Nitrous oxide production and consumption in Calcaric Regosols as related to soil redox and texture**

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A b s t r a c t. The aim of this study was to investigate the effect of redox status on nitrous oxide (N_2O) evolution and transformation in soils of various textures. Soils samples were collected from Calcaric Regosols (according to FAO/UNESCO) developed from sand, silt and loam across various regions in Poland and were incubated anaerobically for 35 days. The initial phase of N_2O production, lasting 2-21 days, was followed by a gradual decrease indicating reducing of N_2O. The total amount of N_2O reached 13-44% of the initial nitrate-N (NO_3^--N) content and was highest in the silty soils and lowest in the sandy soils. It was negatively correlated with the >0.05 mm fraction and positively with the 0.05-0.002 mm fraction. Average daily N_2O production was negatively correlated with the >0.05 mm fraction and positively with finer fractions *ie* with the 0.05-0.002 mm and with the <0.002 mm fraction. The rate of N_2O disappearance averaged 0.56, 4.08 and 11.7 mg N_2O-N kg^{-1}day^{-1} in sandy, loamy and silty soils, respectively. Rate of N_2O consumption and organic matter content for individual soils was positively correlated with the 0.05-0.002 mm fraction and negatively with the >0.05 mm fraction. N_2O reduction to N_2 begins earlier in finely (*eg* loam) than in coarsely textured (*eg* sand) soils. Nitrous oxide content in the headspace existed in equilibrium with the nitrous oxide content in soil within a narrow redox potential interval +190-(+240) mV with maximum at about +200 mV. The redox potential about +200 mV is the limit value between the production of nitrous oxide and its consumption.

K e y w o r d s: nitrous oxide production, consumption, redox potential, soil texture

INTRODUCTION

Soils are important sources of a number of greenhouse gases such as water vapour, CO_2, CH_4 and N_2O. In general, most N_2O is formed from denitrification in an oxygen deficient environment, although it can also be produced from chemolitotrophic nitrification in aerobic conditions (Williams *et al.,* 1992; Martikainen *et al.,* 1993; Rice and Rogers, 1993; Ottow and Benckiser, 1994).

Since the factors affecting N_2O emission are complicated and internally related, a better understanding of this relationship is needed to be able to mitigate the emission of this important greenhouse gas through changes in agricultural practices (Yu *et al.,* 2001).

Nitrous oxide production is affected by many physical and biochemical factors, such as NO_3^- concentration, redox potential, organic matter content, temperature, soil pH, and soil moisture content (Tiedje, 1988; Horn *et al.,* 1994; Yu *et al.,* 2001). These factors interact in a complicated manner with microorganisms on a microscale level in the soil, creating the large spatial and temporal variability in denitrification that has been observed in several studies (Parkin, 1987; Svensson *et al.,* 1991). The oxygen status in soil, which is inversely proportional to soil moisture, appears in many studies to be one of the key factors influencing N_2O production (Parkin and Tiedje, 1984; Abou-Seada and Ottow, 1985; McKenney *et al.,* 2001). When the soil oxygen tension is lower than 1 percent (v/v), the microbial population appears to shift from being predominantly aerobic to anaerobic (Gliński and Stępniewski, 1985). The reduction of various oxidants (O_2, NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-} and CO_2) in homogenous soil suspensions occurs sequentially at the corresponding soil redox potential (E_h) values (Ponnamperuma, 1972). Redox potential is the parameter characterizing the intensity of soil redox transformations. Several researchers have found that

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denitrification can occur in soil if the Eh falls bellow +300 mV (Smith *et al.,* 1983; Patrick and Jugsujinda, 1992).

Under Polish conditions flooding usually occurs in the river valleys constituting about 5% of the territory. Moreover, saturation with water can occur in other soils under the conditions of prolonged rainfalls. It was found that denitrification in soil occurs at redox potentials below a certain limit being usually around +400 mV (Gliński and Stępniewska, 1986). As it was found the time needed to achieve this value under saturation conditions is very short sometimes only a few hours (Stępniewska *et al.,* 1996). An extensive investigation of the soil redox properties of Polish soils (950 profiles) showed that for a plow layer the redox potential dropped under flooded conditions to +400 mV within one day in 44% of the cases at 20°C and in 20% of the cases at 15°C (Stępniewska *et al.,* 1996).

The main purpose of this study was to estimate the potential ability of soils to produce N_2O under flooded conditions where NO_3^- content was a non-limiting factor (100 mg NO_3^--N per kg corresponding to 300 kg NO_3^--N per ha in 20 cm top soil layer) and a potential ability of soils to consume of N_2O. Objectives of this laboratory study with 13 different soils incubated under flooded conditions were: 1) to study the dependence of N_2O production or consumption on the soil redox potential and particle size distribution, and 2) to determine the critical soil redox potential for N_2O production/consumption. The experiments were designed to recognize the expected interrelations between these factors better.

MATERIALS AND METHODS

Soil material

Thirteen arable Polish topsoils (0-30 cm) used in the study were Calcaric Regosols (according to FAO/ UNESCO) developed from different parent materials. According to the granulometric composition the soils under investigation were divided into three groups. The first group (I) developed from sand (S_1-S_5) and loamy sand (ls), the second one (II) developed from sandy silt (uS_1-uS_2) and silty sand (uS) and the third one (III) developed from sandy loams (sL_1-sL_4). The soil texture was determined by the pipette method where the distribution of particle sizes is determined by sedimentation and expressed as percentage (Öhlinger, 1995).

