Studies on greenhouse gas emissions in organic and conventional dairy farms

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1 Zusammenfassung

Untersuchungen zu Treibhausgas-Emissionen in ökologischer und konventioneller Milchviehhaltung

In Deutschland ist die Landwirtschaft für 14 % der gesamten Treibhausgas-(THG)-Emissionen verantwortlich. Ein hoher Anteil (30 %) davon wird durch die Milchviehhaltung verursacht. Aktuelle Debatten zeigen einen vorhandenen Mangel an festen und aussagekräftigen Datensätzen. Aus diesem Grunde zielt das Projekt "Klimawirkungen und Nachhaltigkeit von Landbausystemen - Untersuchung in einem Netzwerk von Pilotbetrieben" darauf ab, genauere Informationen zu erlangen. Insgesamt werden in dem Projekt 80 Betriebe (40 konventionell und 40 ökologisch wirtschaftende Betriebe) in Deutschland miteinander verglichen. Für den Vergleich wurden in den einzelnen Regionen Betriebspaare bestehend aus jeweils einem konventionellen und einem ökologischen Betrieb gebildet. Die Hälfte der Betriebspaare hält neben dem Ackerbau auch Milchvieh. Es wurde darauf geachtet, dass die Betriebspaare gleiche Boden- und Klimaverhältnissen aufweisen. Die gesammelten Daten enthalten unter anderem die Lebensdauer, Erstkalbealter, Milchleistung, Futterregimes, Gesundheitszustand der verschiedenen Milchkuhbestände sowie Daten über das Güllemanagement, Futterbau sowie Boden- und Bodenmanagement. Zur Modellierung der THG-Emissionen und Schwachstellenanalysen in der landwirtschaftlichen Produktion werden die Modelle GAS-EM und REPRO herangezogen. Generelle Unterschiede (zwischen der ökologischen und konventionellen Milchviehhaltung), die die THG-Bilanz beeinflussen, können durch verschiedene Milchleistungen pro Kuh und verschiedene Futterkomponenten entstehen. Auch die Erzeugung von Futterpflanzen und die vorgeschriebene Beweidung in ökologischen Betrieben wirken sich auf die Treibhausgassalden aus. Eine Intensivierung des Fütterungsregimes zur Erhöhung der Milchleistung kann unerwünschte Auswirkungen auf die Klimabilanz haben. Weiterhin sind die allgemeinen Auswirkungen der Verwendung von CH_4-reduzierenden Futterkomponenten unklar. Die Bedeutung der Rolle des Herdenmanagements auf die THG-Salden in der Milchviehhaltung sollte mit betrachtet werden. Die Projektdaten bilden die Grundlage für die Entwicklung der Potenziale zur Reduzierung der THG-Emissionen und für eine Verbesserung der Nachhaltigkeit in der ökologischen Milchviehhaltung.

2 Abstract

In Germany agriculture is responsible for 14 % of the whole greenhouse gas (GHG) emissions. A considerable portion (30 %) of the emissions is caused by dairy farming. Recent dis-

cussions about this issue show that there is a lack of solid data. The project "Climate effects and sustainability of organic and conventional farming systems - examination in a network of pilot farms" aims to attain more precise information. A total of 40 conventional and 40 organic farms in Germany are compared in this project. Half of the farm pairs are dairy systems; they are located as organic/conventional pairs in regions with equal soil and climatic conditions. The collected data includes length of life, first calving, milk yield, fodder regime, state of health of the different dairy herds and data on manure management and fodder production as well as soil and soil management data. Options to increase sustainability in the farming systems are discussed with a special view to GHG emissions. Modelling of GHG emissions and weak point analyses in production shall be undertaken with the models GAS-EM and REPRO. General differences between organic and conventional dairy farming affecting the GHG balance can be expected by different milk production per cow, different feed components and obligatory grazing in organic farms and different GHG balances in the production of fodder crops. An increase in milk yields by a general intensification of feeding might be connected with unwanted effects on the GHG balance. Also, overall effects of the use of CH_4-reducing feed components are unclear. The important role of herd management on the GHG balances in dairy farming is highlighted. The accumulated project data shall serve as a basis for the development of GHG reduction potentials and for an improvement of other sustainability aspects in organic dairy farming.

