Emission of Climate-Relevant Gases in Organic and Conventional Cropping Systems

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Abstract

In 81 commercial farms in Germany, emissions of the greenhouse gases CO_2, CH_4 and N_2O from crop production have been computed by model-based analyses. The considered influence factors comprise farm structure, mass and energy inputs as well as cultivation methods. A linear correlation was found between energy input and greenhouse gas potential. Due to lower N and energy inputs and also higher C sequestration as a result of humus restoration, the organic farms revealed area-related emissions (785 kg CO_2 eq ha^{-1} a^{-1}) that were 2.75 times lower than the emissions from conventional farms (2165 kg CO_2 eq ha^{-1} a^{-1}).

Introduction

According to the latest IPCC report, the mean global temperature is going to increase by 1.0 to 6.3 °C by the end of the 21st century, if greenhouse gas emissions continue to rise unhampered. Rainfall intensity and flood hazards will increase just as the duration of drought and heat periods, with other words: extreme weather situations will occur more frequently. In all spheres of the society, especially in agriculture, strategies have to be developed for an adaptation to the climatic changes, but also for the protection of the global climate. Is organic farming able to render an effective contribution to the protection of the atmosphere? Which level reach greenhouse gas emissions in organic farming compared to other forms of land use? Are there mitigation potentials and if so, how efficient can they be used? Statements to these questions will be made below using results from model-supported analyses of the greenhouse gas emissions from organic and conventional farms in Germany.

Materials and methods

In recent years, a model program has been developed by us that allows to estimate the emission of the greenhouse gases CO_2, N_2O und CH_4 on the level of farm systems in form of energy and mass balances. The emissions are converted into CO_2-equivalents [CO_2 eq]. Depending on the radiation absorption and the retention time in the atmosphere, the greenhouse potential of CH_4 amounts to 23, that of N_2O to 296, related to the efficiency of CO_2 (= 1).

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The following balancing methods have been integrated into the model:

- Balancing of energy fluxes. Consideration is made of direct (diesel fuel, electricity, solid fuels) and indirect energy input (manufacturing and transport of fertilizers, pesticides, machines). The energy input is the basis for deriving CO_2 emissions (Küstermann et al. 2007).
- Balancing of nitrogen fluxes in the system soil – plant – animal – environment. Our model program includes methods for estimating N flows and N pools by means of management data like N_2 fixation efficiency, manure N production, N turnover in the soil (Küstermann et al. 2007). N_2O emissions from the soil are calculated with regard to the N Input.
- Balancing of carbon fluxes in the system soil – plant – animal – environment (Küstermann et al. 2007a). We estimate the C sequestration in soils depending on crop rotation, fertilization and tillage (humus accumulation and depletion). In livestock keeping, metabolic CH_4 emissions are calculated with consideration of feeding.

The model software has been applied in 33 organic (org) and 48 conventional farms (con) located in different soil and climatic regions of Germany. To ensure comparability, only emissions from crop production have been demonstrated.

Results

Between organic and conventional farms, grave differences were dislosed concerning structure, mass and energy inputs, yields, C-sequestration and greenhouse potentials (Table 1), but also among organic as well as conventional farms deviations are enormous. The mean energy input in organic farms reaches 5.6 GJ ha^{-1} a^{-1}. Due to differences in cropping structure und intensity, some farms exceed this level by up to 100 %. In the conventional farms, mineral fertilizer and pesticide application cause markedly higher energy inputs (12.6 GJ ha^{-1} a^{-1}). Yields and energy fixation in the ecofarms (28 to 192 GJ ha^{-1} a^{-1}) reveal a wider variation than the corresponding values of the conventional farms (51 to 192 GJ ha^{-1} a^{-1}). Energy fixation depends on the cropping system, site specific yield potentials and the use of the produced biomass. High energy fixation is achieved with a high harvest index, for example when the byproducts and also catch crops are used. Organic farming consumes clearly less energy per unit area and reaches higher efficiency levels per unit product (output/input ratio, Table 1). C sequestration in the soil organic matter varies broadly. On average, organic farms accumulate humus (+ 110 kg C ha^{-1} a^{-1} = reduction of the greenhouse potential by 415 kg CO_2 eq ha^{-1} a^{-1}), whereas conventional farms have depleting humus contents (-40 kg C ha^{-1} a^{-1} = 150 kg CO_2 eq ha^{-1} a^{-1}). This can be explained by differences in crop rotations (high legume share (org) vs. high root crop and cereal proportion (con)) as well as in quantity and quality of the supplied organic matter.

Due to lower N and energy inputs, clearly lower N_2O and CO_2 emissions were computed for the organic farms than for the conventional counterparts. The conventional farms emitted 2165 kg CO_2 eq ha^{-1} a^{-1} on average. This exceeds the calculated emissions from the organic farms (785 kg CO_2 eq ha^{-1} a^{-1}) by the 2.75 fold. The product-related differences (per GJ) are smaller on grounds of much lower energy fixation on organic farms.

