EIP-AGRI Focus Group
Reducing livestock emissions from Cattle farming

Mini-paper – Farm models/tools to help farmers reducing emissions

Authors

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Introduction

Farm management is widely regarded as one of the main factors affecting not only farm profitability but also farm livestock emissions. Weather and soil conditions also interact with farm management, thus influencing N (N_2O, NH_3, NO_x) and C (CH_4 and CO_2) emissions, N and P diffuse pollution to waters and the potential soil C sequestration.

A number of tools at the farm level have been developed to estimate farm emissions and also to help reduce such emissions. These tools have different scopes, scale and degree of complexity, both structurally and in terms of user-friendliness, which generally determines their specific purpose and level of information requirements to run them.

For instance, predictive farm models to estimate GHG emissions from livestock systems have been developed in the form of process-based simulation (e.g. Schils et al. 2007a), emission factor calculation (Colomb et al., 2012) and LCA-based approaches (e.g. de Boer et al., 2011).
Some of these approaches have the researcher/academic as the final user but, some of the less sophisticated methodologies (e.g. nutrient farm accounting systems and their indicators of nutrient use) have been proposed as a useful way to help farmers directly estimate their emissions whenever farm management, soil and weather data availability is not so detailed.

There are some regions where models (e.g. feeding model) are already in use by farmers or extension officers as a way to help to improve the farm performance both economically and environmentally. The value of these models is clear as they represent a strategic tool for the farmer and allows them to improve efficiency and reduce emissions at specific stages of the farm management. Improving on-farm efficiencies through better use of inputs strongly correlates with reduced production costs per kg of animal product leading to improved profitability for the farm business.

The objective of this paper is to review some of these tools in terms of their main capabilities, role, and uses. The potential of tools to calculate emissions and reduce them at the farm level to be considered as an asset rather than a burden is also discussed in the context of cattle farming.

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Basic structure of a tool (main components)

The main components of a farm tool/model comprise at least the animal and the soil-plant elements in the farm (Figure 1). For cattle systems, as in most ruminants farming systems, the use of home-grown forage by animals and the return and recycling of the animal excreta, either as stored manure or direct excretion, to the soil-plant systems is a unique feature compared to most pig and poultry (monograstric) systems.

