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Evaluating livestock mobility as a strategy for climate change mitigation: Combining models to address the specificities of pastoral systems

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ABSTRACT

Pastoral farming systems have always adapted to the seasonal availability of forage resources and climate variability by moving animals. However, the role of animal mobility as a possible mitigating strategy in response to climate change has not been clearly documented. To understand this role, we investigated *(i)* the major methodological challenges linked to the diversity of grazing areas and other forage resources exploited by these systems and enteric emissions of methane; *(ii)* the impacts of grazing practices (carbon sequestration/emission) on soil and biomass carbon fluxes. We developed an approach based on two existing models (OSTRAL: *Outil de Simulation du TRoupeau ovin ALlaitant* and CASA: Carnegie Ames Stanford Approach) that we adapted and used in combination. This approach was applied to three French Mediterranean sheep and crop farming systems with different degrees of flock mobility (sedentary, single transhumance and double transhumance). The preliminary results produced by the whole farm model OSTRAL showed that two systems (sedentary and double transhumance) causing low carbon emissions. In the sedentary system, higher animal productivity offsets the increase in GHG emissions (in CO_2eq) caused by feed production. In the pastoral system, grazing reduced total GHG emissions (in CO_2eq). The CASA model proved to be useful to simulate the carbon balance under dynamic land cover in natural environments, whether used for grazing or not. This model can help assess the impact of grazing practices and carbon fluxes in systems linked to natural environments. The results of the first application showed that seasonal mobility of livestock increases the contribution of rangeland to feeding systems and improves the non-renewable energy balance of the system. It is thus extremely important to include the specificities of animals grazing in rangelands outside the structural limits of the farm when evaluating GHG emissions.

1. Introduction

The livelihoods of livestock farmers are particularly threatened in regions where a decrease in annual rainfall and an increase in the frequency of extreme climate events are expected. This is the case in marginal highland areas where livestock farming is common and where livestock producers are already vulnerable. Over the ages, farmers and their animals have developed adaptive capacities to face spatial and temporal scarcity and variability of pastoral resources such as water or forage. Animal mobility is one of the main strategies used in different forms: single or double transhumance, or moving herds around the farm.

Abbreviations: ADEME, French Environment and Energy Management Agency (*Agence de l'Environnement et de la Maîtrise de l'Energie*); BW, body weight; CASA, Carnegie Ames Stanford Approach; CH_4, methane; CO%, the proportion of concentrate; CO_2, carbon dioxide; CO_2eq, carbon dioxide equivalent; CW, carcass weight; DGVM, dynamic global vegetation model; DM, dry matter; DMI, dry matter intake; dOM, digestibility of organic matter; DOM, digested organic matter; DOMI, digestible organic matter intake; DREEM, Diversity of feed REssources and Enteric Methane emissions; fc, field capacity; fPAR, fraction of intercepted photosynthetically active radiation; FU, Feed Unit (defined by INRA) for the energy content of feed and for animal feeding needs; GE, gross energy; GHG, greenhouse gases; hResp, soil respiration; INRA, French National Institute for Agricultural Research (*Institut National de la Recherche Agronomique*); LCA, life cycle assessment; LCCM, land cover change module; LULCC, land use land cover change; ME, metabolizable energy; N_2O, nitrous oxide; NDVI, normalized difference vegetation index; NEP, net ecosystem production; NPP, net primary production; NRE, non-renewable energy; OM, organic matter; OSTRAL, Outil de Simulation du TRoupeau ovin ALlaitant and CASA; PAR, photosynthetically active radiation

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Modeling has already demonstrated that livestock mobility is a useful way to face climate variability (Martin et al., 2014). However its precise role in mitigating greenhouse gas (GHG) emissions is not yet known. Unlike strategies that consist in mobilizing external resources or involving significant non-renewable energy (NRE) consumption and GHG emissions for the production and storage of feed, the practice of moving animals around outside the structural limits of the farm is likely to minimize emissions. Although the contribution of the livestock sector to GHG emissions has been underlined for several years by numerous models and in published studies (e.g. Crosson et al., 2011), and several authors have analyzed the advantages of various mitigation strategies (Vellinga et al., 2011; Del Prado et al., 2013; Martin and Willaume, 2016), no study has yet considered livestock mobility as a way to increase the proportion of feed intake from grazing rangelands and to take advantage of heterogeneous landscapes and climate niches.

Compared to the assessment of the environmental performance of sedentary/intensive systems, two major methodological challenges need to be overcome to assess livestock mobility as a climate change mitigation strategy. This is mainly due to the diversity of grazing areas and unconventional forage resources exploited by mobile livestock systems. It is also due to the different combinations of resources mobilized on the farm and beyond and consequently the diversity of systems included in the broad definition of "pastoral systems". The first environmental aspect is methane (CH_4) emissions. A high proportion of the animals' diet is obtained extensively in the "natural" ecosystem, but the diversity of this primary biomass is not referenced in conventional models of CH_4 emissions. The second challenge that needs to be addressed is carbon sequestration/emission resulting from these farming practices. By managing their livestock's grazing, farmers have shaped and continue to maintain dynamic landscapes. In addition to direct GHG emissions from livestock, the effects of alternative uses of grazed rangelands (natural grasslands, heath, and forest) need to be included in the analysis, and the impacts of such practices on soil and carbon biomass fluxes need to be taken into account.

