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Options to reduce greenhouse gas emissions from enteric fermentation and manure handling in dairy farming – An analysis based on farm network data

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Key words: greenhouse gas, feed quality, manure, calculation methods

Abstract

In the project 'Climate Effects and Sustainability of Organic and Conventional Farming Systems' 44 paired organic and conventional dairy farms in Germany were analysed for their greenhouse gas (GHG) emissions from enteric fermentation and from animal excretions in the stables, on the pastures and during storage of manure. In milk production, methane (CH_4) from enteric fermentation of the cows is the dominating GHG source. On the analysed farms the calculation results for CH_4 emissions were strongly dependent on the choice of methodology. Considering crude nutrient contents of the actual feed rations, as opposed to using dry matter intake, generally increased the level of the results and widened their range. This was particularly prominent at lower milk yields when high amounts of fibre rich feed stuff were used. Since feed quality management on farms is crucial for both milk yield and CH_4 emissions from enteric fermentation, it should be of high importance in advisory concepts that aim at reducing GHG–emissions in milk production. Just like CH_4 emissions from enteric fermentation, GHG emissions from dairy manure are also directly connected with the feed intake and feed quality. Technical changes in manure storage and handling (e.g., integration of biogas plants) offer high GHG reduction potential in dairy farming.

Introduction

In the project 'Climate effects and Sustainability of Organic and Conventional Farming Systems', dairy farms in Germany were analysed for their greenhouse gas (GHG) emissions based on the whole process chain (Hülsbergen and Rahmann, 2013). This article focuses on the main GHG from dairy production. The most important source is methane (CH_4) from enteric fermentation of the cows. Second in importance are the GHG from livestock manure: CH_4, nitrous oxide (N_2O) and indirect N_2O-emissions ($N_2O_{indirect}$) by ammonia (NH_3) deposition on soils. They are determined by manure composition, manure management in stables and storage and by excreta of grazing animals dropped on pasture. The results from organic and conventional dairy farms are presented. A view on limits of modelling approaches based on practical farm data is given. Some practical recommendations for farm management to produce climate-friendlier milk are concluded.

Material and methods

In total, 44 farms were explored between 2009 and 2011. Each year, all feedstuffs were sampled and characterized by Weende analysis (crude nutrients). Energy and protein contents were calculated according to GfE (2001). Digestibilities of organic matter were taken from DLG (1997). For each farm, average feed demands of the lactating and dry cows were calculated from the energy demands under consideration of the average winter and summer diets, feed qualities, average milk yields and cow weight. Dairy and manure management were assessed via interviews on the farms. All manures in the different storage facilities of the farms were sampled and the components that are relevant for GHG emissions (N_{total}, NH_4-N = total ammoniacal nitrogen (TAN) and organic matter = volatile solids (VS)) were analyzed. CH_4 emissions from enteric fermentation of the dairy cows were calculated in two ways: (a) based on the results of the feedstuff analysis (formula: CH_4 [g] = (63 + 79 XF + 10 NfE + 26 XP – 212 XL) [kg], Kirchgeßner et al. (1995)) and (b) based on dry matter intake (CH_4 [MJ] = 3.23 + 0.809 TS [kg], Ellis et al. (2007, 2d)).

The excretion of substances that are relevant for GHG-emissions from manure management were calculated by feedstuff composition and feed demand of the dairy cows according to the procedures used for the German National Greenhouse Gas Report (Haenel et al., 2012). They are based on C and N flow models. GHG emissions from excreta dropped on pasture and in the stable and during manure storage were calculated under consideration of the duration animals spent in the respective stable compartments and on pastures. GHG emissions from manure management were calculated by multiplying VS, N and TAN (from analysis of manure or calculation of excretions) with emission factors (IPCC 1996, IPCC 2006). Average annual temperatures and storage conditions of the manure were included in the calculations. So only the rather narrow range of milk production of an average dairy cow was analysed. Pre-chain emissions or credits

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(e.g., emissions from feed production by energy use or soil carbon gains) are not included in the following results.

Results

The highest share of GHG emissions per kg energy corrected milk (ECM) results from CH_4 emissions from enteric fermentation (Fig. 1). With only one exception, results for enteric CH_4 emissions from the Kirchgeßner (1995) formula (using feedstuff quality as input parameters) were higher than those from the Ellis et al. (2007) formula (using dry matter intake as input parameter). Differences between the methods were particularly pronounced on farms with lower milk yields and high amounts of hay or straw in the diet (up to 60%). These were largely organic farms which also fed a low share of concentrate. Another example for a large difference between the methods is a conventional farm that fed 20 % straw in the average diet. If highly digestible feedstuffs are used, lower differences between the calculation methods occurred even at lower milk yields. This can be seen in the results from the farm indicated in Fig. 1: It uses feedstuff with low fibre contents (fresh grass, concentrates, maize-silage, high quality grass silage) and has a relatively low milk yield (6,393 kg ECM cow^{-1} a^{-1}). The higher the milk yields and the higher the contents of concentrate and maize in the diets, the lower the product related differences between the results of the calculation methods.