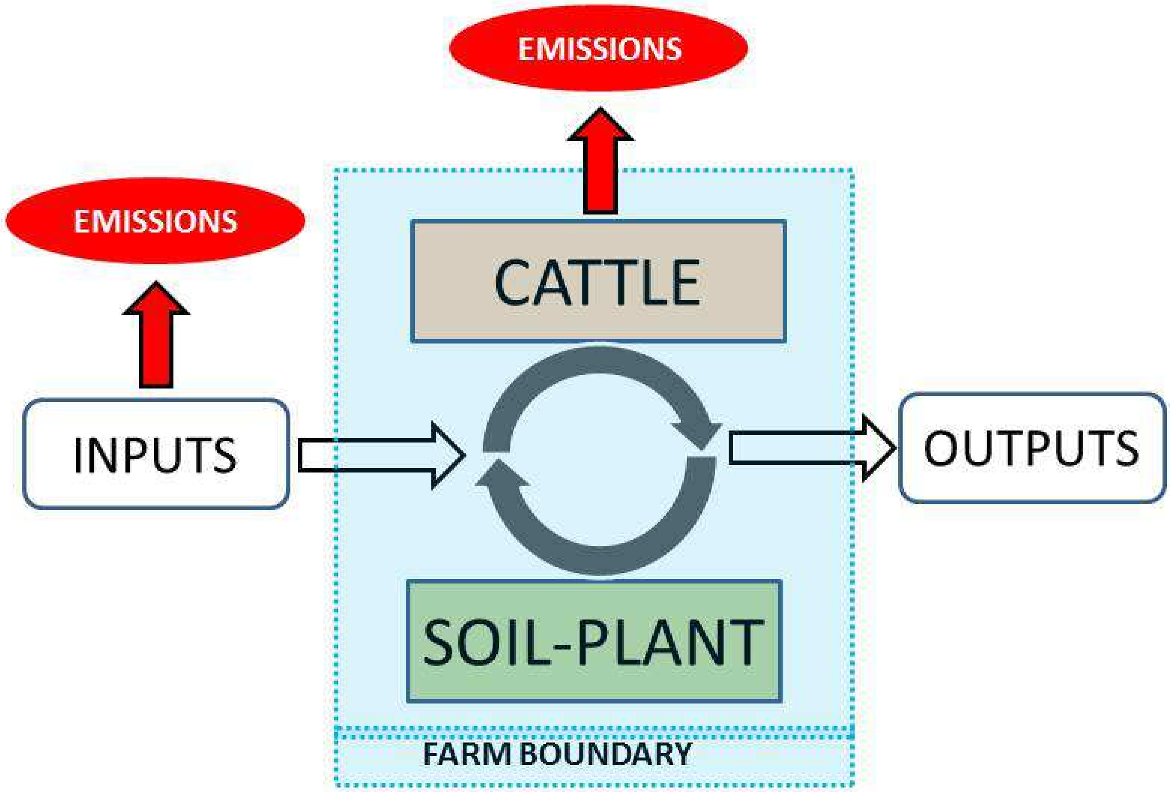

Figure 1. Basic components/elements of modelling emissions at the farm level (illustration modified from Schils *et al.,* 2007a)

Figure 2 illustrates an example of the main components, inputs, outputs, material flows and emissions (e.g. C and N) from a cattle farming system as they can be represented in a farm simulation model. The flows and losses of the C and N cycle through the different farm components are affected by management and site conditions. Carbon dioxide (CO_2) exchange is regulated by processes which fix C in the system and those linked with respiration or direct energy use. Methane is primarily produced in the rumen and in anaerobic storages of organic matter such as manure and silage. Atmospheric N is fixed by leguminous species, soil inorganic N is absorbed by the plant and N_2O emissions are generated directly by both denitrification and nitrification processes in manure storages and soils and indirectly from N lost through ammonia (NH_3) volatilization and nitrate (NO_3) leaching. Greenhouse gas emissions outside of the farm boundaries (off-farm/secondary) are included in some models, such as those coming from the production of resources used, including fuel, electricity, fertilizer, pesticides, herbicides, bedding, purchased feeds and animals not produced on the farm. Designing each of these components and integrating them into a farm model is subject to different modelling approaches in relation to the specific farm component and functionality of the model.

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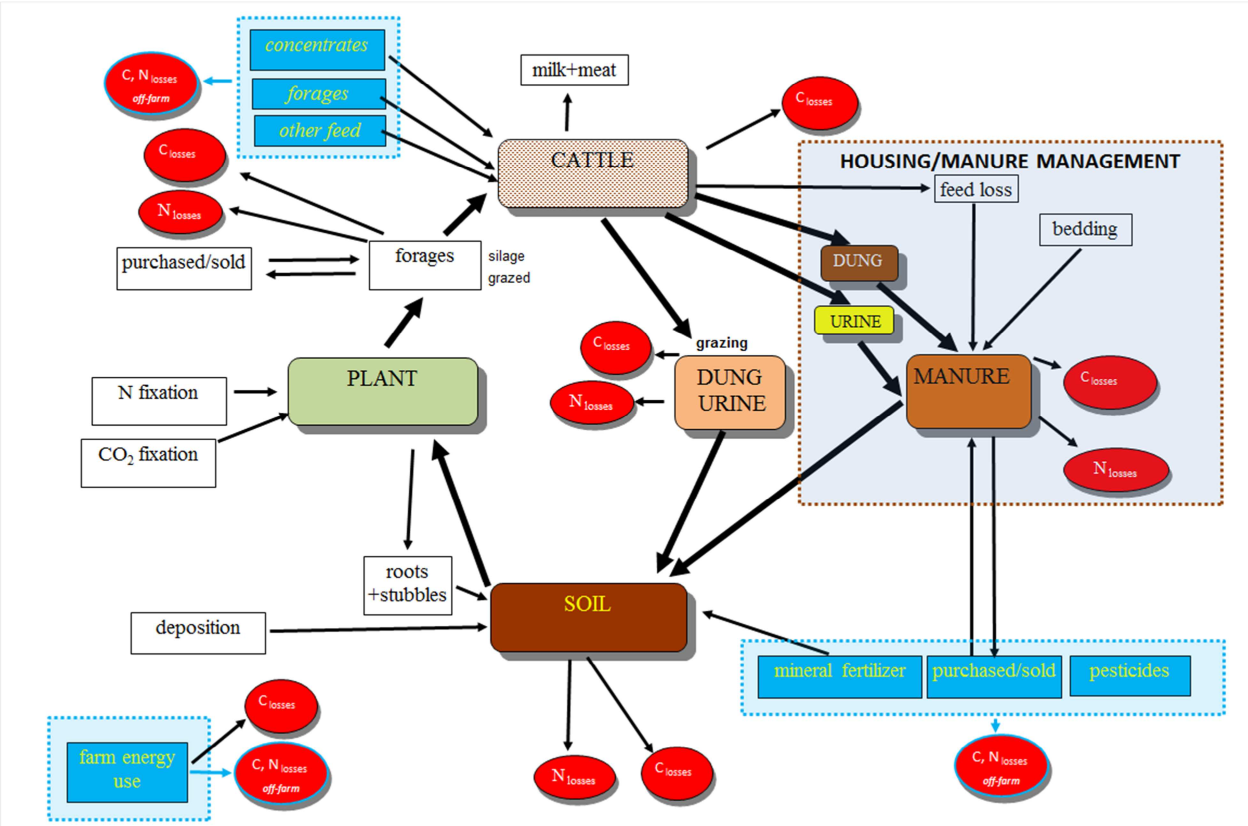

