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Forage management to improve on-farm feed production, nitrogen fluxes and greenhouse gas emissions from dairy systems in a wet temperate region

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ABSTRACT

Improving forage cropping systems and grasslands are key factors to enhance on-farm resources and sustainability in wet temperate regions of North Spain, contributing to the preservation of associated ecosystem services. This study evaluates the potential of agronomic field management for mitigating greenhouse gas emissions (GHG) and enhancing nitrogen (N) fluxes that can support an increase in on-farm forage resources, thus reducing the dependency on external inputs (fertilizers and feed products). A survey conducted in a weighted sample of 40 dairy farms in Cantabria showed four characteristic forage systems according to field management based on grazing, zero-grazing, conserved forages and growth of maize. The semi-dynamic whole farm model FarmAC was used to characterize a model farm representing an average farm in each of the forage systems including field area and use, number of cows and heifers, diet, milk yield and slurry management. The model was applied to simulate carbon (C) and N fluxes at the farm level, and to calculate feed balances, GHG emissions and the N surplus. Farms were simulated under current forage management (baseline) and under scenarios of enhanced forage production. Milk yield, the balance between forage production and consumption in the animal diet, and between manure generation and application in the field, were used as reference for accepting model simulations. The results from the scenarios indicate that increasing forage productivity, not only reduces the external dependence for feeding animals, but also would have a clear potential for mitigating yield-scaled farm GHG emissions. However, this potential appears to have a limit when N surplus exceeds a threshold value. Rotational grass-clover would have additional benefits in terms of reduced N fertilizer costs and soil carbon enhancement.

1. Introduction

Crop-livestock dairy systems are the most common farming systems of the Cantabrian coast and Galicia in North Spain. They account for 60% of milk production in Spain, about 2.7% of the milk produced in the European Union (EU-28) (Eurostat, 2017) and have an economic value of 1300 million euros (MAAMA, 2016). They also represent the characteristic agro-ecosystem in these regions (Galicia, Asturias, Cantabria, País Vasco and Navarra), comprising about 1.2 million ha of permanent grasslands. Forage crops, mainly sowed grasses and maize (*Zea mays*), are the most cultivated crops with almost 350 mil ha (MAAMA, 2016). Cattle feed is the main cost of production for dairy farmers in these areas (Sineiro et al., 2016), with most dependent on purchased feeds and concentrates. This leads to a high sensitivity of milk production costs to changes in livestock feed prices (Casasnovas-Oliva and Aldanondo-Ochoa, 2014). This is one important factor that has contributed to the drastic reduction in the number of dairy farms over the last decade in the area, causing an environmental risk (e.g. related to land abandonment) and the loss of related ecosystem services such as biodiversity or landscape value. It is therefore essential to adopt management practices that can enhance the proportion of feed ration that is produced on-farm, reducing the variable costs for milk production without negatively impacting milk yield or quality (Couvreur et al., 2006; Coppa et al., 2013).

Dairy cattle (including dairy cows, heifers and calves) will produce by 2025 around 30% of total agriculture GHG emissions in the EU-28 according to projections carried out with the CAPRI model (European Commission, 2015). Consequently, this is a key sector for GHG mitigation and most likely decision-bodies will have it into consideration when defining future livestock policies (Garnett, 2009; Bellarby et al., 2013). The adoption of improved management of forage resources can be facilitated with supporting policies if the environmental consequences, e.g., improving milk yield-scaled GHG, of the adopted practices are positive. Dairy farms are often in regions with high N

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surplus (European Commission, 2015), thus improving N efficiency at farm scale would also be necessary (Powell et al., 2010; Vellinga et al., 2011).

The simultaneous quantification of the main C and N flows and of how they are affected by farmer's practices is a very complex task that can be affordable with the support of modelling tools specifically developed for this purpose. Indeed, several whole-farm process-based models have been designed to explore the consequences of farm management at the agronomic, economic and environmental levels for the particular case of dairy systems (e.g, Berntsen et al., 2003; Schils et al., 2007; Del Prado et al., 2013a; Snow et al., 2014; Tedeschi et al., 2014). The FarmAC model is a recently developed, whole-farm model, designed to simulate crop and animal production, and C and N flows, in a wide range of different farming systems and environments (www.farmac.dk). It simulates at the livestock, manure management and field scales, using relatively simple input information that can be obtained from real farms. Simulation results are aggregated at the farm level, including GHG emissions.

This study aims to identify forage management strategies for enhancing the sustainability of current dairy systems by increasing on-farm forage resources and decreasing the dependency on external inputs in a wet temperate region with the support of the FarmAC model. The potential GHG mitigation of these strategies and the resulting N fluxes within the farm are also investigated in the paper.

