N_2O Release During Cultivation of Energy Crops

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The emission of nitrous oxide (N_2O) from the soil has a significant impact on the greenhouse gas balance of energy crops. Factors like soil type, temperature, precipitation, tillage practice (annual or perennial crop), and level of fertilisation can affect the source strength of N_2O emissions and fertiliser-induced N_2O emissions. The N_2O-fluxes from different sites of an experimental field were measured using the flux chamber method in combination with gas chromatography. The sites had three nitrogen fertilisation levels (0 kg N ha^{-1} y^{-1}, 75 kg N ha^{-1} y^{-1}, and 150 kg N ha^{-1} y^{-1}). The soil nitrate concentration was determined by ion chromatography. The mean of annually accumulated emission of N_2O-N from all measuring spots was 1.4 kg N_2O-N ha^{-1} y^{-1}. The accumulated emissions varied between 0.5 kg N_2O-N ha^{-1} y^{-1} to 3.8 kg N_2O-N ha^{-1} y^{-1} depending on fertilisation level, crop variety, and year. The mean annually fertiliser-induced N_2O-N emission from all fertilised sites was 0.7 % for the period from 1999 to 2004. This mean nitrogen conversion factor (ratio of N_2O-N emission to fertiliser-N input) ranged from 0.2 to 1.6 %. The mean conversion factor for perennial crops was lower (0.4 % for both fertilisation levels of 75 and 150 kg N ha^{-1} y^{-1}) than that for annual crops (0.7 % for 75 kg N ha^{-1} y^{-1} and 0.9 % for 150 kg N ha^{-1} y^{-1}). Several enhanced N_2O emission spots with maxima of up to 1400 µg N_2O m^{-2} h^{-1} were observed at sites with the higher level of nitrogen fertilisation, lasting for several weeks, in the course of the measurements. These local peak emissions were mainly responsible for the raise of the nitrogen conversion factor of sites fertilised with 150 kg N ha^{-1} y^{-1} compared to sites with fertilisation level of 75 kg N ha^{-1} y^{-1}. Although N_2O emissions doubtless depend on nitrogen fertilisation and tillage, it could be shown that also climate has a strong effect on N_2O emissions. In contrast to a low correlation between N_2O emissions and soil nitrate concentration, N_2O emissions are relatively close correlated to annual precipitation.

Keywords:
Nitrous oxide, N_2O emission factor, energy crops, precipitation, soil nitrate

Introduction

Agriculture is one of the main contributors to the increasing atmospheric concentrations of N_2O. Nitrogen fertilising is one of the main sources of anthropogenic contribution to the global N_2O emission as shown by Bouwman [1], who found a linear relationship between N_2O emissions and fertiliser input. According to that the conversion factor (ratio of N_2O-N emission to input of fertiliser-N) ranges from 0.25 % to 2.25 % depending on soil type [2]. When the cultivation of energy crops is assessed with regard to greenhouse gas abatement, this conversion factor plays a significant role. The nitrogen fertiliser-induced emission of N_2O-N may counterbalance the CO_2-advantage of biofuels (in case of high nitrogen fertiliser application and conversion factor > 2 %), since N_2O as a greenhouse gas contributes to global warming about 300 times more effectively than CO_2 [3].

Agronomic practices such as tillage and fertilizer applications can significantly affect the production and consumption of N_2O because of alteration in soil physical, chemical, and biochemical activities. Tillage could cause immediate changes in microbial community structure reported by Jackson [4], thus produce large N_2O emissions at the beginning of crop season. N_2O emission from croplands at site scales occurs essentially with great spatial and temporal variability [5-7]. The annual pattern of temporal variation of N_2O emissions is determined in the temperate regions by the seasons and weather conditions. In addition to this background variability, agricultural management such as tillage and fertilising schedule may enhance N_2O emission [7]. However,

there are different short time emission peaks lasting for hours or days and weeks, the source of which is not explicitly known [7-9]. Spatial variability is mainly caused by heterogeneity in soil properties and agricultural management too [5, 6, 10].

