Dedicated to the 80th Anniversary of Prof. Radoš Řezníček

Nitrogen conversion and nitrous oxide hot spots in energy crop cultivation

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Abstract: Since 1999, nitrous oxide (N_2O) soil emissions from sites cultivated with energy plants have been measured by gas chromatography and gas flux chambers in experimental fields. The main aim of this study was the nitrogen conversion factor and its variability for sandy soils under climatic conditions of Central Europe. Annual plants (hemp, rape, rye, sorghum, triticale) and perennial plants (grass, perennial rye, poplar, willow) were fertilised with three different levels of nitrogen (150 kg N/ha/year, 75 kg N/ha/year, and none). The annual nitrogen conversion factors were derived from the annual mean differences between the fertilised sites and non-fertilised control sites. The mean nitrogen conversion factor for the non-cultivated soils was lower (perennial crops: 0.4%) than that for the regularly cultivated soils (annual crops: 0.9%). Few times, enhanced N_2O emission spots with maxima above 1000 μg $N_2O/m^2/h$, lasting for several weeks, were observed in the course of measurements. The influence of these local peak emissions on the nitrogen conversion factor is discussed.

Keywords: nitrogen fertilisation level; N_2O soil flux; cultivated and non-cultivated soils; perennial and annual plants

Nitrogen (N) fertilising is one of the main sources of anthropogenic contribution to the global dinitrogen oxide (nitrous oxide – N_2O) emission. In soil, N_2O is produced predominantly by two microbial processes, the oxidation of ammonium (NH_4^+) to nitrate (NO_3^-; called nitrification) and the reduction of NO_3^- to gaseous forms NO, N_2O, and N_2 (called denitrification; Firestone 1982). The rate of N_2O production depends on the availability of mineral N in the soil and the conversion factor (ratio of nitrous oxide-nitrogen (N_2O-N) emission to the input of fertiliser-N) depend on the soil type and climate (e.g. Bouwman 1990, 1996; Bouwman *et al.* 2002; Granli & Bøckman 1994; Stehfest & Bouwman 2006; Novoa & Tejeda 2006). For N_2O inventories, a default value of 1% (with additions and subtractions dependent on the soil type and climate) is recommended for mineral fertilisers (De Klein *et al.* 2006). When the cultivation of crops is assessed with regard to the greenhouse gas abatement, this conversion factor plays a significant role, e.g. the N fertiliser-induced emission of N_2O may counterbalance the carbon dioxide (CO_2) advantage of biofuels (in the case of a high nitrogen fertiliser application and of the conversion factor greater than 2%; Crutzen *et al.* 2008), since N_2O as a greenhouse gas contributes to the global warming 298 times more effectively than CO_2 (IPCC 2007). N_2O release is controlled by many factors, significant deviations may occur depending on the local conditions. This aspect, to get to know more details on N_2O soil emissions during the cultivation of energy crops, was the motivation to start a long-term study whose results are presented here.

Agronomic practices such as tillage and fertiliser applications can significantly affect the production and consumption of N_2O because of alterations in soil physical, chemical, and biochemical activities. Following N-fertiliser applications, an increase in N_2O flux rates has been observed in field and laboratory experiments (e.g. Mulvaney *et al.* 1997; Kaiser *et al.* 1998; Jackson *et al.* 2003). N_2O emission from croplands at site scales occurs essentially with a great spatial and temporal variability (Veldkamp & Keller 1997; Dobbie & Smith 2003; Hellebrand *et al.* 2003, 2005). The annual patterns of the temporal variation of N_2O emissions are determined in the temperate regions by the seasons and weather

Table 1. Plants at the columns (1–10) of the experimental field since 1999 (each column consists of 4 differently fertilised sites: A, B, C, and D)

Period (month/year)	1	2	3	4	5	6	7	8	9	10
10/1998–03/1999	G*	W*	P1	P2**	P3	F	T	R1*	T1*	F
04/1999–09/1999	G*	W*	P1	P2**	P3	H1	T	R1*	T1*	H2
10/1999–03/2000	G*	W*	P1	P2**	P3	R1	T	H1*	F*	H2
04/2000–09/2000	G*	W*	P1	P2**	P3	R1	T	H1*	Ra*	R1
10/2000–03/2001	G*	W*	P1	P2**	P3	T2	T	R4*	F	G, C
04/2001–09/2001	G*	W*	P1	P2**	P3	T2	H1	R4*	H1	G, C
10/2001–03/2002	G	W*	P1	P2**	P3	R2*	F*	Rc*	H1	G, A, C
04/2002–09/2002	G	W*	P1	P2**	P3	R2*	F*	Rc*	H1	G, A, C
10/2002–03/2003	G	W*	P1	P2**	P3	T2*	Rb*	R2*	H1	G, A, C
04/2003–09/2003	G	W*	P1	P2**	P3	T2*	Rb*	R2*	H1	G, A, C
10/2003–03/2004	G	W*	P1	P2**	P3	Rb*	R3*	T2*	H1	G, A, C
04/2004–09/2004	G	W*	P1	P2**	P3	Rb*	R3*	T2*	Co	S
10/2004–03/2005	G	W*	P1	P2**	P3	F*	T2*	R2*	F	F
04/2005–09/2005	G1	W*	P1	P2**	P3	H1*	T2*	R2*	S*	SF*
10/2005–03/2006	G1	W*	P1	P2**	R5*	R6*	R7*	R2*	F	F
04/2006–09/2006	S	W*	P1	P2**	R5*	R6*	R7*	R2*	H	F
10/2006–03/2007	S	W*	P1	P2**	R5*	R6*	R7*	R2*	H	F
04/2007–10/2007	S	W*	P1	P2**	R5*	R6*	R7*	R2*	F	F

