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Modelling CO_2 footprints and trace gas emissions for milk protein produced under varying performance and feeding conditions

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Introduction

Trace gas emissions are likely to become a threat to milk production in Central Europe and Germany in particular. The European Union have committed themselves to a reduction of greenhouse gas (GHG) emissions. For ammonia (NH₃), the targets for the National Emission Ceiling (NEC) will not be met in Germany. Whereas the emissions of reactive nitrogen, in particular of NH₃, are a regional problem and may lead to difficulties in planning of new farms or extensions, the emission of greenhouse gases is a national problem. Hence, sustainability of milk production has to take emission reduction into account, and the establishment of CO_2 footprints may serve as a tool. The product to be considered here is milk protein. As the whole production chain has to be valuated, scenarios have to be constructed which allow for the evaluation of mitigation options for both greenhouse gases and air pollutants, in particular for ammonia, as any change in production will result in changes of the emissions of carbon dioxide (CO₂), methane (CH₄), non-methane volatile organic compounds (NMVOCs), ammonia (NH₃), nitric oxide (NO), nitrous oxide (N₂O) and primary particles (PM). Also, any measure aiming at a reduction of emissions of one single gas is likely to have effects on almost all other emissions.

The most promising way to study potential effects of modified production systems is the application of emission modelling. However, the models used have to reflect details of the whole production process. The German agricultural emission model GAS-EM can be modified to allow for such calculations. It is a combination of process and mass flow oriented modules.

This contribution aims to illustrate the competitiveness of comprehensive emission modelling for the establishment of CO_2 footprints in milk production and for the evaluation of emission reduction options.

The importance of milk production for greenhouse gas and ammonia emission in Germany

GHG gas emissions from agriculture form only a minor part of the German national total emission (about 7 %). Nevertheless, all reduction potentials have to be identified and evaluated. The most important single source is milk production by dairy cows. The direct CH_4 emissions (red) attributed to dairy cows shown in Figure 1 clearly illustrate their share. However, additional contributions are covered in the categories "manure application" (N₂O) and "grazing" (N₂O). The entire milk production system including calves, heifers and bulls is responsible for about half the agricultural GHG emissions.

German national NH_3 emissions are dominated by agriculture which contributes about 93 %. More than half the total is emitted from cattle, and dairy cows are the largest single source. Emissions have been on the same level for about a decade despite decreasing animal numbers, as emissions per cow increased with increasing performance (Haenel et al., 2009).

Thus, any measure to reduce emissions from agriculture has to address milk production in the first place.

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Figure 1

Shares of single source categories in the German agricultural greenhouse gas and ammonia emissions. Data for 2007, as reported in Haenel et al. (2009).

The treatment of milk production in GAS-EM

The central module in this production chain (see Figure 2) is the dairy cow module. It consists of submodules describing feed intake as a function of milk yield and milk composition, body weight and weight gain and energy content of feeds, energy requirements and enteric fermentation as well as the excretion rates and fates of nitrogen (N) and carbon (C) in the manure management (Dämmgen et al., 2009). The treatment of N in the manure management uses a mass flow approach (Dämmgen and Hutchings, 2008) that makes use of emission factors provided in the international guidance documents (EMEP/CORINAIR, 2002, and IPCC, 2006) as well as national data (Haenel et al., 2010). Typical German housing and manure management systems can be depicted.



The GAS-EM dairy cow module (CDC09) is combined with the GAS-EM crop production module (SCG09) to assess the emissions resulting from feed production including the application of slurry, farm yard manure and mineral fertilizer. Emissions related to the decay of crop residues and indirect emissions of N₂O can be quantified, as can CO₂ emissions from the application of lime.

In combination with data for energy consumption in traction engines during crop production (KTBL, 2006), EMEP/CORINAIR (2002) and IPCC (2006) guidance documents also allow to estimate the emissions from internal combustion engines and from fertilizer production.

Figure 2

Production chain for milk as described in the GAS-EM modules.