3 Introduction

Land and forestry management are important contributors to greenhouse gas (GHG) emissions. Between 10 and 20 % of the global GHG, i.e., between 5.1 and 6.6 bn t CO_{2eq} are caused specifically by agriculture (Freyer & Dorninger 2008). The share of farming in the overall GHG emissions is approximately 14% in Germany (Flessa 2009). GHG emissions of livestock production have enormous global relevance (Steinfeld et al. 2006) and need to be evaluated in more detail (Dämmgen & Döhler 2009). In Germany, 30 % of the GHG emissions from agriculture can be allocated to dairy cows (Osterburg et al. 2009). In that context organic dairy farming is discussed as low output system, and different GHG balances have to be expected compared to conventional systems, which rely on fodder imports and high concentrate levels (Bormuth 2009). Recent system comparisons still rely on single farm comparisons (Thomassen et al., 2008), special regions (Haas, Wetterich & Köpke 2001) or give raw estimates on productivity and on management differences between the farming systems (Basset-Mens, Ledgard & Boyes 2009).

It is still unclear if lower productivity of organic systems in general has adverse effects on the GHG balance of the products. The extent to which these adverse effects are compensated by lower external input and lower energy demand in the upstream chains of production of organic farms or special management differences like grazing frequencies or internal nutrient recycling remains an open question. Representative assessments considering soil, fodder crops, fodder acquisition, animal husbandry and manure handling are necessary to calculate the overall GHG load of the different systems. A nationwide German project "Climate effects and sustainability of organic and conventional farming systems - examination in a network of pilot farms" (www.pilotbetriebe.de) compares the operations of 40 organic and 40 conventional farms in four German regions (North: coastal region, maritime climate; East: continental climate, large farm structure, South: Alpine grassland farms and productive areas in the pre-alpine region; West: low mountain areas, Lower Rhine Basin, continental climate) in the period from 2009 to 2012. Half of the pilot farms (20 organic and 20 conventional farms) are dairy systems. The project ideas, scientific background and different management options to improve sustainability indicators in dairy farming are summarized in this paper with special view to GHG emissions on organic dairy farming.

4 Material and methods

In the research project two main aspects shall be evaluated on the basis of comparisons of organic and conventional farms in Germany:

1. The GHG emissions shall be calculated based on typical processing lines in crop production and dairy farming
2. The ecological burden of operating systems shall be evaluated and described by sustainability indicators.

4.1 Data collection, sampling and analytics

In the pilot farms (Fig. 1), the complete production process is assessed by detailed interviews. In the dairy farms, e.g., herd size, feed management, milk yield, stable type and grazing management and state of health are important points for the assessment. Also the genetic potential of the different breeds play a meaningful role.

To explore so far unknown system differences in the different dairy farming systems, all feed stocks and manure storages of the farms are sampled. The following parameters are analyzed:

- Feed samples: dry matter, crude protein, crude ash, crude fat, crude fibre, nitrogen (N) free extract.
- Manure samples: dry matter, total carbon, total nitrogen, ammonia-nitrogen, soluble P, total K, basic components, pH.

CH_4-emissions will be calculated from the analysed and calculated feeding data as well as the recorded production parameters. Essential factors for methanogenesis and related GHG emissions are the relationship of roughage and concentrates and the carbohydrate type.