The soils showed a large variation of the texture, pH, $C_{org.}$, and endogenous NO_3^- content. Soil samples originated from various region and represent almost all over the territory of Poland (Table 1).

Experimental procedure

The 5 g portions of air-dried sieved (1 mm sieve) soils were placed in 38 cm^3 glass vessels and enriched with KNO_3 at the rate of 100 mg NO_3^--N per kg dry soil. This N rate corresponded approximately to 300 NO_3^--N kg per ha (calculated on 20 cm layer basis). The soil/water ratio was about 1:1 (w/w); 0.5 ml of solution (containing 1g NO_3^--N kg^{-1}) and distilled water (4.5 ml). The vessels with suspensions were tightly sealed with rubber stoppers and

T a b l e 1. Basic properties and topography of the Calcaric Regosols under investigation

Soil developed from/soil group	Texture	Topography	Granulometric composition (%) (dia in mm)			$C_{org.}$ (%)	NO_3^--N_0[1] (mg kg^{-1})	pH_0[2]
			>0.05	0.05-0.002	<0.002			
Sand (I)	Sand (S_1)	Glacial plain	95	5	0	0.67	4.53	4.69
	Loamy sand (ls)	Glacial plain	74	21	5	0.44	29.94	7.07
	Sand (S_2)	Glacial plain	81	13	6	0.74	18.49	4.45
	Sand (S_3)	Glacial plain	84	15	1	0.49	13.66	4.50
	Sand (S_4)	Plain	85	12	3	0.32	6.47	6.32
	Sand (S_5)	Hilly terrain	78	22	0	0.92	58.2	4.95
Silt (II)	Sandy silt (sU_1)	Back of mountainous terrain	32	60	8	2.85	65.76	3.94
	Sandy silt (sU_2)	Hilly terrain	27	67	6	1.24	7.87	4.71
	Silty sand (uS)	Mountainous terrain (slop with slightly gradient)	52	43	5	2.31	32.93	5.37
Loam (III)	Sandy loams (sL_1)	Light undulating terrain	63	23	14	0.77	9.46	6.85
	Sandy loams (sL_2)	Glacial plain	71	21	8	0.57	17.88	7.61
	Sandy loams (sL_3)	Mountainous terrain (slop with slightly gradient)	55	41	4	1.89	5.37	3.83
	Sandy loams (sL_4)	Glacial plain	69	28	3	0.88	9.78	5.99

[1]endogenous nitrate (V) content, [2]values from 0 day of incubation.

incubated in the atmosphere diluted with gaseous nitrogen in order to simulate the lower oxygen content in soil air as compared to the atmospheric one. The initial concentration of O_2 in the gas headspace at the start of the incubation was 10% ±0.5 (replaced by N_2). Paraffin films were used onto the stoppers to ensure hermetic seals. The headspace gas was sampled through the stopper with a gas – tight syringe. The soils were incubated at 20°C for 34 days.

Measurement methods

After 1, 2, 3, 7, 10, 14, 21 28 32 and 34 days the concentration of N_2O and the initial concentration of O_2 in the headspace gas was determined with a gas chromatograph (Shimadzu GC-14, Japan) fitted with a thermal conductivity detector at 60°C. The gas components were separated on two columns (2 m long each) maintained at 40°C. The first column was packed with a Porapak Q and the second – with a molecular sieve 5A. The carrier gas was He flowing at a rate of 40 ml min^{-1}. The contents of N_2O and O_2 were corrected for gas dissolved in the water using literature values of Bunsen absorption coefficients.

A set of 30 incubation vessels was prepared for each soil. These vessels were opened in three replications successively after 1, 2, 3, 7, 10, 14, 21, 28, 32 and 34 days of the incubation in order to measure pH *in situ* (pH meter Radiometer Copenhagen) and the redox potential (Eh) (with a bare platinum wire electrode placed in the soil versus a saturated calomel electrode) (Gliński and Stępniewski, 1985).

The air-dried soil samples (2.5 g) were put into plastics flasks, shaken for 1h with 250 ml of 0.01 M CaCl$_2$, filtered through filter paper. The extracts were analyzed for NO_3^--N using a FIA Star 5000 autoanalyzer (FOSS Tecator). The estimation of organic matter content was based on the reduction of the $Cr_2O_7^{2-}$ ion by organic matter, wherein the unreduced $Cr_2O_7^{2-}$ was measured by titration (Allison, 1965).

The linear (y=a+bx), multiplicative (y=ax^b), exponential (y=e^{a+bx}) and logarithmic (y=alnx+b) models were used in the regression analysis and in each case the model with the highest R^2 was selected as the best fit for the experimental data (using Statgraphics 5.0).

RESULTS AND DISCUSSION

Nitrous oxide production

Both N_2O-N evolution and redox potential changes throughout are presented (as the average values for the three soil groups) in Figs 1a and b. Nitrous oxide content increased in the initial period and then decreased due to its consumption by the soil. Nitrous oxide production and consumption occurred simultaneously throughout the incubation. With prevalence of production before the maximum N_2O-N value and prevalence of consumption

after the maximum of production. In the loamy soils the period of nitrous oxide production lasted only 3 days, in the silty soils 10 days, and in the sandy soils about 21 days.

We hypothesised that N_2O originated from denitrification and not from nitrification under investigated conditions. In order to check this hypothesis we conducted an experiment with Calcaric Regosols with NH_4^+ amendment without NO_3^- additions under flooded conditions where O_2 concentration in the headspace was 21%. After 7 days of incubation no N_2O evolution was found whereas NH_4^+ concentration increased in the soil solution (data not shown).