N_2O is produced in soils by the microbial processes of nitrification and denitrification and may be stimulated after the application of nitrogen fertilizer [e.g. 11]. Soil cultivation and precipitation, affecting the soil air exchange rate, should also influence nitrification and denitrification, which are aerobic and anaerobic processes, respectively. Numerous authors studied the emission of N_2O dependent on soil type, fertilisation and crop species [e.g. 12-16]. There are still uncertainties regarding the soil specific conversion factor, especially the influence of precipitation, soil moisture, temperature, soil nitrate concentration and other variables. The effect of compost and nitrate additions to the soil on N_2O emissions was studied by [17] in anaerobic soil incubations. In loamy sand, an immediate and high N_2O production was observed in all treatments as long as nitrate was available. N_2O production was higher in sandy soils than in loamy soils. Variations in land use and crop rotation altered the fluxes of N_2O. The lowest N_2O-N-emissions, in the range 0.2 - 0.6 kg ha^{-1} y^{-1}, were observed in poplar plantations. Fallow land, rape fields and oak forests had a higher level of N_2O-N-emissions between 1.0 kg ha^{-1} y^{-1} and 2.5 kg ha^{-1} y^{-1} [12, 16]. Very high annual emissions of N_2O-N between 4.2 and 56.4 kg ha^{-1} y^{-1} were found for some fertilised and non-fertilised meadows and fields. Emission of N_2O occurred mainly in the winter when the groundwater level was high. The highest annual N_2O emission by far occurred in the unfertilised field with a very low soil pH of 4.0. At this site, 71% of the seasonal variation of N_2O emission rates can be explained by changes in the groundwater level and soil nitrate content [13]. The type of soil determined the N_2O soil emissions. On average, using the same crop rotation, 1.5 % of fertiliser-N escaped as N_2O-N from sandy loam, whereas the emissions from loamy silt were only 0.8 % [15]. Since the N_2O emission factor depends on local conditions, the main aim of this study was to determine this factor and its typical variability for the cultivation of energy crops on sandy soils under climatic conditions of North-East Germany.

Trial Sites and Measuring Technique

Experimental field

The N_2O flux measurements have been performed since 1999 in an experimental field with various crops cultivated for the production of biofuels. The experimental field was established in 1994. A sufficient homogeneity of the soil is reflected by means and standard deviations (sd) of 40 soil samples (soil horizon 0 to 30 cm): clay content 6.2 % (sd: 1.3), organic carbon content 0.9 % (sd: 0.14) and pH value 6.0 (sd: 0.34). Soil texture of the topsoil was classified as loamy sand (**Tab. 1**). The weather means at the Potsdam Weather Service station (about 10 km away) between 1951 and 1980 were: air temperature 8.6 °C, precipitation 595 mm, and relative humidity 80 % [18]. The means of the period 1999-2004 are given in **Table 2**.

The field was subdivided into 40 sites (624 m^2 each). Ten different plant varieties (**Tab. 3**) or plant combinations were arranged as columns (four sites each, labelled as A, B, C, and D) with a distance of 6 m between each column. Grass (column 1) was

Table 1: Soil texture analysis of different soil horizons of the experimental field.

Horizon type	Soil type	Depth (cm)	Coarse and medium sand 2.0 to 0.2 mm (%)	Fine sand and coarse silt 0.2 to 0.02 mm (%)	Mean and fine silt 0.02 to 0.002 mm (%)	Clay < 0.002 mm (%)
Ap[a]	Loamy sand	0 to 30	32.6	55.2	6.0	6.2
Ah[b]	Loamy sand	30 to 60	32.5	54.5	7.0	6.0
Bt[c]	Sandy loam	60 to 82	29.1	44.2	9.3	17.4
Cv[d]	Sandy loam	> 82	29.2	45.4	13.2	12.2

[a] ploughing horizon
[b] humous mineral horizon with lesser clay
[c] clay enriched horizon
[d] weak decomposed transition horizon

Table 2: Annual precipitation and temperature (Potsdam) [19].

Year	Precipitation (mm)	Temperature (°C)
1999	406.1	10.16
2000	537.8	10.39
2001	626.8	9.25
2002	762.5	9.73
2003	428.3	9.70
2004	630.2	9.37
99-04	**565.3**	**9.77**

Table 3: Plants at the columns 1 – 10 of the experimental field since 1997.
Each column consists of 4 differently fertilised sites: A, B, C, and D.