*Columns with one measuring spot per site A, B, C, and D
**Columns with two measuring spots per site A, B, C, and D
A – Alfalfa (*Medicago sativa*)
C – Clover (*Trifolium repens*)
Co – Corn (*Zea mays*)
F – Fallow land
G – Grass (orchard grass: *Dactylis glomerata* L.)
G1 – Sudangrass (*Sorghum bicolor* (L.) *Moench* ssp. *drummondii*)
H1 – Hemp (*Cannabis sativa* L.) var. Felina 34
H2 – Hemp (*Cannabis sativa* L.) var. Fedrina 74
P1 – Poplar (*Populus maximowiczii* x *P. nigra*) var. Japan 105 with grass
P2 – Poplar (*Populus maximowiczii* x *P. nigra*) var. Japan 105
P3 – Poplar (*Populus maximowiczii* x *P. trichocarpa*) var. NE 42 with grass
Ra – Rape (*Brassica napus* L. spp. *oleifera* Metzg.) var. *Licosmos*
Rb – Rape (*Brassica napus* L. spp. *oleifera* Metzg.) var. *Express*
Rc – Rape (*Brassica napus* L. spp. *oleifera* Metzg.) var. *Artus*
R1 – Rye (*Secale cereale* L.) var. *Amilo*
R2 – Rye (*Secale cereale* L.) var. *Matador*
R3 – Rye (*Secale cereale* L.) var. *Avanti*
R4 – Rye (*Secale cereale* L.) var. *Hacada*
R5 – Perennial Rye (*Lolium parvifolium* L.) var. Waldi
R6 – Perennial rye (*Secale montanum* L.) var. *Permonta*
R7 – Perennial Rye (*Secale cereale* L.) var. RPM 1
S – Sorghum (pearl millet: *Pennisetum glaucum* (L.) R. Br.) var. Rona 1
SF – Sunflowers (*Helianthus annuus* L.) var. KW0411
T – Topinambur (*Jerusalem artichoke*: *Helianthus tuberosus* L.)
T1 – Triticale (X Triticosecale Wittm.) var. Alamo
T2 – Triticale (X Triticosecale Wittm.) var. Modus
W – Willow (*Salix viminalis*) with grass

conditions, since soil N_2O emissions are regulated by temperature and soil moisture, and thus they are likely to respond to climatic changes (Frolking *et al.* 1998; Ruser *et al.* 2006).

In addition to this background variability, agricultural management such as tillage and fertilising schedule may enhance N_2O emission (Hénault *et al.* 1998a, b). Tillage can cause immediate changes

in the microbial community structure as reported by Jackson *et al.* (2003), thus producing large N_2O emissions at the beginning of the crop season. The spatial variability is mainly caused by heterogeneity in the soil properties and agricultural management (Kaiser & Ruser 2000). Additionally, there are different short time emission peaks lasting for hours or days and weeks, whose source is not explicitly known (Veldkamp & Keller 1997; Van der Weerden *et al.* 1999; Brown *et al.* 2002; Dobbie & Smith 2003; Hellebrand *et al.* 2003).

Nitrification and denitrification processes may be stimulated after the application of nitrogen fertilisers (e.g. Firestone & Davidson 1989; Mosier 1994; Dobbie *et al.* 1999; Freney 1997). The balance between the two processes contributing to the N_2O emission will vary with climate, soil conditions, and soil management (Skiba & Smith 2000). Soil cultivation and precipitation, affecting the soil air exchange rate, should also influence nitrification and denitrification, which are aerobic and anaerobic processes, respectively (Pinto *et al.* 2004).

Numerous authors studied the emission of N_2O dependent on the soil type, fertilisation, and crop species (e.g. Flessa *et al.* 1998; Hénault *et al.* 1998a; Dobbie *et al.* 1999). There are still uncertainties regarding the soil specific conversion factor, especially the influence of precipitations, soil moisture, temperature, soil nitrate concentration, and other variables (Maljanen *et al.* 2004). Since the N_2O emission factor depends on the local conditions, the main aim of this study was to determine this factor and its typical variability for the cultivation of annual and perennial crops on sandy soils under climatic conditions of Central Europe.

MATERIALS AND METHODS

N_2O flux measurements have been performed since 1999 at an experimental field with various crops cultivated for the production of biofuels. The experimental field was established in 1994. The topsoil texture was classified as loamy sand with sufficient homogeneity (Hellebrand & Scholz 2000). The weather means at the Potsdam Weather Service station (about 10 km away) between 1951 and 1980 were 8.6°C for air temperature and 595 mm for precipitations. In the period of this study, the mean temperature increased (mean of the years 1999–2006: 9.8°C) and the mean annual precipitations decreased (mean of the years 1999–2006: 563.9 mm; DWD 2007).

The field was subdivided into 40 sites (Figure 1). Different plant varieties (Table 1) or plant combinations were arranged as columns (four sites each, labelled as A, B, C, and D). Grass (column 1) was mowed two to three times every year. The short rotation wood (or "field wood": poplar and willow; column 2 to 5) was periodically harvested (every two to four years). The crops in columns 6 to 10 were annual plants (hemp, rape, rye, sorghum, triticale) and perennial plants with cultivation periods of two to three years (perennial rye and Jerusalem artichoke). These crops were rotated or planted according to the actual research aims.

The four rows A to D, perpendicular to the columns, were fertilised with different levels of nitrogen (fertiliser: calcium ammonium nitrate; A: 150 kg N/ha/year; B and C: 75 kg N/ha/year) supplemented with PK-fertiliser (A), wood ashes (B), and straw ashes (C), and sites without fertilisation (D).