The daily production and consumption rates were calculated by considering linear increase or decrease in the headspace N_2O content (as the production/consumption divided by the time).
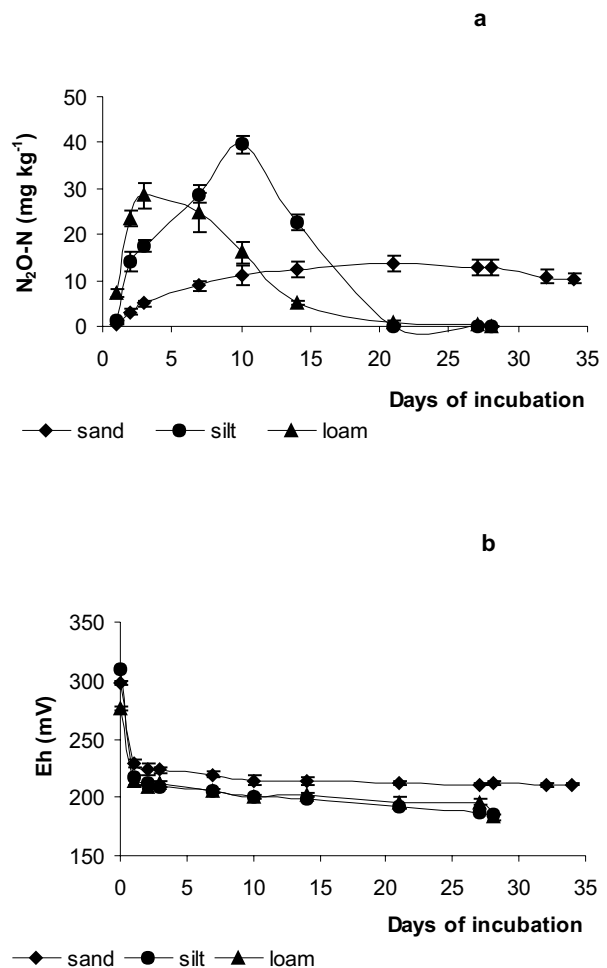

Fig. 1. The course of cumulative nitrous oxide content: a) in the headspace, b) redox potential versus incubation days, during the incubation of the three soil groups (mean values + standard deviations).

The average daily nitrous oxide evolution, the percentage of total (native + added) NO_3^--N denitrified to N_2O-N, as well as the daily N_2O consumption rates and the redox potential values of soils are shown in Table 2. The soil redox potential values measured in this study generally ranged from +332 (at the beginning of incubation) to +172 mV (at the end of incubation).

N_2O-N consumption showed significant differences among all soil grups (Table 3). The average daily nitrous oxide evolution varied from 1.9 (sandy soils) to about 24 (silty soils) mg N_2O-N kg^{-1} day^{-1}. Considering the rate of denitrification the investigated soil groups showed significant differences in the daily evaluation of nitrous oxide only in the case of soils developed from sand and silt (Tables 2 and 3). The

**T a b l e 2.** Redox potential values and N_2O evolution and consumption for the investigated soils

Soil developed from/soil group	Texture	N_2O-N				Eh_0[3]	Eh[4]	Eh final
		Evolution			Consumption			
		Total	Daily[1]	NO_3^--N denitrified	Daily[2]			
		(mg kg^{-1})		(%)	(mg kg^{-1})	(mV)		
Sand (I)	Sand (S_1)	17.28	0.82	16.5	0.86	292	226	218
	Loamy sand (ls)	18.40	6.13	14.2	0.39	268	209	204
	Sand (S_2)	12.86	1.03	10.9	0.19	331	217	219
	Sand (S_3)	15.23	1.19	13.4	0.53	322	211	215
	Sand (S_4)	11.40	0.54	10.7	0.86	238	204	203
	Sand (S_5)	17.84	1.77	11.3	0.53	332	210	207
	Average	15.50	1.91	12.8	0.56	297	213	211
Silt (II)	Sandy silt (sU_1)	66.47	7.78	40.1	8.92	315	205	204
	Sandy silt (sU_2)	64.14	11.6	53.9	15.7	311	204	172
	Silty sand (uS)	52.28	52.3	39.3	10.4	302	204	178
	Average	60.96	23.9	44.4	11.7	309	204	185
Loam (III)	Sandy loams (sL_1)	44.30	22.2	40.5	5.08	220	205	193
	Sandy loams (sL_2)	26.03	12.0	22.1	3.14	286	204	189
	Sandy loams (sL_3)	38.65	4.42	36.7	5.51	248	222	193
	Sandy loams (sL_4)	36.74	10.5	33.5	2.59	298	208	204
	Average	36.43	12.3	33.2	4.08	263	210	195

[1]Values from the day of maximum cumulative N_2O content divided by number of days, [2]N_2O drop after its maximum content to the end of incubation divided by the length of this period, [3] values from 0 day of incubation, [4]Eh values from the day of maximum N_2O content.

The percentage of NO_3^--N evaluated as N_2O-N ranged from about 11 to 54% among the soil, under investigation (Table 2). The percentage of NO_3^--N denitrified to N_2O-N was positively correlated to organic matter content in soil (R^2=0.52, p<0.01) (Fig. 2).

Soils developed from sand showed an average total nitrous oxide production of about 15 mg N_2O-N kg^{-1} and the value of redox potential corresponding to the maximum N_2O content was +213 mV. Soils developed from silt showed the highest average total denitrification (about 61 mg N_2O-N kg^{-1}) and the corresponding redox potential was +204 mV. Soils developed from loam the corresponding values were 36 mg N_2O-N kg^{-1} and +210 mV, respectively. The production of N_2O was accompanied by a drop of redox potential by 84, 105, and 53 mV for the first, second and third group of the soils, respectively (Table 2).