Figure 2. Main farm components, N and C flows and losses in the soil-plant-animal-excretion system of a cattle farm. Colours represent: red: C and N losses, blue: off-farm N and C losses. (illustration modified from Del Prado *et al.,* 2013a)

Most tools will help identify "where and by how much" in the system emissions are occurring, which can be very useful to select the components were management changes can make a bigger effect on the emissions at the whole-farm model (Del Prado *et al.,* 2013b).

Type of tools, from the simple to the most complex

Even though a perfect model does not yet exist, different tools are already in practice for quantifying emissions from farms. We can divide them by the level of sophistication.

The Farm nutrient accounting systems (e.g. nutrient budget methods), which may be considered the simplest approaches to estimate farm emissions, could just consider the elements (nutrients) entering and leaving the farm by the gate, with any internal transformations left accounted for. Alternatively, the "soil systems budget" will record all those nutrients transformations and losses (e.g. emissions such as those related to N denitrification and NH_3 volatilisation). These tools will not require vast amount of data and the basic assumption is that the overall nutrient efficiency of the farm is related to the level of farm emissions. This type of tool can be very useful to link the concept of farm nutrient efficiency with farm emissions. Moreover, the output from this approach could also be used as a proxy for resource use efficiency from the economic viewpoint.

In terms of components (see Fig 3) that the model can consider, the simplest form is the model that evaluates the effect of feed management on animal productivity and emissions derived. For example, in Denmark about 10 % of the dairy farmers have made an annual account and report about feeding efficiency in there herd. The background for this is 6-10 spot samples of data on efficiency. The data are amount of feed used at the day of sampling. All the feed eaten are weight and analysed for dry matter (DM) and nutrients. The data are corrected for purchase, and the amount primo and ultimo of the year. Nitrogen excretion and enteric methane production are calculated. About half of the dairy farmers make spot samples on feed efficiency (4-10 days annual, where

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they weigh feed), analyse feed if it isn't done before, and calculate feed efficiency at that day. Since 2006 in the Netherlands approximately 50 % of the dairy farmers use a balance model to calculate the manure excretion for example. Since 2012 till 2016 every dairy farmer use the Kringloopwijzer/ANCA tool (Aarts et al., 2015) to calculate the whole farm flows at the blue level in Figure 3.