The mass flow is from top to bottom. Emissions occurring at the respective step are indicated by wide sloping arrows. Left hand side: C species; right hand side: N species. Emissions leading to deposition to the soil are indicated by narrow arrows. Hence, these modules can be applied to describe the entire production chain of milk protein from mineral fertilizer production to nitrous oxide emission from the continental shelves in detail. Emission abatement measures can be evaluated; however, abatement costs cannot be quantified.

Uncertainties of the emission factors are in the order of magnitude of 30 % for NH₃. They are considerably higher for N₂O. As dinitrogen (N₂) emissions are linked to N₂O emissions the mass flow of N in the manure management system is also affected. Error propagation calculations (Haenel et al., 2010) result in effective uncertainties of about 50 % for N₂O from storage, and of about 20 % for NH₃ from the overall N flow. For CH₄ from enteric fermentation and from storage, the uncertainties estimated by IPCC (2006) of \pm 20 % are accepted. N₂O emissions from soils are very uncertain. A value of 200 % is taken to be sensible (IPCC, 2006, see also Leip et al., 2005). For N₂O originating from deposition the effective uncertainty is about 400 %, for runoff and leaching about 230 %. Error propagation calculations result in an overall uncertainty for N₂O emissions of about 90 % (Haenel et al., 2010). However, relative uncertainties between the various variants discussed in this paper are much smaller.

We use global warming potentials (GWP) for a time horizon of 100 years as provided by IPCC (2001), i.e. for CH_4 23 kg kg⁻¹ CO₂-eq, for N₂O 296 kg kg⁻¹ CO₂-eq.

Emissions from milk production of "reference cows"

A reference cow is a Holstein Frisian to produce 8000 kg a^{-1} milk with a fat content of 0.043 kg kg⁻¹ fat and 0.033 kg kg⁻¹ protein. The live weight is 650 kg cow⁻¹, the weight gain 20 kg cow⁻¹ a^{-1} .

Two types of feed are considered "standard": The *mixed diet* consists of grass and maize silage, some additional straw, a standard concentrate (MLF 18/3) and rape seed expeller. The *grass based diet* consists of grass silage as sole roughage component, standard concentrate (MLF 18/3) and wheat. The respective shares of concentrates vary with milk yield.

The cow is housed throughout the year in a cubicle house with slurry. Slurry is stored in an open tank with a natural crust. No slurry treatment is involved. 25 % of the slurry thus produced is applied to short vegetation (broad spread), another 25 % to arable land using a trailing hose (incorporation within 4 hrs); 50 % are spread on short grass (broad spread).

Slurry N is taken into account when estimating the amount of mineral fertilizer N required. Mineral fertilizer is calcium ammonium nitrate (CAN). The amount of CO_2 released after application is taken into account.

Feed is produced on horizontal 5 ha fields, with moderately heavy soils. Average yields and amounts of N fertilizer as provided in KTBL (2006) are used for the scenarios. For rape seed expeller, total GHG emissions of 0.28 kg kg⁻¹ CO₂-eq were assumed (see Majer et al., 2008).



Figure 3

Greenhouse gas and ammonia emissions of reference cows

The resulting emissions per cow are collated in Figure 3. They indicate that overall GHG emissions do not differ significantly. Differences are mainly located in feed production. The grass based diet results in larger N excretion rates, which results in larger NH_3 emissions at any step of the nitrogen flow. In addition, more mineral fertilizer is required to produce the feed.

Increasing milk yield as a means of emission reduction

Increased milk production per animal leads to higher emissions per animal, but to lower emissions per unit of product. Figure 4 illustrates that this is the case for both mixed and grass feeds. However, the reduction efficiency decreases with increasing yields. For NH₃ and mixed feed it becomes almost zero above 9000 kg cow⁻¹ a⁻¹. The difference in GHG emissions between mixed and grass based feeds disappears above 8000 kg cow⁻¹ a⁻¹; for NH₃ the difference becomes zero at 10000 kg cow⁻¹ a⁻¹.