Column Year	1	2	3	4	5	6	7	8	9	10
1997 FT-IR	G*	W*	P1	P2**	P3*	R1*	T	H	R2	T1
1998 FTI-R	G*	W*	P1	P2**	P3*	R1*	T	T1	R	R2
1999 GC	G*	W*	P1	P2**	P3	H	T	R2	T1*	H*
2000 GC	G*	W*	P1	P2**	P3	R2	T	H*	R*	R2
2001 GC	G*	W*	P1	P2**	P3	T1	H	R2*	H	G,C
2002 GC	G	W*	P1	P2**	P3	R2*	F*	R*	A	G,A, C
2003 GC	G	W*	P1	P2**	P3	T1*	R*	R2*	A	G,A, C
2004 GC	G	W*	P1	P2**	P3	R*	R2*	T1*	S	S
2005 GC	G	W*	P1	P2**	P3	H*	T1*	R2*	S*	S

FT-IR: Gas flux measurements with Fourier Transform Infrared Spectroscopy [21, 22]
GC: Gas flux measurements with gas chromatography
*: 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)
F: Fallow land
G: Grass (orchard grass: Dactylis glomerata L.)
H: Hemp (Cannabis sativa L.)
P1: Poplar (Populus maximowiczii x P. nigra) with gras
P2: Poplar (Populus maximowiczii x P. nigra)
P3: Poplar (Populus maximowiczii x P. trichocarpa) with gras
R: Rape (Brassica napus L.)
R1: Perennial rye (Secale montanum L.)
R2: Rye (Secale cereale L.)
S: Sorghum (pearl millet: Pennisetum glaucum (L.) R. Br.)
T: Topinambur (Jerusalem artichoke: Helianthus tuberosus L.)
T1: Triticale (Triticosecale Wittmack)
W: Willow (Salix viminalis)

mowed two to three times every year. The short rotation wood (poplar and willow; column 2 to 5) was periodically harvested (every two to four years). The crops in columns 6 to 10 were mostly annual plants, which were rotated or planted according to actual needs. The different types and levels of fertilisation were applied in four rows, perpendicular to the columns. There were sites with different levels of nitrogen input (A: 150 kg N ha^{-1} y^{-1}; B and C: 75 kg N ha^{-1} y^{-1}; Fertiliser - calcium ammonium nitrate) supplemented by PK-fertiliser (A), wood ashes (B), and straw ashes (C) and sites without fertilisation (D).

Gas flux and soil measurements

Since 1999, gas flux measurements have been performed four times a week by means of gas flux chambers and an automated gas chromatograph (GC) [20]. Gas samples were taken from gas flux chambers. The sealing rings (Y profile, sealing by water level) for the cover boxes were embedded in the soil. One ring was put on each measuring spot at the sites A to D of the columns with different crops. The gas flux chambers had a volume (V) to area (A) ratio of V/A = 0.315 m (volume 0.064 m^3, inner diameter 0.509 m). Fluxes were usually measured in the morning. 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 about 60 minutes enclosure time. The samplers were then connected with the automated GC-injection control system. The GC was fitted with an electron capture detector (ECD). The operating temperatures for the ECD and the column temperature were 295 °C and 65 °C respectively. Both the pre-column (length 1 m) and the main column (length 3 m) were packed with Porapak Q (80/100 mesh). In one computer-controlled run up to 64 samples could be analysed. The N_2O detection limit was 5 ppb (5 x 10^{-9}). At atmospheric mixing ratio, the coefficient of variation was 1.2 % for N_2O measurements. For each level of fertilisation, the N_2O emission factor was calculated by taking the difference between the mean values of the fertilised sites and the non-fertilised sites.

Weekly measurements were insufficient to determine fertiliser induced N_2O-N emissions [21, 22] because of high dynamics of the N_2O fluxes from

soil. Data on dynamics and intensity of induced N_2O-N emissions could be gained in the frame of this study by increased measuring frequency (four times a week), sufficient number of measuring spots (25), and a study period of more than six years. Continuous measurements at a great number of spots would be an ideal solution. Because of the techniques applied (gas flux chamber and GC), each measurement disturbs the system under study (darkness for plants and loss of precipitation during measuring time). Therefore, the method used in this study, is a compromise. The impacts on soil and plants are low, but the effects of high variability in time and space can be determined with limited resolution and accuracy only.