Nitrous oxide evolution, consumption and redox potential differentiated significantly soil groups. Nitrate-N denitrified to N_2O-N, total N_2O-N evolution and daily
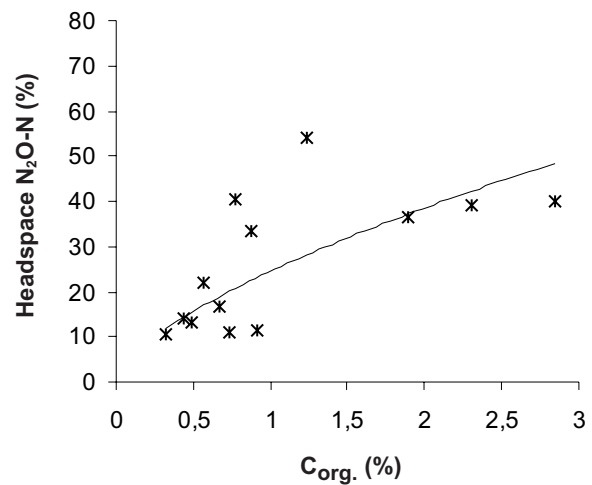
Fig. 2. Relationship between the percentage of NO_3^--N evolved as N_2O-N and the $C_{org.}$

T a b l e 3. Statistical significance of differences in N$_2$O evolution/consumption and redox potential among particular soil groups

Texture (contrast)	NO$_3^-$-N denitrified	Nitrous oxide			Redox potential	
		Evolution		Consumption	At N$_2$O-N maximum	Final value
		Total	Daily	Daily		
Sand - silt	*	*	*	*	NS	*
Sand - loam	*	*	NS	*	NS	*
Silt - loam	*	*	NS	*	NS	NS

* denotes a statistically significant difference at P<0.05, NS – no significant difference.

highest differentiation within particular soil groups in the case of daily N$_2$O-N evolution was found among the soils developed from sand (0.5-6.1 mg N$_2$O-N kg^{-1} day^{-1}), inter-mediate – in the silty ones (7.8-52.3 mg N$_2$O-N kg^{-1} day^{-1}), and the lowest – among the soils developed from loam ones (4.4-22.2 mg N$_2$O-N kg^{-1} day^{-1}) (Table 2).

Nitrous oxide consumption

After the day of maximum content of N$_2$O, its stepwise disappearance from the headspace was observed. All the investigated soils showed an ability to consumption of nitrous oxide after prolonged incubation (Fig. 1a and Table 2).

Soils differentiated the N$_2$O consumption rates, because in the silty and loamy soils practically all the generated nitrous oxide was consumed during incubation while in the sandy soils only about one third was consumed (Fig. 1a). Loamy soils showed an asymmetry in the headspace nitrous oxide content curves with a slower consumption compared to the production. The curve for silty soils was almost symmetric and also the curve of the sandy soils, was probably also symmetric with slow changes on both sides, but the incubation period was too short to confirm such a trend.

The consumption of N$_2$O was accompanied by a further gradual decrease in the redox potential (Fig. 1b). This decrease, however, was much slower than the decrease observed during the initial nitrous oxide production, and was equal to 2, 19 and 15 mV for the first, second and third soil group, respectively (Table 2). The soil groups under investigation showed a significant differentiation (Table 3) in the average daily nitrous oxide consumption (0.56 for sandy soils, 4.1 for loamy, and 11.7 mg N$_2$O-N kg^{-1} day^{-1} for silty soils).

Soil texture effect

It should be emphasized that the soil texture (Table 3) and particle size distribution (Table 4) significantly affected the production and consumption of N$_2$O from the investigated soils. As mentioned above, the lowest rates of N$_2$O production and consumption were observed in light textured soils deve-loped from sand. Whereas heavier textured soils (developed from silt) showed the highest denitrification and consumption rate. The heaviest textured soils (developed from loam) showed intermediate N$_2$O production and consumption rates. Generally, the more favorable conditions for both N$_2$O production and consumption were in the heavier textured soils than in sandy soils.

The results clearly indicate the influence of particle size distribution on N$_2$O evaluation and consumption as well as on the redox potential. The total N$_2$O evolution from soils showed a negative linear correlation (R^2=0.90, p<0.001) with the content of the fraction >0.05 mm (Fig. 3a), a posi-tive linear correlation (R^2=0.85, p<0.001) with 0.05-0.002 mm fraction (Fig. 3b), and the lowest correlation with <0.002 mm fraction (R^2=0.26, p<0.05) (Fig. 3c). The daily N$_2$O evolution (Table 2) were also correlated with the particle size fractions under consideration (Table 4).