2. Material and methods

2.1. Dairy farms and case study location

A survey was conducted from October 2013 to March 2014 in 40 dairy farms in the region of Cantabria (central area of the Cantabrian coast in North Spain). The sampled fraction represented 2.5% of total dairy farms in the region for that season (Flores-Calvete et al., 2017). Farms were selected using stratified random sampling, weighted by milk quota (Mg): ≤ 75; 75–125; 125–225, 225–325, 325–500 and > 500. The survey collected data relative to different aspects of farm structure including, fields, land use, facilities, herd, milk yield and feeding of dairy cows, and of system management. Data from the surveys were analyzed by Villar et al. (2016) who found that three main factors affecting land use, i.e. total farm field area, growth of maize-ryegrass crop rotation, and silage and fresh cuttings from grasslands, defined the different forage management systems of dairy farms in the region. Four forage systems were proposed by these authors as follows: farms with grazing dairy cows (G), farms with fresh forage supplied as zero-grazing (ZG), farms specialized in conserved forages, silage and hay (CF) and farms with maize-ryegrass crop rotation on > 20% of the field area (SM). Main average characteristics of a model farm representing each forage system regarding fields, animals, slurry storage, feeds and milk yield are shown in Table 1.

The region is characterized by a South Atlantic climate, with mild temperatures all the year and a high precipitation concentrated from autumn to spring. For the modelling purposes it was chosen a representative location in the coastal area of Santander with average annual temperature and precipitation for the period 1981–2010 of 14.5 °C and 1129 mm, respectively (AEMET, State Agency of Meteorology, www.aemet.es). Soil properties for the location were obtained from analyses of soil samples in the study area under maize and grassland at the soil laboratory of CIFA. An average soil representative of the area had a loam texture, with 45% sand, 45% silt, 10% clay and 4.2% organic matter in the top layer.

2.2. FarmAC whole farm model

2.2.1. Description

Farms were modelled using the semi dynamic whole farm model FarmAC. This model was selected because of an adequate trade-off between model complexity and the available data relative to the purposes of the study. In addition, it was possible to specifically adapt it to the environmental conditions and farming systems of the study area. FarmAC simulates C and N fluxes in fields and farming systems, quantifying GHG emissions and N losses to the environment. The model implements modules for the dynamic simulation of soil C, adopting the C-tool model (Taghizadeh-Toosi et al., 2014), crops and animals, based on a simplified version of the FASSET whole farm model (Berntsen et al., 2003). Source-specific soil N_2O emissions coefficients (residues, manure and mineralization) are considered in the model. This Tier 3 methodology for soil emissions is combined with and IPCC (Intergovernmental Panel on Climate Change) Tier 2 for processes in the housing and storage modules. In this study emission factors from Tier 2 are for a European Atlantic zone. FarmAC has been used to investigate mitigation measures in dairy and other farming systems (e.g., Hutchings and Kristensen, 2016).

2.2.2. Model configuration

Data required as inputs to characterize the farms in the model can be in practice accessible from real farms. In the study the necessary data for modelling a farm representing each forage system were obtained from the field surveys. These data included fields and crop sequences, forages produced on-farm, dairy herd composition, manure storage, diet supplied to dairy cows, dry cows and heifers and milk yield. Each typology of forage systems was represented in FarmAC as an average model farm with the main characteristics reported in Tables 1 and 2. Considered on-farm forages (baseline situation) were grass (grazed, cut, silage or hay), and silage maize (except for the grazing farm that did not

Table 1
Average field area, field use, feed imported, and milk yield of current forage cropping systems models in Cantabria (North Spain), as identified through detailed surveys conducted in 40 dairy farms between October 2013 and March 2014.

	Grazing (G)	Zero-grazing (ZG)	Conserved forage (silage + hay) (CF)	Maize (> 20% of total field area) (SM)
Total field area (ha)	17	22	43	32
Number of dairy cows/heifers	28/9	23/9	45/13	67/20
Livestock units/ha	2.4	1.5	1.5	3.0
Grazed grassland area (%)	58	26	33	16
Grazed grassland by lactating cows area (%)	34	5	5	0
Maize area (%)	1	4	4	35
Grassland area (%)	99	96	95	65
Grassland, silage area (%)	51	46	53	59
Grassland, cutting area (%)	28	46	8	14
Grassland, hay area (%)	21	8	40	27
Feed bought[a] (Mg DM cow^{-1} $year^{-1}$)	4.7	2.9	3.9	4.6
Slurry storage	Open	Open	Open	Open
Average milk yield (Mg Milk cow^{-1} $year^{-1}$)	6.8	6.7	7.5	9.3

[a] Lactating cows only.