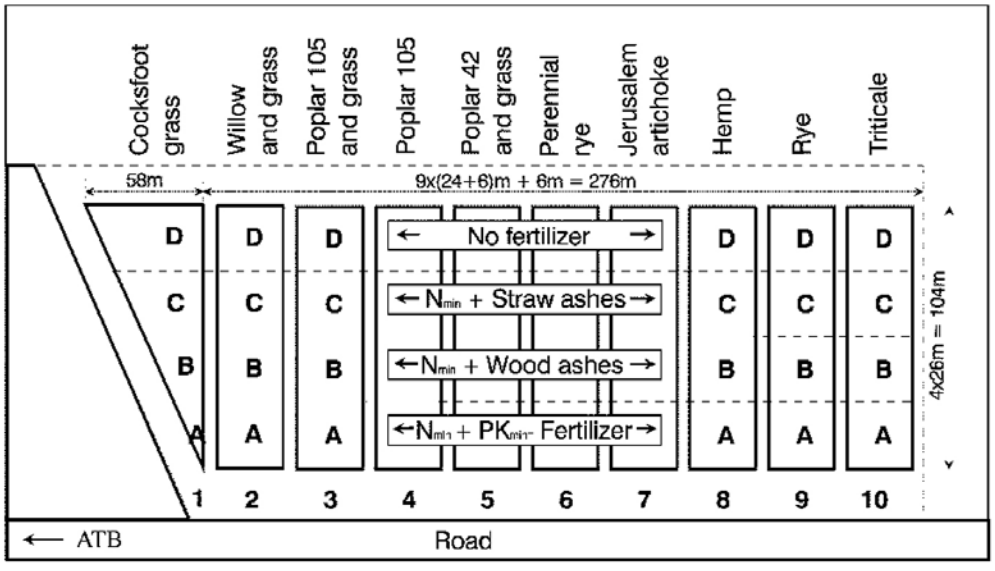

Figure 1. Scheme of experimental field; plant distribution as in 1997 (Hellebrand & Scholz 1998)

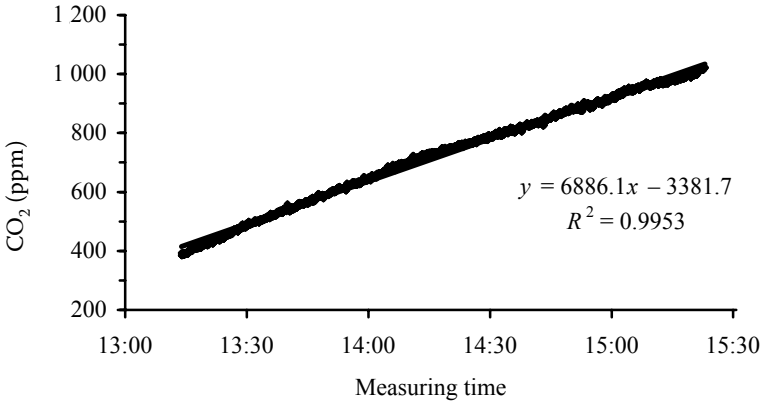

Figure 2. Concentration increase of CO_2 in a flux chamber on bare soil measured on May 16, 2007 with infrared CO_2 sensor (Model 950; Testo AG)

Gas flux measurements were performed usually four times a week by means of the closed chamber technique and a gas chromatograph (GC: Shimadzu GC 14A). PVC-sealing rings (Y profile, sealing by water level) for the gas flux chambers (cover boxes) were embedded in the soil of the sites A to D of the columns measured (Table 1). The PVC-gas flux chambers had the volume (V) to area (A) ratio V/A = 0.315 m, and the volume of 0.064 m^3. The fluxes were measured in mornings between 10 to 12 a.m. Two evacuated gas samplers (100 cm^3 bottles with Teflon sealing and vacuum taps) were connected to each box. The first was filled when the box was put on the water-sealed ring on the soil and the second one after one hour enclosure time. The samplers were then connected with a PC-controlled GC-injection system (Loftfield *et al.* 1997). For each level of fertilisation, the N_2O emission factor was calculated by means of the difference between the annual mean values of the fertilised sites and of the non-fertilised sites.

CO_2 and N_2O, both of them generated in the soil, have nearly equal diffusion constants. The easily measurable CO_2 served for the evaluation of linearity and mixing homogeneity of the measuring chamber (measurements at several heights in the closed chamber). The measurements of the increase of CO_2 concentration in the flux chambers on bare soil showed that the increase in concentration was linear (R^2 higher than 0.99) during the measurement periods of more than two hours (Figure 2 and Hellebrand & Scholz 1998).

The N_2O emission factor, also called N conversion factor, is defined as the ratio of the annual fertiliser induced N_2O-N emission to the annual input of fertiliser-N (De Klein *et al.* 2006). The N conversion factor for the individual crop sites was calculated by taking the difference between the annual N_2O-N emissions from the fertilised sites A, B, or C of a column, and the non-fertilised site D of the same column. The annual N_2O-N emission from the site considered was obtained by averaging all N_2O-N fluxes measured in the course of one year and multiplied by time.

RESULTS AND DISCUSSION

The emission of N_2O followed the expected pattern of fertiliser-induced emissions (Figure 3 to 5, fertilisation date in Table 2). Enhanced N_2O emissions were detectable at the fertilised sites after fertilisation and lasted from three to six weeks. We have also found temporarily and spatially limited high fluctuations throughout the entire study since 1999. N_2O emission peaks over 1000 μg $N_2O/m^2/h$ have been observed in a few measuring spots (Figures 4 and 5).

These findings are in accordance with other studies (e.g. Augustin *et al.* 1998; Röver *et al.* 1998).

