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An enteric methane emission calculator (DREEM) built to consider feed diversity: Case study of pastoral and sedentary farming systems

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ABSTRACT

Ruminant livestock systems are significant sources of greenhouse gases (GHG). Livestock farming in regions with extreme climatic events have to face both scarcity and variability in feed resources. Herd mobility is a known major adaptation strategy to address seasonal availability of forage resources: it allows an increase in herd size, thereby improving labor productivity. The present study quantifies enteric methane (CH_4) emissions from French Mediterranean sheep farming systems, focusing on the use of diversified pastoral feed resources, and developing a calculator (Diversity of feed REsources and Enteric Methane emissions, DREEM). The DREEM calculator was developed to estimate at the animal level enteric CH_4 emissions (g/day) from empirical equations and be subsequently integrated, as a sub-table, into an economic and GHG (kg/year) balance model (Outil de Simulation du TRoupeau ovin ALaitant, OSTRAL) at the whole farm level. Several equations were taken from the literature to estimate enteric CH_4 emissions in DREEM calculator. Nature of forage and feed, animal feeding levels and performance were referenced according to the animal feeding system and tables in France and taking into account the French Mediterranean area studied. DREEM was used to estimate enteric CH_4 emissions from four sheep farming systems covering the main contrasting mobility and situations, from sedentary to highly mobile pastoral systems, in the French Mediterranean area. At the individual level, enteric CH_4 emissions (g/day) of ewes in the sedentary system were slightly higher than those of ewes in other systems. These differences were due mainly to differences in animal feeding level (intake / body weight) and feed resources characteristics. Overall, enteric CH_4 emissions of ewes and rams were slightly lower than French national inventory estimates. When enteric CH_4 emissions of lambs were expressed in g/kg of carcass, were lower in the less pastoral farming systems than in the other systems, because lambs' average daily gains were higher. In double transhuming farming systems, lambs late slaughtering age led to lamb's CH_4 contribution of 15% vs 2–5% in the other systems. Flock management, which depends on land use and ownership, greatly contributed to these results.

1. Introduction

Livestock produces large amounts of greenhouse gases (GHG), among which enteric methane (CH_4) has been reported as one of the main anthropogenic GHG produced by ruminant production systems (Gerber et al., 2013; Steinfeld et al., 2006). Today livestock's contribution to climate change is a major issue in animal science, and many studies have been dedicated to mitigate CH_4 emissions (Doreau et al., 2014; Thomassen and de Boer, 2005). Small ruminant products constitute a relatively small share of globally produced ruminant meat and milk, about 17 and 4%, respectively (Opio et al., 2013). Globally, sheep production (meat and milk) is responsible for 59% of GHG emissions of small ruminants (Opio et al., 2013). Small ruminants' farms are responsible for 0.5 Gt CO_2-eq emissions, 1/3 of GHG emissions of bovine milk production, representing around 6.5% of GHG sector's emissions (Gerber et al., 2013; Opio et al., 2013). When emissions are expressed per unit of output produced, meat and milk from small ruminants represent the second and third highest emission intensities (165 and 112 kg CO_2-eq per kg protein, respectively) among the overall food of animal origin (Gerber et al., 2013). Moreover, the environmental implications of small ruminants systems are also more relevant considering that goat and sheep population is growing steadily worldwide + 22% in 2013 as compared to 2000 (FAO, 2015).

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Recent renewed interest in agropastoral practices has accompanied increased flock sizes in rangeland systems, and a greater contribution of pastoral forage in flock feeding in response to policy initiatives. Pastoralism and flock mobility, especially in sheep production systems, may be a good flock management practice for addressing climate hazards (Dutilly-Diane et al., 2006). Climate uncertainties affect animal feed resources both temporally and spatially, and flock mobility therefore offers a strategy for adapting to climate change: however, few studies relates to it as a potent mitigating GHG emissions strategy (Jouven et al., 2010; Vigan et al., 2017). Sheep production systems, especially in Mediterranean or pastoral areas, are sometimes confronted with a shortage of feed resources (Lasseur, 2005). Farmers thus often have to reconsider local pastoral knowledge and expertise to maintain animal production levels (Meuret and Provenza, 2015). Animal feeding in these agro-pastoral areas is based on the use of a range of forage resources (permanent pasture, forbs, grass, and legumes) that vary in quality and quantity over the year. These flock management practices interact with land use practices (Girard et al., 2001; Lasseur et al., 2013) and land property rights in agropastoral systems, which may limit the mitigation potential of flock mobility. Life cycle analysis (LCA) of Mediterranean systems was recently performed by Vigan et al. (2017), showing that sedentary and double transhumance systems had low carbon emissions. The authors concluded that in the sedentary system, higher animal productivity offsets the increase in GHG emissions caused by feed consumption, whereas in the pastoral system, grazing avoided indirect GHG emissions associated to concentrate consumption.