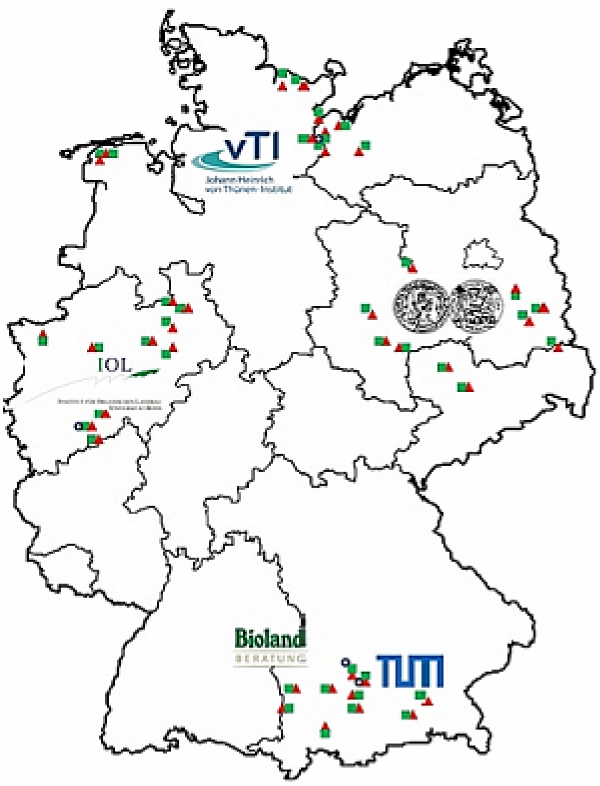

Fig. 1: The location of the selected organic ■ and conventional ▲ dairy farms

4.2 Modelling of GHG emissions

In the project two different models, GAS-EM and REPRO, shall be used to quantify GHG emissions and to identify reduction potentials. GAS-EM is described by Dämmgen et al. (2002). It is used to generate the official National Emission Inventory Reports (Dämmgen 2007). For that purpose agricultural emissions are calculated on the basis of generalized official statistical data. In the research project the similarities and differences of the individual farms and farm pairs shall be analysed and represented with GAS-EM by representative, current and real values generated in the farm survey, as recommended by Dämmgen & Döhler (2009).

The REPRO model is described by Hülsbergen et al. (2000) and can be used, among other things, for the modelling of carbon, nutrient and energy cycling in farms (Küstermann et al. 2008). The interaction of the individual sectors of operation can be shown and an improvement can be derived from the material and energy cycle. The production data of the dairy farming from the pilot farms will be combined with the analysis values from fodder, fertilizers, cash crops and soils. A complete operational modelling of the material and energy flow is possible from the ground to the crop through to the animal and back to the ground (Hülsbergen & Küstermann 2007). Examples for influence factors and model input data are: Livestock and animal performance (life weight, milk yield, milk quality, lactation number, breed), fodder requirement (energy and protein requirement), fodder use (quantity, quality, origin, acquisition), excrement volume (livestock level, fodder use), organic fertilizer management (stable type, storage, application).

Data from both models and a detailed assessment of the production processes in the existing farms will be used for the development of improvement strategies and for the validation of existing GHG estimates in literature.

4.3 Development of sustainability indicators

The influence of different milk yields on the product-related GHG emission will be projected, based on the data explored from the pilot dairy farms as climate related sustainability indicator. Other effects of the different farming systems can be expected in categories like animal welfare or biodiversity. So apart from the climate relevance of the pilot farms, the other sustainability indicators shall be assessed. Causes which can hinder sustained production shall be identified. Measures for the improvement of sustainability can be taken, not only for the pilot ventures but also for other farming systems. However there are few models offering a detailed analysis of weak points with respect to the entire process cycle in agricultural enterprises. Indicators for dairy farming will be consulted and developed for the specification of the sustainability status and checked for their usability. They will refer mainly to the efficiency of the nutrient and the energy use in the livestock management systems. Important points are N use, CO_{2eq} emissions, P-cycle, energy use and veterinary drug application in dairy farming. Concerning the nitrogen cycle, the sustainability indicators N balance (kg N per livestock units, kg N per kg milk), N utilization (%) or amount of organic fertilizer used (kg N $ha^{-1}a^{-1}$) can be consulted. N balances indicate the loss potential of reactive N compounds. Different maintenance systems and yield levels can be compared by means of the N efficiency (= ∑ N-Output / ∑ N-Input * 100) and the influence of management, yields and feeding regime can be clarified. Different values on P efficiency can indicate sustainable use of exhaustible resources. These parameters and also the GHG emissions are expected to be highly dependent on the farming systems and the individual farm management. For instance the influence of length of life, milk production, age of first calving and herd life on the GHG emissions can be worked out with the described models. In other project parts sustainability parameters for soil fertility, soil conservation (soil erosion, harmful soil compression and humus content) and prevention of water pollution, come into the examination.