There are other tools looking at the farm in an incomplete way, just as that for manure management in order to help farmers´ estimate manure volumes in relation to their resources (e.g. tractors, manure storage pit volume…). Also, there are some other tools that can indicate the farmer how much emissions are being reduced after applying best abatement techniques to reduce emissions (e.g. EUBatfarm software).
Linking feed management with manure formation through estimation of excreta certainly adds complexity and versatility to the choices of farmer interventions. This would avoid potential unwanted losses that may happen down the manure stream. Although some chemical analysis across the year in the manure storage pit or land can provide very useful information to calibrate the tool for manure or forage produced on-farm management, the Dutch experience indicates that balance methods are more effective than only chemical analysis to determine manure or forage amount.
Further complexity, in terms of components considered, can be by integrating land management, to produce on-farm forage, with feed and manure management. This type of tool could include manure application with different techniques. This may provide a feedback loop to the animal feeding management as manure together with mineral fertiliser application both have direct implications for forage productivity and quality (e.g. amount of protein). Forage basic chemical analysis, both as fresh and after conservation, across the year together with an estimation of productivity per unit of area will be very useful to make the model more precise. Weather conditions need to be included in this type of models in order to address differences between years. From simple thumb-based rules linking monthly or seasonal average rainfall and temperature and potential forage productivity to more sophisticated models that may, in some cases be used as a DSS (e.g. NGAUGE: Brown et al., 2005) to predict results within an ongoing year, updating previous months' weather conditions (if they have diverted from the average conditions).

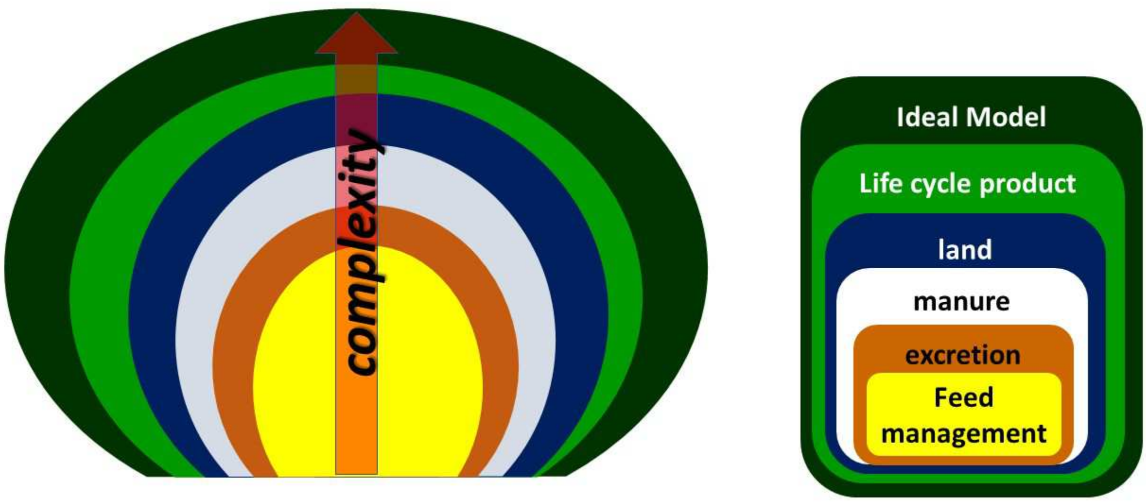

Figure 3. Schematic diagrams showing the complexity level of the farm model regarding their number of components included.

Finally, the most complex whole-farm models are tools that incorporate most of the elements on a farm and try to represent some of feedback nutrient loops amongst the different components of the system (Del Prado et al., 2013a). All of the processes affecting emissions and farm productivity involve the cycling of C and N within the farm, most of which will be affected by weather and soil conditions, farm management and plant/animal genetics. However, not all whole-farm models include such responses to these drivers. Simulation farm models attempt to represent the flows and transformation of carbon (C) and nitrogen (N) and thus, predict resulting emissions. Their use may in general be limited to research both for scientific and strategic purposes and mainly applicable to generalised farm typologies, however there are also examples of models that are widely used to support directly farmers (e.g. OVERSEER).

