



Impact of the intensity of milk production on ammonia and greenhouse gas emissions in Portuguese cattle farms

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Abstract

The aim of this study was evaluate the relationship between the intensity of milk production for a wide range of Portuguese commercial cattle farms and NH₃ and greenhouse gas (GHG) emissions from manure management and enteric fermentation. A survey was carried out at 1471 commercial dairy cattle farms (Holstein-Friesian) and the NH₃, N₂O and CH₄ emissions at each stage of manure management were estimated as well as CH₄ losses from enteric fermentation. Gaseous emissions were estimated by a mass flow approach and following the recommendations of IPCC guidelines. The manure management and enteric fermentation in a typical Portuguese cattle farm contributes with 7.5±0.15 g N/L milk produced as NH₃ and 1.2±0.22 kg CO₂ equivalent per litre of milk as GHG. Increasing milk production will significantly reduce NH₃ and GHG emissions per litre of milk produced. It can be concluded that a win-win strategy for reducing NH₃ and GHG emissions from dairy cattle farms will be the increase of milk production on these farms. This goal can be achieved by implementing animal breeding programs and improving feed efficiency in order to increase productivity.

Additional key words: dairy cattle; enteric fermentation; gaseous emissions; manure management.

Abbreviations used: CP (crude protein); GHG (greenhouse gas); LU (livestock unit); M (annual milk production).

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The intensive cattle production has led to severe environmental problems, such as ammonia (NH₃) and greenhouse gas (GHG) emissions, due to the large amounts of slurry (liquid manure) resulting from this activity (Hristov *et al.*, 2011, 2013; Montes *et al.*, 2013). The most common liquid manure handling systems for cows in Europe are scraping and flushing systems where a mixture of urine, faeces and litter materials (*i.e.*, cattle slurry) are drained together from housing to manure storage facilities (Pereira & Trindade, 2014). Then, the cattle slurry stored is applied to land as organic fertiliser. Gaseous emissions are related with animal health (*e.g.*, mucous membrane irritation and pulmonary diseases related with NH₃ exposure), nutrition (*e.g.*, methane (CH₄) losses from rumen and N excretion) and environmental (*e.g.*, air quality, atmospheric deposition,

global climate change) issues and occur at all stages of animal manure management, namely housing, storage and soil application (Sommer *et al.*, 2006; Hristov *et al.*, 2011, 2013; Montes *et al.*, 2013; Beccaccia *et al.*, 2015; Hou *et al.*, 2015). Consequently, mitigation measures have been proposed in Northern Europe countries, but few data are available for Southern Europe countries. Also, recent Portuguese legislation (NREAP, 2013) regarding manure management refer to the use of the best available techniques by farms but their inclusion at one stage of manure management could lead to pollution swapping between NH₃ and nitric oxide (NO)/nitrous oxide (N₂O) emissions and nitrate leaching. Hence, further practical solutions to reduce gaseous emissions from manure management are needed in order to achieve reduction targets.

Previous studies (Casey & Holden, 2005; Fanguero *et al.*, 2008; Gerber *et al.*, 2011) reported that, for a proper comparison between different farm intensities or milking systems, the environmental impacts generated should be expressed in function of production output (*e.g.*, milk produced) together with per animal head or per hectare. The aim of this study was to evaluate the relationship between intensity of milk production for a wide range of Portuguese commercial cattle farms and NH₃ and GHG emissions from manure management and enteric fermentation.

A survey was carried out at 1471 commercial dairy cattle farms (Holstein-Friesian) each with more than 20 dairy cows. The farms were located at Northwest Portugal, being the main dairy production area of the country (about 50% of the national milk production). Each farm was visited and a questionnaire was completed. Data for the whole year were collected and included the following parameters: cattle numbers and types (dairy cows, bulls, heifers and calves), milk production (liquid milk) and diets supplied (dry matter intake of concentrates, forages and crude protein). The dairy cattle buildings were freestall-type housing, naturally ventilated and equipped with solid and slatted concrete floors. The slurry was stored in concrete slurry pits, with a mean capacity of 7.6 m³ per livestock unit (LU), enough for a 5 month storage period. Animal numbers were expressed in Portuguese LUs, considering that 1 LU was an adult animal (>24 months age and >500 kg liveweight) of the bovine species or a dairy cow with <7000 L/yr of milk produced. A dairy cow with ≥7000 L/yr of milk produced was 1.2 LU. A heifer was 0.6 LU (6-24 months age) and calves (<6 months age) were 0.4 LU.