Table 2. Fertiliser application and fertilisation rates

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007
1st fertilisation	March 26	April 14	April 17	April 9	April 8	April 21	April 18	April 24	April 2
2nd fertilisation	May 7	May 5	May 7	May 13	May 14	May 6	May 10	May 5	May 3
3rd fertilisation	May 18	May 25	May 14	May 21	June 2	May 18	May 19	May 26	June 1

1st fertilisation – A: 50 kg N/ha/year; B: 50 kg N/ha/year; C: 50 kg N/ha/year; D: –
2nd fertilisation – A: 50 kg N/ha/year; B: 25 kg N/ha/year; C: 25 kg N/ha/year; D: –
3rd fertilisation – A: 50 kg N/ha/year; B: –;C: – ; D: –

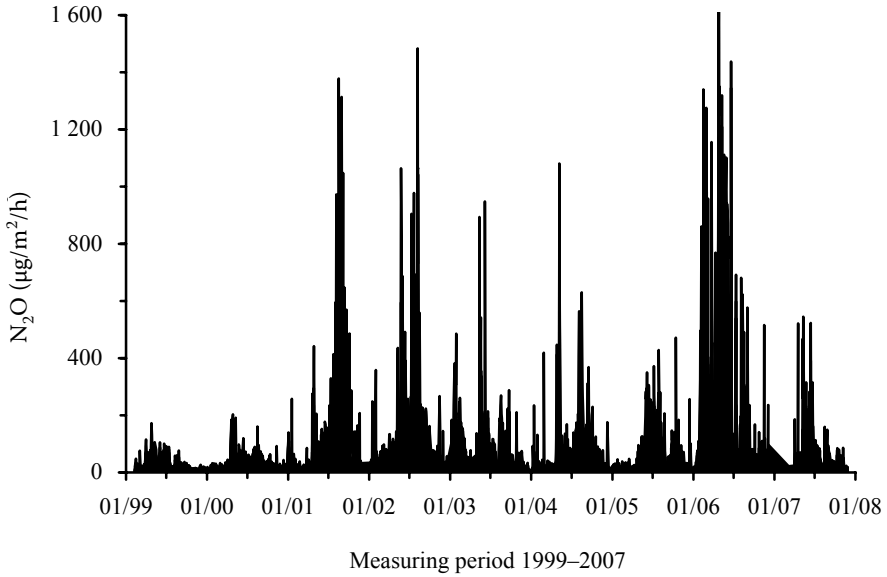

Figure 3. Time series of N_2O (dinitrogen oxide) emissions from all sites of the experimental field

Because the measurements were taken four times a week, the emissions could be studied with a sufficient temporal resolution at different crop sites. Except during the few freeze-thaw cycles in the course of the winter season, the N_2O emission rate usually dropped to less than 30 µg $N_2O/m^2/h$ between October and March.

No clear frost-induced emission rates were found during the winter seasons of 1999/2000, 2004/2005, and 2006/2007. Frost-induced N_2O-emissions are related to the course of temperature and could be dependent on several factors such as groundwater level, water-filled pore space, soil pH, soil nitrate content, soil texture, and soil structure (Mogge *et al*. 1996; Flessa *et al*. 1998; Röver *et al*. 1998; Teepe *et al*. 2001, 2004). However, the frost-induced emissions we measured at a couple of sites are small compared to the total annual N_2O emission budget from the sandy soil of the experimental field. Therefore, these emissions were not excluded from the calculation of the nitrogen conversion factor.

There have been several high emission periods at the fertilised sites within the course of the measurements since 1999. The highest emission rates of more than 1000 µg $N_2O/m^2/h$ were observed in 2001, 2002, and 2006 (Figure 3). The high N_2O emission rates in 2001 were measured at the poplar site with the fertilisation level of 150 kg N/ha/year over a period from July till October (Figure 4). Similarly high N_2O emissions occurred at several poplar plots in 2006, just after the harvest (cutting of short rotation wood) and fertilisation (Figure 5). In 2002, rye and rape sites had high N_2O emissions and in 2006, enhanced emissions were observed at the sites with annual and perennial rye as well. Longer lasting high N_2O emissions, called "hot spots" or

Table 3. Mean annual N_2O-N emissions (in kg N_2O-N/ha/year) and mean nitrogen conversion factor (in %)

Year	N_2O-N flux from fertilised sites*	N_2O-N flux from nonfertilised sites*	Conversion factor*	Conversion factor**
1999	0.96	0.74	0.21	0.21
2000	1.28	0.86	0.32	0.21
2001	1.50	0.73	0.64	0.50
2002	2.75	1.68	1.01	0.96
2003	1.55	0.89	0.65	0.62
2004	1.29	0.45	0.82	0.71
2005	1.16	0.57	0.55	0.48
2006	3.46	1.30	2.20	1.64
2007***	1.60	0.59	0.94	0.94
1999–2007	1.73	0.87	0.82	0.70

*N_2O hot spots included; **N_2O hot spots excluded; ***2007: Results till November 26