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For example, evaluation of mitigation strategies requires an integrated systems approach to capture internal feed-backs and loops between farm components (Del Prado et al., 2013a). Nutrients are calculated at each time-step as the difference between inputs and outputs, and the processes at one stage depend on what happened at previous stages. Mitigation measures that benefit one farm component may affect C and N flows in other components. For example, a measure to reduce GHG emissions at the animal level may reduce crude protein (CP) intake and this may have large effects on the different farm components and the whole system (manure composition and emissions from manure storage and soil-plant emissions and productivity) (Del Prado et al., 2013a). Examples of complex farm models include: $SIMS_{DAIRY}$ (Del Prado et al., 2011), MELODIE (Chardon et al. 2012l) FarmGHG (Olesen et al., 2006), IFSM, manure-DNDC (Li et al., 2012), DairyWise (Schils et al., 2007b) FARM-AC, OVERSEER, FASSET (Berntsen et al., 2002).
Some of these more complex models have shown their capability to simulate a range of interacting factors beyond the feeding system. Furthermore, this type of tool has shown the shortcomings of assuming additive mitigation effects when combining mitigation measures to reduce emissions (Del Prado et al., 2010).
The more complex the tool it maybe also be too difficult to parameterise at the farm scale and therefore, it is of little use for practical uses. For example, the shorter the calculation time step, the greater the capability of the model to represent interactions between the farmer, climate and management, but this may also require more environmental and management data, which are most often than not difficult to obtain.
Also, it becomes apparent that we can differentiate between tools that can be useful as a strategic management tool (e.g. OVERSEER) and tools that are intended to be useful for tactical reasons in real time (e.g. BATFARM). It is interesting if the tool can provide the means to investigate alternative farm management options to improve the efficiency of nutrient use so as to optimise production and reduce the risk of adverse environmental impacts.

Examples of existing tools that are already used for farmers and advisors

In the Netherlands, the calculation tool, named "FeedPrint" (Vellinga et al., 2013), which was developed to assess GHG emissions from feed products, has been used by organizations that formulate feed products (either in a factory or on the farm) to allow internal assessment of the existing life cycle upstream GHG emissions of feed products, give support in the evaluation of alternative feed configurations, sourcing and manufacturing methods, raw material choices and supplier selection on the basis of upstream life cycle emissions of feed ingredients and feed formulation and ultimately, to create a benchmark for ongoing programs aimed at reducing GHG emissions (Vellinga et al., 2013).
Also for feed, in the UK, the Software "altech-CO" is indicated to help ruminant livestock farmers identify profitable opportunities and improve efficiency. Based in the UK, it has already carried out more than 5,000 farm consultancy visits across Europe.
In the UK, E-CO2 from DairyCo LCA Provide a Carbon Trust verified average carbon footprint figure for GB milk production based on actual farm data.
In Denmark the dairies have tools to calculate GHG for milk production. The very small dairies make calculations on most of their farms, but the very big dairy, make this check on about 7 % of their farms every year.
In northern Spain, Salcedo (2015) (DAIRYcant tool) and Mas et al. (2016), for different regions, have applied different farm models to estimate GHG emissions and N emissions from 60 and 35 dairy farmers, respectively.
In New Zealand, they have used OVERSEER. This is a tool that generates information about the flow of nutrients on and off the farm. This information is provided as a nutrient and also produced reports on emissions (e.g. GHG emissions per ha). The budget is useful as it tells the farmer how well they are using the available nutrients, what fertiliser is required to maintain soil fertility and indicates the impacts of the farm practices on emissions and N and P losses to waters. It requires easily obtainable input data to model a representation of a farm. In New Zealand, using other type of calculators, Fonterra has assessed the emissions profiles of a sample of dairy farms and found a wide range of emissions intensity. It was found that the most efficient farmers were generally also the most economically efficient farmers.
The Carbon Farming Initiative, in Australia, created a framework for crediting farmers for practices that have been proven to reduce GHG emissions or remove C from the atmosphere. This was tested by different approaches including farm tools. For example, if feeding dairy cattle with lipids was proven to reduce methane output, a dairy farmer could receive a credit for every unit of lipid that they fed. Also, in Australia a farm Emissions Reduction Planning approach (ERP) was developed in Australia using a CO_2 calculator which considers

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emissions from the whole farming system and recommends emission reduction strategies to suit individual farmers' specific circumstances. Reducing emissions
intensity - measured as tonnes of carbon dioxide equivalent (tCO_2e) per unit of product – is strongly related to increases in resource use efficiency, productivity and profitability.

