Preliminary report on the applicability of process-oriented models for GHG reporting

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1. Introduction

Simulation models of on-farm greenhouse gas (GHG) emissions have an important role to play in understanding the potential impact of mitigation strategies on farm systems. These models can also be used to incorporate experimental measurements of GHG emissions to assess wider implications and potential trade-offs for the total system. In 2017, an international project entitled: *Capturing the Effects of Diet on Emissions from Ruminant Systems* (CEDERS) started. The main goals of CEDERS are (1) to examine dietary effects on on-farm GHG emissions and their trade-offs, both at the farm and national scales, (2) to support GHG mitigation research and (3) to align national agricultural GHG inventory research across a consortium of ten countries (Chile, Denmark, Finland, France, Germany, Ireland, Netherlands, New Zealand, Sweden and United Kingdom).

This short report is part of the CEDERS project and specifically aims to a) identify the most common on-farm GHG accounting tools used by the participating countries, b) explore the livestock GHG accounting approach used by these tools, and c) understand the potential benefits of adding further diet characteristics to on-farm GHG accounting tools for dairy cattle systems. The focus is on methane (CH_4) emissions from enteric and manure management sources and nitrous oxide (N_2O) emissions from excreta and manure management sources.

2. Approach

On-farm GHG tools can be classified into four major categories: calculators, protocols, guidelines and models. This review focuses on farm calculators, animal models and farm-scale models (herein ***on-farm GHG models***) that have either been developed to aid estimation of enteric fermentation (the prevalent source of GHG from ruminant systems), or developed with the aim of quantifying GHG emissions from ruminant systems under varying animal nutrition.

We selected on-farm and animal models from CEDERS participant countries based on published literature as well as the level of adoption and use of the models. Information on these models was either publicly available or provided by experienced users in the participant countries. For each on-farm model, we evaluated the key GHG sources, as well as the way the model included diet characteristics and digestion kinetics in calculating enteric CH_4 and manure-derived CH_4 and N_2O.

It is important to note that most of the available models, and all those selected in this review, were developed for temperate conditions and associated animal breeds and feed nutritive values. These models often focused on adult Holstein-Friesian and Jersey cattle under grazed and/or housed European and New Zealand conditions.

3. Results

In most ruminant systems, the prevailing source of GHG emissions is enteric CH_4 from fermentation of feed in the rumen. N_2O emission from animal excreta is the second most important GHG source in ruminant systems, followed by CH_4 emissions from manure. On-farm models generally use one of three generic approaches for estimating CH_4 and N_2O emissions from livestock systems that highlight the effects of diet characteristics on GHG emissions. The three approaches (herein Types) differ in the aim of what the model is trying to predict and quantify. This is reflected by the degree of diet-related details that are represented and is often associated with the number of variables used and the modelling approach that was chosen. A Type 1 approach does not include any diet-related details, while Type 2 and 3 approaches include progressively greater detail. Most selected on-farm GHG models adopted a Type 2 approach largely through the use of CH_4 and N_2O emission factors (EF). Recently, a few hybrid Type 2/Type 3 approaches have been adopted, which combine empirical modelling (through the use of either CH_4 or N_2O EF) and process-based modelling (mostly of rumen and whole tract fermentation and digestion).

An essential first step to accurately predict GHG emissions is to obtain an accurate estimate of dry matter intake (DMI) because it is such an overriding factor in assessing enteric CH_4 emissions. Moreover, DMI is also a major driver for manure excretion (and consequently manure CH_4 emissions) and N excretion, the major predictor of N_2O emissions. All models we reviewed estimated DMI from either feed tables or based on animal energy requirements and feed energy concentration, although in principle, more sophisticated feed intake models could be used. A second step in this process is the incorporation of acceptable EF values (i.e., CH_4 per unit of DMI and per unit of faecal excreta at grazing, CH_4 and N_2O per unit of animal excreta and manure management). Emission factors are often obtained from literature surveys, databases of experimental data (Type 2 approach), or based on predictions from process-based models that are explanatory and consider further details (Type 3 approach).

