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Article

Estimation of enteric methane production in family-run dairy farms in the south of the State of Querétaro, Mexico

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Abstract:

The objective was to estimate the emission factor (EF) of methane (CH_4) and the daily losses of gross energy (GE) converted to CH_4 (LCH_4), by means of prediction equations of the Level 2 method of the Intergovermental Panel of Climate Change (IPCC) or based on technical information from the family-run dairy farming system. The study was carried out in 10 farms, obtaining technical information on the type and quantity of the ingredients offered to the herd during three visits in different periods of the year. The technical information —body weight, milk production and amount of each ingredient consumed, together with laboratory analysis of dry matter (DM) and GE content of the sampled ingredients— was used to calculate the DM and GE intake; the EF and the PCH_4 were estimated using the IPCC methodology. The same variables were estimated using the prediction equations of the IPCC. In cows in milking conditions, the EF (81 and 70, kg CH_4 yr^{-1}) and the LCH_4 (2.95 and 2.56, Mcal d^{-1}) obtained using the IPCC equations were similar to those obtained through the observations in the farms; the weighted EF per farm was similar (49.06 and 54.09, kg CH_4 yr^{-1}), but the LCH_4 estimated using the IPCC equations was lower than that obtained through farm observations (1.11 and 1.97, Mcal d^{-1}; $P<0.01$, respectively). In general, the use of technical information from the farms, made it possible to estimate the EF and to show a higher LCH_4 per farm, and, consequently, a lower energetic efficiency, compared to the IPCC methodology.

Key words: Stable, Subsistence production, Ruminal fermentation, Environmental contamination, Energy loss.

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Introduction

Dairy farming is very important for meeting the demand for high quality food for human consumption; however, it also contributes to the emission of greenhouse gases (GHGs) such as methane (CH_4), which is produced by enteric fermentation and is eliminated mostly through the burp[1,2]. CH_4 is one of the main GHGs emitted by the systems of production of bovine cattle, which has been associated with the global warming and climate change, as evidenced by comparison with the pre-industrial era[1,2]. The issued CH_4 also contributes to the energy leaks in the livestock production systems, as it amounts to the loss of 6 to 12% of the total gross energy (GE) consumed by the dairy producing livestock[2].

An important reference for estimating the CH_4 production is the methodology proposed by the Intergovernmental Panel on Climate Change (IPCC)[3]. This methodology is used in different countries in order to generate the inventories of GHGs, and applies the corresponding procedures depending on the information available at levels 1, 2 and 3. Level 1 (Tier 1) is applied to Mexico and other developing countries; it is based on the use of an emission factor (EF) of CH_4 yr^{-1} $animal^{-1}$ that is multiplied by the national inventory within each category of livestock. A criticism made to this methodology is that it employs an EF that in many situations does not represent the reality of the particular conditions of production, particularly with regard to the characteristics of the food consumed by the dairy cattle raised in different regions of the country, which varies according to the agro-ecological, environmental, economic and health characteristics[4.5].

CH_4 emissions have also been estimated for dairy cattle in Mexico, according to the methodology of Level 2, which requires calculating the requirement of GE and using a conversion factor of CH_4 by default, which on average is 6.5 %, amounting to the percentage of the GE of the food turned into CH_4. Based on this method, an EF of 166 and 182 kg CH_4 yr^{-1} has been estimated in primiparous and multiparous cows in milking conditions of herds registered at the Holstein Association of Mexico(6), and 115 kg CH_4 yr^{-1}, for the total dairy cattle of Mexico(7). The variability in the EF obtained in these studies is probably related to factors within each production system, such as the degree of technification, genetic capacity of animals for milk production and environmental influences. Due to the diversity of factors that may influence the EF, it is recommend having an EF for each type of system, and within these, an EF for each subtype, taking into account the particular characteristics of production and, in particular, the power schemes, including the type, concentration and quality of inputs used in the formulation of rations(3).