The objective of this paper is to discuss methodological challenges and to propose a method to integrate the particularities of pastoral systems in the evaluation of GHG emissions. To this end, we developed an approach based on a combination of models and applied them to three contrasted farms in the southern part of the Mediterranean region of France to provide preliminary results and derive methodological implications. Modeling is mainly used as a tool to simulate livestock GHG emissions with OSTRAL (*Outil de Simulation du TRoupeau ovin ALlaitant*). A sub-model, DREEM (Diversity of feed REssources and Enteric Methane emissions) was then developed to tackle enteric CH_4 emissions in systems that include animal mobility in their resource uses. Finally, an existing model for ecosystem biogeochemical carbon cycling, CASA (Carnegie Ames Stanford Approach) was adapted to capture the effects of grazed rangeland ecosystems on GHG emissions/sequestration. The following section describes these models and details the adjustments that made it possible to incorporate the specificities of mobile livestock farming in the modeling chain. Two types of results are then presented. On the one hand, GHG emission/sequestration results from the sequential modeling approach using DREEM and CASA are compared to the emissions/sequestration results from the initial version of OSTRAL to identify the differences between the two methods and to analyze the performances of this approach in more detail. On the other hand, the comparison of three French Mediterranean farms (sedentary, single or double transhumance) supplies insights into the influence of mobility and the contribution of grazed forage from rangelands on environmental performances. Methodological implications and future research areas are discussed in the concluding section.

2. Materials and methods

Several models were combined: the main model was OSTRAL, a simulator for meat sheep farms. This model was chosen as it is used in many French sheep breeding situations, with a systemic approach (at farm scale) and includes an environmental approach (GHG emissions and energy consumption) in the assessment of the performance of the farming systems. This model matched our objectives and was easy to combine with the biogeochemical cycle modeling (CASA). The CASA model was chosen to reinforce the evaluation of grazing uncultivated areas and improve our understanding of carbon sequestration in these areas. We also designed a new model (DREEM) especially for this study to account for enteric CH_4 emissions, where our aim was to make it easy to combine with the OSTRAL model. This section describes how the central OSTRAL model was fed with outputs from the DREEM and CASA models, including enteric CH_4 emissions from the DREEM model and carbon emission and sequestration in grazed rangeland areas from the CASA model to obtain final outputs at the level of the farming system: *(i)* the GHG balance and *(ii)* the non-renewable energy balance (NRE).

2.1. Original models, adaptations and combinations to include animal mobility

2.1.1. OSTRAL

The OSTRAL model simulates the functioning of sheep farms for meat production, with the aim of calculating their technical and environmental performances. A central module is designed to represent the steady state functioning of the flock (batches of animals, reproduction, and organization) at the scale of one year (12 months) (Benoit, 1998). The simulation model is suitable for the majority of the French and European sheep farming systems (Benoit, 1998; Benoit and Laignel, 2010). Several additional modules are connected to the core module; the ones used in this study are described below:

- An animal feeding module: because of the wide range of agro-ecological contexts of sheep farming and because the aim was to develop a "generic" tool that works in a range of different environments, there is no *a priori* qualitative estimation of the resources or links with the needs of the flock. The user decides on the diets for each batch of animals, depending on *(i)* expected performances; *(ii)* knowledge of the characteristics of the environment and resources; *(iii)* the expected stages of mobilization or reconstitution of body reserves by the animals;
- A land management module: the levels of nitrogen, phosphorus and potassium fertilization are defined for each managed area, crop yields, and the stocking rate. These are used to calculate the surface area of each type of land required;
- A mechanization module: description of the farm equipment used for harvesting, manure spreading, etc. The equipment and its cost and amortization as well as environmental costs in a life cycle analysis (LCA) are estimated along with the volume of use (as a function of the surface area, hours of use, etc.). Other facilities including buildings are also estimated;
- GHG emissions and NRE consumption module: emissions and energy consumption are calculated using an LCA approach and based on the Dia'Terre tool developed by ADEME, the French Environment and Energy Management Agency (ADEME, 2013). This model takes into account carbon sequestration in cropland, temporary pasture, grassland and rangeland according to the equations of Arrouays et al. (2002). However, according to Dollé et al. (2015), it contains up-scaled values of carbon sequestration by grassland. Enteric CH_4 is usually estimated using the overall coefficient, 11 kg CH_4 yr^{-1} per ewe (live weight 65 kg), 14.7 kg CH_4 yr^{-1} per ram (live weight 110 kg) (Vermorel, 1997) and 9.3 kg CH_4 yr^{-1} per ewe lamb between birth and first lambing (at 15 months) (Vermorel et al., 2008), for a 65 kg ewe. We modified this level of emission according to the average weight of the ewes of the flock. The extrapolation is based on the metabolic weight of the ewe (body weight $^{0.75}$), on the basis of 9.3 kg CH_4 yr^{-1}. For example, for