, molasses, milled sorghum, wheat meal, chopped roughage corn and minerals
IMT	Citrus peels, cottonseed, corn silage, molasses, fresh alfalfa, pre-wilted alfalfa, rich pasture, granulated feed concentrates and minerals
S-IMT	Rich pasture, green native grass, corn silage, milled corn roughage, oat straw and feed concentrate
EDPT	Native grass, corn roughage, barley straw and oat straw

I = Intensive, SI = Semi-intensive, E = Extensive, M = Milk, B = Beef, DP = Dual purpose, SF = Special Feed, T = Temperate, W = Warm.

Methane emission factors (kg per head per year), as required by the IPCC, for each production system in each climate, were obtained using equation 2:

$$\frac{kg\,CH_4}{head \bullet year} = \frac{kg\,CH_4}{kg\ fresh\,manure\,DM} \bullet \frac{kg\ fresh\,manure}{head \bullet day} \bullet \frac{\%\,DM}{100} \bullet 365\ \frac{day}{year} \qquad (2)$$

Manure dry matter (DM) and the ashes or fixed solids (FS) were determined for the collected fresh samples, by mean of a proximate chemical analysis, following the Official Methods of Analysis of the Association of Official Agricultural Chemists (AOAC, 1990), in the Laboratory of Chemical Analysis for Foods (SARH 0950693) at the Veterinary and Zootechnics School, National Autonomous University of México (UNAM). Volatile solids (VS) in equation 1 are defined as a fraction of total solids in manure loss upon ignition at 550 °C. Therefore, VS = DM – FS.

Values for maximum CH_4 yield are obtained using equation 3:

$$CH_4\ emissions = \frac{\dfrac{\rho_{CH_4}}{M_{CH_4}}}{VS} = \frac{v_{CH_4}\left[m^3\right]}{VS[kg]} \qquad (3)$$

where:

ρ_{CH_4} = Methane density

M_{CH_4} = Methane mass

ν_{CH_4} = Methane volume

Methane density was determined experimentally from a fixed volume of dm^3. Mass of produced methane was obtained experimentally per each fermentation trial of cattle manure for each production system and climate.

B_0 from fermentation in SMMS can be obtained as defined in equation 1, knowing that the emissions from SMMS at 35 °C are 80% of the respective B_0 (Steed and Hashimoto, 1994; IPCC, 1997). MCF can be also obtained in a straightforward manner from these values for each production system and the actually measured emission factors for those production systems but with a wider set of MMS and climates (González-Avalos and Ruiz-Suárez, 2001).

3. Results and discussion

3.1. Methane emission factors from slurry manure management systems

Methane emission factors for several MMS in México, except for SMMS, were reported by González-Avalos and Ruiz-Suárez (2001). In this work, cattle feed from different production systems in temperate and warm climates are described in Table I. Feed composition described in such a table shows that the quality of food decreases from the intensive systems to the extensive ones, and that cattle feed varies as a function of climate.

MEF from cattle manure fermented in a simulated SMMS, for cattle production systems and climates described in Table I, are shown in Table II. It can be seen that values range from 0.57 kg CH_4 /head • year for EDP systems to 7.05 kg CH_4 /head • year for IMT systems, pointing out the key role of diet composition.

Table II. Methane emission factors, in kg CH_4 / head • year, from cattle manure fermented in a simulated slurry manure management system (SMMS).

Type	Intense dairy cattle (IM)	Semi-intensive dairy cattle (S-IM)	Intensive beef cattle (IB)	Extensive DP cattle (EDP)
T - 35 °C	7.05 ± 4.08%	0.79 ± 5.12%	1.07 ± 7.62%	0.57 ± 8.37%
T - 35 °C (SF)[a]	ND	ND	1.71 ± 6.03	ND
W - 35°C[b]	ND	ND	0.76 ± 6.80	ND

T = Temperate, W = Warm, SF = Special feed, DP = Dual pupose, ND = No data.

[a] Manure was collected from temperate climates.

[b] Manure was collected from warm climates.

3.2 Methane emissions

Although manure fermentation periods in a simulated SMMS are in general longer than 17 days, in order to compare methane production from this MMS with any others MMS, methane production from SMMS was measured during such a period because, in agreement with the amount of manure mass fermented in slurry (100 g), that was the longest period of time for almost total manure fermentation, with the highest values of methane, produced from any MMS, including SMMS.

Cumulative daily methane production for the simulated SMMS fermentation for samples taken from the different production systems and climates are shown in Figure 1. All samples were fermented at 35 °C during 17 days. IMT systems yielded the highest amount of methane, up to 4.9 mg CH_4 / mg VS, followed by IBT-SF systems, yielding 36.4% of the former one.

