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Modelling the interactions between C and N farm balances and GHG emissions from confinement dairy farms in northern Spain

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HIGHLIGHTS

- This study describes a new model to calculate GHG from dairy production.
- The C-footprint in confinement dairy systems in northern Spain is calculated.
- Cow diet choice is the main factor affecting the C-footprint.
- Efficiency-based indicators are good proxies to estimate milk C-footprint.
- The choice of methodology greatly affects the final C-footprint result.

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ABSTRACT

There is world-wide concern for the contribution of dairy farming to global warming. However, there is still a need to improve the quantification of the C-footprint of dairy farming systems under different production systems and locations since most of the studies (e.g. at farm-scale or using LCA) have been carried out using too simplistic and generalised approaches.

A modelling approach integrating existing and new sub-models has been developed and used to simulate the C and N flows and to predict the GHG burden of milk production (from the cradle to the farm gate) from 17 commercial confinement dairy farms in the Basque Country (northern Spain). We studied the relationship between their GHG emissions, and their management and economic performance. Additionally, we explored some of the effects on the GHG results of the modelling methodology choice.

The GHG burden values resulting from this study (0.84–2.07 kg CO_2-eq kg^{-1} milk ECM), although variable, were within the range of values of existing studies. It was evidenced, however, that the methodology choice used for prediction had a large effect on the results. Methane from the rumen and manures, and N_2O emissions from soils comprised most of the GHG emissions for milk production. Diet was the strongest factor explaining differences in GHG emissions from milk production. Moreover, the proportion of feed from the total cattle diet that could have directly been used to feed humans (e.g. cereals) was a good indicator to predict the C-footprint of milk. Not only were some other indicators, such as those in relation with farm N use efficiency, good proxies to estimate GHG emissions per ha or per kg milk ECM (C-footprint of milk) but they were also positively linked with farm economic performance.

1. Introduction

The contribution to the global man-made greenhouse gas (GHG) emissions from milk production has been recently estimated at about 3% (FAO, 2010; Hagemann et al., 2012). There are however many uncertainties associated with these estimates due to over-simplification of methodologies and lack of site-specific activity data.

Dairy farming in the EU is facing numerous changes that add instability and vulnerability to the existing challenges in the sector. New green payments across farms within the latest CAP reform and the removal of the European Union (EU) milk quota system in 2015 are expected to result in large changes for EU dairy farmers such as a price decline and an increase in raw milk production (Lips and Rieder, 2005).

So far there have been studies that have estimated the GHG emissions from specific dairy systems using different approaches such as

Abbreviations: CAP, Common Agricultural Policy; LCA, Life Cycle Analysis; CP, Crude Protein; ADF, Acid Detergent Fibre; TDN, Total Digestible Nutrients; PET, Potential Evapotranspiration; LU, Livestock Units; DM, Dry Matter; NPP, Net Primary Production; ECM, Energy Corrected Milk; FiM, Feed into Milk; WFPS, Water Filled Pore Space; FYM, Farm Yard Manure; TAN, Total Ammonium Nitrogen; EFs, Emission Factors; VS, Volatile Solids; FCE, Feed Conversion Efficiency; HEF, Human Edible Feed.

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farm-modelling (e.g. Schils et al., 2007) or life cycle analysis (LCA). A summary of those studies that have applied LCA approach to milk products can be found in De Vries and de Boer (2010) and Yan et al. (2011). There is still however a lack of understanding about the links between the nitrogen (N) and carbon (C) cycles and the GHG burden of livestock products. Most studies do not include the short-term C cycle (except for Rotz et al., 2010), indirect emissions or farm economic information.

Using LCA, there have been recent efforts to estimate the global warming potential of the production of milk in the Iberian Peninsula, such as in Galicia (Spain) (Hospido et al., 2003) and Portugal (Castanheira et al., 2010). These studies have used very simple and generalised approaches for the prediction of GHG emissions. The typical dairy farm system in the Basque Country (northern Spain), as a consequence of lack of available land, has the strategy to keep the animals in the house and to use both a total mixed ration and grass silage for feeding the animals (confinement dairy farms). So far there have already been some studies focusing on the GHG burden from confinement dairy systems elsewhere (e.g. Arsenault et al., 2009; O'Brien et al., 2012a). However, there is still a need to study the potential effect of local conditions (management, soil and climate) on total GHG emissions and, in order to implement strategies of mitigation, on the GHG contribution of each source.

This paper presents a new modelling approach for estimating GHG emissions from milk production using a cradle to the farm partial life cycle assessment.