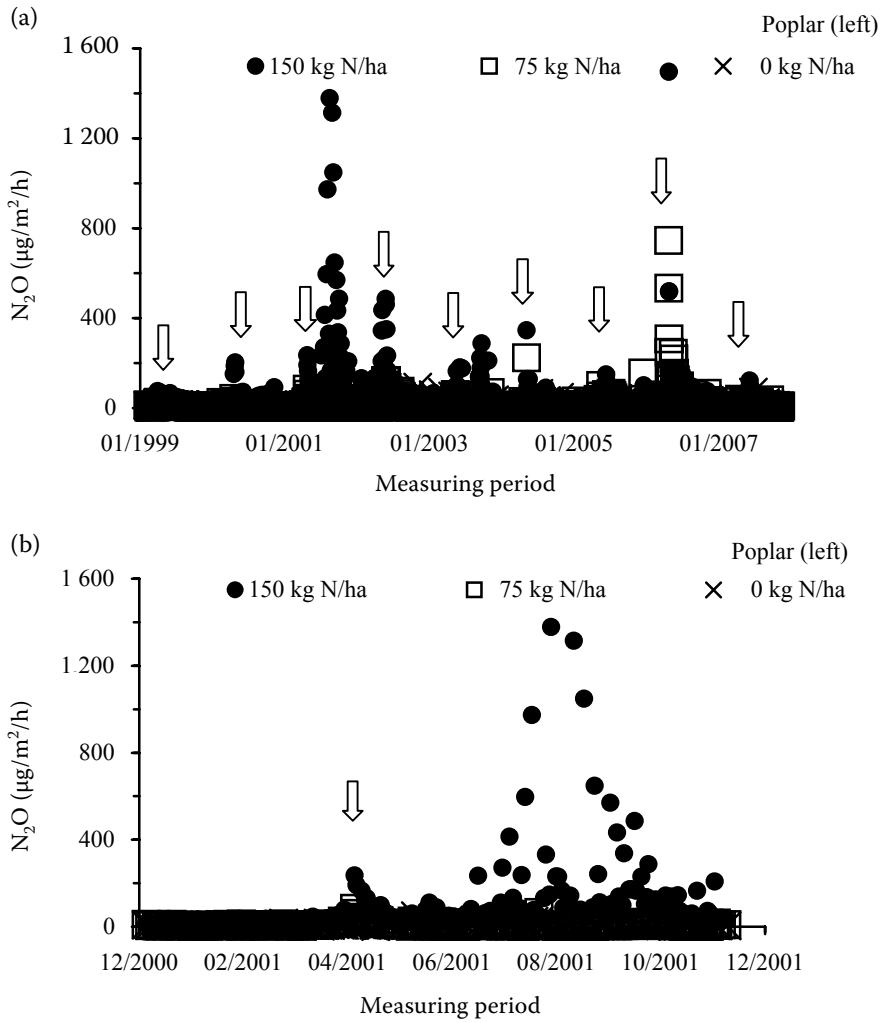

Figure 4. Time series of N_2O emissions from poplar sites of the experimental field; fertiliser induced N_2O emissions are indicated by arrows (⇩); fertilisation data are given in Table 2. "Left measuring spots" at poplar sites of column 4 (Figure 1 and Table 1) with three fertilisation levels (150 kg N/ha/year, 75 kg N/ha/year, 0 kg N/ha/year); the N_2O emissions from sites with a fertilisation rate of 150 kg N/ha/year in Figure 4 part b (measurements of 2001) are assigned to an N_2O hot spot
(a) Measuring period 1999–2007;
(b) Measuring period 2001

"hotspots" (e.g. Christensen *et al*. 1990; Röver *et al*. 1999; Wanga *et al*. 2006), were detected at the fertilised sites only. Besides the highly emitting N_2O hot spots with maxima above 1000 µg $N_2O/m^2/h$ in 2001, 2002, and 2006, one or two less emitting N_2O hot spots with maxima above 100 µg $N_2O/m^2/h$ were also observed in all other years of this study, except in 1999. These lower N_2O hot spots occurred usually in late summers and autumns. The reason for these high emissions is not clear. High emissions after harvesting had been observed several times and might be connected with soil distortions.

When determining the nitrogen conversion factor, the question arose, which part of the time course should be chosen, a period of few weeks after fertilisation or the whole plant-growing period or the corresponding year. Additionally, different results will be obtained in the dependence on the method of the calculation of the conversion factor like the determination of the background flux (Bouwman 1996; Simojoki & Jaakkola 2000; Model & Hellebrand 2006), including or excluding N_2O hot spots, taking the annual mean of daily differences between the fertilised and non-fertilised sites, or taking the difference between the fertilised and non-fertilised sites in annually cumulated N_2O fluxes. The results, presented here, are based upon the differences between the annual means of site-specific N_2O fluxes. In order to evaluate the influence of N_2O hot spots, both possibilities – including and excluding N_2O hot spots – are considered (Tables 3 and 4). It is reasonable to exclude N_2O hot spots in the calculation of the conversion factor, since the sources of these N_2O hot spots are unknown and apparently seem not to be directly connected with the fertilisation level. On the other hand, N_2O hot spots were observed at fertilised sites only. Thus, a more detailed analysis and discussion must be given to this question. Therefore, the influence of the calculation methods and the choice of periods and emission data will be discussed elsewhere.

There is an obvious difference between total annual N_2O emission rates and nitrogen conversion factors from the sites without soil cultivation (columns 1–5) and those of cultivated soils (columns 6–10; Table 1 and Table 4). The emissions from sites

Table 4. Mean N_2O-N emissions (in kg N_2O-N/ha/year) and mean nitrogen conversion factor (in %)

	N_2O-N flux from fertilised sites*	N_2O-N flux from non-fertilised sites*	Conversion factor*	Conversion factor**
Sites with non-cultivated soil				
Grass	1.17	1.06	0.09	0.09
Willow	0.99	0.56	0.45	0.45
Poplar	1.42	0.50	0.89	0.65
Mean	1.19	0.71	0.48	0.40
Sites with cultivated soil				
Rye	2.00	0.95	0.97	0.89
Per. Rye***	2.98	1.32	1.54	1.50
Triticale	1.75	0.74	1.04	0.92
Hemp	1.02	0.67	0.33	0.33
Rape	2.50	1.40	0.92	0.62
Mean	2.05	1.02	0.96	0.85

*N_2O hot spots included; **N_2O hot spots excluded; ***Last soil cultivation in autumn 2005 (see Table 1, columns 5–7, period 10/2005–19/2007)

with cultivated soils were about twice those from soils at columns 6 to 10. It is to remark that difficulties arise if the conversion factors of different plant types are to be evaluated using data from different years. One main problem with the comparison is the variability of the weather conditions which causes