What inputs are easily available and what outputs are useful for the farmer?

Like all models, tools that are focused to help reduce cattle farm emissions must include a simplified representation of the system under study (the farm) and complex processes in reality have to be simplified. These simplifications will imply that these tools predictions/results are subject to large uncertainties. Data quality to enter the tool is most often one of the greatest sources of uncertainty. The tools results are most sensitive to specific input parameters. This depends on the structure of the tool. Emissions are generally greatly influenced by inputs that affect the size of source of the nutrient (e.g. number of animals, fertiliser input, feed input….). If the tool has sufficient sophistication, the site conditions (e.g. temperature, rainfall) will also affect the amount and form of emissions.
For housed cattle farming systems, emissions from housing and manure are especially large and therefore, data on manure properties and conditions (e.g. temperature) in the storage tank and house would be very helpful to assist with estimates of NH_3 and CH_4 emissions. Also, feeding information quality is essential in order to provide a good estimation of CH_4 emissions from cattle enteric fermentation. For grazing systems, it becomes more important to obtain quality data on the pasture/forage growth (amount and quality) in order to be able to properly estimate CH4 from enteric fermentation and N excretion, which will be an excellent proxy or be used to calculate NH_3 and N_2O emissions from excretion patches.
As mentioned before, producing reports for the farmer whereby nutrient use efficiency can be directly linked with the potential risk for emission loss is crucial in order to provide with the right information that can help adjust management to the farmer according to criteria of both productivity and environment. Moreover, indicators that show the efficiency in nutrient use at the same time of showing the emissions can be a useful output in order to persuade farmers to change management in the right direction.
Also, there must be special innovation emphasis on the usability and accessibility of individual data to the farmer and his advisers (for example on-line via computer or via smartphone). Looking into innovative ways that allow farmers to actually use relevant data for "day-to-day" management and more strategic decisions should be a priority issue.

Benchmarking as one of the main uses of these tools

For benchmarking current industry performance in terms of emissions, these tools allows to measure year-on-year improvement and can provide each participating farmer with an emissions footprint figure, identifying 'hot spots' of emissions and how these may be reduced. It is an on-going process aimed at continuous improvement. In this type of process where these tools are utilised it becomes paramount to record any "successful story" which leads to reducing emissions.
The emissions footprint shows how many emissions are being produced through routine activities on your farm. It highlights areas of the business where emissions seem high and allows you to compare your farm performance against other similar enterprise types (benchmarking like for like). High farm emissions reflect poor utilisation of costly inputs, highlighting scope to implement efficiency savings – benefiting both the farm business and the wider environment. Some supermarkets already ask suppliers to provide this information.
Benchmarking should also incorporate a focus on the production, resource management, human resources and business management practices and processes used in the business. Completing benchmarking at whole farm level helps focus on-farm and business performance allowing managers to identify areas of success and where improvements and changes are needed. Improving on-farm efficiencies through better use of inputs strongly correlates with reduced production costs per kg of product, either milk or meat, leading to improved profitability for the farm business.
To establish a starting point, baseline information on available land area and type, breeding cow numbers, stock and milk sales is recorded along with feed, fertiliser and fuel use. The carbon footprint is expressed on a 'per net unit of food product leaving the farm' basis. For a dairy unit, this would be in kg of greenhouse gas (normally a measure of all greenhouse gases but expressed as a carbon dioxide equivalent CO_2e) per litre of milk sold (emissions intensity). Emissions intensity provides a useful benchmark for comparing efficiency with industry averages and gives an extra incentive for producers to engage with reducing emissions projects as it allows for

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comparison with other producers. It is particularly useful when engaging farmers within a discussion group setting and for monitoring farm emissions over time.