The impact of flock management practices on GHG, especially on enteric CH_4 is scarce in the literature. For the LCA study of Vigan et al. (2017) we specifically adapted a CH_4 calculator in order to accurately evaluate the impact of flock mobility on CH_4 emissions, as a component of the LCA analysis. The literature describes various methods for estimating enteric CH_4 emission from ruminants. These methods are based mainly on mathematical or biophysical models (Alemu et al., 2011; Sauvant and Nozière, 2016) and empirical equations (Ramin and Huhtanen, 2013; Sauvant and Giger Reverdin, 2007). Several studies have shown that feed quantity (dry matter intake), feed quality (energy digestibility), feeding levels (dry matter intake/body weight) (Ellis et al., 2009; Sauvant and Nozière, 2016) and physiological stages (Ramin and Huhtanen, 2013; Ricci et al., 2013) are the main factors driving enteric CH_4 production in the rumen of ruminants at the animal level. The DREEM (Diversity of feed REsources and Enteric Methane emissions) calculator was specially developed for the LCA study of Vigan et al. (2017). The present study describes DREEM calculator structure, the results when applied on 4 sheep farming systems and highlights the influences of the temporal variations of feed and of the animal categories on enteric CH_4 estimates used in LCA studies.

2. Materials & methods

2.1. Calculator development

The DREEM calculator was built with several equations and the relationships with the economic and GHG balance model at the farm level (OSTRAL) (Benoit et al., 2010; Vigan et al., 2017) are shown in Fig. 1. It estimates enteric CH_4 emission from sheep farming systems, based on yearly feeding calendar (on a week basis), and the physiological stage of each batch of animal category. It was meant to be combined with the OSTRAL model (Benoit et al., 2010) to replace the fixed enteric CH_4 emission factor (kg/year) of Vermorel et al. (2008). Enteric CH_4 is produced in ruminants' rumen, and is related to feed intake and feed quality. Several equations were therefore chosen from literature data (Vermorel et al., 2008; Sauvant et al., 2011) to assess the temporal impact of feed pattern, feed quality, feed quantity and feeding level from diets on enteric CH_4 emissions from sheep farming systems. Consequently, those influences were integrated and evaluated at a larger scale, the farm scale, in the study of Vigan et al. (2017), where the tradeoffs between the different GHG were taken into account. The structure of sheep farming systems (animal categories and flock size) and their management (breeding and feeding calendars) were modeled from OSTRAL (Benoit et al., 2010), and implemented with a detailed feeding calendar adapted for Mediterranean resources (CERPAM, 1996; INRA, 2007).

2.1.1. Daily feed intake estimates

In the DREEM calculator, daily intake estimates were based on the French national feed unit system (INRA, 2007). Dry matter intake (DMI) was estimated from the animal's energy requirements, according to its live weight and feeding conditions (INRA, 1978, 2007). Energy requirements' increase, was taken into account according to INRA feed requirement and ruminants nutrition principles (INRA, 1978). Physical activity induces additional energetic expenditures, which are estimated based on the speed of animals 'movement and on the slope of the hill they climbed. For sheep, when animals were on rangelands with no slope, energetic requirements for maintenance were increased by 5 to 15%. When the slope was higher it was increased by 40%. Additionally, daily intake of grazing ewes during the maintenance period was estimated based on expert skills to evaluate DREEM calculator results (Meuret and Provenza, 2015; Appendix B). We obtained ranges of digestible organic matter intake (DOMI) that took into account the broad variations in feeding level observed in free rangeland conditions. Estimates were built considering the impact of previous diets, the season of grazing, and availability of feed resources. Finally, daily concentrate and forage intakes (group fed animals) were provided by farmers in the four farming systems, and we did not take into account intake variability between animals within a group.

2.1.2. Enteric CH_4 emission equations used in the DREEM calculator

Four equations were specifically chosen from the literature to estimate enteric CH_4 emissions (Table 1). The first one was based on an inventory of French CH_4 emissions from small ruminants (Vermorel et al., 2008), which is an official statement for IPCC. The other three were chosen from a meta-analysis of a large literature database on CH_4 emission from ruminants (Sauvant et al., 2011). They were established from a large database built from selected publications based on 167 *in vivo* calorimetric studies of enteric CH_4 and energy balance from ruminants (cattle, sheep and goats). Treatments (1 131) from this database were mainly dietary from various feeding practices with high and low concentrate and/or forage proportions in the diet. The other available quantitative data selected were organic matter (OM) digestibility (OMD, %), DMI (kg), animal body weight (BW, kg) and feeding level (FL, is DMI (kg) expressed as a percentage of BW (kg)). Some chemical composition parameters of the diet were also selected, such as crude protein (CP) and neutral detergent fibre (NDF) contents of the diet, and concentrate percentage (CON%) in the diet.

The four equations were chosen because they were based on different parameters that allowed different ways to estimate enteric CH_4 emissions and that are more sensitive to changes in the diet, but may be hard to collect accurately. Moreover, in this study, the digestive interaction factor was taken into account to adjust OMD, for the sheep species, as reported by Chapoutot et al. (2013).

A last equation was used to estimate enteric CH_4 emissions from lambs. This equation was based on lambs' age at slaughter and the amount of concentrates (CO, kg) fed to them in one year. For ewe lambs (< 1 year), it was decided to use a fixed value for all four systems, based on Vermorel et al. (2008) (Table 1).

2.1.3. Description of feed pattern in feeding calendar

To determine enteric CH_4 estimates using the DREEM calculator, the nature of the feed used in the case study had to be known, as precisely as possible to increase accuracy. Feed pattern was determined by a farm survey using a weekly feeding calendar detailing one year of a farming