Figure 4

Effect of increased milk yield per cow on GHG and NH_3 emissions (related to the amount of milk protein produced).

The effects of grazing and bedding material

Part-time grazing (10 h per day, 150 days per year) and the addition of straw (5 kg per place and day) result in variations in GHG and NH_3 emissions (Figure 5). Grazing has adverse effects on GHG emissions, as the additional

amount of N_2O released during grazing is significant. The addition of straw results in slightly reduced GHG emissions due to the fact that CH_4 emissions during storage are more than halved. Grazing has no influence on the overall NH_3 emissions, however the pattern changes. Straw leads to immobilization of renal nitrogen and greatly reduces emissions from storage and spreading.



Figure 5

GHG and NH₃ emissions of various housing systems. The system denoted "slurry" has all year round housing in a cubicle house. "Grazing" has cows also in a cubicle house with slurry. "Straw" means a cubicle house with bedding and without grazing.

The nitrogen input into soils in a straw based system exceeds that of the other variants. This results in reduced emissions from mineral fertilizer application and hence in reduced GHG emissions from fertilizer production.

Effects of milk composition

In Germany, the demand for milk products has changed over the last decade: the amount of milk bought is slowly decreasing, so is the consumption of butter. On the contrary, the consumption per head of yoghurt and cheese has increased. We assume that the future milk market will ask for lower fat contents and higher protein contents in milk. Figure 6 illustrates this will also result in reduced GHG and NH_3 emissions.



Figure 6

GHG and NH₃ emissions resulting from reduced milk fat and increased milk protein contents.

"ref" denotes the reference cow on slurry, "prot" fat reduced and protein enriched milk, i.e. 0.034 instead of 0.043 kg kg⁻¹ milk fat and 0.0375 instead of 0.033 kg kg⁻¹ milk protein, "prot+straw" shows the effect of a combination of "prot" and housing in a straw based cubicle house, "comb" illustrates the additional effect of a milk yield increase to 10000 kg cow⁻¹ a⁻¹.

Milk fat synthesis is an energy intensive process. Reduced fat content therefore means reduced energy requirements and thus less CH_4 from enteric fermentation and less excretion of volatile solids. The reduction in NH_3 emissions is even more distinctive. A reduced nitrogen intake is coupled with an increased N excretion with milk. As shown in Figure 5, the combination of reduced fat / increased protein scenarios with straw based housing and an increased milk yield leads to a drastic reduction of NH_3 emissions and reasonable reductions of GHG emissions.

Whereas the change in housing is a quick (mid-term) measure if the prerequisites are met, the breeding of cows with milk properties as described above is far from being trivial: Unfortunately, there is a very close positive relationship between milk fat and milk protein content. As a rule, cows with a very high milk protein output have also a very high milk fat output (and *vice versa*). At the same time, the relationship between the level of the milk quantity (per cow and lactation) and the milk contents are clearly negative. In other words: there are distinct, undesirable quality antagonisms in cattle breeding which are difficult to overcome (Brade, 1999). However, it becomes clear that selective genetic breeding for changes in the milk composition - with a targeted increase in milk protein levels - appears more justified.

Discussion

(1) The calculation of emissions using a mass flow approach is generally accepted in Northwest Europe for NH_3 emission modelling (Reidy et al., 2008, 2009). In general, the different models agree well when input data are similar. The applicability of such models is in line with UNECE guidance documents (EMEP/CORINAIR, 2002).

(2) Truly, the data base from which the emission factors are derived needs improvement. This is in particular true for straw based systems (treatment of immobilisation, CH_4 emissions from straw) and for N₂O emission factors in general. However, we assume that comparisons like those performed in this investigation yield reliable relative results which can support policy making.

(3) The comparisons shown also indicate that future investigations will have to consider in more detail the complex effects of livestock production on the one hand and feedstuff production and resource conservation (soil, water fossil fuels, fertilizers, transport expenditure, etc.) on the other, as restrictions due to environmental pollution are likely to affect the *entire* production chain.

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