The effectiveness of emissions calculators as an engagement tool is generally reliant on the link between improving productivity and reducing emissions. Whilst there is some interest in calculating emissions for personal knowledge or reducing emissions specifically, in practice the 'hook' for farmers is being able to understand the link between their farm's emissions and improvements in management practices that also improve productivity and returns. In this sense, in the Netherlands, for example, a group (or two) of farmers are being just formed to work specifically on NH_3 losses and how to reduce these losses by management (feeding, grazing...).

Increased productivity will almost always reduce emissions intensity. For example, increased weaning percentage will result in fewer emissions per unit of meat produced.

As a more practical usage these tools can be used for the livestock sector in close cooperation with farmer to raise awareness; if the tool is simple enough to be used extensively it becomes an ideal instrument for less trained users as no major training is required but they may help reveal main hotspots of emissions in the farm.

For researchers, these tools have been developed and used to advance on fundamental understanding of how mitigation measures to reduce emissions occur and what are the main controlling factors and possibilities to be manipulated.

Proposal for potential operational groups

An operational group could be considered about testing existing available tools or use of tools and data management. Complexity will depend on the region as accustomedness of such use is region-specific. For those regions which farmers are less familiar with this type of tools and generally, have also more limited accountability of general inputs to perform emissions assessment, the tools to be tested should require the minimum amount of inputs are should be focused on nutrient balances at the simplest. For any farmer, it is important to transfer the knowledge about linkages between nutrient cycling, nutrient losses (emissions) and money saving from improving nutrient use efficiency.

Other potential operational group could emerge from the possibility of identifying existing tools for farm management used by farmers and potential to incorporate environmental outputs based on existing farm models.

Proposals for (research) needs from practice

There is a need to integrate existing measured data in farms (e.g. through precision farming) with the models. Also, it would be interesting to couple some of this farm modelling activities with the approaches that are carried out at the regional level (e.g. national emissions inventories.)

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References

Altech-CO: http://www.allaboutfeed.net/Home/General/2015/9/Methane-emissions-down-farm-efficiency-up-2681630W/

Aarts, H.F.M.; Haan, M.H.A. de; Schroder, J.J.; Holster, H.C.; Boer, J.A. de; Reijs, Joan; Oenema, J.; Hilhorst, G.J.; Sebek, L.B.; Verhoeven, F.P.M.; Meerkerk, B. 2015. Quantifying the environmental performance of individual dairy farms - the Annual Nutrient Cycling Assessment (ANCA). In: Grassland and forages in high output dairy farming systems. - Wageningen : Wageningen Academic Publishers (Grassland Science in Europe) - ISBN 9789090289618 - p. 377 - 380.

Berntsen J, Jacobsen BH, Olesen JE, Petersen BM and Hutchings NJ 2003. Evaluating nitrogen taxation scenarios using the dynamic whole farm simulation model FASSET. Agricultural Systems 76, 817-839.

Brown L, Scholefield D, Jewkes EC, Lockyer DR and Del Prado A 2005. NGAUGE: A decision support system to optimise N fertilisation of British grassland for economic and environmental goals. Agriculture, Ecosystems and Environment 109, 20-39.

Chardon X, Rigolot C, Baratte C, Espagnol S, Raison C, Martin-Clouaire R, Rellier J-P, Le Gall A, Dourmad JY, Piquemal B, Leterme P, Paillat JM, Delaby L, Garcia F, Peyraud JL, Poupa JC, Morvan T and Faverdin P 2012. MELODIE: a whole-farm model to study the dynamics of nutrients in dairy and pig farms with crops. animal 6, 1711-1721.

Colomb V, Bernoux M, Bockel L, Chotte JL, Martin S, Martin-Phipps C, Mousset J, Tinlot M and Touchemoulin O 2012. Review of GHG calculators in agriculture and forestry sectors. A guideline and appropriate choice and use of landscape based tools. http://www.fao.org/fileadmin/templates/ex_act/pdf/Review_existingGHGtool_FR.pdf

De Boer IJM, Cederberg C, Eady S, Gollnow S, Kristensen T, Macleod M, Meul M, Nemecek T, Phong LT, Thoma G, van der Werf HMG, Williams AG and Zonderland-Thomassen MA 2011. Greenhouse gas mitigation in animal production: towards an integrated life cycle sustainability assessment. Current Opinion in Environmental Sustainability 3, 423-431

Del Prado A, Chadwick D, Cardenas L, Misselbrook T, Scholefield D and Merino P 2010. Exploring systems responses to mitigation of GHG in UK dairy farms. Agriculture Ecosystems and Environment 136, 318-332.