The particle size distribution may explain the very low denitrification activity of the Calcaric Regosols where the content of the >0.05 mm fraction was predominant ranging from 74 to 95% (first group of investigated soils). On the other hand, the higher N$_2$O evolution of second group of the investigated soils was due to the finer fraction (0.05-0.002) content, ranging from 43 to 67%. Generally, fine-textured soils evolved more N$_2$O than the light soils. This tendency was confirmed by many authors (McKenney *et al.,* 1980;

T a b l e 4. Correlation equations for the daily nitrous oxide evolution versus percentage of granulometric soil fractions

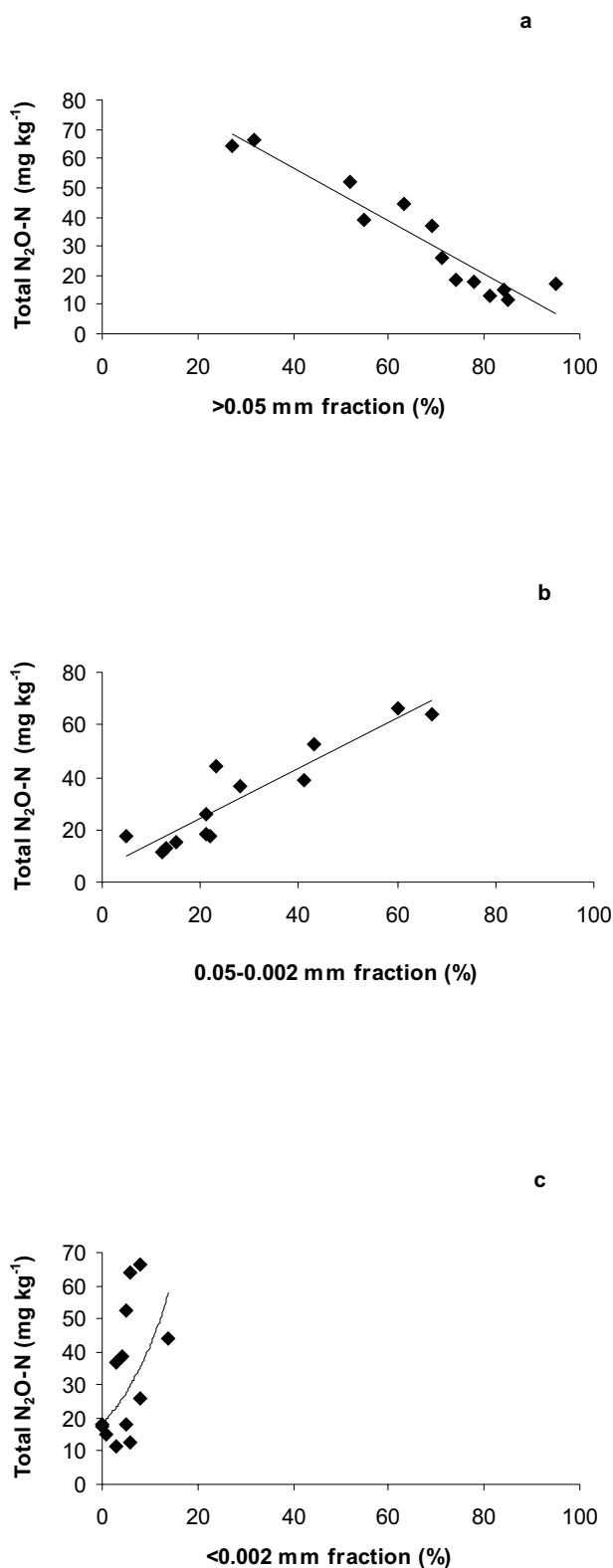| Granulometric fractions (dia in mm)	Function	Correlation coefficient (R^2)	Significance level	Number of repetitions (n)
>0.05	y = 99.705e$^{-0.046x}$	0.452	*P*<0.01	13
0.05-0.002	y = 0.0563x$^{1.3986}$	0.503	*P*<0.01	13
<0.002	y = 1.5256e$^{0.2248x}$	0.374	*P*<0.05	13

Fig. 3. Total N_2O-N content in the headspace versus the content of particle size fractions.

Webster and Dowdell, 1982; Matson *et al.,* 1990; Skiba *et al.,* 1992) that nitrous oxide production from heavier-textured soils exceeds that from coarse-textured soils up to 6-times.

Since N_2O is an intermediate product of denitrification and by product of nitrification it may be produced and consumed in the soil. We observed a consumption after its production from soil. The daily consumption of N_2O defined here as the linear decrease in the N_2O content of the headspace divided by the time period, showed a negative non-linear correlation (R^2=0.86, p<0.001) with the fraction of >0.05 mm (Fig. 4a) and a positive linear correlation (R^2=0.84, p<0.001) with the 0.05-0.002 mm fraction (Fig. 4b). Thus the particle size distribution of soil may explain the N_2O consumption of sandy soils (group I) and higher N_2O consumption in the second group of soils which were characterized by a higher the content of the finer fraction (0.05-0.002). It should be emphasized that N_2O reduction to N_2 begins earlier in finely (*eg* loam) than in coarsely-textured (*eg* sand) soils. Table 1 shows that organic matter percentages changes substantially among the textural groups with the silts having the highest organic matter content. The effect of the organic matter content on production and consumption of N_2O has been shown before as testimonial by the significant correlation between these two parameters. The particle size distribution was negatively correlated with organic matter content in the fraction >0.05 mm (y=-23.637 ln(x)+63.572; R^2=0.579; p<0.001) and positively correlated with the 0.05-0.002 mm fraction (y=22.491 ln(x)+31.434; R^2=0.612; p<0.001).

The final value of the redox potential showed a positive linear correlation (R^2=0.53, p<0.01) with the fraction of >0.05 mm (Fig. 5a) and a negative linear correlation (R^2=0.49, p<0.01) with the 0.05-0.002 mm fraction (Fig. 5b).

