Greenhouse gas fluxes in agricultural soils under organic and non-organic management

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Key words: nitrous oxide, methane, farming systems, climate change

Introduction

Farming practices are known to exert strong control over the soils' function to act as sources or sinks for greenhouse gases (GHG). A recent meta-analysis based on the evaluation of 74 published long-term system comparisons provides a comprehensive data base regarding soil organic matter development (SOM) and C sequestration potential of organic systems (Gattinger et al., 2012). Furthermore, the impact of sustainable land management practices including organic farming on soil carbon was also analysed for agricultural systems under Mediterranean climate (Aguilera et al., 2013. A comprehensive literature review on GHG (= non-CO_2) fluxes in agricultural soils under organic and non-organic management is missing. The generally lower N input level in organic agriculture compared to non-organic supports the expectation of lower nitrous oxide emissions and enhanced methane uptake in organically managed soils. There are some indications that organic agriculture leads to less soil-born greenhouse gas emissions than conventional agriculture (Niggli et al., 2009), but this phenomenon has, however, never been investigated systematically. Thus a comprehensive literature review followed by a meta-analysis was conducted to compare non-CO_2 GHG emissions from soils under organic and non-organic management. In addition we provide first GHG flux data from the well-known DOK farming system trial in Therwil/CH.

Material and methods

A literature search on measured soil-derived greenhouse gas (GHG) (nitrous oxide and methane) fluxes under organic and non-organic management from farming system comparisons was conducted and followed by a meta-analysis. Eligible data originates from paired comparisons on organic and non-organic farming systems from peer-reviewed research papers that report field measurements of nitrous oxide and methane fluxes from agricultural soils. Most of the collected research papers were published in scientific journals but also studies from conference proceedings, book chapters and dissertations were included to enlarge the data set, since those contributions also undergo a peer-review process. All studies are based on farming system comparisons where the organic practice was explicitly defined as such by the respective authors. In the current paper the term non-organic is applied to a range of modern management systems which are defined as conventional or integrated and, as such, its exact meaning varies across studies. We thus take non-organic to mean any farming system, which could rely on the use of synthetic nitrogen fertiliser and chemical plant protection means. We employed random effects meta-analysis to investigate our data as described by Gattinger et al. (2012). Meta-analysis is a statistical technique to combine and compare results from a range of independent studies, by weighing these results according to their different precisions, reflected in their standard deviations and underlying replications. We employed the inverse-variance method conventionally used in meta-analysis as well as in meta-analysis on GHG flux data as a weighing function of the various studies. All the analyses were done with the "Comprehensive Meta-Analysis 2.0" software (Biostat, Englewood, NJ/USA). Further informations can be obtained from Skinner et al. (2014).

In addition to the meta-analytical evaluation of the already published GHG flux data, GHG flux measurements in organic and conventional treatments of the DOK farming systems trial (Mäder et al., 2002) are conducted since 2012 by weekly gas samplings with the closed chamber technique according to Hutchinson and Mosier (1981). These activities are paralleled by molecular analyses of the underlying soil microbial communities by quantifying functional genes involved in nitrification and denitrification (Harter et al., 2013), the main processes for nitrous oxide formation in soil.

Results

Meta-analysis

Up to date 19 GHG studies from pair-wise farming system comparisons could be retrieved (Skinner et al., 2014). All 19 retrieved studies were conducted in the Northern hemisphere under temperate climate. Based

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on 12 studies that cover annual measurements, it appeared with a high significance that area-scaled nitrous oxide emissions from organically managed soils are 492±160 kg CO_2 eq. ha^{-1} a^{-1} lower than from non-organically managed soils (Table 1). For arable soils the difference amounts to 497±162 kg CO_2 eq. ha^{-1} a^{-1}. However, yield-scaled nitrous oxide emissions are higher by 41±34 kg CO_2 eq. t^{-1} DM under organic management (arable and use). To equalize this mean difference in yield-scaled nitrous oxide emissions between both farming systems, the yield gap has to be less than 17% (data not shown). For a comprehensive GHG assessment of a given farming system not only the soil-derived emissions but also all other emissions caused by the production of different (synthetic) fertilisers, energy use from farm machinery and irrigation, as well as emissions caused by livestock and manure, need to be accounted for as well (Gattinger et al., 2012). This, however, is beyond the scope of the current study.

The higher nitrous oxide emissions determined for non-organic farming systems can be linked with the higher N inputs applied. In average non-organic farming systems received 156 and 191 kg N ha^{-1} a^{-1} as external (only fertiliser) and total N (fertiliser + plant residues) inputs, respectively, as opposed to 89 and 123 kg N ha^{-1} a^{-1} applied in the organic systems. However, according to the results from the meta-regression N inputs appear to be an important determinant for nitrous oxide emissions in soils under non-organic but not for those under organic management. This can be explained by the higher bioavailability of the synthetic N fertiliser in non-organic farming systems, whereas the N inputs in the organic systems consist mainly of farmyard manures and plant residues including those from grass-clover leys where N availability is much lower. These findings on influential factors have been derived with meta-regression on rather small data sets and have thus descriptive indicative character only and should not be used for statistical inference.