5 Results and Discussion

Potentials for the reduction of GHG emissions and an improvement of sustainability in organic farming can only be determined with the help of a qualitative assessment of organic management (Freyer & Dorninger 2008). This is the purpose of the research project described above. GHG emissions could be lowered with higher area efficiency or less energy-intensive input in production. General optimization potentials would be, for example, regenerative energy systems and the regional utilization of resources. To which extent intensification in production will decrease the product-bound GHG emissions is an open question.

5.1 System comparisons

General differences between organic and conventional dairy farming impacting the GHG balance can be expected by lower milk production per cow, different feed components, limited use of veterinary drugs, obligatory grazing in organic farms and different GHG balances in the production of fodder crops.

In newer studies, the important role of farm management in the GHG balance of milk production is obvious. But it becomes clear that the further disaggregation of the actual production processes to avoid relying on general assumptions on system differences is inevitable. This is intended in the research project described in this paper.

Dämmgen & Döhler (2009) calculated and compared emissions from different conventional dairy farming systems with data for an organic system on the basis of GAS-EM. Beyond the legally based differences in fertilizer use, system differences were assumed in higher fossil fuel (diesel) consumption in organic production due to lower area yields in fodder production. Another difference was made in the housing and manure system which was based on straw in organic production. In both farming systems concentrates were made from different locally grown crops. Equal milk yields per cow were assumed in both systems. Herd management aspects were not included. The results of the calculation are shown in Table 1.

Based on their model assumptions, the authors concluded that the emission of GHG per cow in organic dairy farming is lower than in conventional farming. The differences were mainly explained by the use of synthetic fertilizers and higher N_2O emissions in the conventional systems. The use of mineral fertilizers and their production are linked to high CO_2 emissions, as is the use of diesel engines. The system comparison assumed and considered further that grazing of the dairy cattle calls for a higher energy requirement and therefore also higher feed consumption. The digestive activity increases and consequently leads to a higher CH_4 emission. If the grazing is combined with straw based housing, the CH_4 emission from the manure management is reduced. With regard to the N_2O emission, the grazing leads to a reduction and the use of straw litter and beds leads to an increase in emissions.

The evaluation shows the important influence of the special management in the farms (e.g. housing conditions) on the GHG emissions (Dämmgen and Döhler, 2009). Grazing causes relatively low N_2O emissions in relation to the N content of the dung and urine patches, but is globally seen as an important source of GHG emissions. Unclear is the role of livestock-related soil compaction on the N_2O emissions. These factors could be optimised, e. g., by a low livestock density (Oenema et al. 1997, Witzke & Noleppa 2007).

