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Short communication: Identifying key parameters for modelling the impacts of livestock health conditions on greenhouse gas emissions

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ABSTRACT

Improved animal health can reduce greenhouse gas (**GHG**) emissions intensity in livestock systems while increasing productivity. Integrated modelling of disease impacts on farm-scale emissions is important in identifying effective health strategies to reduce emissions. However, it requires that modellers understand the pathways linking animal health to emissions and how these might be incorporated into models. A key barrier to meeting this need has been the lack of a framework to facilitate effective exchange of knowledge and data between animal health experts and emissions modellers. Here, these two communities engaged in workshops, online exchanges and a survey to i) identify a comprehensive list of disease-related model parameters and ii) test its application to evaluating models. Fifty-six parameters were identified and proved effective in assessing the potential of farm-scale models to characterise livestock disease impacts on GHG emissions. Easy wins for the emissions models surveyed include characterising disease impacts related to feeding.
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Implications

A comprehensive list of model parameters required to fully characterise interactions between animal health conditions and dairy farming systems is presented. A preliminary assessment of emissions models demonstrates how the parameters can be used to assess the extent to which farm-scale models incorporate the impacts of health conditions and management responses to them. The list provides a shared framework facilitating collaboration between emissions modellers and animal health experts to better characterise the impact of animal health on greenhouse gas emissions. This is a vital step towards identifying the most effective farm management actions to reduce disease-related emissions from dairy systems.

Introduction

There is increasing recognition of the urgency of reducing greenhouse gas (**GHG**) emissions from livestock farming (Gerber et al., 2013). Tackling animal health conditions presents an opportunity to reduce emissions intensity from livestock systems while improving production efficiency (Gerber et al., 2013). To reduce disease-related GHG emissions effectively, an integrated assessment of health impacts on emissions is essential and can be achieved using whole farm system models (Özkan Gülzari et al., 2018). Recent literature highlights barriers to improving such modelling, including data availability, data quality and challenges of interdisciplinary communication (Kipling et al., 2016; Özkan et al., 2016). To fully characterise the impacts of health conditions on GHG emissions, farm-scale models need to incorporate the different ways health conditions interact with farming systems. While life cycle assessment studies – e.g., MacLeod et al. (2018) have A preliminary assessment of emissions impacts of disease and its control, a comprehensive list of disease-related model parameters has not

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been presented and compared with existing model coverage. Defining disease/farm system interactions in the language of model parameters would facilitate the communication of needs between modellers and experimental researchers, enable current farm-scale models to be assessed for their potential to incorporate the impacts of health conditions on emissions, and support improvements in the inter-compatibility of disease models and GHG emissions models. Since global emissions from cattle constitute around 65% of livestock GHG emissions (Gerber et al., 2013), we focus on dairy cattle as an exemplar. Here, our objectives are to:

i) Present a comprehensive list of model parameters representing interactions between health conditions and dairy farming systems; and.
ii) Demonstrate the value of the identified parameters in assessing the extent to which emissions models incorporate (or have the potential to incorporate) health conditions.

The level and nature of the parameters defined is such that they could form a basis for modelling the emissions impacts of disease in any dairy system, albeit that some country-specific health conditions and systems might require some additions to the list.

Material and methods

The steps taken to achieve objectives i and ii (Fig. 1) originated from previous work exploring challenges and priorities for livestock health modellers in relation to climate change (Özkan et al., 2016). In the process reported here, health experts and farm-scale modellers within a working group (18 modellers) of the Modelling European Agriculture with Climate change for Food Security (MACSUR) project, a Joint Programming Initiative on Agriculture, Food Security and Climate Change (JPI FACCE), prioritised actions for the group, establishing the importance of developing a comprehensive list of model parameters for characterising livestock health conditions (objective i) (see summary of initial workshop outcomes in Supplementary Material S1).

A small-scale, facilitated workshop (two animal health experts, two modellers and a social scientist) was then held to i) define health conditions affecting cattle; ii) identify the on-farm variables, including management responses, affecting and affected by each condition (variables relevant to both housed and grassland-based dairy systems were covered to ensure comprehensive coverage); iii) convert the variables described into parameters deemed practical for modelling, working through any misunderstandings between modellers and animal health experts. Such challenges mainly centred on converting the knowledge of animal health experts – for example, of disease symptoms – into forms that could be conceptualised as parameters by modellers, while not losing any characteristics of the conditions. The small size of the workshop enabled a working through of differences in perspective between disciplines in a manageable way to form a parameter list that bridged the disciplinary divide. The draft list was then distributed to animal health experts at Moredun Research Institute (United Kingdom) to verify that the parameters defined for were correct and complete. Parameters were adjusted and updated to reflect these comments, and the updated list was shared with the MACSUR group to verify the practical value of the parameters for modelling purposes (see Supplementary Material S1 for details of changes made).