In Mexico, there are various dairy production systems, the most predominant of which is intensive production, characterized by the use of modern, efficient technologies at all stages of the production process(6). At the other extreme is the backyard or family-run production system, which contributes 10 % of the national milk production, and which is based mainly on traditional schemes of production and is characterized by a wide range of subsystems, and varying degrees of modernization and of productive efficiency(5,8,9). In general, the backyard dairy farming systems have been little studied, and EFs have not been generated for this category of dairy production; these are relevant for estimating the GHGs corrected for each type of system, for determining the degree of impact of this kind of farming on emissions and energy losses in the form of CH_4, and for designing and implementing strategies for the research, transfer of technologies and innovations to improve the sustainability of backyard dairy farming systems. Therefore, the aim of the present study was to estimate the EF and the PCH_4, using the predictor equations of the level 2 method of the IPCC and the technical information gathered on family-run dairy farming units.

Material and methods

The study was carried out at farms in the municipalities of El Marqués, Pedro Escobedo and San Juan del Río, in the state of Querétaro. All three municipalities are nestled in the Neovolcanic Axis, which is characterized by geomorphological contrasts between hills situated at an latitude between 2 and 3 thousand meters above sea level and valleys located at 800 to 900 m asl; temperate subhumid climates are prevalent in them, with a mean annual temperature of 17.3 ºC and a mean annual precipitation of 542.9 mm. Visits were made to 20 stables of the family system belonging to the Livestock Producer Groups for Technology

Validation and Transfer of the State of Querétaro, with low level of modernization and in the process of adopting new technologies. The owners were interviewed in order to obtain technical information; for this purpose, at least three visits per producer were carried out in different months of the year during the period from April to August.

The body weight of the adult animals was estimated based on the thoracic perimeter, and that of the young animals was estimated subjectively by the producers themselves; the milk production was calculated using a plastic bucket with a scale in liters. The data analysis included only 10 stables, since those participating farms that did not provide complete information or whose data were not considered to be reliable were discarded.

The structure of the herd was divided, according to the terminology used by the producers interviewed, as follows: lactating or milk-producing cows; gestating cows with a 210-270 days' pregnancy that were not being milked; heifers weighing 200-400 kg; calves weighing 100-200 kg; stud bulls, and young bulls in fattening. Table 1 shows the number of animals per category.

Table 1: Inventory of animals and milk production of lactating cows

	No.	Average±SD	Minimum	Maximum	CV
Inventory of animals					
Cows in milking condition	10	17.90±7.4	5	27	41.34
Pregnant cows	9	4.60±2.6	0	9	63.45
Heifers	8	6.50±5.42	0	18	83.4
Calves	9	6.70±4.88	0	17	72.8
Bulls	5	0.60±0.7	0	2	116.53
Young bulls in fattening	4	1.60±2.27	0	6	141.91
Total	10	39.10±19.73	5	55	50.45
Milk production of lactating cows					
Milk production, kg/d		8.90±3.84	3	14	43.36
Duration of the lactation, days		253.10±131.77	180	420	52.06
Milk production, kg/lactation		2130±1620.2	669	5546	76.08
Milk production, kg/yr		3231±1401.2	1253	5263	43.36

No.= number of farms that had animals in each category; SD= standard deviation; CV= coefficient of variation.

Samples of the food ingredients were obtained from all the stables, and the type and amount of the ingredients offered to the animals in the different phases of production were recorded. With this information, it was calculated the levels of inclusion of each ingredient in kilograms of fresh matter for each category of animals. Table 2 lists the food ingredients utilized and the number of samples taken. In the laboratory, the ingredients were dried in a forced air oven at a temperature of 55°C for a period of 24 to 72 h, depending on the moisture content, and ground with a Wiley type mill through a 2 mm sieve. The content of dry matter (DM) was determined in accordance with the AOAC official method 930.15[10], while the GE content was determined by combustion of the samples in an adiabatic calorimetric bomb.