Tab. 1: Emissions from dairy farming depending on the farming method (according to Dämmgen & Döhler 2009)

Greenhouse gas	Emissions from different methods [kg cow^{-1} a^{-1}]			
	conv., stable silage, slurry	conv., pasture, silage, slurry	conv., pasture, straw bed	organic, pasture, straw bed
CH_4 (Digestion)	91.8	92.9	92.9	92.9
CH_4 (Stored)	18.2	15.1	4.4	4.4
CH_4 (Diesel)	0.0	0.0	0.0	0.0
Sum CH_4	*110.0*	*108.0*	*97.3*	*97.3*
N_2O (Stored)	0.94	0.77	0.83	0.83
N_2O (Fertilizer)	2.80	3.24	3.30	1.60
N_2O (Indirect)	2.88	3.86	3.88	4.19
N_2O (Fertilizer-manufacture)	0.13	0.12	0.12	0.00
N_2O (Diesel)	0.09	0.08	0.08	0.14
Sum N_2O	*6.83*	*8.07*	*8.21*	*6.75*
CO_2 (Fertilizer)	69	72	72	0
CO_2 (Fertilizer manufacture)	101	92	92	0
CO_2 (Diesel)	231	210	210	353
Sum CO_2	*401*	*375*	*375*	*353*
Sum greenhouse gases [Mg $Animal^{-1}$ a^{-1} CO_2-eq]	***5.36***	***5.62***	***5.42***	***4.94***

In contrast to the calculations of Dämmgen & Döhler (2009) a review of Rahmann et al. (2008), showed almost double the energy input in conventional systems, due to the production of concentrates. Further the authors postulate that the sum of the emissions calculated in kg CO_2-eq per t of milk for the two farming systems is approximately the same. The CH_4 emission per product unit is higher in organic farming than that in conventional farming, due to the lower milk yields, the intensive maintenance requirement and the more frequent use of roughage. The two production systems are not fundamentally different from each other in terms of N_2O release. It is obvious that in a comparison between organic and conventional enterprises, it is important to consider the individual farm management which can, e.g., depend on the education and expert advisory of the farmers and on the farm location (Rahmann et al. 2008).

Life cycle assessments done in organic and conventional dairy farms in the Netherlands by Thomassen (2008) show that organic farms are more sustainable in energy consumption and eutrophication potential per kilogram milk than conventional farms. He highlighted the role of off-farm emissions on the GHG balance. Whereas higher CH_4 and CO_2 emissions and a higher acidification potential occur on-farm in the organic farm, the complete emissions of the whole process chains are at the same level in both farm types. Conventional dairy farms use less land per kg of milk in contrast to organic farms. A reduction of the use of concentrate ingredients which have a high climate burden and a reduction of concentrate use per kilogram of milk are recommended to lower the GHG emissions (Thomassen 2008).

5.2 Possibilities to reduce GHG emissions by improved management

The overwhelming impact of farm management on the environment is verified in several studies. A total of 100 farms were examined in Germany over several years under the criteria of organically compatible land management. This evaluation based on 20 criteria for the ecological situation and sustainability of the enterprises. The results make clear that there are no general connections between the farm structure or location and environmental deficits. Additionally there were no clear indications that the intensity of production had any influence on the degree of the environmental damage. Ecological damage was in most cases due to the particular aspects of management (Eckert, Breitschuh & Sauerbeck 1999). For example the introduction of non-renewable energy resources could significantly change GHG balances of the whole production process. A possible contribution of dairy farming in that field could be the use of livestock effluents and litter in biogas plants. A simple analysis of the fossil energy use per farm area, per kg milk and of the energy efficiency of fodder production alone would provide a national and international benchmark for improvements in that field (Kraenzlein & Mack 2007). Those optimization processes are of overriding importance for the whole farm. The whole farm efficiencies will be described in the meta-data generated by the overall project. In the special field of dairy production, GHG balances and sustainability indicators are expected to be sensitive to the following management aspects.