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). Studies on the concentration increase of CO_2 in a flux chamber on bare soil and on grass sites demonstrated that the increase in concentration was linear (R^2 between 0.9973 and 0.9986) during measurement periods of 60 minutes [21, 22].

Since 2003, soil samples were drawn from 12 sites with the three fertiliser levels (A: 150 kg N ha^{-1} y^{-1}; B: 75 kg N ha^{-1} y^{-1} and D: no fertiliser) and four crops (perennial crops: willow and poplar; annual crops: 2003- Triticale and rye, 2004- rape and rye, 2005- hemp and Triticale; Tab. 3). The samples were taken from the 0-30 cm soil depth (Tab. 1) close to the corresponding measuring rings. The water content of the soil samples was obtained by gravimetric determination of weight loss when soil samples were dried at 105 °C for 24 h. The concentration of mineral nitrogen (ammonia nitrogen NH_4^+-N and nitrate nitrogen NO_3^--N) and other ions was determined by ion chromatography after extracting by distilled water and filtering. In the present paper, only the course of concentration of soil nitrate is considered.

Results and Discussion

Fertiliser-induced N_2O emissions

The emission of N_2O followed the expected pattern of fertiliser-induced emissions (**Fig. 1a, Tab. 4**). The fertiliser-induced N_2O emissions had maximum intensities of between 100 and 600 µg N_2O m^{-2} h^{-1}. These enhanced emissions were detectable at all fertilised sites after fertilising and lasted from four to eight weeks. We also found temporarily and spatially limited high fluctuations throughout the entire study since 1999. N_2O emission peaks of up to 1400 µg N_2O m^{-2} h^{-1} were observed from few measuring spots (**Fig. 1b**). These findings are in accordance with other studies [e.g. 23-25]. Because measurements were taken four times per week, the "regularities" (induced emissions) and fluctuations could be studied with sufficient temporal resolution at different crop sites on a relatively homogeneous sandy soil. Except during the few freeze-thaw cycles (Fig. 1b), the N_2O emission rate usually dropped to less than 30 µg N_2O m^{-2} h^{-1} between October and March.

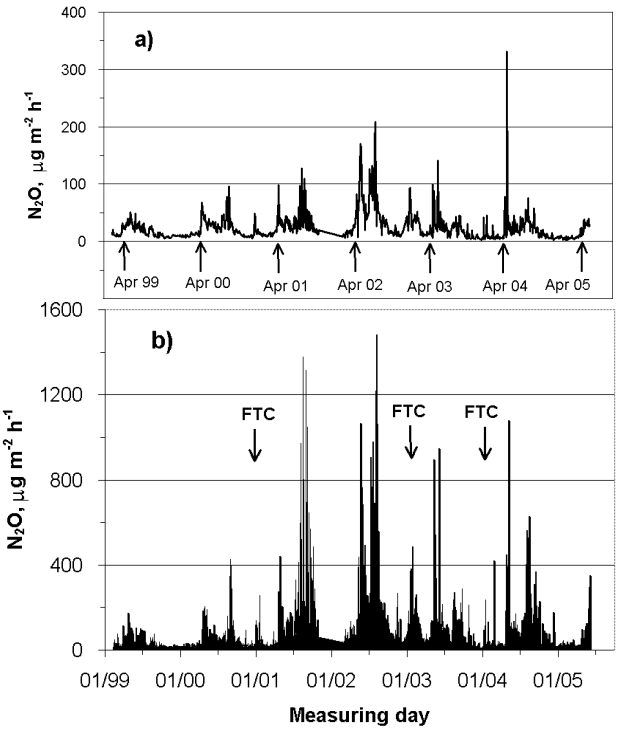


Figure 1: Time series of N_2O emissions from all sites of the experimental field

a) Daily mean values of emission rates from all measuring spots. Arrows indicate the start of fertilisation usually in April, (see Tab. 4).

b) Daily emission values from each of all measuring spots, FTC: Arrows indicate periods of freeze thaw enhanced N_2O emissions.