Tab. 1: Farm structure, mass and energy budget as well as greenhouse gas emissions in crop production. Analysis of 81 commercial farms in Germany

Parameter	Measuring unit	org (n = 33)		con (n = 48)	
		Mean	(Min – Max)	**Mean**	(Min – Max)
Farm structure					
Livestock density	LSU ha^{-1}	**0.3**	0 – 1.5	**0.6**	0 – 2.7
Cereal proportion	% of AA	**48**	14 – 67	**57**	30 – 77
Legume proportion	% of AA	**33**	15 – 46	**7**	0 – 18
Inputs and Outputs					
Energy input	GJ ha^{-1}	**5.6**	3.6 – 11.3	**12.6**	6.8 – 17.8
N input	kg N ha^{-1}	**149**	69 – 285	**236**	116 – 339
Energy fixation	GJ ha^{-1}	**75**	28 – 192	**127**	51 – 192
Output/Input ratio	GJ GJ^{-1}	**12.6**	5.6 – 24.4	**9.9**	6.4 – 13.6
Greenhouse gas potential					
CO_2 emission, (energy input)	kg CO_2 eq ha^{-1}	**349**	215 – 526	**707**	337 – 1023
C sequestration in humus*	kg CO_2 eq ha^{-1}	**-415**	-575 – 1766	**150**	-915 – 1255
N_2O emission	kg CO_2 eq ha^{-1}	**852**	387 – 1552	**1307**	643 – 1865
Greenhouse potential	kg CO_2 eq ha^{-1}	**785**	-155 – 1709	**2165**	937 – 4109
Greenhouse potential	kg CO_2 eq GJ^{-1}	**12.6**	-1.1 – 28.7	**17.4**	10.7 – 27.4

* Positive values indicate humus reduction and release of soil-bound C to the atmosphere, negative value indicate humus accumulation and recovery/return of C from the atmosphere into the soil.

There is a linear relationship between energy input and greenhouse potential; with increasing input of mineral N and energy rise the area-related N_2O and CO_2 emissions (Fig. 1). Calculations of greenhouse potentials take into account also C sequestration, symbiotic N_2 fixation, energy inputs with the use of machines and fuel. This explains the enormous variability of CO_2 emissions from organic and conventional farms.

Discussion

The statements made here agree basically with the results obtained by use of the same method in a spatially more limited agricultural region, the Tertiary hills in Bavaria (Küstermann et al. 2007). The increased number of investigated farms (81 vs. 28) makes the results presented in this paper more reliable. Moreover, farm-specific and site-related effects on greenhouse gas emissions can be analysed more profoundly because of the widely differing farm systems involved in this study.

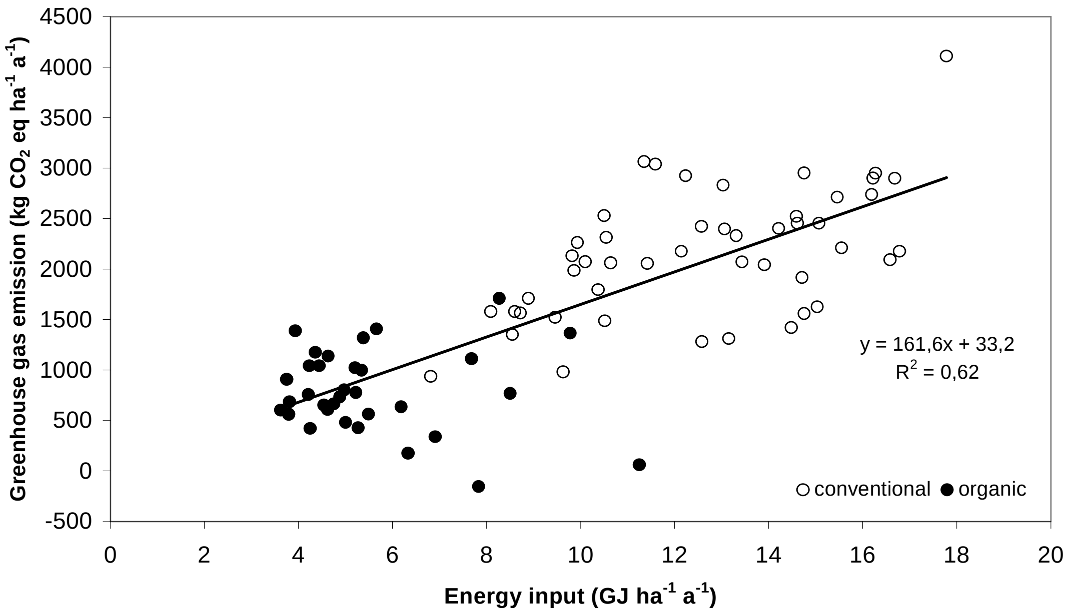

Figure 1: Greenhouse gas emissions in dependence on the energy input

At present, major uncertainties exist in modelling N_2O emissions; our model as well can only estimate potential emissions. This is problematic because of the high specific greenhouse gas potential of N_2O. Therefore, additional N_2O measurements have to be made in order to survey site and management effects, to mark the scope of error and to improve the model software.

Conclusions

Our investigations allow to draw conclusions on management optimization and mitigation of greenhouse gas emissions. The farm enterprise lies in the focus of our analyses, because on this level management decisions have to be taken, which have impacts on environment and climate. The mitigation of emissions requires to identify problematic sectors in farms and to derive coordinated measures and strategies.

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