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N_2O-emissions following long-term organic fertilization at different levels
(N_2O-Emissionen als Langzeitwirkung unterschiedlich intensiver organischer Düngung)

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N_2O-emissions following long-term organic fertilization at different levels

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1 Introduction

N_2O-production of soil microbiology in agricultural fields is a very important anthropogenic N_2O-source. It is an object of N_2O-research to estimate usual agricultural management in its short- and long-term effects on N_2O-release. Agricultural practice influences many factors controlling N_2O-production in soils through nitrification and denitrification as aeration, water content, nitrogen availability, soil-pH, availability of oxydizable carbon-structures e. g.. Therefore the "guide of good agricultural practice" is to be extended about chances to minimize N_2O-emissions.

An investigation was performed to study the effect of long-term different fertilizing strategies with organic components on N_2O-losses. Long-term organic fertilizing together with an enhancement of soil organic matter is likely to increase N_2O-losses by a general stimulation of microbial turnover. Regarding the aspect should not be ignored at every lasting increase of soil fertility. Related subjects are intense use of farmyard manure at high density of livestock or utilization of various composts in farming.

2 Experimental sites

N_2O-fluxes were measured at several long-term field experiments situated near Freising, all brown earth from loess.

1. Field Experiment 031 about the effects of compost from green material and biological refuse, started in 1991 with crop rotation silage maize (1994) - winter wheat (1995) - oats (1996). Three treatments were used for N_2O-flux measurements in 1996:

A Control Plot without compost applications

B 600 kg $N*ha^{-1}$ since 1991 as compost, last application 130 kg $N*ha^{-1}$ October 1995

C 1200 kg $N*ha^{-1}$ since 1991 as compost, last application 180 kg $N*ha^{-1}$ October 1995

All treatments got the same mineral fertilization in former years and in 1996 (2 x 30 kg $N*ha^{-1}$ calcium ammonium nitrate 16.04. and 23.05.).

Table 1 shows a gradual increase of nitrogen and carbon content in soil corresponding to higher compost applications, leading to a heavy enrichment.

Table 1: Total N- and C-contents in the topsoils (0-30cm depth) of the field experiments 031 and 034 in May 1996 [% of dry matter]

Tabelle 1: Gesamt-N und –C-Gehalte in den Oberböden (0-30 cm Tiefe) der Feldversuche 031 und 034 im Mai 1996 (% in der Trockensubstanz)

	031 A	031 B	031 C	034 A	034 B/D	034 C
Total-N	0.182	0.217	0.253	0.235	0.245	0.247
Total-C	1.26	1.43	1.84	1.79	1.90	1.91

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Field experiment 034 about different intensity and use patterns of slurry applications at a cattle-keeping farm, started in 1990, crop rotation winter wheat (1994) - winter barley (1995) - silage maize (1996). Four treatments were used for N_2O-flux measurements in 1996:

A Control plot,only min.fert. (∅ 147 kg $N*ha^{-1}*a^{-1}$), N-balance (fert.-harvest)+2 kg $N*ha^{-1}*a^{-1}$

B 120 $kg*ha^{-1}*a^{-1}$ slurry-N (total N) + ∅ 123 $kg*ha^{-1}*a^{-1}$ min. N, N-balance +91 kg $N*ha^{-1}*a^{-1}$

C 240 $kg*ha^{-1}*a^{-1}$ slurry-N (total N) + ∅ 73 $kg*ha^{-1}*a^{-1}$ min. N, N-balance +162 kg $N*ha^{-1}*a^{-1}$

D treatment B with an additional slurry application in 1996

All treatments got 30 kg $N*ha^{-1}$ calcium ammonium nitrate to maize cultivation (29.04.1996).

No slurry applications were given to the treatments B and C in 1996. Therefore long-term effects of C- and N-enrichment on soil microbiology were examined without the disturbance of recent organic fertilization.

2. Field experiment 053 about different intensity of mineral fertilization and combined slurry applications of different use patterns, started in 1979, crop rotation silage maize (1994) - winter wheat (1995) - winter barley (1996). Four treatments were used for N_2O-flux measurements in 1995 and 1996:

A Control plot without N-fertilization

B Mineral fertilization (calcium ammonium nitrate, ∅ 170 kg $N*ha^{-1}*a^{-1}$), high yield

C Reduced mineral fertilization (ca. amm. nitr., ∅ 137 kg $N*ha^{-1}*a^{-1}$), suboptimal yield

D Reduced mineral fertil. (∅ 128 kg $N*ha^{-1}*a^{-1}$) +slurry (∅ 142 kg $N*ha^{-1}*a^{-1}$), high yield

Treatments B and C showed a slight N-surplus for years (table 2), which is supposed to be typical for contemporary grain farming. As expected, there is no noticeable C- or N-enrichment in the topsoil compared to the control plot (table 2). Treatment D shows a distinct enrichment of both carbon and nitrogen in the topsoil, characteristic of farms with animal production.