Enhanced N_2O emissions

Enhanced emission of N_2O due to freeze thaw cycles (January 2001, January till March 2003, and January 2004) is indicated in Fig. 1b. No clearly frost increased emission rates were found in January 2000 and 2005. No information of freeze thaw cycles can

Table 4: Date of fertiliser application and fertilisation rates in kg N ha^{-1} y^{-1}

A: 50 **B: 50** **C: 50** **D: -**	**A: 50** **B: 25** **C: 25** **D: -**	**A: 50** **B: -** **C: -** **D: -**
26/03/1999	07/05/1999	18/05/1999
14/04/2000	05/05/2000	25/05/2000
17/04/2001	07/05/2001	14/05/2001
09/04/2002	13/05/2002	21/05/2002
08/04/2003	14/05/2003	02/06/2003
21/04/2004	06/05/2004	18/05/2004
18/04/2005	10/05/2005	19/05/2005

be given for 1999 and 2002 since this project started in February 1999 and was interrupted between December 2001 and February 2002. 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 [13, 25-27]. However, the frost-induced emissions we measured at a couple of the sites are small compared to the total annual N_2O emission budget from the sandy soil of the experimental field.

There were several unusual high emission periods at fertilised sites within the course of the measurements since 1999. In 2000, emission rates between 400 and 800 µg N_2O m^{-2} h^{-1} were measured at the rape site with fertilisation level of 150 kg N ha^{-1} y^{-1} from the end of July till to the harvest in the beginning of September. In 2001, very high N_2O emission rates of up to 1400 µg N_2O m^{-2} h^{-1} were observed from one poplar measuring spot with fertilisation level of 150 kg N ha^{-1} y^{-1} over a period from July till October. There were high emission rates between 350 and 900 µg N_2O m^{-2} h^{-1} from all fertilised rape sites for several weeks in July 2002 and in July 2004. Additionally, four non-fertilised sites of fallow land (Tab. 3) were measured in 2002 (**Fig. 2**). High emission rates between 200 and more than 1200 µg N_2O m^{-2} h^{-1} were observed from the sites of the fallow land during the period from end of May 2002 till middle of August 2002. This fallow land, which was cultivated and fertilised the years before, even had the highest annual emission rate of 5.3 kg N_2O-N ha^{-1} y^{-1} although no fertiliser was applied during the year of study. As the fallow land was only ploughed and harrowed in March but no drilled ("black fallow"), the high precipitation in 2002 could have caused enlarged anaerobic zones within the topsoil resulting in enhanced N_2O emissions.

Only once a visible difference was observed at one measuring ring. In October 2001, fungi (probably *Agaricus campestris* and *Tricholoma terreum)* occurred inside the measuring ring of the one intensive emitting poplar site. The sources for this high emission spots of N_2O are not fully understood, but it is assumed that this should be predominantly caused by an enhanced mineralisation of soil organic matter due to the presence of fungi or other organisms as reported by [28-34].

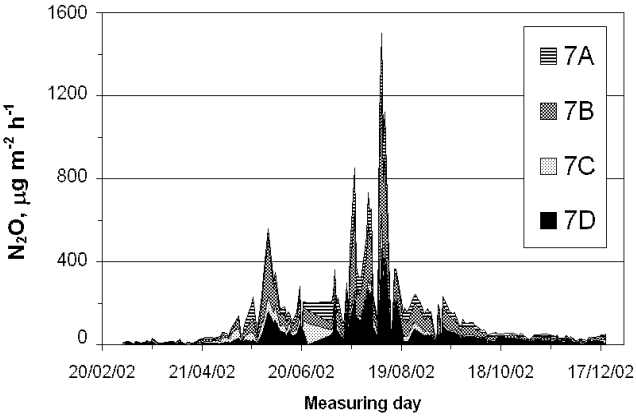


Figure 2: N_2O Emission rates from four measuring spots at fallow (Part of Fig. 1b).

