Influence of plants and fertilisation level on the microbial uptake of methane in soils

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Abstract

Soil fluxes of greenhouse gases and other gases during cultivation of crops influence the environmental balance of renewable raw materials. Methane uptake by soils can improve this eco-balance. Agricultural and not cultivated upland soils remove methane from the atmosphere due to microbial activity. The uptake rates of cultivated soils are usually lower than the methane consumption by forest soils and other non-fertilised soils. Until now, the ranges of the soil sources and sinks are highly uncertain. In the present study, soil emissions were measured at an experimental field, where different short rotation crops were cultivated for the use of biomass as biofuels. The aim of the soil emission measurements was the evaluation of environmental effects in connection with different fertilising levels of the cultivated plants. Four times weekly, gas samples were taken from gas flux chambers (cover boxes) and analysed by gas chromatography. The results showed that soil temperature was the main reason for the seasonal change of the methane uptake. Whereas the uptake dropped near to zero during the winter period, the specific uptake rates reached values up to 0.6 mg CH_4 m^{-2} d^{-1} (25 µg CH_4 m^{-2} h^{-1}) in the summer. These highest values were measured at areas with cocksfoot (orchard grass - Dactylis glomerata) and rye plots with a fertilisation level of 150 kg N ha^{-1} a^{-1}. At poplar plots, only maxima of about 0.25 mg CH_4 m^{-2} d^{-1} were found. In contradiction to reports found in literature, nitrogen fertilising (saltpetre of lime and ammonia) did not inhibit, but enhance the methane uptake in soils except the plots with willows, where an inhibition effect due to nitrogen fertilising was observed.

Introduction

Biological activity causes gas fluxes between soil and atmosphere. Many soil organisms consume oxygen and produce carbon dioxide and other gases. Depending on soil conditions, some of the soil species can utilise hydrogen (H_2), carbon monoxide (CO), or methane (CH_4) as an energy source. Especially in anoxic natural environments like in hydromorphic soils (wetland soils), methanogens produce CH_4 and methanotrophs consume CH_4 (Heyer 1994, Conrad 1996). The remaining CH_4-balance leads to a CH_4-soil partial pressure, which results in the emission of CH_4 or in the uptake of CH_4. This depends on the difference to the atmospheric CH_4-level. Temperature, moisture, soil properties, and other conditions determine the concentration gradient, and thus the flux rate.

Agricultural and not cultivated upland soils remove methane from the atmosphere. The uptake rates of cultivated soils are usually lower than methane consumption by forest soils and other non-fertilised soils. The fluxes of trace gases between soil and atmosphere show a high variability with respect to site and time. Until now, the ranges of the soil sources and sinks are highly uncertain. The actual global estimates indicate that the soil uptake of methane reduces atmospheric methane by 15 to 45 Tg a^{-1}. On the other hand, the total annual emissions of methane, caused by human activity, are estimated to be about 300 - 400 Tg a^{-1} (IPPC 1992). There are some values for the methane uptake rate in soils, covering only selected soil types and climatic conditions. The observed uptake rates range from 0.1 to 0.6 mg CH_4 m^{-2} d^{-1} (e.g. Heyer 1994, Teepe 1999, Goossens et al. 2000, Erda 2000).

Although methylotropic bacteria, which oxidise CH_4, have been known for two decades (Colby et al. 1979), the species responsible for methane uptake in soils at the atmospheric mixing ratio could not be isolated so far (Bender and Conrad 1992, Conrad 1996). It is assumed that methanotrophs are responsible for methane oxidation at higher concentration levels as well as at an atmospheric mixing ratio (Bender and Conrad 1994, Conrad 1996). The oxidation of methane at atmospheric mixing ratios is not clear in all details up to now (Koschorreck and Conrad 1993, Yamulki et al. 1999). The known methanotrophs are unable to grow on atmospheric methane. Methanotrophs reduce methane emissions especially in wetland soils, where intensive methane production can be found (Higgins et al. 1981, King 1992).

Fertilisation as nutrient supply influences the biological activity in the soil. Since nitrate ions (Steudler et al. 1989) and ammonia ions (Moiser et al. 1991, Hütsch et al. 1994) can hamper the methanogens, nitrogen fertilising should reduce the production of methane. The consumption of methane in the soil generates a concentration gradient. As the transport of methane usually is controlled by diffusion, the soil properties (pore volume, pore distribution, pore structure, water content, air capacity etc.) determine the diffusion resistance, and therefore the uptake rate. Different uptake rates are expected for cultivated land. Climatic conditions, soil type, cultivation practice and cultivars control gas exchange between soil and atmosphere and thus the methane flux rates.

