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A holistic, dynamic model to quantify and mitigate the environmental impacts of cattle farming

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Introduction

Cattle farming is the most important agricultural contributor to environmental impacts (Steinfeld *et al.,* 2006; Gerber *et al.,* 2013a). Steinfeld *et al.* (2006) point out that cattle farming is significant contributor to greenhouse gas (GHG) emissions, water depletion and biodiversity loss. GHG emissions from cattle farming include CO_2, CH_4 mainly from enteric fermentation and N_2O from fertiliser and manure use. Largest contributors to total GHG emissions of cattle farming are direct non-CO_2 emissions from enteric fermentation and manure, which from cattle alone account for 47% of all agricultural GHG emissions (Gerber *et al.,* 2013b). Steinfeld *et al.* (2006) point out that there is large variation in the volumes of CH_4 emissions from enteric fermentation of cattle, depending on management systems and regional characteristics. Quantity and quality of feed, animal age and activity level all have an impact on methane emissions as well as energy intake. Generally, standard emission factors are used in life cycle assessment.

Decomposition of organic material in manure also releases CH_4. Temperature, moisture and storage time have an impact on emissions from manure together with livestock's diet that has its impact on energy content of manure, reflecting to CH_4 emissions. However, higher digestibility in feeds can reflect to higher feed efficiency and thus lower the emissions per product unit.

Nitrogen emissions are also significant contributors to total GHG emissions of cattle farming. Improved feeding practices can aid mitigation of N_2O emissions. However, nitrogen excretion with tailored diets is still high and large quantities remain in the manure. Manure management, housing, storage and field application practices have a large effect on the volume of volatilized emissions. Nutrient surpluses from cattle farming also cause water depletion and eutrophication. Of all causes of water depletion, livestock's share was estimated to be 93% and of all livestock cattle is the largest contributor to eutrophying N emissions with 58% (Steinfeld *et al.,* 2006). Mitigation potential of GHG emissions of global livestock sector has been estimated to be 1.8 Gt CO_2-equivalents, cattle having the largest potential of this with 65% (Gerber *et al.,* 2013a).

Glatzle (2014) has questioned the magnitude of emissions presented in FAO reports (Steinfeld *et al.* 2006; Gerber *et al.,* 2013a) as they unjustifiably burden grazing animals; in addition, Herrero *et al.* (2011) point out the uncertainties of different assessments of livestock's GHG-emission magnitude owing to methodological differences. As the debate is ongoing, it is understood that more detailed modelling is needed to achieve better understanding of mitigation potentials in the cattle and livestock sectors. Still, for example, the climate impacts of cattle farming are estimated using default IPCC emission factors (IPCC, 2006), which only give a rough estimate rather than a detailed picture of a real farm. More detailed modelling and optimization of specific parts of the production system, such as grass production, enteric fermentation, etc., has been made, but holistic studies on whole farming systems are rare.

The objective of this project is to model and assess the environmental impacts of a cattle production system and to find the areas with largest mitigation potentials. The overall aim is to find ways to mitigate environmental footprints of beef production without unwanted trade-offs.

Material and methods

In order to gain more knowledge of the environmental impacts and mitigation potentials in beef production systems, a dynamic model integrating biological farm models and an environmental life cycle assessment approach together with most advanced GHG emissions models was developed. Model is built as a

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dynamic LCA model where biological plant and animal models are integrated. Here, nutrient flow through the whole beef production system is described using dynamic biological functions in sub models. Model connects animal growth, feeding intensity and composition, feed production and manure and fertilizer use on different soil types. Effects of changing diet, inputs or manure management processes to different environmental impacts can be seen directly. To avoid sub optimization, this is done by summarizing different environmental impacts (global-warming potential, eutrophication and acidification) from all sources at the same time.

The model can be used to achieve knowledge of a current status of a specific system based on available data or it can be used for automatic assessment of different scenarios. The structure of the model is auto regulative allowing only biologically acceptable input values in scenarios. In scenario modelling, recent previous research is reviewed to achieve realistic frames for mitigation.

Comparisons of different evaluation methods of the largest GHG-emission sources are also possible; for example, the biological animal model enables two different approaches, in addition to IPCC tier 2, for evaluation of methane emissions from enteric fermentation (using Ramin and Huhtanen, 2013) and Finnish N_2O-emission factors for direct soil emissions (Regina *et al.,* 2013) are compared with IPCC defaults.

So far environmental impacts and effects of management changes of beef production have been commonly evaluated with statistical models; therefore, our newly developed dynamic model will give new insights. The new model, with various development options possible in practical farming, pinpoints the challenges within the sector. It also gives an understanding of contradictions between different mitigation options and helps in choosing the most sustainable practices.

Discussion

Comparing mitigation options is difficult based on rough or partial estimates, especially in developed countries where mitigation potential is already considered low. Mitigation design is often difficult as emissions originate from point sources in complex biological processes. Mitigation options usually have impacts outside the actual emission source, and thus decreasing environmental impacts in one part of the system can lead to an increase in impacts in another part. Mitigation strategies need to be pointed towards decreasing the negative environmental impacts of the whole system. Therefore, an holistic approach should be preferred to avoid unwanted trade-offs. So far there has not been a tool available for evaluating the effect of management changes in the whole system.

Environmental impacts of cattle farming are very diverse, thus detailed observations are needed in order to gain knowledge of the sector's holistic impact. Our model gives an understanding of contradictions between different production practices and helps in choosing the most efficient and environmentally optimal ways to develop production. Holistic, detailed assessments of the production systems can lead to direct development actions and innovations.

Focusing on single impact can burden certain production sectors disproportionately. In future, biodiversity, ecotoxicity and water footprint should be included. Cattle farming is contributing a large share to GHG emissions via enteric fermentation. Mitigation strategies can be designed to be more efficient and trade-offs between impact categories can be avoided.

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Further information

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