A survey was sent to modellers within the group working on six models selected purposefully to test the utility of the identified parameters for assessing model capacity across a range of relevant model

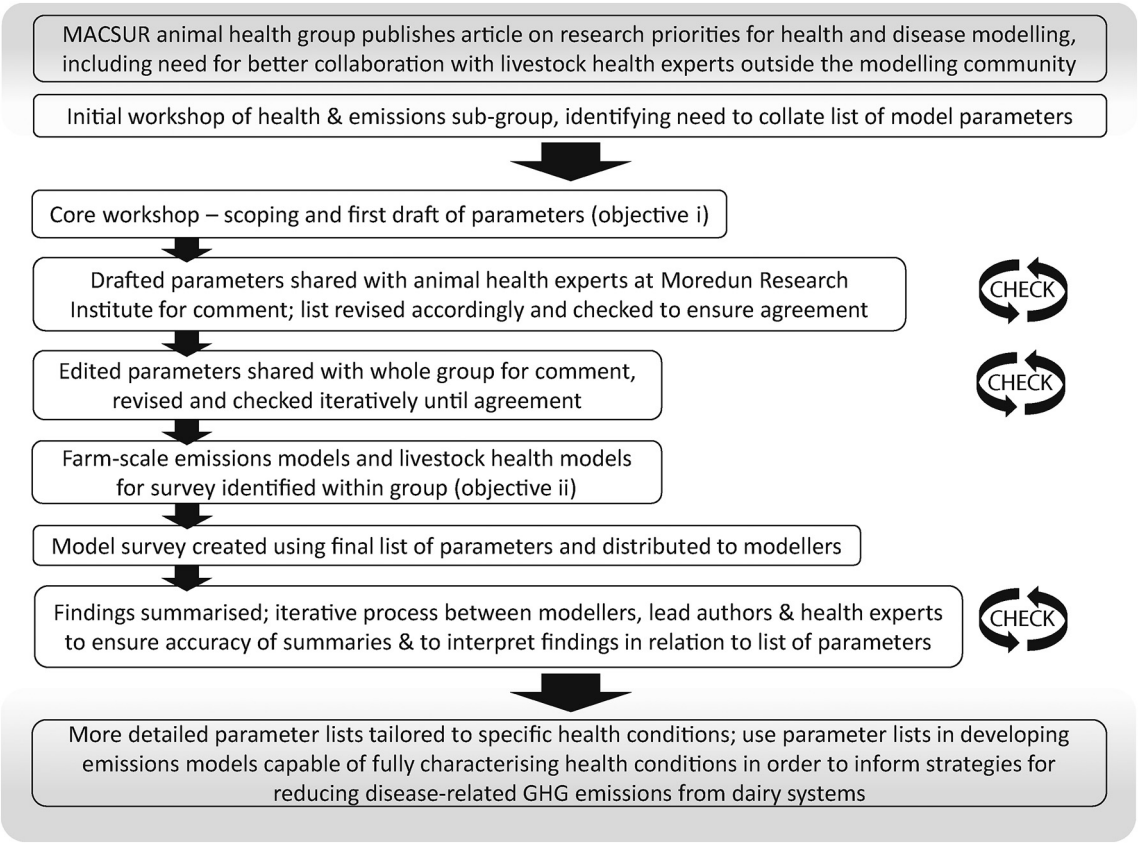

Fig. 1. Overview of research process by which the modelling parameters affecting and affected by cattle health were transpired. Grey areas indicate actions undertaken before and anticipated to follow the activities presented here (white areas). Supplementary Material S1 includes further details of each step. GHG: greenhouse gas, MACSUR: Modelling European Agriculture with Climate Change for Food Security.

types (objective ii). Specifically, the purpose was to test how well the parameter list enabled assessment of: 1) the potential for farm-scale emissions models to incorporate disease, 2) the extent to which global scale emissions modelling and 3) farm-scale production models incorporating disease captured the different aspects of health conditions. Three of the surveyed models were farm-scale emissions models not previously used to characterise health conditions: MELODIE (Chardon et al., 2012), DairyWise (Schils et al., 2007) and FarmAC (Hutchings and Kristensen, 2015). The fourth was a farm-scale emissions model, HolosNor (Bonesmo et al., 2013) previously applied to assess the impact of subclinical mastitis on GHG emissions intensity (Özkan Gülzari et al., 2018). The fifth model, the Global Livestock Environmental Assessment Model (GLEAM) had been used to evaluate the effects of Trypanosomiasis on GHG emissions in East Africa (MacLeod et al., 2018). Finally, SimHerd (Østergaard et al., 2005) was designed to model diseases and their interactions but was limited in terms of modelling GHG emissions, estimating only enteric methane (CH_4) emissions (see Supplementary Material S1 for further model details).