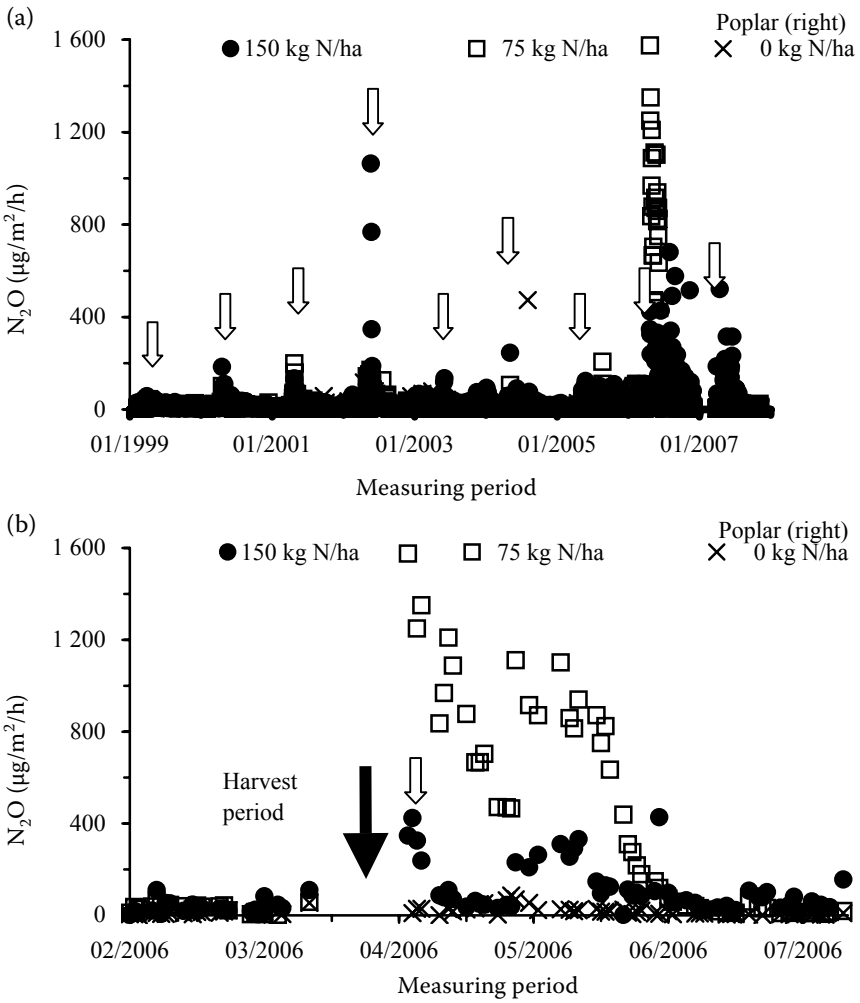

Figure 5. Time series of N_2O emissions from poplar sites of the experimental field; fertiliser induced N_2O emissions are indicated by arrows (⇩); fertilisation data are given in Table 2; "Right measuring spots" at poplar sites of column 4 (Figure 1 and Table 1) with three fertilisation levels (150 kg N/ha per year, 75 kg N/ha/year, 0 kg N/ha per year); the N_2O emissions from sites with a fertilisation rate of 75 kg N/ha/year in Figure 5 part b (measurements of 2006) are assigned to an N_2O hot spot
(a) Measuring period 1999–2007;
(b) Measuring period 2006

different N_2O emission levels in the dependence on the precipitations and temperature of the year considered. Nevertheless, the soil cultivation obviously enhances the N_2O emission level. Although this phenomenon is not fully understood, the changes in physical structure caused by the soil tillage may alter biological activity and thus N_2O emissions over the crop season (Mulvaney *et al.* 1997; Kaiser *et al.* 1998; Kaiser & Ruser 2000; Jackson *et al.* 2003).

CONCLUSIONS

N_2O flux measurements, having been carried out for nine years, showed periodical variations. Whereas in the course of autumns and winters the emissions were comparatively low (below 30 μg $N_2O/m^2/h$), the N_2O fluxes had peaks above 100 μg $N_2O/m^2/h$ after nitrogen fertilisation in springs. In summers and autumns, increased N_2O flux rates were observed with several fertilised sites. N_2O hot spots caused a measurable increase of the annual N_2O emission budget. As N_2O hot spots were found on fertilised sites only, they might cause increased nitrogen conversion factors, if not excluded from the calculation of the fertiliser induced emissions. The emissions due to the freezing-thawing periods in winters did not considerably contribute to the annual N_2O budget and thus do not have a measurable influence on the nitrogen conversion factor.

The mean nitrogen conversion factor of about 0.8% is comparatively low. Therefore, the energy crop production on sandy loam soils under climatic condition of Central Europe will not lose their CO_2 advantage by nitrogen fertilisation as long as fertilising results in an adequately higher biomass yield (Scholz & Ellerbrock 2002).

The nitrogen fertilisation, precipitations and soil cultivation altered N_2O emissions from the soil. Fertiliser induced N_2O emissions from cultivated soils are higher as compared to non-cultivated soils. As an explanation, it is assumed that tillage and other soil treatments change the soil structure and thus influence the water filled space as well as the soil-air exchange rate. The influence of tillage and plant varieties on N_2O emissions needs further investigations in various crop systems.

References

Augustin J., Merbach W., Steffens L., Snelinski B. (1998): Nitrous oxide fluxes of disturbed minerotrophic peatlands. Agribiological Research, **51**: 47–57.

Bouwman A.F. (1990): Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. In: Bouwman A.F. (ed.): Soils and the Greenhouse Effect. John Wiley & Sons, Chichester New York, 61–127.

Bouwman A.F. (1996): Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems, **46**: 53–70.

Bouwman A.F., Boumans L.J.M., Batjes N.H. (2002): Emissions of N_2O and NO from fertilised fields: Summary of available measurement data. Global Biogeochemical Cycles, **16**: 1058.

Brown L., Syed B., Jarvis S.C., Sneath R.W., Phillips V.R., Goulding K.W.T., Li C. (2002): Development and application of a mechanistic model to estimate emission of nitrous oxide from UK agriculture. Atmospheric Environment, **36**: 917–928.