Table 2: List of food ingredients, number of samples, dry matter content and of gross energy content in a dry base

Ingredients	No.	Dry matter, %	Gross energy Kcal/kg Average ± SD	Minimum	Maximum	CV
Concentrate	14	90.76	3927±288.53	3206	4649	7.35
Medicago sativa L., green forage	13	33.11	3602±298.76	2787	3824	8.29
Medicago sativa L., hay	14	84.69	3724±302.26	2963	4090	8.12
Zea mayz, grain	15	92.80	4068±669.22	2395	5741	16.45
Zea mayz, ensiled	15	32.46	3694±181.81	3239	4148	4.92
Zea mayz, stubble	15	92.12	3713±311.79	2933	4492	8.40
Avena sativa, hay	9	92.32	3790±236.74	3198	4382	6.25
Lolium perenne, green forage	1	91.87	4412±0	4412	4412	0
Brassica oleracea, green forage	1	21.85	3407±0	3407	3407	0
Mixture of pasture, hay	4	74.34	3787±321.74	3020	4554	8.49
Chicken droppings	5	77.12	3375±769.33	1452	5298	22.79

Number of samples analyzed; SD= standard deviation; C= coefficient of variation.

Estimation of the CH_4 using the information of the production units

DM consumption (DMC) and of GE (GEC) animal^{-1} d^{-1} was estimated based on the consumption of each ingredient and the laboratory results for DM and GE. The interviewed owners provided the total amount of each ingredient offered on a wet basis to each category of animals in the herd. This value was divided by the number of animals per category in order to estimate the average consumption in kilograms per animal. The EF was calculated for each category of animal, using equation (1) recommended for level 2[3]:

$$EF = \langle GEC * (|Ym/100| * 365)\rangle / 55.65$$

Where: EF= Emission Factor, kg CH_4 head^{-1} yr^{-1}; GEC= Gross energy consumption MJ head^{-1} yr^{-1}; Ym= CH_4 conversion factor as a percentage of the gross energy of the food converted into CH_4 (6.5 %).
The factor 55.65 (MJ/kg of CH_4) is the energy content of CH_4.

Estimation of the CH_4 production using the IPCC methodology

Based on the technical information recorded in each production unit, such as body weight, milk production and weight gain, and on the use of predictor equations[3], the following variables were obtained:

Net energy for maintenance (equation 2: ENm)[11]:

$$ENm = Cfi * (Body\ weight)^{0.75}$$

Where: ENm= EN required by the animal for its maintenance, MJ day^{-1}; Cfi= a coefficient that varies for each category of animals: lactating cows = 0,386; non-lactating cows = 0,322; other bovines and bulls = 0,370 MJ day^{-1} kg-^{1}[12].
Body weight = Weight of live animal, kg.

Net energy for growth (equation 3: ENg)[12]:

$$ENg = 22.02 * [PCm/(C * PChm)^{0.75}] * GDP^{1.097}$$

Where: ENg= EN for growth, MJ day^{-1}; MBW= mean body weight of the animals of the population, kg; C= coefficient with a value of 0.8 to for females, 1.0 for oxen, and 1.2 for bulls; BWmf= body weight a mature female in moderate body condition, kg; ADG= average daily gain of the animals of the population, kg d^{-1}.

Net energy for lactation (equation 4: ENl)[13]:

$$ENl\ Milk * (1.47 + 0.40 * Fat)$$

Where: ENl= EN for lactation, MJ d^{-1}; Milk= Amount of milk produced, kg milk d^{-1}; Fat= fat content of milk, %. The fat content in milk is taken from a previous work that analyzed the chemical composition of milk from stables of the family-run farming system in municipalities in the state of Querétaro[14].

Net energy for pregnancy (equation 5: ENp):

$$ENp = Cpregnancy*ENm$$

Where: ENp= EN for pregnancy, MJ d^{-1}; Cpregnancy= coefficient of pregnancy. For cows, it is 0.10.
ENm= EN required by the animal for their maintenance, MJ d^{-1}.