Empirical models that include commonly measured dietary inputs can predict CH_4 and N_2O emissions reasonably accurately. Type 2 models can capture a varying range of diet characteristics, including total DMI, organic matter digestibility (OMD), metabolisable energy (ME) and gross energy (GE), and concentration of lipids, crude protein (CP), dietary carbohydrate fractions, and dietary forage and concentrate proportion. Most models then use a CH_4 EF (g CH_4 kg^{-1} DMI) and a N_2O EF (N_2O-N emitted as % of N excreted) to estimate GHG emissions. Some models include different CH_4 EF for different diets or dietary ingredients (e.g., DairyWise, Schils et al. (2007)) rather than CH_4 EF purely based on animal species (e.g., OverseerFM, Wheeler et al. (2008)). However, the impact of dietary mitigation strategies to reduce CH_4 and N_2O emissions needs to be assessed in a more holistic way, and empirical models (Type 1 and Type 2) often do not have the biological foundation to do this. Only Type 3 models can represent underlying mechanisms such as ruminal fermentation, total-tract digestive processes and excreta composition (e.g., Karoline, Danfaer et al. (2006); Dairy Tier 3, Dijkstra et al. (1992); Whole Farm Model, Beukes et al. (2010)). This requires a proper representation of volatile fatty acid production and absorption kinetics, ruminal digestibility of, and competition for, different substrates, bypass fractions, and the rate of fermentation, as well as adequate descriptions of OM chemical composition.

Recently, DairyWise was updated by making use of Dairy Tier 3 simulation results. Lookup tables for enteric CH_4 EF of feedstuffs and diet ingredients have been derived, including a correction for DMI, diet type and roughage quality (Bannink et al., 2020). Furthermore, DN levels were corrected downwards to become more realistic (Bannink et al., 2018).

4. Key findings

In general, the better a model can simulate rumen function (ruminal degradation characteristics and end-products of fermentation), the greater the opportunity to capture diet characteristics beyond the common variables DMI or OMD. This leads to more accurate on-farm GHG predictions, and an increased ability to capture dietary mitigation strategies.

Process-based models can be used as a Tier 3 model for national emission reporting, but such models require an increasing number of dietary characteristics as input variables to predict CH_4 and N_2O emissions. Although this increases opportunities for capturing dietary mitigation strategies, the need for additional input and activity data should be carefully balanced against any gains in the accuracy of the estimates. For the largely pasture-based systems in New Zealand these gains may be restricted due to the limited variability in ration composition and feed characteristics. However, as pasture can vary in ME content and the use alternative forages and supplements is increasing, better capturing the effect of ration composition and ME content in on-farm models will provide more accurate farm-specific GHG estimates. Any improvements to on-farm models will also need to be balanced against the need for consistency between different approaches used for different purposes (inventory vs. on-farm accounting vs. carbon foot printing and Life Cycle Analysis).

5. Acknowledgements

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6. References

Bannink, A., Spek, W.J., Dijkstra, J., Šebek, L.B.J., 2018. A Tier 3 method for enteric methane in dairy cows applied for fecal N digestibility in the ammonia inventory. Frontiers in Sustainable Food Systems 2, 66.

Bannink, A., Zom, R.L.G., Groenestein, K.C., Dijkstra, J., Sebek, L.B.J., 2020. Applying a mechanistic fermentation and digestion model for dairy cows with emission and nutrient cycling inventory and accounting methodology. Animal 14:S2, s406-s416.

Beukes, P.C., Gregorini, P., Romera, A.J., Levy, G., Waghorn, G.C., 2010. Improving production efficiency as a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand. Agriculture, Ecosystems and Environment 136, 358-365.

Danfaer, A., Huhtanen, P., Uden, P., Sveinbjornsson, J., Volden, H., 2006a. The Nordic dairy cow model, Karoline - description. In: Kebreab, E., Dijkstra, J., Bannink, A., Gerrits, W.J., France, J. (Eds.), Nutrient digestion and utilization in farm animals: modelling approaches. CABI Publishing, Wallingford, pp. 383-406.

Dijkstra, J., Neal, H.D.S.C., Beever, D.E., France, J., 1992. Simulation of nutrient digestion, absorption and outflow in the rumen: model description. Journal of Nutrition 122, 2239-2256.

Schils, R.L.M., de Haan, M.H.A., Hemmer, J.G.A., van den Pol-van Dasselaar, A., de Boer, J.A., Evers, A.G., Holshof, G., van Middelkoop, J.C., Zom, R.L.G., 2007. DairyWise, a whole-farm dairy model. Journal of Dairy Science 90, 5334-5346.

Wheeler, D.M., Ledgard, S.F., DeKlein, C.A.M., 2008. Using the OVERSEER nutrient budget model to estimate on-farm greenhouse gas emissions. Australian Journal of Experimental Agriculture 48, 99-103.