Christensen S., Simkins S., Tiedje J.M. (1990): Spatial Variation in Denitrification: Dependency of Activity Centers on the Soil Environment. Soil Science Society of America Journal, **54**: 1608–1613.

Crutzen P.J., Mosier A.R., Smith K.A., Winiwarter W. (2008): N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics, **8**: 389–395. Available at: http://www.atmos-chem-phys.net/8/389/2008/acp-8-389-2008.pdf (accessed April 29, 2008).

De Klein C., Novoa R.S.A., Ogle S., Smith K. A., Rochette P., Wirth T. C., McConkey B.G., Walsh M., Mosier A., Rypdal K., Williams S.A. (2006): N_2O emissions from managed soils, and CO_2 emissions from lime and urea application. In: Eggleston H.S., Buendia L., Miwa K., Ngara T., Tanabe K. (eds): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, National Greenhouse Gas Inventories Programme, IGES, Japan: 11.11. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf (accessed December 4, 2007).

Dobbie K.E., Smith K.A. (2003): Nitrous oxide emission factors for agricultural soils in Great Britain: The impact of soil water-filled pore space and other controlling variables. Global Change Biology, **9**: 204–218.

Dobbie K.E., McTaggart I.P., Smith K.A. (1999): Nitrous oxide emissions from intensive agricultural systems: variations between crops and seasons; key driving variables; and mean emission factors. Journal of Geophysical Research, **104**: 26891–26899.

DWD (2007): Deutscher Wetterdienst online (German Weather Service online). Available at: http://www.dwd.de/de/FundE/Klima/KLIS/daten/online/nat/index_mittelwerte.htm (data 1961–1990), data since 1991: http://www.dwd.de/de/FundE/Klima/KLIS/daten/online/nat/ausgabe_tageswert.htm (accessed December 4, 2007).

Firestone M.K. (1982): Biological denitrification. In: Stevenson F.J. (ed.): Nitrogen in Agricultural Soils, American Society of Agronomy, Madison, 289–326.

Firestone M.K., Davidson E.A. (1989): Microbiological basis of NO and nitrous oxide production and consumption

in soil. In: Andreae M.O., Schimel D.S. (eds): Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere, John Wiley & Sons, New York, 7–21.

Flessa H., Wild U., Klemisch M., Pfadenhauer J. (1998): Nitrous oxide and methane fluxes from organic soils under agriculture. European Journal of Soil Science, **49**: 327–335.

Freney J.R. (1997): Emission of nitrous oxide from soils used for agriculture. Nutrient Cycling in Agroecosystems, **49**: 1–6.

Frolking S.E., Mosier A.R., Ojima D.S., Li C., Parton W.J., C.S. Potter E. ,Priesack R., Stenger C., Haberbosch P., Dorsch F., Lessa H., Smith K.A. (1998): Comparison of N_2O emissions from soils at three temperate agricultural sites: simulations of year-round measurements by four models. Nutrient Cycling in Agroecosystems, **52**: 77–105.

Granli T., Bøckman O.C. (1994): Nitrous oxide from agriculture. Norwegian Journal of Agricultural Sciences (Suppl. 12) **8**: 1–128.

Hellebrand H.J., Scholz V. (1998): Gaseous emissions from cultivating energy plants. In: AgEng98. August 24–28, 1998, Oslo, Paper No. 98-D-004 and Proceedings Part II: 1010–1011. Available at: http://www.atb-potsdam.de/hauptseite-deutsch/Institut/Abteilungen/Abt2/Mitarbeiter/jhellebrand/jhellebrand/publikat/AgEng98-d-004.pdf (personal communication, accessed December 4, 2007).

Hellebrand H.J., Scholz V. (2000): Determination of soil-related trace gas fluxes during the cultivation of renewable raw materials. Agrartechnische Forschung, **6**: E74–E79.

Hellebrand H.J., Kern J., Scholz V. (2003): Long-term studies on greenhouse gas fluxes during cultivation of energy crops on sandy soils. Atmospheric Environment, **37**: 1635–1644.

Hellebrand H.J., Scholz V., Kern J., Kavdir Y. (2005): N_2O release during cultivation of energy crops. Agrartechnische Forschung, **11**: E114–E124

Hénault C., Devis X., Page S., Justes E., Reau R., Germon J.C. (1998a): Nitrous oxide emissions under different soil and land management conditions. Biology and Fertility of Soils, **26**: 199–207.

Hénault C., Devis X., Page S., Justes E., Reau R., Germon J.C. (1998b): Influence of different agricultural practices (type of crop, form of N-fertilizer) on soil nitrous oxide emissions. Biology and Fertility of Soils, **27**: 299–306.

IPCC (2007): IPCC WG1 AR4 Report, Technical Summary, Table TS2. In: Climate Change 2007 – The Physical Science Basis Contribution of Working Group I to the 4th Assessment Report of the IPCC. Cambridge University Press, 33. Available at: http://ipcc-wgl.ucar.edu/wg1/Report/AR4WG1_Print_TS.pdf (accessed December 4, 2007)

Jackson L.E., Calderon F.J., Steenwerth K.L., Scow K.M., Rolston D.E. (2003): Responses of soil microbial processes and community structure to tillage events and implications for soil quality. Geoderma, **114**: 305–317.

Kaiser E.A., Ruser R. (2000): Nitrous oxide emissions from arable soils in Germany – An evaluation of six long-term field experiments. Journal of Plant Nutrition and Soil Science, **163**: 249–260.

Kaiser E.A., Kohrs K., Kücke M., Schnug E., Heinemeyer O., Munch J.C. (1998): Nitrous oxide release from arable soil: importance of N fertilization, crops and temporal variation. Soil Biology & Biochemistry, **30**: 1553–1563.