Precipitation and N_2O emissions

The maximum of the mean annual N_2O emissions (**Tab. 5**) and the maximum of the mean nitrogen conversion factor (**Tab. 6**) of the differently fertilised rows A, B, and C were observed in 2002, the year with the highest precipitation since 1999. There is a clear correlation between annual precipitation and annual total N_2O emissions (R^2 = 0.76) and fertiliser-induced emissions (R^2 = 0.77), respectively (**Fig. 3**).

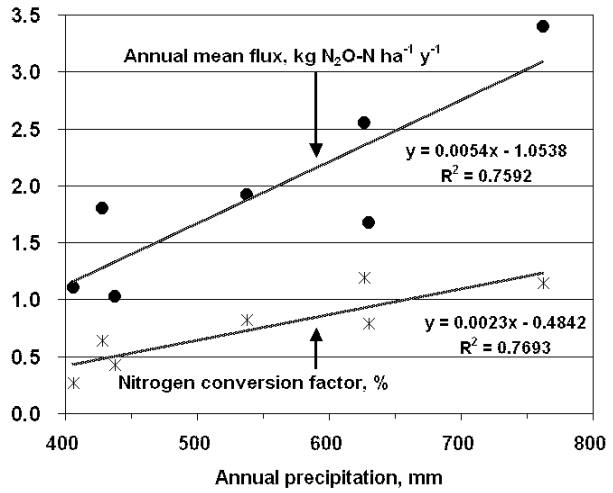
Table 5: Annual mean N_2O-N emissions from sites at the differently fertilised rows A, B, C, and D

Year	N_2O-N Emission (kg N_2O-N ha^{-1} y^{-1})			
	A	**B**	**C**	**D**
1999	1.11	0.84	0.88	0.70
2000	1.92	0.88	0.98	0.69
2001	2.55	0.89	1.13	0.77
2002	3.40	1.70	3.17	1.68
2003	1.80	1.30	1.45	0.84
2004	1.68	1.11	1.00	0.49
2005	1.03	0.75	0.76	0.38
1999-2005	**2.20**	**1.17**	**1.47**	**0.90**

Table 6: Annual mean nitrogen conversion factor of the differently fertilised rows A, B, and C

Yaer	N_2O-N Emission factor (%)		
	Mean sites A	**Mean sites B, C**	**Mean sites A, B, C**
1999	0.27	0.21	0.23
2000	0.82	0.32	0.48
2001	1.19	0.33	0.61
2002	1.15	1.00	1.05
2003	0.64	0.71	0.68
2004	0.79	0.76	0.77
2005*	0.43*	0.50*	0.48*
1999-2005	**0.87**	**0.57**	**0.67**

* 2005: 01/01/2005 – 15/06/2005



Figur 3: Mean annual N_2O-N flux from sites at A-rows and mean nitrogen conversion for A-rows related to annual precipitation.

Soil Nitrate and N_2O emissions

The correlation between soil nitrate and N_2O emissions was much lower than initially expected. The close relationship between N_2O generation and extractable soil nitrate (denitrification) and ammonia (nitrification) is well understood [e.g. 34, 35]. The seasonal change of soil nitrate concentration and N_2O fluxes were similar (**Fig. 4**), but due to the temporal and local fluctuations of N_2O emissions and of nitrate concentrations, the correlation might depend on the locations and schedule of soil sampling compared to the N_2O flux measurements. The soil samples were taken outside the measuring rings (in order not to disturb the soil surface) in distances of 30 to 50 cm, neither synchronous nor daily but only weekly. There is nearly no correlation between daily flux measurements and weekly nitrate concentration measurements ($R^2 = 0.03$) (**Fig. 5a),** whereas a slight correlation exists for the monthly means ($R^2 = 0.20$) (**Fig. 5b**). This is interpreted as a result of the high dynamics of N_2O flux, which can considerably vary at the same measuring ring in the course of one week. On the other hand, the monthly means reflect a general tendency. Therefore, the correlation increases, as both quantities show similar seasonal changes (Fig. 4).