Respondents were asked to state whether and how each identified parameter was represented in their model. To guide responses, three levels of representation were defined: i) manual input (parameter can be defined manually by the user as an input variable, rather than being calculated within the model); ii) empirical modelling (parameter value is the output of endogenous calculation based on an empirically derived statistical relationship between variables, without modelling of the processes which drive this relationship); iii) mechanistic modelling (parameter value is determined endogenously using a mechanistic representation which incorporates the drivers for this parameter value (Kipling et al., 2016)).

Results and discussion

Animal health conditions were defined broadly to cover both infectious and non-infectious (including conditions such as heat stress) diseases. Fifty-six model parameters were defined. These parameters (Supplementary Table S1) were grouped into 29 themes within three categories: parameters affected by health (Table 1), parameters affecting health (Table 2) and management response parameters. Management response parameters formed five themes: environmental, economic or health-related triggers for changes in management; limitations on available management changes; variation in timing of management change.

For some parameters, different commonly used definitions exist. In the full list, we provide suggested definitions (Supplementary Table S1), but the intention is for users to adapt these definitions to their own needs. The purpose is to include all elements of interaction between health conditions and farming systems, not to impose new standard definitions of parameters. As such, there is some overlap in aspects covered by different parameters (e.g. between conception rate and fertility rate), to provide flexibility for different interpretations.

The three categories of parameter differ in their implications for modelling. If 'Parameters affected by health' are included in the model, at the simplest level there is potential to simulate the impacts of health conditions on GHG emissions by manual alteration of these parameters (e.g., the impact of heat stress on feed intake could be characterised by manual alteration of feed parameters in a model). In contrast, for parameters affecting health (e.g. genotype), inclusion is necessary, but not sufficient to simulate health impacts. This is because a model also needs to include a mechanism linking such parameters to changes in health-affected parameters such as mortality or milk yield. For example, manure management can affect health if pathogens survive in excreta (such as *Mycobacterium avium paratuberculosis* which causes Johne's disease), so that effluent spread on pastures becomes a source of infection for grazing cattle. Manure management is often included in emissions models but without a mechanism for this to affect health and subsequently milk yield. In the same way, 'management responses' must be linked to changes in 'parameters affected by health'. Therefore, identifying parameters is a starting point to exploring how such parameters need to be linked to fully characterise disease.

Survey responses indicated that all models included at least some of the parameters affected by health (Table 1). In MELODIE, inclusion of most of these parameters is indirect via the GEDEMO model, which

Table 1
Coverage of parameters affected by cattle health in surveyed models. I: user input, E: empirical modelling, M: mechanistic modelling, GLEAM: Global Livestock Environmental Assessment Model.

Affected parameter themes	MELODIE	HolosNor	DairyWise[1]	FarmAC	GLEAM	SimHerd
Feeding	Intake (specific life stages (M); feed requirement (specific functions) (E/M)	Intake (specific life stages) (E), feed requirement (specific functions) (E)	Intake (specific life stages) (I/E), digestion (E) & feed requirement (specific functions) (E)	Intake (specific life stages) (M), digestion (M) & feed requirement (specific functions) (E)	Intake (specific life stages) (E), grazing behaviour (level of activity) (I) digestion (E), feed requirement (specific functions) (E)	Intake (specific life stages), digestion & feed requirement (specific functions) (M)
Live weight	Daily gain (I)	Live weight (I), at slaughter (I)	Daily gain (E)	Daily gain (M), at slaughter (M), at first parturition (M)	Daily gain, at slaughter, at first parturition (E)	Daily gain, at slaughter, at first parturition (M)
Condition	–	–	–	–	–	Body conformation (M)
Mortality	(I)	–	–	(I)	(I)	(M)
Reproduction	Fertility rate (I)	–	–	–	Fertility rate (I)	Conception rate (M)
Age	First parturition (I)	–	–	–	First parturition, slaughter (I)	First parturition, slaughter (M)
Calving	Calving interval (I)	Calving interval via number of days in milking and dry (I)	Calving interval (I)	–	Calving rate & interval (I), loss of progeny (I), abortion/stillborn rates (I)	Calving rate & interval (M), loss of progeny (M), abortion/stillborn rates, prolificacy (M)
Milk yield	Herd level (M)	Herd/animal level (I)	Herd/animal level (I/E)	Herd/animal level (M)	Herd/animal level (I)	Herd/animal level (M)
Milk quality	(M)	(I)	(I/E)	(I)	(I)	(M)
Carcass	Quantity (M)	Quantity (I)	Quantity (E)	–	Quantity (M)	Quantity (M)
Condemnation rate of products	–	Discarded milk via % of kg milk produced (I)	–	–	–	Discarded milk (M)

[1] In DairyWise the user can choose to run the model with system products as inputs and feed intake as the output, or vice versa.