Loftfield N., Flessa H., Augustin J., 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 and "Loftfields Analytical Solutions", Dr. Norman S. Loftfield GbR, http://www.loftfield.de/index_e.htm

Maljanen M., Komulainen V.-M., Hytönen J., Martikainen P.J., Laine J. (2004): Carbon dioxide, nitrous oxide and methane dynamics in boreal organic agricultural soils with different soil characteristics. Soil Biology & Biochemistry, **36**: 1801–1808

Model A., Hellebrand H.J. (2006): Determination of crop specific management-related background flux rates to discriminate fertilizer induced emissions. In: Proc. Workshop on Agricultural Air Quality: State of the Science. June 5–8, 2006, Potomac, 930–933. Available at http://www.ncsu.edu/airworkshop/Posters-M.pdf (accessed December 4, 2007).

Mogge B., Heinemeyer O., Kaiser E.-A., Munch J.C. (1996): N_2O-emissions of forest soils in Northern Germany – Seasonal variability and influencing parameters. In: Van Cleemput O., Hofman G., Vermoesen A. (eds): Progress in Nitrogen Cycling Studies. Kluwer Academic Publishers, Dordrecht, 585–588.

Mosier A.R. (1994): Nitrous oxide emissions from agricultural soils. Fertilizer Research, **37**: 191–200.

Mulvaney R.L., Khan S.A., Mulvaney C.S. (1997): Nitrogen fertilizers promote denitrification. Biology and Fertility of Soils, **24**: 211–220.

Novoa R.S.A., Tejeda H.R. (2006): Evaluation of the N_2O emissions from N in plant residues as affected by environmental and management factors. Nutrient Cycling in Agroecosystems, **75**: 29–46.

Pinto M., Merino P., Del Prado A., Estavillo J.M., Yamulki S., Gebauer G., Pietrzak S., Lauf J., Oenema O. (2004): Increased emissions of nitric oxide and nitrous oxide following tillage of a perennial pasture. Nutrient Cycling in Agroecosystems, **70**: 13–22.

Röver M., Heinemeyer O., Kaiser E.-A. (1998): Microbial induced nitrous oxide emissions from an arable soil during winter. Soil Biology & Biochemistry, **30**: 1859–1865.

Röver M., Heinemeyer O., Munch J.C., Kaiser E.-A. (1999): Spatial heterogeneity within the plough layer: high variability of N_2O emission rates. Soil Biology & Biochemistry, **31**: 167–173.

Ruser R., Flessa H., Russow R., Schmidt G., Buegger F., Munch J.C. (2006): Emission of N_2O, N_2 and CO_2 from soil

fertilized with nitrate: effect of compaction, soil moisture and rewetting. Soil Biology & Biochemistry, **38**: 263–274

Scholz V., Ellerbrock R. (2002): The growth productivity, and environmental impact of the cultivation of energy crops on sandy soil in Germany. Biomass and Bioenergy, **23**: 81–92.

Simojoki A., Jaakkola A. (2000): Effect of nitrogen fertilization, cropping and irrigation on soil air composition and nitrous oxide emission in a loamy clay. European Journal of Soil Science, **51**: 413–424.

Skiba U., Smith K.A. (2000): The control of nitrous oxide emissions from agricultural and natural soils. Chemosphere, **2**: 379–386.

Stehfest E., Bouwman L. (2006): N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modelling of global annual emissions. Nutrient Cycling in Agroecosystems, **74**: 207–228.

Teepe R., Brumme R., Beese F. (2001): Nitrous oxide emissions from soil during freezing and thawing periods. Soil Biology & Biochemistry, **33**: 1269–1275.

Teepe R., Vor A., Beese F., Ludwig B. (2004): Emissions of N_2O fromsoils during cycles of freezing and thawing and the effects of soilwater, texture and duration of freezing. European Journal of Soil Science, **55**: 357–365.

Van der Weerden T.J., Sherlock R.R., Williams P.H., Cameron K.C. (1999): Nitrous oxide emissions and methane oxidation by soil following cultivation of two different leguminous pastures. Biology and Fertility of Soils, **30**: 52–60.

Veldkamp E., Keller M. (1997): Nitrogen oxide emissions from a banana plantation in the humid tropics. Journal of Geophysical Research, **102**: 15889–15898.

Wanga H., Wanga W., Yina C., Wang Y., Lua J. (2006): Littoral zones as the "hotspots" of nitrous oxide (N_2O) emission in a hyper-eutrophic lake in China. Atmosphere and Environment, **40**: 5522–5527.

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Abstrakt

Hellebrand H.J., Scholz V., Kern J. (2008): **Dusíková konverze a aktivní body kysličníku dusného při pěstování energetických plodin.** Res. Agr. Eng., **54**: 58–67.

Od r. 1999 byl měřen plynovou chromatografií tok emisí kysličníku dusného z půdy experimentálních pozemků. Hlavním cílem této studie bylo učení faktoru dusíkové konverze a jeho variabilitu pro písečné půdy v podmínkách střední Evropy. Jednoleté rostliny (konopí, řepka, žito, čirok, triticale) a víceleté rostliny (tráva, trvalé žito, topol, vrba) byly hnojeny ve třech různých hladinách dusíku (150 kg N/ha/rok, 75 kg N/ha/rok, nehnojeno). Roční faktor dusíkové konverze byl odvozen z ročních průměrných rozdílů mezi hnojenými a nehnojenými kontrolními místy. Získané hodnoty byly nižší pro neobdělávaná místa (s víceletými plodinami – 0,9 %) než u řádně obdělávaných ploch (jednoleté plodiny – 0,9 %). Několikanásobně zvýšené N_2O aktivní body s maximy nad 1000 μg $N_2O/m^2/h$ s dobou trvání několika týdnů byly pozorovány během měření. Je diskutován vliv těchto lokálních emisních vrcholů na velikost faktoru dusíkové konverze.

Klíčová slova: hladina hnojení dusíkem; půdní tok N_2O; obdělávané a neobdělávané půdy; víceleté rostliny a jednoleté rostliny

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