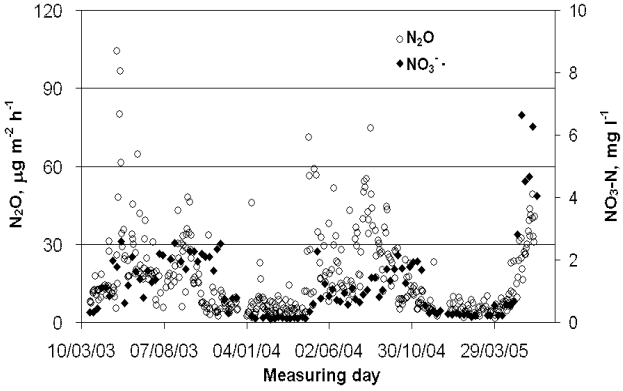


Figure 4: Seasonal change of mean soil nitrate concentration and mean N_2O fluxes

Influence of cultivation and tillage

An obvious difference exists between N_2O emission rates from sites with perennial crops and annual crops (**Tab. 7**). The emissions from sites with annual crops were about 50 % higher than from sites with perennial crops. This is true, independent on fertilisation level. Considering the conversion factor, it was nearly twice for sites with annual crops com-

pared to perennial crops (**Tab. 8**). Although this phenomenon is not fully understood, changes in physical structure by soil tillage may alter biological activity [4, 11] and thus N_2O emission over the crop season.

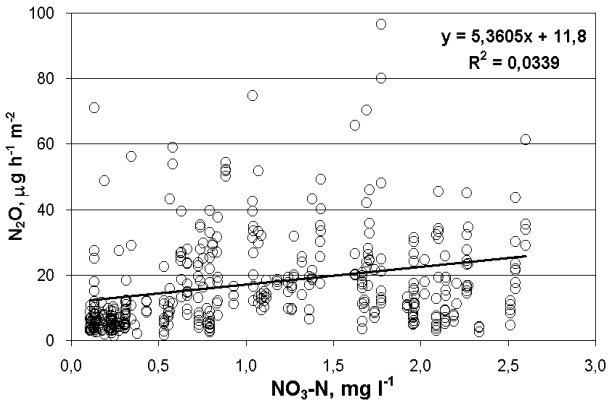


Figure 5a: Mean of daily N_2O flux measurements related to weekly measurements of soil nitrate

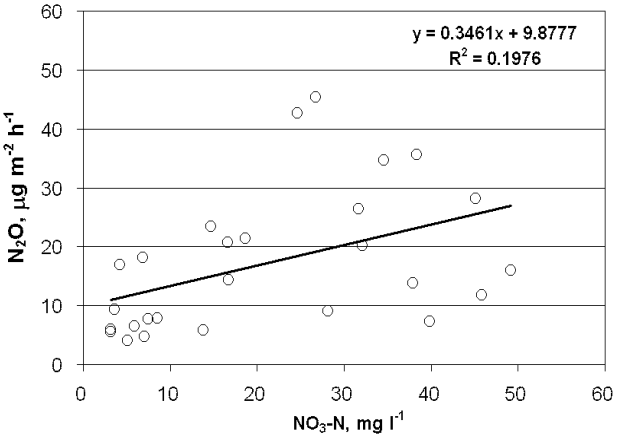


Figure 5b: Monthly means of N_2O flux measurements related to monthly means of soil nitrate

N_2O emission and CO_2 mitigation of energy crops

The mean N_2O-N emission factor was approximately 0.7 % for all A-, B-, and C-sites (0.9 % for A-sites and 0.6 % for B- and C-sites) for the year period from 1999 to 2005 (Tab. 6). Additionally, the emission factor shows variation depending on crop type (annual or perennial) and year (precipitation). Due to the local enhanced N_2O emissions from several measuring spots at A-sites, the mean of the emission factor increased with the nitrogen fertilisation level (annual means of induced emissions; sites A to B, C; Tab. 6) and annual crops emitted more N_2O than perennial crops (Tab. 8). Reason could be variations in biological activity in dependence on

Table 7: Mean N_2O-N emissions from sites with perennial crops and annual crops and from fallow land sites (differently fertilised rows A, B, C and D)