The relationship between the available EN in the diet for maintenance and the digestible energy (DE) consumed was estimated with equation 6[15]:

$$\mathrm{REM} = [1.123 - (4.092 * 10^{-3}) + \{1.126 * 10^{-5} * (\mathrm{DE\%}^2)\} - (25.4/\mathrm{DE\%})]$$

Where: REM= relationship between available EN in a diet for maintaining and DE consumed DE%= DE expressed as a percentage of the GE.

The relationship between the available EN in a diet for growth and DE consumed was estimated with equation 7[14]:

$$\mathrm{REG} = [1.164 - (5.160 * 10^{-3} * \mathrm{DE\%}) + \{1.308 * 10^{-5} * (\mathrm{DE\%})^2\} - (37.4/\mathrm{DE\%})]$$

Where: REG= relationship between the EN available in the diet for growth and DE consumed DE%= DE expressed as a percentage of the gross energy.

The requirement of GE was derived on the basis of the sum of the requirements of EN and the characteristics of availability of energy from food. For lactating cows were used the requirements of: ENm, ENl and ENg; in gestating cows: ENm, ENp and ENg; and, in growing animals: ENm and ENg. The general equation (8) was the following:

$$\mathrm{GE} = [\{(\mathrm{ENm} + \mathrm{ENl} + \mathrm{ENp})/\mathrm{REM}\} + (\mathrm{ENg}/\mathrm{REG})]/(\mathrm{DE\%}/100)$$

Where: GE= gross energy, MJ d^{-1}; ENm= EN required by the animal for their maintenance, MJ d^{-1}; ENl= IN for lactation, MJ d^{-1}; ENp= EN required for pregnancy, MJ d-^{1}; REM= relationship between available EN in a diet for maintaining and DE consumed; ENg= EN for growth, MJ d^{-1}; REG= relationship between available EN in a diet for growth and the DE consumed; DE%= DE expressed as a percentage of the GE.

The estimated requirement of GE was utilized as the equivalent of the GEC in order to calculate the EF using the equation recommended for level 2, for each category of animals. The DMC per day was also estimated, by dividing the requirement of GE by the density of energy from food, using a default value of 6.45 MJ kg-1 of DM[3].

In addition to the estimation of the EF, we calculated the daily loss of GE in the form of CH_4 for each animal category using the equation 9:

$$\mathrm{PCH4} = [\mathrm{GE} * (\mathrm{Ym}/100)]/0.236$$

Where: PCH_4= daily loss of GE in the form of CH_4, Mcal $animal^{-1}$. The 0.236 factor was used to convert the energy values from MJ to Mcal.

Subsequently, the weighted averages of EF and PCH_4 were estimated for each farm, considering all phases of production. The weighted average of the loss of GE kg $milk^{-1}$ d^{-1} (ML) was also estimated using the equation 10:

$$\mathrm{ML\ PCH4\ Milk}^{-1}$$

Where: ML= loss of GE in the form of CH_4, Mcal kg $milk^{-1}$ d^{-1}; PCH_4= daily loss of GE in the form of CH_4, Mcal $animal^{-1}$ d^{-1}; Milk= milk production, kg d^{-1}.

The inventories of animals, milk production of lactating cows and the GE concentration of the ingredients were subjected the PROC MEANS procedure of SAS[16] in order to calculate the means and the minimum and maximum values. In addition, the coefficient of variation (CV) was estimated according to the following formula: CV= (standard deviation ÷ average) * 100. The results of DMC, GEC, EF, HCP_4 and ML using the equations of the IPCC were compared with the results of DMC, GEC, EF, HCP_4 and ML using the technical data of the farms with variance analyses and the GLM procedures of SAS[16]. It was used a completely random model with 10 repetitions per treatment. For these variables, the results tables show the means of the least-squares and the standard error of the mean. In the case of statistical significance, the differences between means were compared with the Minimum Significant Difference test.