Table 2
Coverage of parameters affecting cattle health in assessed models. I: user input, E: empirical modelling, M: mechanistic modelling, GLEAM: Global Livestock Environmental Assessment Model.

Parameters affecting health conditions	MELODIE	HolosNor	DairyWise[1]	FarmAC	GLEAM	SimHerd
Genotype	–	Breed (I)	–	–	–	–
Environmental conditions	External environmental conditions (I)	External environmental conditions (I)	–	Housing environment (I)	External environmental conditions (E)	External environmental conditions (I)
Contagion	–	–	–	–	–	From environment, between animals (M)
Culling rate	(I)	(I)	(I/E)	–	(I)	(M)
Replacement rate	(I)	–	(I)	–	(I)	(M)
Feeding strategy	Feed type (I); Diet change through life (M)	Feed type (I)	Feed type (I); Timing (I); Diet change through life (I/E)	Feed type (I); Diet change through life (I)	Feed type (I/E), Diet change through life (can change for different cohorts) (I)	Feed type, Diet change through life (I)
Cattle use for labour	–	–	–	–	(I)	–
Housing and grazing strategies	% time housed / grazed (I)	% time grazed (I)	% time housed / grazed (I)	% time housed / grazed (E)	–	% time housed / grazed (I)
Insemination strategy	(I)	–	–	–	–	(I)
Manure management	(I)	(I)	(I)	(M) including management options	(I)	–
Milking conditions	–	–	–	–	–	–
Water management	–	–	(I)	–	–	–
Herd Management	(I)	(I)	–	–	(I)	(I)

[1] In DairyWise, the user can choose to run the model with system products as inputs and feed intake as the output, or vice versa.

generates a demography matrix for the dairy herd as an input file. Across all models, the most comprehensive coverage was of parameters in the feeding and live weight themes, although the level of coverage and the number of parameters covered varied. Several parameters affecting health (e.g., environmental conditions, feeding strategy) were incorporated in the models sampled (Table 2) but these were not necessarily connected to other parameters in ways that characterised all pathways for disease impact.

As the only model in the sample designed to incorporate economic impacts of health conditions, SimHerd was assessed for its potential to characterise management responses to disease. The main response modelled is culling rate which is i) directly altered by disease incidence and ii) indirectly altered through the impacts of disease on milk yield, with yield reductions triggering changes in culling rate. However, in terms of GHG emissions, SimHerd only characterises CH_4 emissions relating to feed intake (including the effects of disease-related changes on intake) and does not include other important GHGs such as nitrous oxide and carbon dioxide (CO_2). This limitation is important as changes in feed intake will also affect CO_2 emissions associated with feed production and supply, while diseases can have direct physiological impacts on emissions, in addition to feed-related impacts.

Limitations

The disease-related parameters identified were effective for gaining an overview of the potential of models to incorporate health conditions into emissions modelling. However, this initial study revealed the following challenges:

Work remains to better characterise some broadly defined parameters, particularly parameters affecting health (e.g., to develop a full list of external environmental conditions affecting health) and to create condition-specific lists highlighting the subsets of parameters most relevant to particularly important diseases for dairy systems, such as mastitis.

Characterisation of model coverage of parameters using three levels (input, empirical, mechanistic) was relatively uncontentious at the input and empirical level but was more problematic at the mechanistic level. As modelled relationships are multilayered, mechanistic modelling at one level will rely at some more detailed level on assumption or empirical characterisation. For example, modelling of aspects of feeding labelled as 'M' in Table 1 is unlikely to represent full mechanistic modelling of the entire digestive process of an animal. SimHerd, for example, uses mechanistic modelling of many parameters at herd level based on empirical modelling at individual animal level. Therefore, this categorisation requires deeper investigation to get a firm idea of what is present and what is missing in the modelling of the parameters involved.

Conclusion

The list of disease-related model parameters presented here provides a basis for collaboration between research disciplines to enable modellers to incorporate health conditions into emissions modelling, with the ultimate goal of identifying the most effective strategies for reducing disease-related GHG emissions from dairy systems. Further work is required to define some parameters more precisely, to identify subsets of parameters relevant to specific health conditions, and to understand the relative importance of each parameter in terms of its impact on GHG emissions.

Supplementary materials

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2020.100023.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository (available upon request).

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Author contributions

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Declaration of interest

None.

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