In the present study, soil emissions have been measured in an experimental field, where different short rotation crops were cultivated for the use of biomass as biofuels. The aim of the soil emission measurements was the evaluation of environmental effects in connection with different fertilising levels of the cultivated plants.

Materials and Methods

The measurements were performed in an experimental field (Fig. 1). The soil had sufficient homogeneity. The mean and standard deviations (s) of 40 soil samples were (Pagel et al. 1995, Scholz et al. 1999): clay content 6.4 % (s: 1.3 %), organic carbon content 0.91 % (s: 0.14 %) and pH value 6.0 (s: 0.34). The field had been subdivided into 40 plots (624 m^2 each, except Orchard grass - also called Cocksfoot grass; Fig. 1). Ten different plant varieties or plant combinations were arranged as columns, and the different fertilisation was realised in four rows. There were plots without fertilisation (D), and plots with a different level of nitrogen fertilising (A: 150 kg N ha^{-1} a^{-1}; B and C: 75 kg N ha^{-1} a^{-1}) supplemented by PK-fertiliser (A), wood ashes (B), and straw ashes (C).

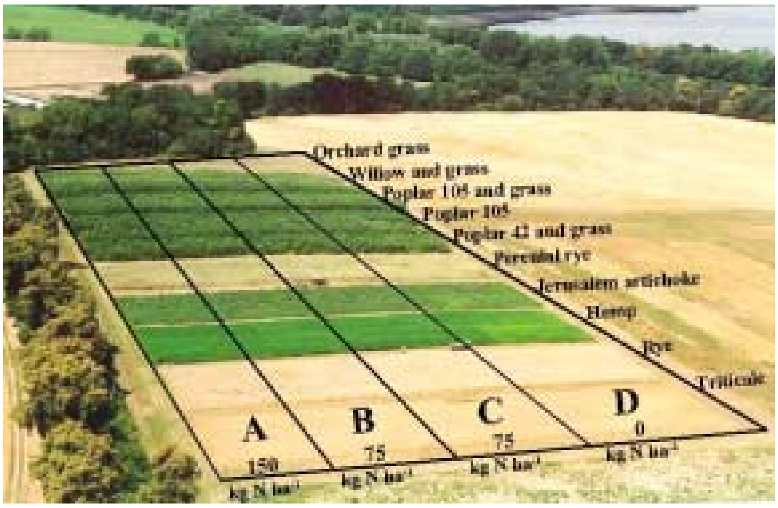

Fig. 1 Experimental field for the cultivation of energy plants. Plots with different plants and different type of fertilising level are indicated.

The gas flux measurements have been performed four times a week by utilisation of an automated GC (Loftfield et al. 1992 & 1997). On measuring days, gas samples were taken from 25 gas flux chambers at different plots. The gas flux cambers (volume 64 dm^3) had a volume to area ratio of V/A = 0.315 m. Two evacuated gas samplers (100 cm^3 bottles with taps) were connected with each box. The first was opened, when the box was put on the water-sealed ring at the soil and the second one after about 100 minutes' collecting time. Then the boxes were removed and the samplers were connected with the GC-injection control system. In the course of the automatic GC-measurement, the samplers were checked, the GC calibrated and the concentrations determined. Automated GC analysis improves the accuracy. For CH_4 analysis, the FID detector of the GC was applied. 64 samples could be analysed in one computer-controlled run. From the sample volume, 3 cm^3 were injected. At atmospheric mixing ratios, the coefficient of variation was 2.1% for CH_4 measurements. The standard deviation for complete flux determination (gas sampling and concentration measurement) was 0.6 $\mu g\ m^{-2}\ h^{-1}$ (50 g ha^{-1} a^{-1}) for CH_4.

Results and discussion

In the first two years of this study (1997-1998), the gas analysis was performed weekly by means of an FT-IR-spectrometer (Hellebrand and Scholz 1997, 1998, 2000). Methane uptake could be observed only qualitatively because of the lower accuracy of the FT-IR gas analysis in comparison to GC measurements. In addition, the weekly gas sampling hampered a quantitative evaluation. Due to GC analysis, a significant improvement could be achieved and the methane uptake was measurable with sufficient accuracy.

The methane uptake clearly depended on soil temperature (Fig. 2). Whereas the uptake dropped to values of around 0 to 5 $\mu g\ CH_4\ m^{-2}\ h^{-1}$ from December till April, the uptake rates reached values in the range from 10 to 20 $\mu g\ CH_4\ m^{-2}\ h^{-1}$ between May and November. Since we find different units in literature, the conversion is:
10 $\mu g\ CH_4\ m^{-2}\ h^{-1}$ are equal to 0.24 mg $CH_4\ m^{-2}\ d^{-1}$, to 2.4 g $CH_4\ ha^{-1}\ d^{-1}$, or to 0.876 kg $CH_4\ ha^{-1}\ a^{-1}$.