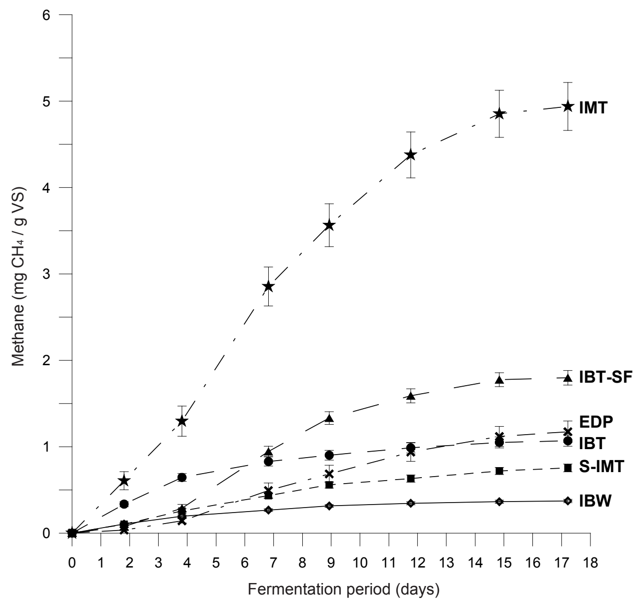

Fig. 1. Methane emitted from cattle manure fermented in slurry management system at 35 °C. Manure samples were collected from several cattle production systems; IB, intensive beef cattle, IB-SF, intensive beef cattle with special feed; IM, intensive cattle; S-IM, semi-intensive cattle; EDP, extensive dual propose cattle. Manure samples were taken from two climates: T, temperate; W, warm. If error bars were too small, they are not shown.

The volume values of methane production per kg of VS, calculated using equation 3, are shown in Table III. The upper part shows methane emissions for different production systems, MMS and climates estimated from samples took under actual production conditions. The lower part of Table III shows the experimental results of the production of methane under the simulated SMMS conditions from the same kind of samples.

By comparison, the IPCC (1996) B_0 values for intensive dairy cattle are for Latin America (LA) 0.13 m^3 CH_4 / VS, and for the United States of America (USA) 0.24 m^3 CH_4 / VS. In this work we obtained 0.188 m^3 CH_4 / VS for the same production system, which is 44.6% greater than the IPCC value for LA, and 27.6% smaller than the value proposed for the USA. This means that the values obtained for central México in this work are consistent with those of the IPCC, because dairy cattle feedstuffs in México are, in general, of better quality than the average in LA, and cattle feed in USA are commonly much better than those in México. As for intensive beef cattle, in this study the value 0.064 m^3 CH_4 / VS is 34% lower than the recommended value for LA by the IPCC.

Table III. Methane emissions from manure collected in different production systems and climates.

Type	Intensive dairy cattle (IM)[s]	Semi-intensive dairy cattle (S-IM)[sg]	Intensive beef cattle (IB)[c]	Extensive DP cattle (EDP)[g]
	Methane emissions from manure collected in drying process x (m^3 CH_4 / kg VS)			
C - 12 °C	$4.27 \times 10^{-4} \pm 1.62\%$	$1.26 \times 10^{-4} \pm 3.13\%$	$6.34 \times 10^{-5} \pm 3.46\%$	$1.08 \times 10^{-5} \pm 2.74\%$
T – 17 °C	$5.68 \times 10^{-4} \pm 1.78$	$1.61 \times 10^{-3} \pm 1.78$	$2.12 \times 10^{-3} \pm 3.08$	$2.78 \times 10^{-4} \pm 2.66$
T – 21 °C	$4.45 \times 10^{-4} \pm 1.29$	$6.53 \times 10^{-4} \pm 0.78$	ND	$7.17 \times 10^{-4} \pm 0.69$
T – 22 °C	$1.43 \times 10^{-3} \pm 2.38$	$1.29 \times 10^{-3} \pm 2.94$	$6.58 \times 10^{-3} \pm 2.39$	$5.92 \times 10^{-4} \pm 1.03$
T - 27 °C	$2.25 \times 10^{-3} \pm 0.80$	$4.65 \times 10^{-3} \pm 3.31$	$1.35 \times 10^{-2} \pm 1.06$	ND
W - 27 °C	$1.12 \times 10^{-3} \pm 2.13$	ND	$1.97 \times 10^{-4} \pm 1.59$	$2.66 \times 10^{-3} \pm 1.35$
T – 35 °C	$4.00 \times 10^{-3} \pm 2.18$	$2.89 \times 10^{-3} \pm 0.62$	$1.36 \times 10^{-3} \pm 3.36$	ND
W - 35 °C	ND	$1.91 \times 10^{-3} \pm 1.65$	$2.35 \times 10^{-3} \pm 0.23$	$2.73 \times 10^{-2} \pm 2.26$
			$3.29 \times 10^{-3} \pm 0.89$[Y]	
	Methane emissions from SMMS conditions[z] (m^3 CH_4 / kg VS)			
T – 35 °C	$1.69 \times 10^{-1} \pm 2.82\%$	$3.30 \times 10^{-2} \pm 2.93\%$	$3.65 \times 10^{-2} \pm 2.92\%$	$4.01 \times 10^{-2} \pm 5.24\%$
T – 35 °C (SF)			$5.80 \times 10^{-2} \pm 2.31\%$	
W – 35 °C	ND	ND	$1.27 \times 10^{-2} \pm 2.61\%$	ND