Nitrous oxide content versus redox potential

Two threshold E_h values characterize N_2O production and consumption: +240 mV corresponded the beginning of N_2O formation whereas the lower value of +190 mV corresponding to N_2O disappearance due to consumption (Fig. 6). The maximum N_2O concentration in the headspace occurred at about E_h = +200 mV. It should be emphasized that the interval of redox potentials allowing the existence of gaseous nitrous oxide in the equilibrium or 'quasi-equilibrium' with the soil is very narrow and does not exceed 50 mV.

There is few data in the literature about the relationship between N_2O emission and the soil redox potential. For the first time this relationship was studied by Smith *et. al.*, (1983) who found that soil, dependently on its redox potential, can be both a source and a sink of N_2O. These studies performed with a silt loam (Typic Fluvaquents) soil with different pH values, the N_2O production occurred at Eh values >+300 mV for pH 5 and >+250 mV for pH values 6, 7,

a

b

c
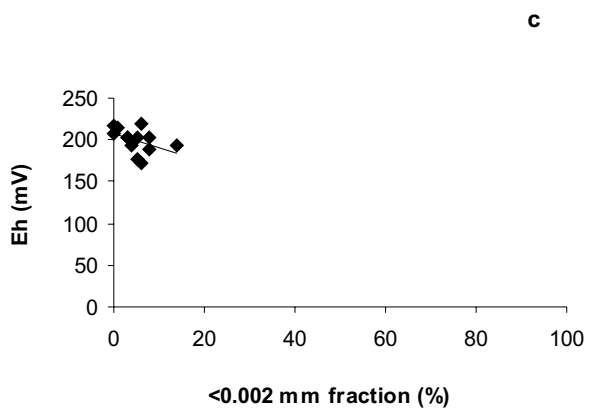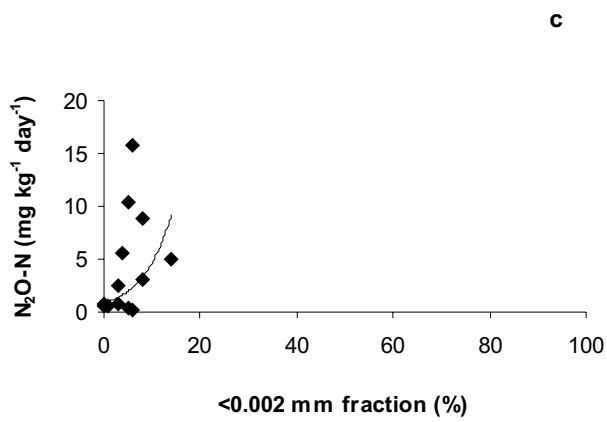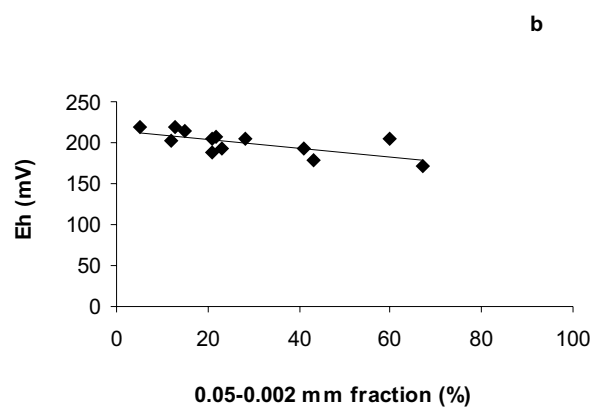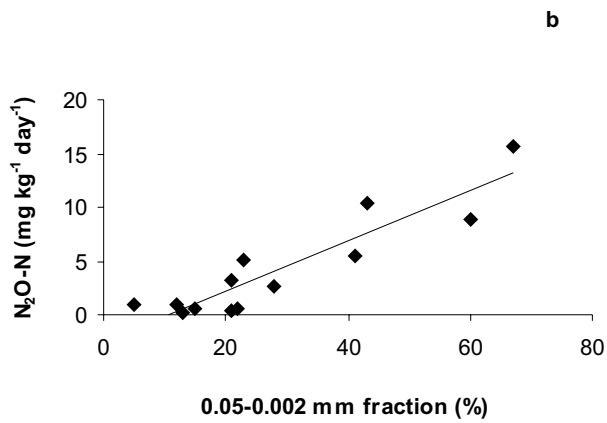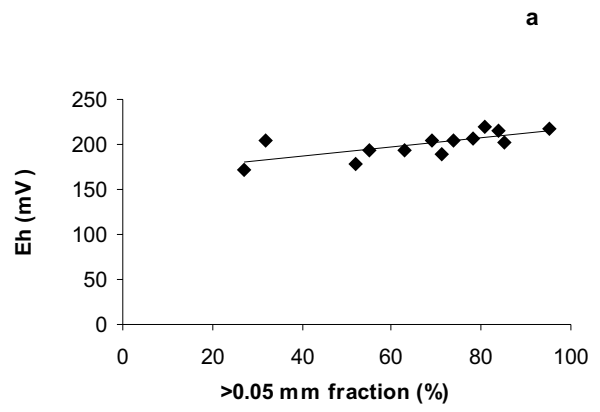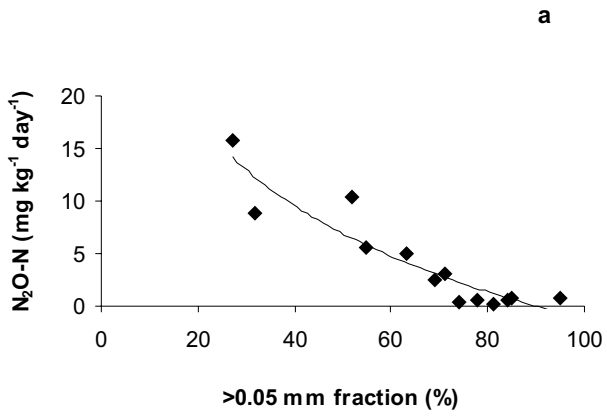
Fig. 4. Daily N_2O-N consumption versus the content of the particle size fractions.