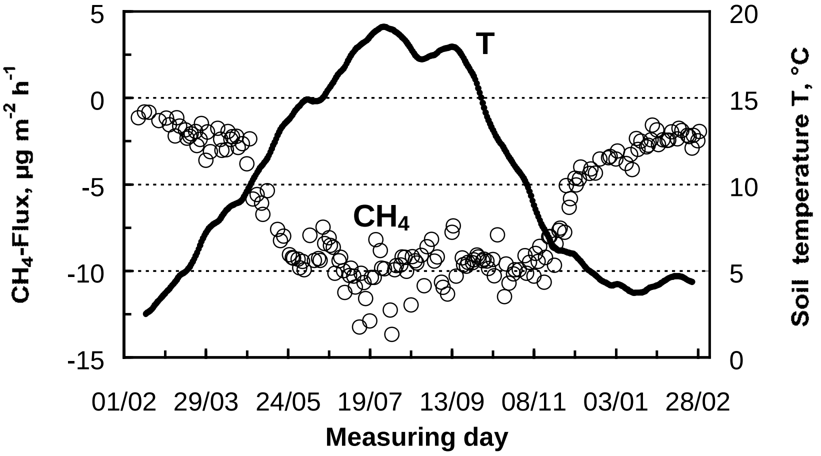

Fig. 2 Soil temperature in 20 cm depth (sliding mean value of 30 days) and mean soil uptake of atmospheric methane in the course of 1999/2000.

The highest values were measured in areas with cocksfoot (orchard grass - Dactylis glomerata) and rye plots with a fertilisation level of 150 kg N ha^{-1} a^{-1} (Fig. 3). In poplar plots, only maxima of about 10 µg CH_4 m^{-2} h^{-1} were found for this fertilisation level. Methan uptake was at its highest in willow and triticale plots, when no fertiliser was applied (Fig. 4). In dependence on plant variety, a different influence of fertilisation (saltpetre of lime and ammonia) was observed. The methane uptake was reduced by 30% for plots with willows in case of fertilisation.

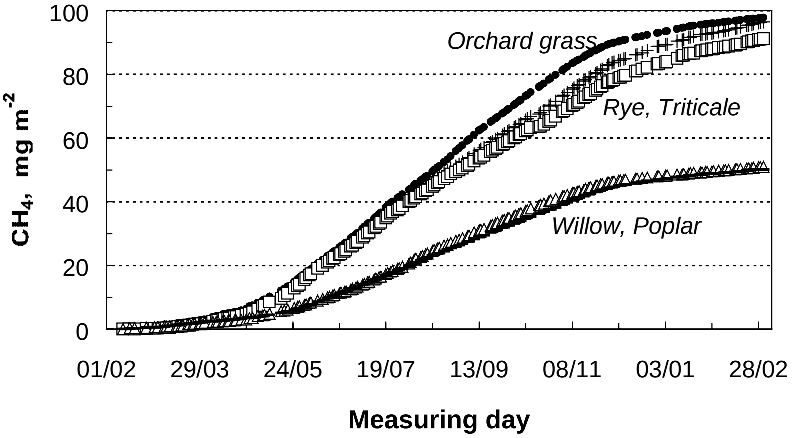

Fig. 3 Cumulated methane uptake at plant plots A with fertilisation level of 150 kg N ha^{-1} a^{-1}.

On the other hand, a near doubling of the uptake rate was observed at the highest fertilisation level (150 kg N ha^{-1} a^{-1}) in plots with rye and in plots with orchard grass. In case of plots with poplars and with triticale, no significant influence of fertilisation on the methane uptake was found. In contradiction to reports in literature, a clear inhibition of methane uptake due to nitrogen fertilising cannot be stated, except for plots with willows. Moreover, nitrogen fertilising seems to enhance the methane uptake of cultivated soils (Table 1).