5.2.1 Increased production

In general an increased milk production can be reached by improvements in the existing system, which is mainly a problem of knowledge transfer. Controversial intensification processes within the legal frameworks of organic dairy farming have to be discussed. A study on 26 organic dairy farms (Haas & Deitert 2004) resulted in dairy cows with high roughage and low concentrate use bearing average milk yields of 6 700 kg a^{-1} cow^{-1}. But the output per area unit as a measure of the production efficiency amounts to just 7 000 kg of milk per ha forage area (Scheringer & Isselstein 2000, Hug-Sutter 2007, Gruber et al. 2001). The study showed that high individual animal yields were not necessarily related to high area yields. In the study P and K nutrient balance were generally outweighed on the farm level. But with increasing imports of feedstuff, the nutrient surpluses increased up to 85 kg N $hectare^{-1}$. It was shown that under organic conditions, an increased yield in dairy farming of up to 9 000 kg per cow would be possible. However, this could only be achieved with an increase in concentrate use and external feed acquisition. Apart from the increased N surpluses this probably has influences on the GHG balances of production. Furthermore these additional investments did not always improve economic results. So whole farm assessments are necessary to conclude on preferable management options lowering the GHG emissions. For a further development and weak-points analysis of organic dairy farming, the use of sustainability indicators remains indispensable (Haas & Deitert 2004).

5.2.2 Feeding management

The CH_4 emission by the digestive process of the ruminants lies between 84 to 123 kg per cow and year (Monteny et al. 2006). A change in the feed rations can be used to reduce the CH_4 emissions from dairy farming. The carbohydrates play an important role concerning the CH_4 production. The more structural-carbohydrates (roughage) present, the more the CH_4 formation in the rumen increases (Brade et al. 2008), and an improved milk yield - obtained by an increased use of concentrates - abates the ruminal CH_4 emissions per cow. Also an increase of fats in the ration or the addition of food additives to decrease ruminal CH_4 genesis is discussed. The total effect on the GHG balance is open, because additional farmland would be necessary for concentrate or fat production.

As mentioned above, CH_4 emission from farm manure could be reduced by prolonging of grazing periods because the amount of manure is reduced and the storage emissions are obviated. But it should be taken into account that exact control of the fodder rations is difficult in the case of grazing (Osterburg et al. 2009). Also a reduction of the N content in the ration leads to a reduction in the N_2O emission from the manures during storage and application (Ahlgrimm & Clemens 2001, Amon 2002). Furthermore in this way, the emissions by gaseous NH_3 or NO_3 leaching are indirectly reduced (Osterburg et al. 2009). In dairy farming, the urea content in the milk is a good indicator of the N secretions. It is estimated that the application of N reduced fodder rations in the entire swine and poultry stock would obtain a reduction in GHG emissions of approximately 0.5 Mio. t. CO_{2eq}. If it were possible to lower the N secretions in dairy farming by approximately 10%, the same degree of GHG emission reduction could be expected (Osterburg et al. 2009).

5.2.3 Herd management

The GHG emissions per product might be the critical point in organic dairy farming. Therefore improvement opportunities should be attached here. Especially aspects of herd management seem to be important. Good animal health, diminished replacement rates and prolongation of herd life count among the possibilities (Renkema & Stelwagen 1979) for reducing GHG emissions in production. Also, an improved stable environment might have indirect effects on the gas balance due to fewer illnesses, and therefore fewer deaths (Rahmann et al. 2008). Also, the use of high-performance breeding animals for the production of milk and meat as co product is an essential measure to reduce CH_4 emissions per product unit (Ahlgrimm & Clemens 2001). Consequent selection and breeding management could lead to reductions in the reserve rate for herd replacement. GHG emission would be changed indirectly by lower feed demand and feed production and directly by lower numbers of heifers kept for herd replacement (Cederberg & Mattsson 2000).

6 Outlook

Since farming makes a great contribution to the emission of GHG, it is necessary to make use of the available reduction potentials for climate protection (Freyer & Dorninger 2008). The accumulated project data should serve as a basis for the development of GHG reduction potentials and for an improvement of other sustainability aspects in organic dairy farming. A detailed consideration and deep analyses of the data generated in the farm survey might show causes for different GHG emissions and sustainability values in the farms. It has to be established which parameters have a decisive influence on the GHG emissions and which measures can reduce them (Wegener 2006).

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Webpage: www.pilotbetriebe.de

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