GHG emissions from manure in stables, storage and during gazing on pasture were dependent on the type of manure (solid or liquid), grazing duration and manure storage conditions on farms. In the two farms with biogas plants, the GHG emissions from stable and storage were significantly reduced (Figure 1). The farm with solid manure only (farm with 5,285 kg ECM cow^{-1} a^{-1} in Figure 1) showed the highest product-related emissions from this source. This results from the high emission factors for N_2O and CH_4 for solid manure (IPCC 1996) and the low milk yield of this farm. In all farms the GHG emissions from manure in the milking parlour were negligible because (a) only NH_3-emissions were considered here (the rest of the emissions of the excreta that were excreted in the milking parlour occurred in the manure storage) and because (b) the animals spent a comparatively small amount of time here. For the product-related GHG emissions for milk there is a strong negative correlation of milk yield for all evaluated emission sources, except for the emissions in the milking parlour (Tab. 1).

Table 1: Pearson correlation matrix for the interrelationship of the sources of product-related greenhouse gas emissions in milk production.

	Enteric fermentation (EF) acc. to Kirchgeßner/Ellis	Stable and storage	Milking parlour	Pasture	Sum
Milk yield a^{-1}	-0.89***/ -0.93***	-0.62***	-0.08	-0.42**	-0.68***
EF Kirchgeßner	– / 0.96***	0.6 ***	0.23	0.38*	0.65***
EF Ellis		0.58***	0.13	0.42***	0.65***
Stable & Storage			0.10	0.22	0.9 ***
Milking parlour				0.07	0.12
Pasture					0.63***

significance of correlation: * 0.05 ≥ p < 0.01, ** 0.01 ≥ p < 0.001, *** p ≤ 0.001

The lower coefficients for the correlation of manure emissions in stable and storage and on pasture with the milk yield can be hypothesised to be influenced by parameters that are determined by management (type of manure, duration of grazing). The positive correlation between the sum of the product-related GHG-emissions and these from manure in stable and storage was high (90%). This reflects interrelationship in calculation between digestibility of feed, milk yield and the amount of manure. On the other hand this shows the possibilities for reduction by technique and management on the farms, e. g., increasing digestibility of feed or optimising manure storage.

Only small differences between organic and conventional farms were found in the mean concentrations of VS, N_{total} and TAN in the manures, in the resulting potential to emit GHG (called 'potential greenhouse effect' in the following), and in the storage conditions. In both systems, storage of solid manure and storage of liquid manure had comparable potential emissions of approximately 32 kg t^{-1} CO_2-eq. based on fresh matter (FM) (Table 2). Based on dry matter (DM) the mean potential greenhouse effect of stored solid manures was higher than that from liquid manures. CH_4 was the most relevant source for emissions in liquid manures, whereas N_2O and CH_4 were equally relevant in solid manures (Table 2). The mean values show high standard deviations. This reflects (a) the wide range of manure composition, (b) the effects of the individual storage conditions on the farms and (c) the setting of emission factors. The latter influences results and complicates interpretation and adequate management reactions.