a

b

c

Fig. 5. Final redox potential values versus the content of particle size fractions.

and 8.5, while below these values the reduction of N_2O was observed. Kralova *et al.* (1992) studied denitrification in a soil suspension amended with NO_3^-. The maximum amount of N_2O evolved at a redox potential value of 0 mV, while denitrification rates and N_2 emission continued to increase with lower redox levels. Masscheleyn *et al.* (1993) reported N_2O emission from rice paddy soils at various redox potentials, ranging from +500 to -250 mV. Two maxima for N_2O evolution were found, corresponding +400 mV when nitrification was the N_2O source and at 0 mV when N_2O was produced by denitrification. The results obtained by Yu *et al.* (2001) showed that the N_2O emission from 4 different mineral soils (loamy sand, two different silt

loams, and clay loam) was regulated within a narrow redox potential range of +120 to +250 mV, due to the balance of N_2O production and its further reduction to N_2. The latter results agree with ours from 13 soils considered together.

The correlation equations and coefficients of the headspace nitrous oxide content versus the redox potential, both for evaluation and consumption phase and for all the soil groups, are presented in Table 5 and Fig. 6. In almost all the cases significant curvilinear correlations were found. They were positive for the consumption phases and negative for the production phase. The highest influence both on production and consumption of N_2O was found in the case of silt fraction.

T a b l e 5. Correlation equations (and their statistical parameters) for N_2O –N content versus soil redox potential for the evolution and consumption phase in particular soil groups and in all the soils considered together

Texture	N_2O	Function	Correlation coefficient (R^2)	Significance level	Number of repetitions (n)
All soils	evolution	$y = 1E+41x^{-17.248}$	0.293	*P*<0.001	218
	consumption	$y = 2E-81x^{35.219}$	0.392	*P*<0.001	138
Sand	evolution	$y = -0.1924x+49.612$	0.182	*P*<0.001	138
	consumption	NS			46
Silt	evolution	$y = 2E+21e^{-0.2228x}$	0.620	*P*<0.001	36
	consumption	$y = 1E-20e^{0.2314x}$	0.427	*P*<0.001	28
Loam	evolution	$y = 6E+10e^{-0.1062x}$	0.304	*P*<0.001	44
	consumption	$y = 4E-19e^{0.2148x}$	0.280	*P*<0.001	64

NS – no significant differences.
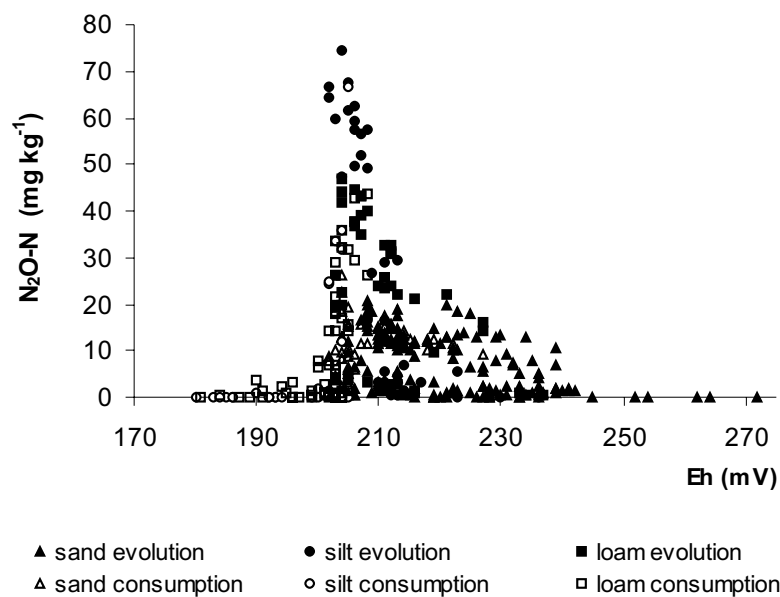
Fig. 6. Relationship between the N_2O-N content and the redox potential of the evolution and consumption phases.

CONCLUSIONS

1. The period of nitrous oxide production in the investigated soils was followed by its consumption.

2. Soil texture affected significantly the N_2O evolution and consumption as well as the redox potential.

3. Nitrous oxide existed in equilibrium with the soil in a narrow redox potential interval +190-(+240) mV with the maximum at about +200 mV being the limit value between N_2O production and its consumption.

4. The average maximum cumulative evolution of N_2O ranged from about 15.5 mg N_2O-N kg^{-1} for sandy soils through 36.4 mg N_2O-N kg^{-1} for loams to 61 mg N_2O-N kg^{-1} for silty soils.

5. The total N_2O reached 13-44% of the initial nitrate-N content.

6. All the investigated soils showed an ability to nitrous oxide consumption being 0.56 for sandy soils, 4.08 for loamy ones and 11.7 mg N_2O-N $kg^{-1}day^{-1}$ for the silty soils.

7. N_2O reduction to N_2 begins earlier in finely (*eg* loam) than in coarsely-textured (*eg* sand) soils.

8. Both production and consumption and organic matter content showed a significant positive correlation with the fraction 0.05-0.002 mm and a negative one with the fractions >0.05 mm.