Table 2: Long-term N-balances and total C- and N-contents in the topsoils (0-30cm depth) of field experiment 053 in May 1995

Tabelle 2: Langjährige N-Salden und Gesamt-C und –N-Gehalte im Oberboden des Feldversuchs 053 im Mai 1995

	053 A	053 B	053 C	053 D
N-balance[x] [kg $N*ha^{-1}*a^{-1}$]	– 52	+ 32	+ 12	+ 135
Total-C [% in dry matter]	1.10	1.14	1.14	1.27
Total-N [% in dry matter]	0.166	0.165	0.163	0.187

[x] N-balance means total fertilizer-N input minus N-removal by harvest

3 Methods

All N_2O-fluxes were measured using the closed-chamber technique described by HUTCHINSON and MOSIER (1981). Three times per week chambers were placed on the same low plastic base fixed in the ground to avoid spatial variation. The tested field-trials were small sized and cultivated carefully, therefore the number of replications per plot and date was limited to eight. Head space gas was sampled two times per chamber and date, collected and stored in evacuated glass-containers. Samples were analyzed within weeks by gas chromatography according to MOSIER and MACK (1980). Furthermore the CO_2-flux rates were measured as a by-product, validated from FREIJER and BOUTEN (1991).

Denitrifier enzyme activity was determined in fresh soil samples using a procedure described by TIEDJE (1994). In this anaerobic short-term incubation the current population of denitrifying microorganisms is the only limiting factor for the observed denitrification rates. Total microbial activity in the soil sample is reflected, because the majority of soil microorganisms is capable of denitrification.

4 Results and Discussion

4.1 Effects of organic fertilizing on soil microbiology

Parallel to the C- and N-enrichment of the soil, the plots with former applications of organic fertilizers showed a significant and lasting increase in denitrifier enzyme activity. On the contrary, reduced mineral fertilization had no clear effect (see figure 1).

The remarkable increase of the denitrification potential by fertilizing strategies with organic components agrees well with present conceptions of their effect on microbial activity in general. MÄDER et al. (1995) report a significant increase of total microbial biomass and enzyme activity by organic fertilizing in a long-term experiment, intensified at fertilizing strategies without mineral components (Organic Farming). At the same time the metabolic quotient decreased, meaning less carbon-consumption per unit of microbial biomass and therefore an enhancement of further carbon-enrichment.

The observed CO_2-flux rates at the soil surface (figure 2) confirm an intensified microbial turnover according to organic fertilizing. They increased overproportionally with increasing former compost amounts. In the case of field experiment 034 the effect of the former slurry applications does not clearly differ from the control. An integral calculus over time (table 3) elucidates the trend. Previous twofold slurry amount did not enhance the CO_2-output (data not shown in figure 2), it did not cause any further C- or N-enrichment in the soil (table 1) nor increase denitrifier enzyme activity. On the other hand the slurry injection in June 1996 increased the CO_2-output persistently (figure 2 and table 3). The CO_2-emissions partly resulted from root respiration, but growth of oats or silage maize differed in no way. Therefore soil microbiology has been responsible for the CO_2-effects. The observed peak patterns strictly followed the course of the soil temperatures.

Plots with former organic fertilization constantly showed higher levels of nitrate in the topsoils compared to the control plots (figure 3). This signifies a normal situation due to an enhanced N-mobilisation, which results from an elevated pool of oxidizable carbon-structures.

4.2 Organic fertilization and N_2O-emissions

Both nitrification and denitrification occur as sources for N_2O-emissions from soils. In our field experiments both processes are promoted by former organic fertilization. More N-mobilisation leads to more nitrification and more soil microbiology means more denitrification potential, if the soil atmosphere turns to anaerobic conditions, what is likely to be accelerated by higher O_2-consumption. But nevertheless higher N_2O-emissions from these plots are avoidable: Higher denitrification activity raises the consumption of electron acceptors, therefore the probability of a complete reduction of nitrate-ions to molecular N_2 through denitrifiers increases (GRANLI and BØCKMAN, 1994). In the end, the N_2O-output may decrease despite of higher denitrification activity. On the other hand the extended nitrate pool in the soil obviates this possibility (GRANLI and BØCKMAN, 1994). Predicting the combined net effect on N_2O-losses at soil surface seems to be impossible.

In the described field experiments, the increased microbial activity after former organic fertilizing is scarcely reflected in the observed N_2O-emissions (figure 4). Integrating over time indicates higher N_2O-losses from the plots with former compost or slurry applications (table 3). The patterns of detected N_2O-peaks can be explained with influence of the weather (soil moisture) and farming (fertilizer application, tillage).