Results and discussion

Table 1 shows the number of animals by category and milk production of cows in milking condition. The total number of cows in milking condition and pregnant cows averaged 22.5, and the heifers amounted to 13.2 animals, amounting to 57.5 and 33.8 % of the total number of animals; the young bulls added up to merely 4 and 1.5 % of the total herd, respectively. The total number of animals was 39.1, with a minimum of 5 and a maximum of 55. Due to the fact that cows in milking condition were found in all the farms, but bulls in fattening were found only in four, since the rest of the producers sold to intermediaries; this was reflected in a lower and a higher CV in these two groups of animals. Only one farm had five cows in milking condition, while the rest of the units had 8 to 27 cows in milking condition and a total of 23 to 55 animals. The size of the herd in the present study was within the range reported in the family-run dairy farms in various states of the Republic[5,8,9]. Eight farms had only Holstein animals, and Holstein and Brown Swiss American animals were found in two farms.

The average, minimum and maximum milk productions were 8.9, 3.4 and 14.4 kg d^{-1}, respectively. The duration of lactation was on average 253.1 d, with a minimum and a maximum of 180 and 420 d, respectively. The average, minimum, and maximum production of milk $lactation^{-1}$ kg^{-1} was 2.130, 670 and 5.546 kg. Milk production in kg^{-1} yr averaged 3.231, with minimum and maximum values of 1.253 and 5.263 kg. The milk production reported in other assessments of family systems was 10.7, 11 and 17.3 kg of milk cow^{-1} d^{-1}[5,8,9], which is greater than that reported in this paper. At the same time, milk production in kg yr^{-1} was lower than that reported for family systems of milk production with traditional management (3.417 kg of milk yr^{-1}) or improved through a program of validation and transfer of technology (4.632 kg of milk yr^{-1})[5].

The average content, minimum and maximum values, and CV of the GE are presented in Table 2. In general, the average values and CV found in this study agree with those of other reports and reflect the natural variation of the ingredients available for the animals(12,17). The minimum and maximum CV occurred in corn silage (4.9 %) and chicken dung (22.8 %). Various agro-ecological and management conditions reportedly influence the content of GE at different times of the year, depending on the weather, on whether the production is seasonal or utilizes irrigation, and on the doses of fertilization. Probably, the greatest extremes in terms of availability and quality of the ingredients occur between the dry and rainy season; in the present work it was tried to minimize this effect when carrying out the samplings between spring and summer. Other factors that influence the GE content are the variety of plants, the harvest time, the conditions of post-harvest handling and storage, and the type of processing(12,17,18).

During visits to the farms it was noted that various alfalfas occurred in adjoining plots, but the majority of the producers had no knowledge of the seed variety, the age of the crop, the number of cuts or the age of the forage at the time of the cutting; some alfalfas were offered fresh, sugar-coated or dried. Other producers who bought alfalfa in bales, usually dehydrated, were unaware of the information mentioned before and did not know for how long the bales had been stored before acquiring them. This lack of information was observed in most of the sampled ingredients.

Table 3 shows the DMC, GEC, EF and PCH_4 are shown by productive phase 3. In cows in milking condition, the DMC (11.28 and 10.42, kg d^{-1}), GEC (45.42 and 39.41, Mcal d^{-1}), EF (81 and 70, kg CH_4 yr^{-1}) and PCH_4 (2.95 and 2.56, Mcal d^{-1}) estimated with IPCC equations of the IPCC were similar to the estimates of the observations carried out at the farms. This indicates that, in cows in milking condition, the results of the IPCC equations constitute a good point of comparison or verification for the prediction of these variables with the use of procedures recommended for level 2. Concentrates were included in the food of the cows in milking condition in all stables, accounting for the largest portion of the ration, in an average proportion of 33 %; in order of frequency, they were followed by the alfalfa and corn silage. According to the majority of the interviewed producers interviewed, the family-run dairy production systems follow similar feeding schemes of cows in milking condition to that of cows in intensive systems within the study area. This is probably the reason why there were no differences in the variables evaluated at the farms and those estimated with the IPCC.