Crop	**N_2O-N Emission** (kg N_2O-N ha^{-1} y^{-1})			
	A	**B**	**C**	**D**
Grass (3 years)	1.30	0.97	1.22	0.70
Willow (6 years)	1.00	0.70	0.93	0.55
Poplar (7 years)	1.51	0.82	0.88	0.56
Mean Perennial crops	**1.27**	**0.83**	**1.01**	**0.60**
Rye (6 years)	2.51	1.31	1.60	0.90
Triticale (4 years)	1.78	1.64	1.35	0.66
Hemp (2 years)	1.10	0.60	0.84	0.60
Rape (4 years)	3.84	1.67	2.11	1.44
Mean Annual crops	**2.31**	**1.31**	**1.47**	**0.90**
Fallow land 2002 of sites A, B, C, and D. A, B, C fertilised till 2001, 2002 non-fertilised.				
Fallow (1 year)	***6.74***	***2.66***	***7.60***	***4.40***

Table 8: Mean nitrogen conversion factor for sites with perennial crops and annual crops and differently fertilised rows A, B, and C

Crop	**N_2O-N Emissions factor** (%)		
	Mean sites A	**Mean sites B, C**	**Mean sites A, B, C**
Grass (3 years)	0.40	0.52	0.48
Willow (6 years)	0.30	0.36	0.34
Poplar (7 years)	0.64	0.39	0.47
Mean Perennial crops	**0.45**	**0.42**	**0.43**
Rye (6 years)	1.07	0.74	0.85
Triticale (4 years)	0.75	1.12	1.00
Hemp (2 years)	0.33	0.16	0.21
Rape (4 years)	1.60	0.60	0.94
Mean Annual crops	**0.94**	**0.65**	**0.75**

type and level of soil fertilisation. This is being examined at present. The results measured here are at the lower end of the range of the N_2O emission

factor, which is recommended by IPCC [2] for the fertilisation-based N_2O inventories. Thus, it can be stated that the emission of N_2O is comparatively low on the sandy soils of our experimental field. The CO_2 advantage of energy crops will not be reduced by nitrogen fertilising as long as fertilising results in an adequately higher biomass yield [37, 38]. This result is also true for other crops, cultivated on sandy soils as source for renewable vegetable raw materials, if excessive fertilising is avoided.

Conclusions

N_2O release from the soil is affected by temporary emissions. In contrast to freeze thaw cycles, nitrogen fertilisation largely contributes to the annual budget of N_2O emission. There were comparatively high local emissions, which were observed over several weeks and months. This local emission was observed once at a poplar site and several times at rape sites. These local emission spots increase the N_2O-N emission factor as they are only found on fertilised sites. The enhanced N_2O emissions are ascribed to local and temporal changes in mineralisation of soil organic matter as well as changes in soil biological activity.

Tillage and thus the type of crop could have influenced the N_2O emission rates too. The annual emissions from sites with annual crops are about 50 % higher than from sites with perennial plants. Fallow land generated the highest annual emission rates. The high precipitation in 2002 could have caused enlarged anaerobic zones within the topsoil resulting in enhanced N_2O emissions.

Precipitation had a great impact on the emission of N_2O and on the induced emissions (nitrogen conversion factor). The correlation between annual precipitation and accumulated annual N_2O emission (or conversion factor, respectively) was close. On the other hand, there was a very weak correlation between N_2O emission and soil nitrate content. This weak correlation is ascribed to the high temporal and local variability, as times and positions of soil sampling and gas sampling were not identical.

Fertilisation of sandy soils generally causes only moderate N_2O emissions. This is demonstrated by the total mean value of 0.7 % for the N_2O-N emission factor (N_2O-N to fertiliser N) and by the mean N_2O-N emissions from all sites studied (1.4 kg N_2O-N ha^{-1} y^{-1}). The annual mean values for the emission factor were in a range of between 0.2 % (1999) to 1.1 % (2002) and the annual mean N_2O-N fluxes varied between 0.9 kg N_2O-N ha^{-1} y^{-1} (1999) and 2.5 kg N_2O-N ha^{-1} y^{-1} (2002). The fertiliser-induced N_2O emissions were detectable at all fertilised sites after fertilising for a period of four to eight weeks. The moderate fertiliser-induced N_2O emissions from sandy soils do not affect essentially the CO_2 advantage of energy crops and of other crops for renewable vegetable raw materials cultivated on sandy soils, if excessive fertilising is avoided.

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