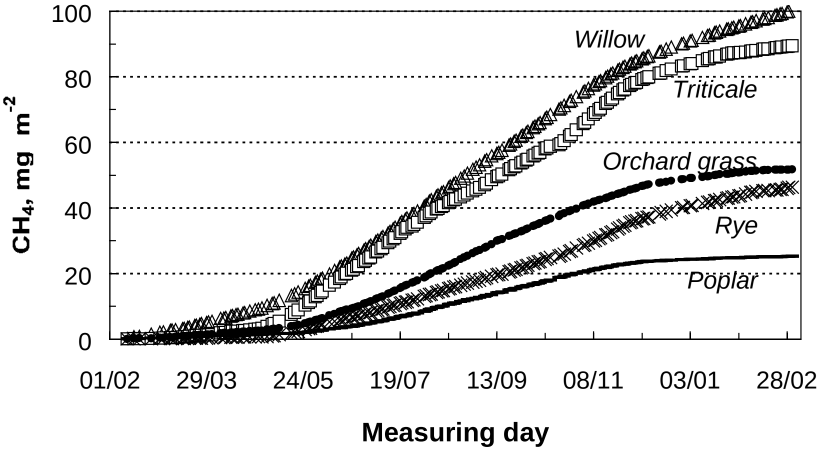

Fig. 4 Cumulated methane uptake at plant plots D with no fertilisation.

Further measurements over several years are necessary to strengthen the findings here and to clarify, if these effects are really caused by the different cultivars, and not by the variability of the soil. As a final result, 700 g CH_4 ha^{-1} a^{-1} is the mean value for the methane uptake in loamy sandy soils (Table 1). Considering the environmental balance of renewable raw materials, the methane uptake discussed above results in a comparatively small CO_2-compensation of 15 kg CO_2 ha^{-1} a^{-1}, when the CH_4 global warming potential (GWP = 21) for a 100 year time horizon is used (IPPC 1995).

Table 1: Soil uptake of methane at plant plots with a different level of fertilisation in kg CH_4 ha^{-1} a^{-1}

Plants	**Level of fertilisation**			**Mean value**
	0 kg N ha^{-1} a^{-1}	75 kg N ha^{-1} a^{-1}	150 kg N ha^{-1} a^{-1}	
Poplar	0.25	0.29	0.50	0.35
Willow	1.00	0.57	0.51	0.69
Rye	0.46	0.63	0.96	0.68
Orchard grass	0.52	0.75	0.98	0.75
Triticale	0.89	1.02	0.91	0.94
Mean value	0.62	0.65	0.77	0.68

Conclusions

Methane uptake rates could successfully be determined using gas flux chambers and gas analysis by means of an automated gas chromatograph. It turned out to be that gas analysis by FT-IR measurements does not reach the required accuracy.

The methane uptake strongly anti-correlates with the soil temperature, having lows between 0 and 5 µg CH_4 m^{-2} h^{-1} during the winter season and highs near 10 to 20 µg CH_4 m^{-2} h^{-1} during the summer. The annual mean value of the methane uptake over all measurements is 0,7 kg CH_4 ha^{-1} a^{-1}.

The methane uptake by soils depends on the type of cultivar and on the level of fertilisation. The highest values were measured in areas with grass and rye plots at a fertilisation level of 150 kg N ha^{-1} a^{-1}. Plots with willows had a reduced methane uptake of 30 %. The methane uptake in plots with poplars and triticale was not influenced by fertilising.

References

Erda, L.Y.L. (2000): The impact of grassland conversion on CO_2 emission and CH_4 uptake. in "Non-CO_2 Greenhouse Gases: Scientific Understanding, Control and Implementation", edited by van Ham, J., Baede, A.P.M., Meyer, L.A., Ybema, R., Kluwer Academic Publishers, Dordrecht, 115-120

Bender, M., Conrad, R. (1992). Kinetics of CH_4 oxidation in oxic soils exposed to ambient air or high ch4 mixing ratios. FEMS Microbiol. Ecol. 101, 261-270

Bender, M., Conrad, R. (1994). Methane oxidation activity in various soils and freshwater sediments: occurrence, characteristics, vertical profiles and distribution on grain size fraction. J. Geophys. Res. 99. 16531-16540

Colby, J., Dalton, H., Whittenburry, R. (1979). Biological and biochemical aspects of microbial groth on C-combounds. Annu. Rev. Microbiol. 33, 481-517

Conrad, R.: Soil microorganisms as controllers of atmospheric trace gases (H_2, CO, CH_4, OCS, N_2O, and NO). Microbiol. Rev. 60, 4 (1996), S. 609-640

Goossens, A., De Visscher, P., P. Boeckx, Van Cleemput, O. (2000). Influence of land use on long-term methane uptake. in "Non-CO_2 Greenhouse Gases: Scientific Understanding, Control and Implementation", edited by van Ham, J., Baede, A.P.M., Meyer, L.A., Ybema, R., Kluwer Academic Publishers, Dordrecht, 89-94

Hellebrand, H.J. and Scholz, V. (1997). Düngerstimulierte Gasemissionen - Lachgas beim Anbau von Energiepflanzen (Fertiliser-induced gaseous emissions - Nitrous oxide gas from cultivating energy plants). Landtechnik 52, 6 (1997), 302-303