Table 3: Dry matter intake and gross energy consumption, methane emission factor and loss of energy in the form of methane by productive phase, using the equations of the IPCC or the technical data of the farms

	IPCC	Farms	SEM	*P* <
Dry matter intake, kg d^{-1}				
Lactating cows*	11.28	10.42	0.757	0.43
Pregnant cows**	11.47^{c}	9.28^{d}	0.456	0.01
Heifers	7.09	6.93	0.545	0.84
Calves	4.51	4.49	0.367	0.98
Bulls	14.88^{e}	9.75^{f}	1.217	0.02
Young bulls	6.95	7.4	0.819	0.75
Gross energy intake, Mcal d^{-1}				
Lactating cows	45.42	39.41	3.896	0.28
Pregnant cows	26.58^{c}	34.97^{d}	1.662	0.01
Heifers	14.63^{c}	25.96^{d}	2.271	0.01
Calves	10.57^{c}	16.77^{d}	1.385	0.01
Bulls	34.26	37.11	4.505	0.46
Young bulls	15.55^{e}	22.88^{f}	2.191	0.05
Emission factor (kg of CH_4 head^{-1} yr)				
Lactating cows	81.02	70.3	6.95	0.28
Pregnant cows	47.41^{e}	62.36^{f}	2.964	0.01
Heifers	26.10^{e}	46.29^{f}	4.049	0.01
Calves	18.86^{e}	29.91^{f}	2.469	0.01
Bulls	61.12	66.17	8.033	0.46
Young bulls	27.74^{g}	40.82^{h}	3.908	0.05
Loss of energy in the form of methane, Mcal d^{-1}				
Lactating cows	2.95	2.56	0.253	0.28
Pregnant cows	1.73^{c}	2.27^{d}	0.108	0.01
Heifers	0.95^{c}	1.69^{d}	0.148	0.01
Calves	0.69^{c}	1.09^{d}	0.09	0.01
Bulls	2.23	2.41	0.293	0.46
Young bulls	1.01^{g}	1.49^{h}	0.136	0.05

IPCC = using the equations recommended by the IPCC; Farms= using the technical information of the farms; SEM= standard error of the mean.

*Means without a superscript in the same row are not statistically different (*P*>0.05).

**Means with a different superscript in the same row are statistically different (*P*<0.05).

The EF values of the cows in milking condition were between 41.6 and 65.8 % lower than those found in milk-producing cows in other studies conducted in Mexico in which the procedures recommended for level 2 were also utilized. The EF in primiparous and multiparous cows of 16 herds registered at the Holstein Association of Mexico was 166 and 182 kg CH_4 yr^{-1}, in lactations of 305 d, respectively(6); in order to calculate the EF, the DE content of the diet was estimated using a default value and the content of total digestible nutrients (TDN), and subsequently converted to GE using another default value, while an EF of 115 kg CH_4 yr^{-1} was estimated for the total milk-producing herd of Mexico, with a lactation period of 305 d(7). The EF was calculated based on an estimate of the GE contents of five diets reported in studies of dairy cattle in Mexico published between 1971-2009. The lower EF estimated in the present work can have two explanations: 1) differences in the methodologies used to estimate the GEC in relation to the previous work, which emphasize that the content of DM and GE in the ingredients or food consumed by animals included in the studies was not analyzed in a laboratory, and 2) the differences in the levels of milk production, which directly affect the level of consumption of nutrients, and the GEC in the case of the estimates based on the IPCC equations. The conversion factor of CH_4 (Ym) is a value that represents a fixed percentage of the GE (6.5%), which is converted to CH_4 (Equation 1) and, therefore, the higher the GEC, the greater the production of CH_4(3). In the present work, the production of milk per lactation adjusted to 305 d was 2.715 kg; for the Holstein cows, it was 9.985 kg(6) and for the milk-producing herd of Mexico, it was 3.795 kg(7). Thus, the EF is greater in the cows with higher milk production, intermediate in the cows with intermediate production of milk, and lower in the cows in milking condition included in this study. This same trend is observed in several reports where the EF ranged between 102 and 128 kg CH_4 $year^{-1}$ in cows in milking condition with an annual milk production of 5.365 to 8.270 kg, respectively(19.20).