REFERENCES

Abou-Seada M.N.I. and Ottow J.G.C., 1985. Effect of increasing oxygen concentration on total denitrification and nitrous oxide release from soil by different bacteria. Biol. Fertil. Soils 1, 31-38.

Allison L.E., 1965. Organic carbon. In: Methods of Soil Analysis (Eds C.A. Black, D.D, Evans, L.E, Ensminger, J.L. White, F.E. Clark). Part 2. Chemical and Microbiological Properties. American Society of Agronomy, Inc. Publisher Madison, Wisconsin, USA, 1367-1378.

Gliński J. and Stępniewski W., 1985. Soil Aeration and Its Role for Plants. CRC Press Inc., Boca Raton, Florida.

Gliński J. and Stępniewska Z., 1986. An evolution of soil resistance to reduction processes. Polish J. Soil Sci., 19, 15-19.

Horn R., Stępniewski W., Włodarczyk T., Walenzik G., and Eckhardt F.E.W., 1994. Denitrification rate and microbial distribution within homogenous model soil aggregates. Int. Agrophisics, 8, 65-74.

Kralova M., Masscheleyn P.H., Lindau C.W., and Patrick W.H., Jr, 1992. Production of dinitrogen and nitrous oxide in soil suspensions as affected by redox potential. Water Air Soil Pollut., 61, 37-45.

Martikainen P.J., Lehtonen M., Lang K., De Boer W., and Ferm A., 1993. Nitrification and nitrous oxide production potentials in aerobic soil samples from the soil profile of a Finnish coniferous site receiving high ammonium deposition. FEMS Microbiology Ecology, 13, 113-122.

Masscheleyn P.H., DeLaune R.D., and Patrick W.H., 1993. Methane and nitrous oxide emissions from laboratory measurements of rice soil suspension - effect of soil oxidation-reduction status. Chemosphere, 26, 251-260.

Matson P.A., Vitousek P.M., Livingstone G.P., and Swanberg N.A., 1990. Sources of variation in nitrous oxide flux from Amazonian ecosystems. J. Geophys. Res., 95, 16789-16798.

McKenney D., Drury C.F., and Wang S.W., 2001. Effect of oxygen on denitrification inhibition, repression, and depression in soil columns. Soil Sci. Soc. Am. J., 65, 126-132.

McKenney D.J., Shuttleworth K.F., and Findlay W.J., 1980. Nitrous oxide evolution rates from fertilised soil: Effects of applied nitrogen. Can. J. Soil Sci., 60, 429-438.

Ottow J.C.G. and Benckiser G., 1994. Effect of ecological conditions on total denitrification and N_2O release from soils. Nova Acta Leopoldina, 288, 251-262.

Öhlinger R., 1995. Methods is soil physics and chemistry. In: Methods in Soil Biology (Eds F. Schiner, R. Öhlinger, E. Kandeler, R. Margesin). Springer, Berlin-Heidelberg, 385-390.

Parkin T.B., 1987. Soil microsites as a source of denitrification variability. Soil Sci. Soc. Am. J., 51, 1194-1199.

Parkin T.B. and Tiedje J.M., 1984. Application of soil core method to investigate the effect of oxygen concentration on denitrification. Soil Biol. Biochem., 16, 331-334.

Patrick W.H. Jr and Jugsujinda A., 1992. Sequential reduction and oxidation of inorganic nitrogen, manganese, and iron in flooded soil. Soil Sci. Soc. Am. J., 56, 1071-1073.

Ponnamperuma F.N., 1972. The chemistry of submerged soils. Adv. Agron., 24, 29-41.

Rice C.W. and Rogers K.L., 1993. Denitrification in subsurface environments: potential source for atmospheric nitrous oxide. In: Agricultural Ecosystems Effects on Trace Gases and Global Climate Change (Eds D. Rolston *et al*.). ASA Special Publication, 55, 121-132.

Skiba U., Hargreaves K.H., Fowler D., and Smith K.A., 1992. Fluxes of nitric and nitrous oxide from agricultural soils in a cool temperate climate. Atm. Environ., 26A, 2477-2488.

Smith C.J., Wright M.F., and Patrick W.H., Jr, 1983. The effect of soil redox potential and pH on the redaction and production of nitrous oxide. J. Environ. Quality, 12, 186-188.

Stępniewska Z., Stępniewski W., Gliński J., and Ostrowski J., 1996. Atlas of the Redox Properties of Arable Soils in Poland. Lublin-Falenty, 37-39.

Svensson B.H., Klemedtson L., Simkins S., Paustian K., and Rosswall T., 1991. Soil denitrification in three cropping systems characterized by differences in nitrogen and carbon supply. I. Rate distribution frequencies, comparison between systems and seasonal N-losses. Plant Soil, 138, 257-271.

Tiedje J.M., 1988. Ecology of denitrification and dissimilatory nitrate reduction to ammonium. In: Biology of Anaerobic Microorganisms (Eds A.J.B. Zehner). John Wiley, New York, USA, 179-244.

Webster C.P., and Dowdell R.J., 1982. Nitrous oxide emission from permanent grass swards. J. Sci. Food Agric., 33, 227-230.

Williams E.J., Hutchinsen G.L., and Fehsenfeld F.C., 1992. NO_x and N_2O emission from soil. Global. Biogeochem. Cycles, 6, 351-388.

Yu K.W., Wang Z.P., Vermoesen A., Patrick W.H. Jr, and Van Cleemput O., 2001. Nitrous oxide and methane emission from different soil suspensions: effect of soil redox status. Biol. Fertil. Soils, 34, 25-30.