Hellebrand, H.J. and Scholz, V. (1998). Gaseous emissions from cultivating energy plants, AgEng98, Oslo August 24-28, Paper No. 98-D-004 (8 pages on CD-ROM) and Proceedings Part II, 1010-1011

Hellebrand, H.J. and Scholz, V. (2000). Gas chromatographic studies on soil emission of nitrous oxide in dependence on nitrogen fertilising. The XIV Memorial CIGR World Congress 2000, Tsukuba, Nov 28-Dec 1

Heyer, J. (1994): Methan (Methane). Study C in „Landwirtschaft Studienprogramm" (Agriculture study programme), edited by Enquete-Commission of the 12th German Bundestag, Volume 1, Economica Verlag, Bonn, 91 p.

Higgins, I.J., Best, D.J., Hammond, R.C., Scott, D. (1981). Methane-oxidizing microorganisms (Methan oxidierende Mikroorganismen). Microbiol. Rev. 45, 556-590

Hütsch, B.W., Webster, C.P., Powlson, D.S. (1994). Methan oxidation in soil as affected by land use, soil pH, and N fertilization. Soil Biol. Biochem. 26, 1613-1622

IPCC (1992). Climate Change 1992 - The Supplementary Report to the IPCC Scientific Assessment. Intergovernmental Panel on Climate Change, Press Syndicate, University of Cambridge, 200 p.

IPCC (1995). IPCC Guidelines for National Greenhouse Gas Inventories. Workbook, 3 Volumes, Cambridge University Press, Cambridge

IPCC (1996). Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Workbook, 3 Volumes http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm, and additional software under http://www.ipcc-nggip.iges.or.jp/public/gl/software.htm

King, G.M. (1992). Ecological aspects of methane oxidation, a key determinant of global methane dynamics. Adv. Microb. Ecol. 74, 431-468

Koschorreck, M., Conrad, R. (1993). Oxidation of atmospheric methane in soil: measurements in the field, in soil cores and in samples. Global Biogeochem. Cycles 7, 109-121

Loftfield, N.S., Brumme, R., and Beese, F. (1992). Automated monitoring of nitrous oxide and carbon dioxide flux from forest soils. Soil. Sci. Soc. Am. J., 56, 1147-1150

Loftfield, N., Flessa, H., Augustin, J. and Beese, F. (1997). Automated gas chromatographic system for rapid analysis of the atmospheric trace gases methane, carbon dioxide, and nitrous oxide. Journal of Environmental Quality 26, 560-564

Moiser, R.L., Schimel, D., Valentine, D., Bronson, K., Patron, W. (1991). Methane and nitrous oxide fluxes in native, fertilized and cultivated grasslands. Nature 350, 330-332

Pagel, R., Scholz, V., and Ellerbrock, R. (1995). Nachwachsende Brennstoffe - Ziele, Methoden und erste Ergebnisse des Projektes „Biomasseversuch Bornim“ (Renewable resources - aims, methods and first results of the project "Biomass experiment Bornim"). Güterfelder Pflanzenbau-Mitteilungen III, 5-20

Steudler, P.A., Bowden, R.D., Melillo, J.M., Aber, J.D. (1989). Influence of nitrogen fertilisation on methane uptake in temperate soils. Nature 341, 314-316

Scholz, V., Beier, W., Ellerbrock, R., Hellebrand, H.J., Höhn, A., Kaulfuss, P. Krüger, K., Kühling, M., and Pagel, R. (1999). Umwelt- und technologiegerechter Anbau von Energiepflanzen. ATB-Forschungsbericht 1999/1, ATB, Potsdam-Bornim (Environmental friendly and technology adapted cultivation of energy crops. ATB research report 1999/1, Institute of Agricultural Engineering ATB, Potsdam Bornim)

Teepe, R. (1999). Quantifizierung der klimarelevanten Spurengasflüsse Lachgas (N_2O) und Methan (CH_4) beim Anbau der nachwachsenden Rohstoffe Pappelholz und Rapsöl (Quantification of the greenhouse gas fluxes of nitrous oxide (N_2O) and methane (CH_4) during cultivation of poplars and rape as renewable resources). Berichte des Forschungszentrums Waldökosysteme (Reports of the Research Centre for Forest Ecosystems), University of Göttingen, Series A, Vol. 158, 126 p.

Yamulki, S., Jarvis, S.C., Owen, P. (1999). Methane emission and uptake from soils as influenced by excreta deposition from grazing animals. Journal of Environmental Quality 28, 676-682