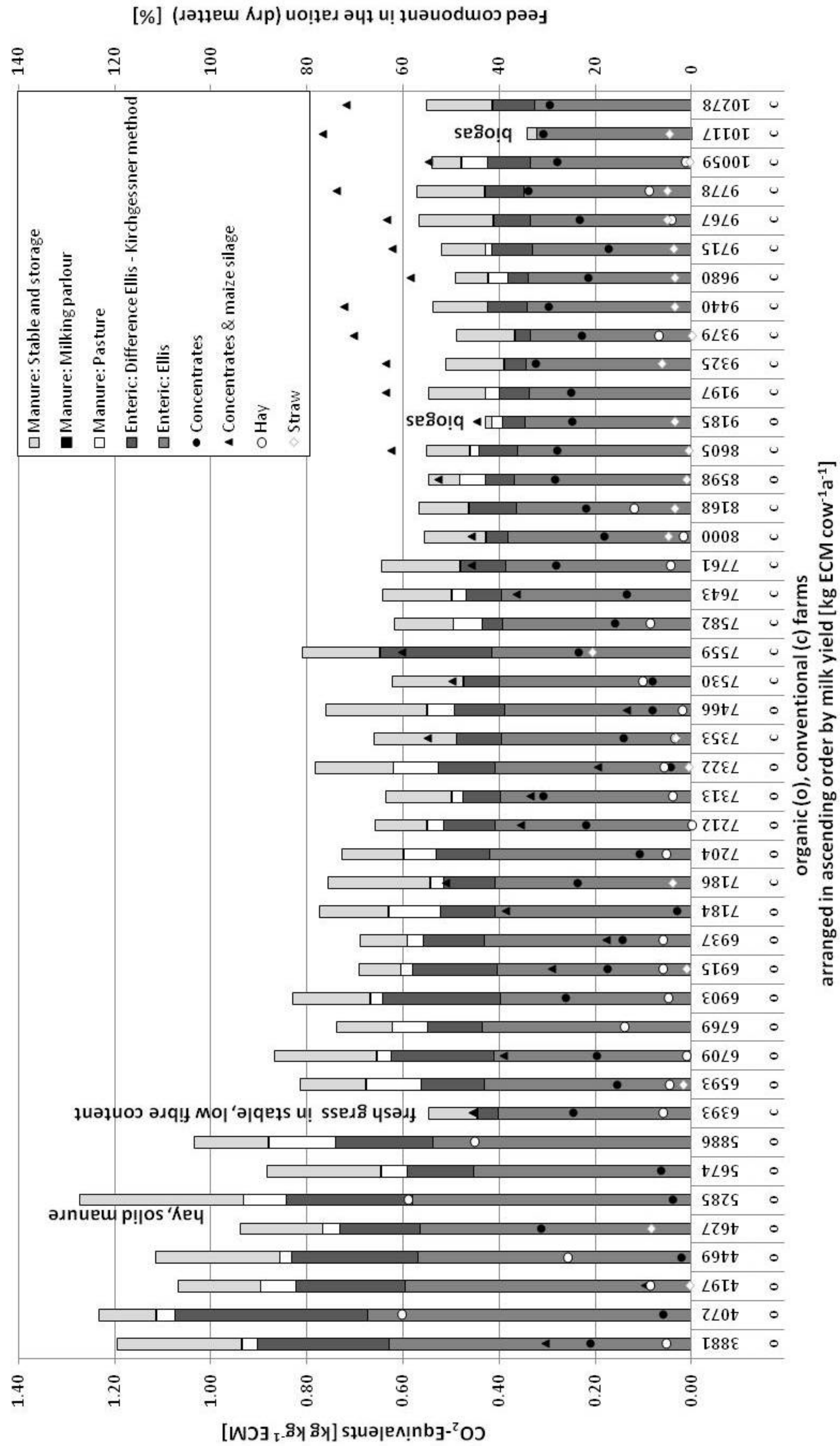

Figure 1: Product related greenhouse gas emissions of milk production from enteric fermentation and from manure in stable, storage and pasture and share of selected feed components in the average yearly feed rations of dairy cows on 44 organic and conventional farms in Germany.

Table 2: Mean concentration of substances relevant for GHG emissions and calculated potential GHG effects from livestock manures under consideration of the storage conditions in 44 dairy farms in Germany based on dry (DM) and fresh matter (FM).

		Solid manure (n=36)*				Liquid manure (n=38)*			
		[kg t^{-1} DM]		[kg t^{-1} FM]		[kg t^{-1} DM]		[kg t^{-1} FM]	
VS		778	±121^{A}	208	±43^{a}	727	±65^{B}	40	±21^{b}
N_{total}		20.0	±3.7^{B}	5.3	±1.1^{a}	63.7	±39^{A}	2.7	±1.6^{b}
TAN		3.1	±1.58^{B}	0.81	±0.4^{b}	36.5	±28^{A}	1.3	±0.7^{a}
CO_2-eq. from	CH_4	62.6	±9.8^{B}	16.7	±3.4^{a}	526	±47^{A}	27.5	±16.5^{b}
	N_2O	46.8	±8.6^{B}	12.4	±2.5^{a}	113	±102^{A}	4.5	±3.1^{b}
	N_2O (indirect)**	8.85	±4.46	2.27	±1.1^{a}	6.83	±6.16	0.25	±0.15^{b}
	Total	118	±16^{B}	31.4	±5.2	646	±11^{A}	32.2	±18.3

[*] mean values of the different manures on the farms (sampling in 2009-2011); [**] resulting from NH_3 deposition; [ABab] results of comparison of the mean of solid and liquid manures (t-test, $p \leq 0.05$), different capital or small letters are indicating significant differences in the dry or fresh matter content, respectively

Discussion

CH_4 emission from enteric fermentation of dairy cows is the most important on-farm source of GHG emissions in dairy farming, independent of the estimation method used. However, the choice of methodology to calculate these CH_4 emissions is highly relevant for the level of both the animal related and the product related GHG emissions of milk. Compared to the estimation formula based on dry matter intake (Ellis et al. 2007) the weighted diversification of crude nutrients in the formula of Kirchgeßner et al. (1995) increased the level of GHG emissions from enteric fermentation in almost all cases. Highest differences between the methods were found in both organic and conventional dairy farms that use high amounts of fibre rich feed stuff and have lower milk yields. Detailed feedstuff analyses and feed quality management on farms are absolutely necessary to govern milk yields. Additionally, the inclusion of these data in calculations of GHG loads from enteric fermentation and manure allows a systematic management of GHG emissions on dairy farms based on feed quality management. Hence, systematically optimising feedstuff quality serves to stabilise milk-yields while simultaneously reducing CH_4-emissions from enteric fermentation in dairy farming. Therefore, feed quality data should also be included in management recommendations aiming at reducing GHG emissions in milk production. As shown by the analyses of practical farm data, changes in storage and management of manure also have a high reduction potential for GHG emissions. They should be clearly addressed for reducing GHG emissions in organic and conventional dairy farms. However, overall approaches to reduce GHG-emissions in milk production must include the complete farm organisation.

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