The manure management system for the studied farms was the following: excreta was removed daily from concrete floors of housing as slurry (liquid system) and then stored outside buildings in concrete slurry pits. The dairy system is based on zero-grazing with two forage crops per year: maize silage and a winter crop (*i.e.*, ryegrass). All untreated slurry of each dairy farm was applied (mean rate of 95 m³/ha/yr or 266 kg total N/ha/yr) by traditional broadcast at the sowing of each forage crop as organic fertiliser source. The inputs of mineral fertilisers in dairy farms were not included in the present study. More details of the dairy farming system can be found in Fanguero *et al.* (2008), Pereira *et al.* (2010, 2016) and Brito *et al.* (2011).

At each dairy farm, NH₃ and N₂O emissions were estimated following a mass-flow approach as described by Webb & Misselbrook (2004) and Dämmgen & Webb (2006), considering the N gaseous losses at each stage of manure management (*e.g.*, housing, storage, land

spreading and crop growing period). The gaseous N losses were estimated by Eq. [1]-[4].

$$E_{\text{Housing}} = N_{\text{Housing}} \times EF_{\text{NH}_3} \quad [1]$$

$$E_{\text{Storage}} = (N_{\text{Housing}} - E_{\text{Housing}}) \times (EF_{\text{NH}_3} - EF_{\text{N}_2\text{O}}) \quad [2]$$

$$E_{\text{Land_spreading}} = (N_{\text{Storage}} - E_{\text{Storage}}) \times (EF_{\text{NH}_3} - EF_{\text{N}_2\text{O}}) \quad [3]$$

$$E_{\text{Crop_growing}} = (N_{\text{Land_spreading}} - E_{\text{Land_spreading}}) \times EF_{\text{N}_2\text{O}} \quad [4]$$

where, E_{Housing} , E_{Storage} , $E_{\text{Land_spreading}}$, and $E_{\text{Crop_growing}}$ are the amounts of gaseous losses at each stage of manure management considering proper emission factors for each gas (EF_{NH_3} , $EF_{\text{N}_2\text{O}}$) and stage (Table 1). N_{Housing} , N_{Storage} , $N_{\text{Land_spreading}}$, and $N_{\text{Crop_growing}}$ are the N contents available for gaseous losses at each stage of manure management.

The emission factors employed in our study were selected following the recommendations of IPCC and EMEP-EEA for the Portuguese conditions (Table 1). The annual N excretion for dairy cows was estimated by Eq. [5], as a function of annual milk production and crude protein (CP) supplied in the diet (Vérité & Delaby, 1998). The default N excretion for non dairy cows was 50 kg N/yr as recommended by EMEP-EEA (2013).

$$N_{\text{Excreted}} = (9.635\text{CP} - 39.114) + \left[\frac{(9.635\text{CP} - 39.114) \times 0.005(M - 6000)}{100} \right] \quad [5]$$

where, N_{Excreted} was the annual N excretion for dairy cows (in kg N/yr), CP was the percentage of crude protein in diet (16%), and M was the annual milk production (in L/yr).

In order to assess gaseous N losses using the emission factors described in Table 1, the NH₄⁺-N content in excreta deposited in housing was 29% of total N excreted (Pereira *et al.*, 2010) and the mineral N content in cattle slurry was 50% of total N applied at soil spreading (Trindade *et al.*, 2009; Pereira *et al.*, 2016). Considering Portuguese legislation (NREAP, 2013) regarding animal manure management, it was assumed a 30% reduction in NH₃ emissions at land spreading, since the untreated cattle slurry was subjected to broadcast application and incorporation by plough within 12 h (EMEP-EEA, 2013).

The CH₄ emissions from manure management of all cattle, as well as emissions from enteric fermentation of the non dairy cows, were estimated by Tier 1 ap-

proach of IPCC (IPCC, 2006) for Portuguese conditions (Table 1). For dairy cows, the CH₄ emissions from enteric fermentation were estimated by Tier 2 approach of IPCC, and in function of milk production of each farm (Table 1) as used by Casey & Holden (2005).

The relationship between milk production and gaseous emissions was established using regression analysis (e.g., fitting exponential equations). The software used was STATISTIX 7.0 (USA) and significant statistical differences correspond to $p < 0.05$.