Table 1: Mean differences as revealed by meta-analysis of area- and yield-scaled nitrous oxide (N_2O) emissions under organic compared to non-organic management for the different land use types

	Area-scaled N_2O emissions (kg N_2O-N ha^{-1} a^{-1})					Area-scaled GWP [d] N_2O emissions (kg CO_2-eq. ha^{-1} a^{-1})					Yield-scaled GWP [d] N_2O emissions (kg CO_2-eq. t^{-1} DM)				
land-use	MD [a]	CI [b]	p	studies	comp. [c]	MD [a]	CI [b]	p	studies	comp. [c]	MD [a]	CI [b]	p	studies	comp. [c]
all (annual)[f]	-1.05	0.34	0.00	12	70	-492	160	0.00	12	70	42.4	33.1	0.01	7	25
arable	-1.06	0.35	0.00	11	67	-497	162	0.00	11	67	41.1	34.2	0.02	6	23
grassland	-2.33	5.40	0.40	2	3	-1091	2531	0.40	2	3	45.6	190.3	0.64	2	2
rice-paddies	-1.38	2.22	0.22	1	3	-646	1040	0.22	1	3	-25.4	49.2	0.31	1	3
overall[g]	-0.93	0.25	0.00	18	98	-434	118	0.00	18	98	30.7	28.9	0.08	8	30

[a] MD, Mean Difference under organic treatments; negative values mean less emissions compared to non-organic treatment, [b] ± 95%confidence interval (CI), [c] comparisons, [d] Greenhouse Warming Potential (GWP) [f] all annual measurements excl. rice (arable & grassland), [g] all landuse types excl. rice; annual and short time measurements, [h] no data available for respective land-use type

Table 2: Mean differences as revealed by meta-analysis of area- and yield-scaled nitrous oxide (CH_4) emissions under organic compared to non-organic management for the different land use types

	Area-scaled CH_4 fluxes (kg CH_4-C ha^{-1} a^{-1})					Area-scaled CH_4 fluxes (kg CO_2-eq. ha^{-1} a^{-1}) [f]					Yield-scaled CH_4 fluxes (kg CO_2-eq. t^{-1} DM)				
land-use	MD [a]	CI [b]	p	studies	comp. [c]	MD [a]	CI [b]	p	studies	comp. [c]	MD [a]	CI [b]	p	studies	comp. [c]
Arable	-0.10	0.15	0.01	3	8	-3.2	2.5	0.01	3	8	-2.10	2.33	0.08	2	5
Rice paddies	9.37	8.19	0.00	1	3	950	415	0.00	1	3	128.3	26.1	0.00	1	3

a MD Mean Difference under organic treatments; negative values mean (higher) uptake, positive (higher) emissions compared to non-organic treatment;
b ± 95%confidence interval (CI); c comparisons

Our literature evaluation further revealed a net methane uptake in arable soils (3 comparative studies) independent from the farming system. In organically managed soils, methane uptake is more pronounced compared to non-organic with a mean difference of 3.2±2.5 kg CO_2 eq. ha^{-1} a^{-1} (Table 2). This might be related to higher mineral N contents in the soil solution under non-organic management suppressing the activity of the relevant enzymes for microbial methane oxidation.

GHG fluxes in organic and conventional treatments of the DOK farming systems trial

To further broaden the knowledge base on the climate impact of organic and conventional farming systems, since August 2012 GHG fluxes are measured weekly in the well-known DOK farming systems trial (Mäder et al., 2002) for a time span of 48 months. First evaluation of the 12 months data of a grass-clover/maize sequence revealed highest nitrous oxide and highest methane emissions in those treatments which are managed conventionally and receive farm yard manure (data not shown). Most of the emissions of both gases occurred in the spring period and early summer after ploughing of the grass-clover ley and application of fertilizers when soil temperature and moisture content were most favourable. Unexpectedly high nitrous oxide emissions were also determined in the unfertilised treatments, which serves as control. This might be an indication, that in systems which receive neither mineral nor organic N fertiliser, nitrous oxide losses can be substantial, when a vigorous plant cover for N uptake is missing. On-going molecular analyses will reveal if the observed differences in nitrous oxide emissions between organically and conventionally managed soils is due to different functionalities of the underlying soil microbial communities.

Conclusions

There is scientific evidence for lower nitrous oxide emissions from organically managed soils when scaled to the area. However, further data from farming system comparisons are required, particularly from long-term GHG measurements covering several cropping seasons or ideally entire crop rotations. This enables closing knowledge gaps concerning N fluxes and pools under organic management as well as the formation of the new soil ecosystem (soil quality) equilibrium after implementing organic practices. Substantial reductions of nitrous oxide emissions as well as enhancement of methane uptake can be reached by consequent application of "good agricultural practice" and simple adoptions of soil management, forming together a balanced set of GHG mitigation mechanisms.

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