In pregnant cows, the observed DMC was 19 % lower ($P<0.01$), but the observed GEC, EF and the PCH_4 were 32 % higher ($P<0.01$) than those estimated with the equations of the IPCC (Table 3). These results indicate that, in gestating cows, the use of the equations of the IPCC overestimated the DMC and underestimated the GEC, the EF and the PCH_4 and therefore they do not constitute a good point of comparison or verification for the prediction of these variables using the level 2 method. The difference in the DMC was 2.2 kg d^{-1} below the expected value, and the GEC was 8.0 Mcal kg^{-1} above the expected value. In gestating cows, the most frequently utilized forages were stubble and oats hay, in a higher concentration than those used for cows in milking condition. Probably, these ingredients caused a greater filling of the rumen, which, associated with the pressure of the fetus, reduced the DMC, but at the same time contributed to a greater GEC.

The estimated and observed EF was of 47 and 62 kg CH_4 yr^{-1} in pregnant cows. There are few researches on the CH_4 emissions by these animals. A report found that the EF was 55.15 kg CH_4 yr^{-1} in heifers aged over one year until delivery, with a body weight of 310-520 kg[19]. In the present study, the weight of the pregnant cows averaged 475 kg, which is within the range mentioned above; however, the requirement of GE for non-pregnant heifers and pregnant cows was calculated separately because, at the same weight, pregnant cows have a higher requirement of GE. This is due to the use of the ENp (equation 5), and in cows of between 210-270 d of gestation, the ENc increases in parallel with the growth of the fetus and also depends on the expected weight of the calf at birth[21].

The DMC was similar in the heifers and the calves, but the GEC, EF and the PCH_4 estimates were lower (P<0.01) with the equations of the IPCC than those observed in farms (Table 3). The observed GEC, EF and the PCH_4 were 56 % higher in the heifers and 63 % higher in calves with respect to the corresponding estimated values. In most of the farms, corn stalks were the ingredient utilized most frequently and in the greatest proportion (on average, 50 % of the ration) and provided the largest amount of the GE in growing females. For calves up to one year of age, with body weight of 43 to 320 kg, the reported EF was 34 to 35 kg CH_4 yr^{-1}, and in females aged one to two years, with weights of 310 to 530 kg, the EF was 49 kg CH_4 yr^{-1}[19]. In heifers of 499 kg of weight and kept in solitary confinement or grazing, the EF was of 77 and 67 kg CH_4 yr^{-1}, respectively[22]. The EF of heifers (estimated= 26 and observed= 46 kg CH_4 yr^{-1}) and calves (estimated= 19 and observed= 30 kg CH_4 yr^{-1}) were lower than those reported on previous occasions. This is likely due to differences in body weight and has an impact on the requirement of ENm and ENc and on the DMC[3,12].

In bulls, the estimated DMC was 53 % higher (9.32 vs 9.75 kg d^{-1}; P<0.02) than that observed (Table 3). The estimated and observed values of GEC, EF, and PCH_4 were similar, despite the large difference in the DMC. For bulls aged over two years, a DMC of 8.6-9.2 kg d-^{1}, a GEC of 37.95 Mcal d^{-1} and an EF of 62.18 kg CH_4 yr^{-1}[19] were estimated; these values are consistent with those observed in the present study. In four of five farms whose herds included bulls, these were fed food concentrates and, in general, the composition of the rations for bulls was more similar to that for cows in milking condition. Probably, the inclusion of concentrates and more digestible ingredients caused the observed DMC to be lower than expected, and the GEC to be similar to the expected value.

In young bulls in fattening, the DMC (6.95 and 7.40, kg d^{-1}) was similar, but the GEC (15.55 and 22.88, Mcal d^{-1}), EF (27.74 and 40.82, kg CH_4 yr^{-1}) and the PCH_4 (1.01 and 1.49, Mcal) estimates were 69 % lower (P<0.05) than those observed in the farms (Table 3). In young bulls aged one to two years, a DMC, 8.3 kg d^{-1}, GEC 36.0 Mcal d^{-1} and an EF of 60.1 kg CH4 yr^{-1}[19] were estimated. These values are greater than those found in the present study, probably due to the greater weight of the growing bulls (on average, 540 kg) and quality of the diet in the above-mentioned study. In the present work, the average weight of the growing bulls was 290 kg, and in three of four farms, corn stalks were the predominant ingredient in the food.