Del Prado A., Crosson P., Olesen J.E. and Rotz A. 2013a. Whole-farm models to quantify greenhouse gas emissions and their potential use for linking climate change mitigation and adaptation in temperate grassland ruminant-based farming systems. Animal. 7 (suppl.2), 373-385.

Del Prado A, Mas K, Pardo G., Gallejones. P. 2013b. Modelling the interactions between C and N farm balances and GHG emissions from confinement dairy farms in northern Spain. Science of The Total Environment. 465, 156-165.

Del Prado A, Misselbrook T, Chadwick D, Hopkins A, Dewhurst RJ, Davison P, Butler A, Schröder J and Scholefield D 2011. SIMSDAIRY: A modelling framework to identify sustainable dairy farms in the UK. Framework description and test for organic systems and N fertiliser optimisation. Science of The Total Environment 409, 3993-4009.

ECO2: https://dairy.ahdb.org.uk/media/623464/greenhouse_gas_emissions_on_british_dairy_farms.pdf

Emissions Reduction Planning approach (ERP) http://search.informit.com.au/documentSummary;dn=661344179283024;res=IELHSS

EU-Batfarm software. http://www.intiasa.es/en/batfarm-software.html?lang=en_US

FARM-AC: http://www.isa.ulisboa.pt/proj/nitroportugal/docs/2016/NitroPortugal_FarmAC.pdf

Integrated Farm System Model (IFSM) https://www.ars.usda.gov/ARSUserFiles/np212/LivestockGRACEnet/IFSM.pdf

Kringloopwijzer/ANCA: KringloopWijzer, goed geborgd!Annual Nutrient Cycling Assessment (ANCA), adequately assured!? (in Dutch). In: Holster, H.C.; Haan, M.H.A. de; Plomp, M.,Timmerman, M. 2015. Wageningen UR Livestock Research (Livestock Research report 839) - 34 p. http://library.wur.nl/WebQuery/wurpubs/490374

Li C, Salas W, Zhang R, Krauter C, Rotz A and Mitloehner F 2012. Manure-DNDC: a biogeochemical process model for quantifying greenhouse gas and ammonia emissions from livestock manure systems. Nutrient Cycling in Agroecosystems 93, 163-200.

Mas, K., Pardo, G., Galán, E., & del Prado, A. 2016. Assessing dairy farm sustainability using whole-farm modelling and life cycle analysis. Advances in Animal Biosciences, 7(3), 259-260.

Olesen JE, Schelde K, Weiske A, Weisbjerg MR, Asman WAH and Djurhuus J 2006. Modelling greenhouse gas emissions from European conventional and organic dairy farms. Agriculture Ecosystems and Environment 112, 207-220.

OVERSEER model. http://overseer.co.nz/OVERSEERModel.aspx

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Salcedo, G. 2015. DairyCant: a model for the reduction of dairy farm greenhouse gas emissions. Advances in Animal Biosciences, 6(1), 26.

Schils RLM, Olesen JE, del Prado A and Soussana JF 2007a. A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. Livestock Science 112, 240-251.

Schils RLM, de Haan MHA, Hemmer JGA, van den Pol-van Dasselaar A, de Boer JA, Evers AG, Holshof G, van Middelkoop JC and Zom RLG 2007b. DairyWise, A Whole-Farm Dairy Model. Journal of Dairy Science 90, 5334-5346.

The carbon farming initiative: **https://www.environment.gov.au/climate-change/emissions-reduction-fund/cfi/about**

Vellinga Th.V.,Blonk H. Marinussen M. van Zeist W.J. de Boer I.J.M. and Starmans D.2013. Methodology used in FeedPrint: a tool quantifying greenhouse gas emissions of feed production and utilization. Report 674. ISSN 1570 -8616 **http://edepot.wur.nl/254098**

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