We aim with this study:

(i) to describe a new modelling approach capable of simulating C and N flows and GHG emissions (from the cradle to the farm gate) in typical confinement dairy farms in the Basque Country (northern Spain).
(ii) to calculate the total GHG burden of milk production in these farms.
(iii) to evaluate the relationship between management and economic parameters on the GHG burden of milk production.
(iv) to evaluate the potential limitations and improvements for the approach.

2. Material and methods

In the following section we first describe the farm specific management and site base data and thereafter; the basic approach of the modelling framework used and the analysis carried out are described.

2.1. Farm specific management and site base data

Management and soil data from 17 commercial dairy farms were collected in 2010. Dairy farms were situated at the Karrantza valley in northern Spain (Bizkaia, Basque Country). This area produces about 62% of the total milk production in the province of Bizkaia (65,519 t in 2010). Livestock farming, besides, represents the main economic activity in this area. The climate is classified as maritime with high precipitation all year round (mean = 1500 mm) and moderate temperatures, and provides favourable conditions for grass growth (Estavillo et al., 1996) and also for microbial soil processes such as denitrification (Estavillo et al., 1994) potentially resulting in large N_2O emissions (Merino et al., 2001). Weather conditions for 2010 were drier than the average (970 mm) which led to summer conditions with high potential evapotranspiration.

Data collection was based on surveys, farm visits, interviews and information from previous projects (e.g. soil types). Input data collected include raw materials (purchased feed, bedding, inorganic fertilisers, and herbicides), fuels, electricity and ancillary materials. The collected data on farm outputs and internal farm matter flows (silage and slurry: volume, % DM, N, P, K) include information on materials/products (milk: volume, % protein and % butterfat, silage and hay), co-products (meat) and by-products such as slurry. Management data comprised information on the mixed-feed ration offered and grassland management.

Table 1 shows the mean and the range of farm input data for the surveyed farms and Supplementary Tables S1 and S2 show for each individual farms and their input data the % difference compared with their mean values. Farm management was quite heterogeneous. For example, purchased DM feed over total DM intake ranged between 42% and 89% (73% on average). Most on-farm feed is produced as grass and clover silage. Animal grazing is mostly limited to dry cows and followers, with animals remaining housed during the rest of the year. Farm grasslands are generally not concentrated in the same area, which makes the grazing activity complex and unattractive for the farmer. This seems to be an important factor for farmers not to aim to maximise the use of grazed grass in the feed budget of lactating cows (Mas, personal com.)

Common local expertise knowledge indicates that much of the grasslands comprise natural or semi-natural swards including white clover (about 10% on average, this was not recorded for each specific grassland field). Mineral fertilizer N application was almost negligible and cow slurry was spread in most farms on their grassland fields. A small amount of slurry was exported.

Factors that may provide an indication of the intensity of the systems were very variable (e.g. milk output per cow ranged between 4000 and 11,000 L milk cow^{-1}; stocking rate: 1.3–3.7 livestock unit (LU) ha^{-1} or milk output per hectare: 3000–26,000 L milk ha^{-1}).

2.2. Basic approach of the modelling framework

A novel modelling framework was developed in order to simulate the effect of site and management conditions on the C-footprint of the studied farms (from cradle to farm gate). This framework simulated the GHG emissions occurring at the farm level (on-farm) comprising emissions, both biogenic and non-biogenic, from the farm facilities (housed animals, manure, silage making) and grassland. The assessment

Table 1
Mean (minimum and maximum in parenthesis) values for each key management input data and economic farm characteristics expressed as a total, per cow, per ha, per t of milk and per t of purchased feed.

	Total	Cow^{-1} yr^{-1}	Area (ha^{-1})	Milk (t^{-1})	Purchased feed (t^{-1})
LU	58 (28–85)	1.4 (1–2.2)	2.1 (1.3–3.7)		
Followers	34 (9–62)	0.45 (0.25–0.53)	34 (9–62)		
Milk (t)	330 (109–664)	8 (4–11)	12 (3–26)		
Purchased feed (t)	249 (69–508)	6 (3–9)	9 (3–19)	0.8 (0.6–1.4)	
Electricity used (kWh)	14,435 (5604–32,540)	355 (118–807)	528 (160–1197)	49 (13–121)	64 (18–128)
Diesel used (l)	5078 (503–12,000)	125 (20–238)	188 (31–500)	17 (3–36)	23 (2–40)
Manure (m^3)	1583 (225–5412)	36 (13–83)	52 (13–104)	5 (2–9)	7 (2–14)
Net margin (€)	31K (8K–68K)	739 (421–1137)	1100 (421–2265)	103 (50–175)	138 (66–281)
Gross margin (€)	39K (8K–112K)	894 (348–2878)	1297 (397–3301)	122 (49–389)	168 (55–608)
Subsidies (€)	17K (9K–28K)	445 (241–703)	664 (241–1049)	64 (28–106)	83 (42–132)