Table 4 shows the weighted averages of the EF, HCP_4 and ML farm-1. The EF (49.06 and 54.09, kg CH_4 yr^{-1}) was similar, but the PCH_4 (1.11 and 1.97, Mcal d^{-1}; $P<0.01$) and ML (0.13 and 0.27, Mcal kg $milk^{-1}$; $P<0.03$) estimates were 44 and 52 % lower, respectively, than those observed in the farms. The lack of difference in the weighted EF between the estimated and the observed values coincide with the results observed in cows in milking condition; the estimates appear to be appropriate when applied to the herd as a whole, probably due to the specific weight of lactating cows, when the IPCC methodology is used. The PCH_4 and ML are not included in the estimates of the IPCC; however, they make it possible to know the impact of nutritional practices on the inefficiency of energy use and can be used to estimate economic inefficiencies associated with these losses, with additional information on input costs. The strength of these variables is that their estimation takes into account both the productive and the non-productive animals in the herd, in addition to the cows in milking condition. The results suggest that, using the technical information of the farms, it was possible to demonstrate a greater PCH_4 and ML $farm^{-1}$, and, consequently, a lower efficiency, with respect to the IPCC methodology, probably due to the greater PCH_4 observed in pregnant cows, heifers, calves and young bulls (Table 3).

Table 4: Emission Factor and energy losses in the form of methane per unit of production using the equations of the IPCC or the technical data of the farms

	IPCC	**Farms**	**SEM**	***P*** **<**
CH_4 Emission Factor, kg yr^{-1}*	49.06	54.09	3.889	0.37
Loss of GE in the form of CH_4, Mcal d^{-1}**	1.11^{c}	1.97^{d}	0.161	0.01
Daily loss of GE, Mcal kg $milk^{-1}$	0.13^{e}	0.27^{f}	0.043	0.03

IPCC= using the equations recommended by the IPCC; Farms= using the technical information of the farms; SEM = standard error of the mean.

*Means without a superscript in the same row are not statistically different ($P>0.05$).

**Means with a different superscript in the same row are statistically different ($P<0.05$).

The findings suggest that the estimates of DMC, GEC, EF AND PCH_4 with the level 2 methodology recommended by the IPCC were similar only to those observed in cows in milking condition, but there were contrasting results in the rest of the animals of the herd. This is probably due to the fact that most of the case studies where they have been derived from the equations have been conducted in cows in milking condition, but there is little work done on animals at other stages of production. The largest PCH_4 and ML observed in the farms may be due to the fact that predictor equations have been derived from studies on animals with higher levels of production and in experimental conditions with adequate nutritional, environmental and sanitary control; while the visited farms used the ingredients available according to the time of year, they do not apply a proper balancing of rations, their facilities are poor, and they do not implement appropriate preventive actions[5,8,9].

Conclusions and implications

The estimates of DMC, GEC, EF and PCH_4 using the procedures proposed by the IPCC level 2 method agreed with the observed values only in cows in milking condition; however, the results were inconsistent when applied to the rest of the animals in the herd. In general, the use of technical information of the farms made it possible to estimate the EF and demonstrate a greater PCH_4 and ML farm^{-1}, and, consequently, a lower efficiency, with respect to the IPCC methodology. There are several nutritional factors that influence the degradability of food, the patterns of enteric fermentation and ruminal production of CH_4 —such as the amount and type of starches, the type and solubility of proteins, the type and concentration of the fractions of fiber, among others—, that should be considered in future work to improve the precision of the estimates of CH_4. Other limitations of the study were that the producers did not have systematic records of information; part of the technical data were estimated on the basis of the subjective perception of producers, and there was no means of verification.

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