C = Cool, T = Temperate, W = Warm, s = storage, c = corral, g = grazing, SF = Special feed, DP = Dual purpose, ND = No data, SMMS = Slurry manure management systems.

x Methane emissions obtained from methane emission factors in Table V of González-Avalos and Ruiz-Suárez (2001).

[Y] This value is from semi-intensive beef cattle in warm climates.

[Z] Methane emissions correspond to methane emission factors in Table II.

3.3. Methane conversion factors

Methane conversion factors (MCF) as percentages, for different production systems, climates, and MMS are shown in Table IV. For all production systems considered in this work, MCF for SMMS are considered to be 80% of B_0. For all other MMS, the MCF are derived from actual MEF. In Table V, the MCF values determined in the present work are compared with those proposed by IPCC (1997). IPCC values for storage and grazing are about 3.5 and 17.3 times larger than the values in the present work. Whereas for corral MCF, this work yields a value that is about 4.1 times larger than the IPCC one. To produce Table V, some categories in Table IV were averaged, *i.e*. EDP in W-27 ºC and W-35 ºC were averaged to compare with IPCC value for warm climates.

Table IV. Methane conversion factors from manure collected in different production systems and climates.

Type	Intensive dairy cattle (IM)[s]	Semi-intensive dairy cattle (S-IM)[sg]	Intensive beef cattle (IB)[c]	Extensive DP cattle (EDP)[g]
	Methane conversion factors from manure in drying process x (%)			
C - 12 °C	0.20	0.30	0.09	0.02
T - 17 °C	0.27	3.91	2.92	0.55
T - 21 °C	0.21	1.58	ND	1.43
T - 22 °C	0.68	3.14	9.08	1.18
T - 27 °C	1.07	11.28	18.57	ND
W - 27 °C	0.53	ND	0.28	5.32
T - 35 °C	1.89	7.01	1.88	ND
W - 35 °C	ND	4.63	3.24	5.45
			4.54*	
	Methane conversion factors from SMMS conditions (%)			
T - 35 °C	80.00	80.00	56.68	80.00
T - 35 °C (SF)			80.00	
W - 35 °C	ND	ND	19.72	ND

C = Cool, T = Temperate, W = Warm, s = storage, c = corral; g = grazing, SF = Special feed, DP = Dual purpose, ND = No data, SMMS = Slurry manure management systems.

* This value is from semi-intensive beef cattle in warm climates.

Table V. Comparison of methane conversion factors from IPCC (1997) and this work, in %.

Climate	Slurry			Storage		Corral		Grazing	
	IPCC	This work		IPCC	This work	IPCC	This work	IPCC	This work
	M B	M	B	M B	M[a]	M B	B[a]	M B	DP[a]
Cool	65	80	80	1	0.20	1	0.09	1	0.02
Temperate	65	80	80	1.5	0.39	1.5	6.00	1.5	1.05
Warm	65	80	80	2	1.16	5	5.70	2	5.38

M = Milk, B = Beef, DP = Dual purpose.

[a] Cells in "this work" columns are produced by averaging corresponding cells in Table IV. *i. e*. value in (warm, grazing this work) is made of the average of cells W–27 °C, EDP and W–35 °C, EDP in Table IV.

4. Conclusions

B_0 and MCF for a wide range of cattle production systems and climate conditions in the central part of México are reported. Although slurry manure management system fermentation is not commonly used in México for different reasons, including climate and lack of economic driving forces, it was experimentally simulated to yield the reference B_0 needed to apply IPCC methodologies. Methane Emission Factors for different MMS were experimentally determined from a large set of samples collected under actual production conditions from a large number of production units applying different production practices. Combining these B_0 and MEF, MCF were obtained to report the basic data needed to apply IPCC methodologies. In comparison to current IPCC data, these can be different up to one order of magnitude. In addition, these results offer a wider option of reference data with larger resolution on production systems and climates, that may be of interest to GHG emissions inventories practitioners in countries sharing some features such as climate, economic development and production practices in the cattle raising and dairy production industries.

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