The main characteristics (mean±standard deviation) of the typical Portuguese dairy cattle farms studied ($n=1471$) were as follows: dairy cows and non-dairy cows=48±32.1 and 25±23.0 animals/farm/yr, respectively; milk production=6601±1634.5 L/cow/farm/yr; LU=67.4±48.25; total N excreted in manure=118.5±9.38 and 50±0.0 kg N/yr for dairy cows and non-dairy cows, respectively. It was observed that the cattle numbers ranged considerably between the studied farms. The number of dairy cows varied between 20 and 441 animals and milk production varied between 2000 and 13000 L/yr/cow. The non dairy cows were about 34% of total cattle housed in each farm and 42% of the 1471 commercial dairy cattle farms had an annual milk production higher than 7000 L/cow.

Table 2 shows the mean values of gaseous emissions from all stages of manure management. We observed important NH₃ emissions (>25% of total losses) at all stages of manure management, but soil application was the main source of NH₃ emissions followed by housing. A significant ($p < 0.05$) negative relationship was observed between the intensity of milk output per cow and NH₃ emissions per litre of milk produced in each farm (Fig 1A). In our study, the NH₃ emissions were 92% of N emissions (NH₃+N₂O) of which were contributed 35, 25 and 40%, respectively, from housing, storage and soil application (Table 2). So, these values observed in each stage of manure management are comparable to values obtained in other studies, with higher NH₃ emissions in soil application followed by housing (Sommer *et al.*, 2006). In addition, our estimates of emissions of NH₃ (expressed per litre of milk produced) are comparable with average values observed in dairy cattle farms located at Germany, Portugal and UK, with emissions that ranged between 7.5 and 7.7 g N/L milk (Fangueiro *et al.*, 2008).

The N₂O emissions (2.6 kg N/LU/yr) from all stages of manure management were small relative to NH₃ emissions (34.7 kg N/LU/yr) observed in the farms, being less than 8% of N emissions (NH₃+N₂O) (Table 2). The main source of N₂O emissions was soil

Table 1. Emission factors of NH₃, N₂O and CH₄ from dairy cattle farms

Emission sources		Emission factor	Reference
<i>Housing</i>			
NH ₃	12% of N excreted		EMEP-EEA (2013)
<i>Storage</i>			
NH ₃	6% of N excreted		EMEP-EEA (2013)
N ₂ O	0.57% of N excreted		Amon <i>et al.</i> (2001)
<i>Soil application</i>			
NH ₃ - land spreading	40% of NH ₄ ⁺ -N available in slurry		IPCC (2006)
N ₂ O - land spreading	0.5% of NH ₃ -N lost at this stage		Velthof <i>et al.</i> (1998)
N ₂ O - crop cycle	1.25% of N applied at this stage		IPCC (2006)
<i>Enteric fermentation</i>			
CH ₄ - Non-dairy cows	57 kg CH ₄ /yr		Table 10.11, IPCC (2006)
CH ₄ - Dairy cows	85-95 kg CH ₄ /yr for dairy cows with 3000-4000 L/yr milk output		Casey & Holden (2005); IPCC (2006)
	95-105 kg CH ₄ /yr for dairy cows with >4000-5000 L/yr milk output		
	105-115 kg CH ₄ /yr for dairy cows with >5000-6000 L/yr milk output		
	115-125 kg CH ₄ /yr for dairy cows with >6000-7000 L/yr milk output		
	125 kg CH ₄ /yr for dairy cows with >7000 L/yr milk output		
<i>Manure management</i>			
CH ₄ - Non-dairy cows	37 kg CH ₄ /yr		Table 10.14, IPCC (2006)
CH ₄ - Dairy cows	11 kg CH ₄ /yr		Table 10.14, IPCC (2006)

application with 75% of total losses against less than 25% in storage and housing. Considering the N₂O emissions from all stages of manure management, it was observed a significant ($p < 0.05$) negative relationship between the increase of milk production in farms and N₂O losses per litre of milk produced (Fig 1B).

Enteric fermentation contributes with 46% of total CH₄ emissions (110 kg CH₄/LU/yr) from farms and manure management was responsible for the remaining CH₄ losses. The GHG (N₂O+CH₄) emissions, expressed in CO₂ equivalent, from the studied Portuguese dairy cattle farms were about 6.0 t/LU/yr, wherein about half of these losses are emitted from enteric fermentation and the other half coming from manure management (Table 2). In addition, the increase of milk production in farms reduces significantly ($p < 0.05$) the CH₄ and GHG emissions per litre of milk produced in studied farms (Fig. 1C-1D).

The GHG emissions observed in the studied dairy cattle farms (1.2 kg CO₂ equivalent/L milk) (Table 2) are higher than a previous study by Castanheira *et al.*

(2010) who reported a environmental impact (using life cycle assessment methodology) of 1.0 kg CO₂ equivalent/L milk in a typical Portuguese dairy farm (including diesel consumption). Our study does not include N₂O from mineral fertilisers, indirect N₂O emissions and CO₂ losses from direct and indirect energy use in dairy farms. Also, differences between our estimates and the previously referred study are related with an underestimate of GHG emissions coming from enteric fermentation of dairy cows reported by Castanheira *et al.* (2010), since they used a Tier 1 approach to estimate emissions whereas this study used a Tier 2 approach. Nevertheless, Casey & Holden (2005) calculated GHG emissions ranged from 0.9 to 1.5 kg CO₂ equivalent per litre of milk in typical Irish dairy cattle farms and found a negative relationship between GHG emissions and the intensity of milk production, being comparable with the present study. In addition, increasing milk yield/cow will reduce GHG emissions, if these emissions are expressed per kg milk and reduction in associated beef production is not considered (Zehetmeier *et al.*, 2012).

Table 2. Average values (mean±standard deviation) of NH₃, N₂O and CH₄ emissions from dairy cattle farms ($n=1471$).

Emission sources	kg/LU/yr	g/L milk
<i>NH₃-N emissions</i>		
Housing	12.3 ± 0.66	2.6 ± 0.67
Storage	10.7 ± 0.58	1.9 ± 0.48
Soil application	11.7 ± 0.63	3.0 ± 0.77
Total	34.7 ± 0.04	7.5 ± 0.15
<i>N₂O-N emissions</i>		
Housing	0.0 ± 0.00	0.0 ± 0.00
Storage	1.5 ± 0.08	0.1 ± 0.03
Soil application	1.1 ± 0.09	0.4 ± 0.06
Total	2.6 ± 0.05	0.5 ± 0.03
<i>N (NH₃+N₂O) emissions</i>		
Housing	12.3 ± 0.47	2.6 ± 0.47
Storage	12.2 ± 0.35	2.0 ± 0.32
Soil application	12.8 ± 0.38	3.4 ± 0.51
Total	37.3 ± 0.00	8.0 ± 0.08
<i>CH₄ emissions</i>		
Enteric fermentation	110 ± 10.5	23 ± 5.6
Manure management	30 ± 2.9	7 ± 2.2
Total	140 ± 10.0	30 ± 8.0
<i>GHG (N₂O+CH₄) emissions (CO₂ equivalent)</i>		
Enteric fermentation	2742 ± 262.7	586 ± 141.2
Manure management	3196 ± 119.5	638 ± 81.8
Total	5939 ± 382.3	1224 ± 222.9

The results obtained in our study are a logical consequence of the mathematical equations (Eq. [1]-[5]) of the methodology. Thus, Eq. [5] for N excretion and IPCC equations are very sensitive to milk yield and crude protein (for N excretion). Since emission per animal increases with production intensity, but productivity increases at a higher rate, emissions per product unit decrease and this originates the trend shown in Fig. 1. Therefore, increasing the production will reduce emissions, and improving genetics, nutrition and management will both improve productivity and reduce emissions. There were substantial differences among farms in these factors, probably related to their production objective, which explain the important differences obtained in milk production (2000-13000 L/yr) and emissions.

Previous studies (Hristov *et al.*, 2011; Pereira & Trindade, 2014) reviewed mitigation strategies for

reducing gaseous from cattle farms and are in agreement that pre-excretion techniques designed for lowering excreta (*e.g.*, optimised crude protein in diet and increased milk production at farm level) are more efficient than post-excretion strategies (*e.g.*, floor type and manure handling). In the present study, results obtained showed that increasing milk production in farms will reduce significantly ($p < 0.05$) NH_3 and GHG emissions per litre of milk produced in each farm. Hence, a win-win strategy for reducing NH_3 and GHG emissions from dairy cattle farms will be the increase of milk production in these farms. For example, a farm with 10000 L/cow of annual milk production should had an amount 25% lower of NH_3 and GHG emissions, expressed per litre of milk produced, relative to a farm with a annual milk production of 6600 L/cow. A high milk production per cow will result in fewer cows to achieve the same level of production relative to less

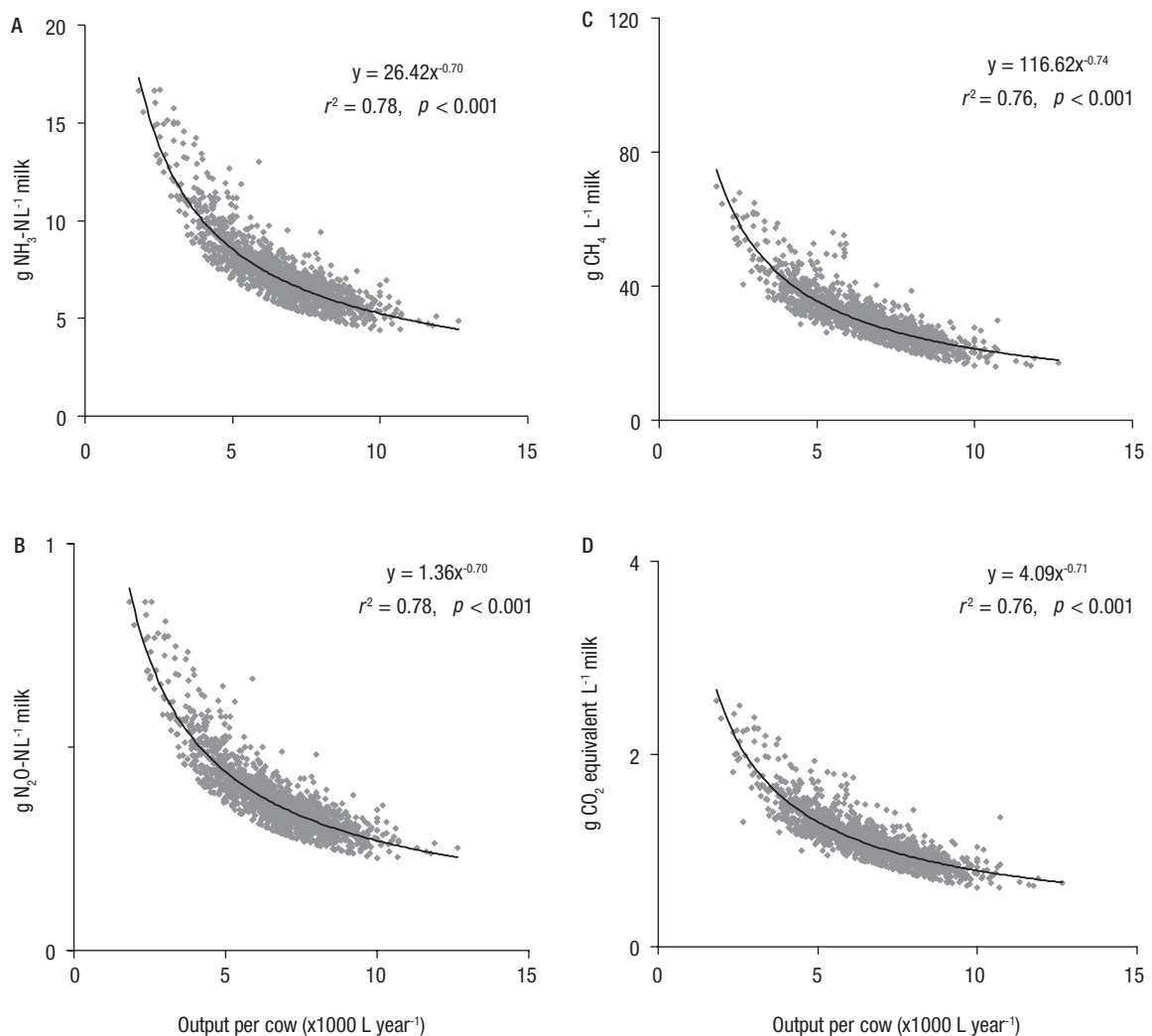


Figure 1. The relationship between NH_3 (A), N_2O (B), CH_4 (C) and greenhouse gas ($\text{N}_2\text{O} + \text{CH}_4$) (D) emissions and the intensity of milk production in cattle farms ($n=1471$).

intensive dairy farm. On the other hand, the reduction of replacement animals (heifers) has a similar effect than high milk production per cow and could reduce NH₃ and GHG emissions in farms.

In conclusion, the manure management and enteric fermentation in a typical Portuguese cattle farm contributes with 7.5±0.15 g N/L milk produced as NH₃ and 1.2±0.22 kg CO₂ equivalent per litre of milk as GHG. Besides, increasing milk production in farms will reduce significantly NH₃ and GHG emissions per litre of milk produced in each farm. It can be concluded that a win-win strategy for reducing NH₃ and GHG emissions from dairy cattle farms will be the increase of milk production on these farms. This goal can be achieved by implementing animal breeding programs and improving feed efficiency in order to increase productivity.

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