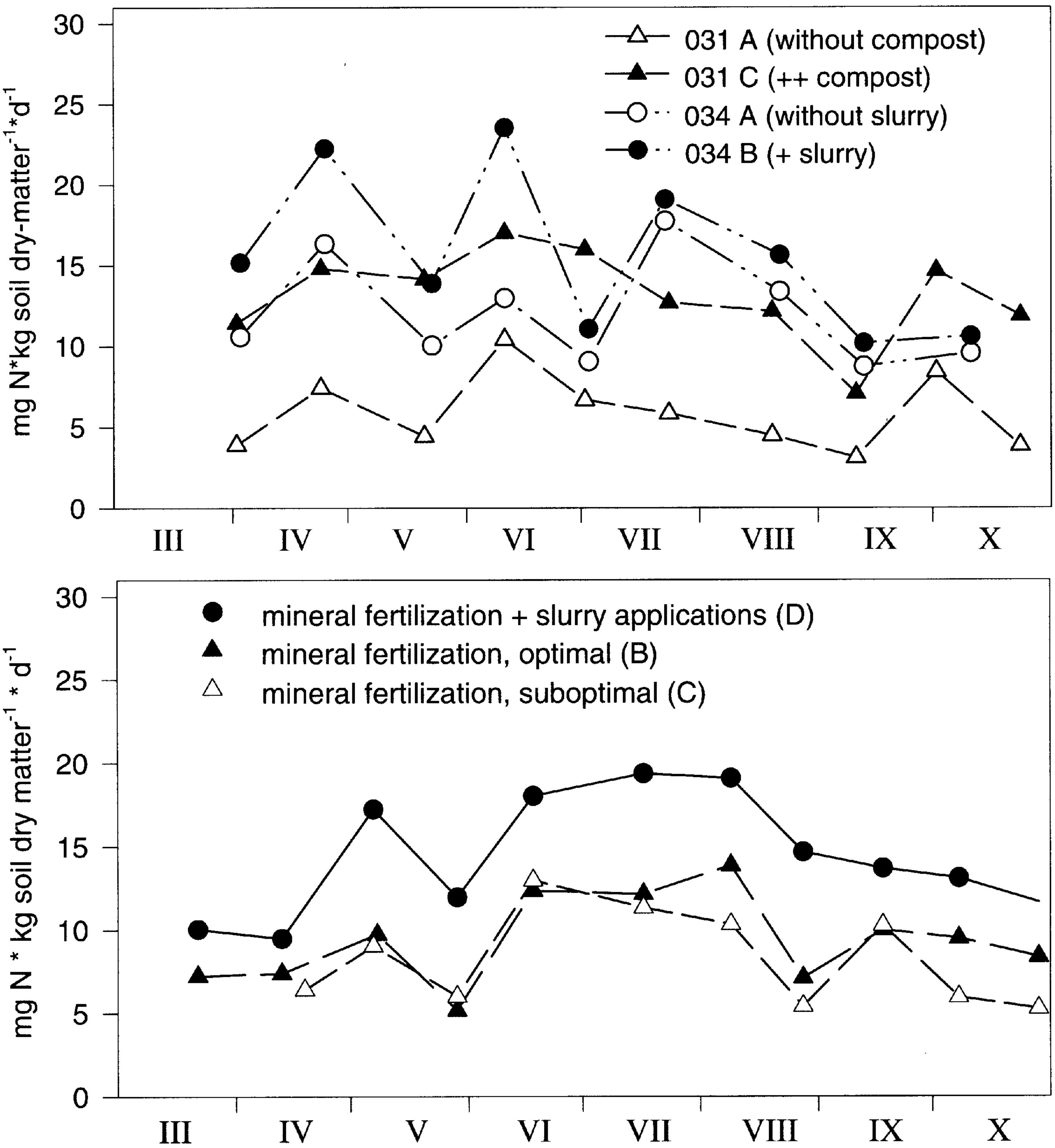


Figure 1: *Annual course of denitrifier enzyme activity in 1996 at the field experiments 031, 034 (above) and 053 (below)*

Abbildung 1: *Jahresgang 1996 der Denitrifikationspotentiale innerhalb der Feldversuche 031 und 034 (oben) sowie 053 (unten)*

Table 3: *Integrated N_2O- and CO_2-losses of the field experiments 031 and 034 from April to September 1996*

Tabelle 3: *Summen der N_2O- und CO_2-Abflüsse von den Feldversuchen 031 und 034 im Zeitraum von April bis September 1996*

trial plot	treatment	kg N_2O-N*ha^{-1}	t CO_2-C*ha^{-1}
031 A	– compost	5.0	7.9
031 B	+ compost	5.2	9.4
031 C	++ compost	5.7	12.5
034 A	– slurry	2.2	7.3
034 B	+ slurry	2.7	7.8
034 D	slurry also in 1996	4.8	9.2

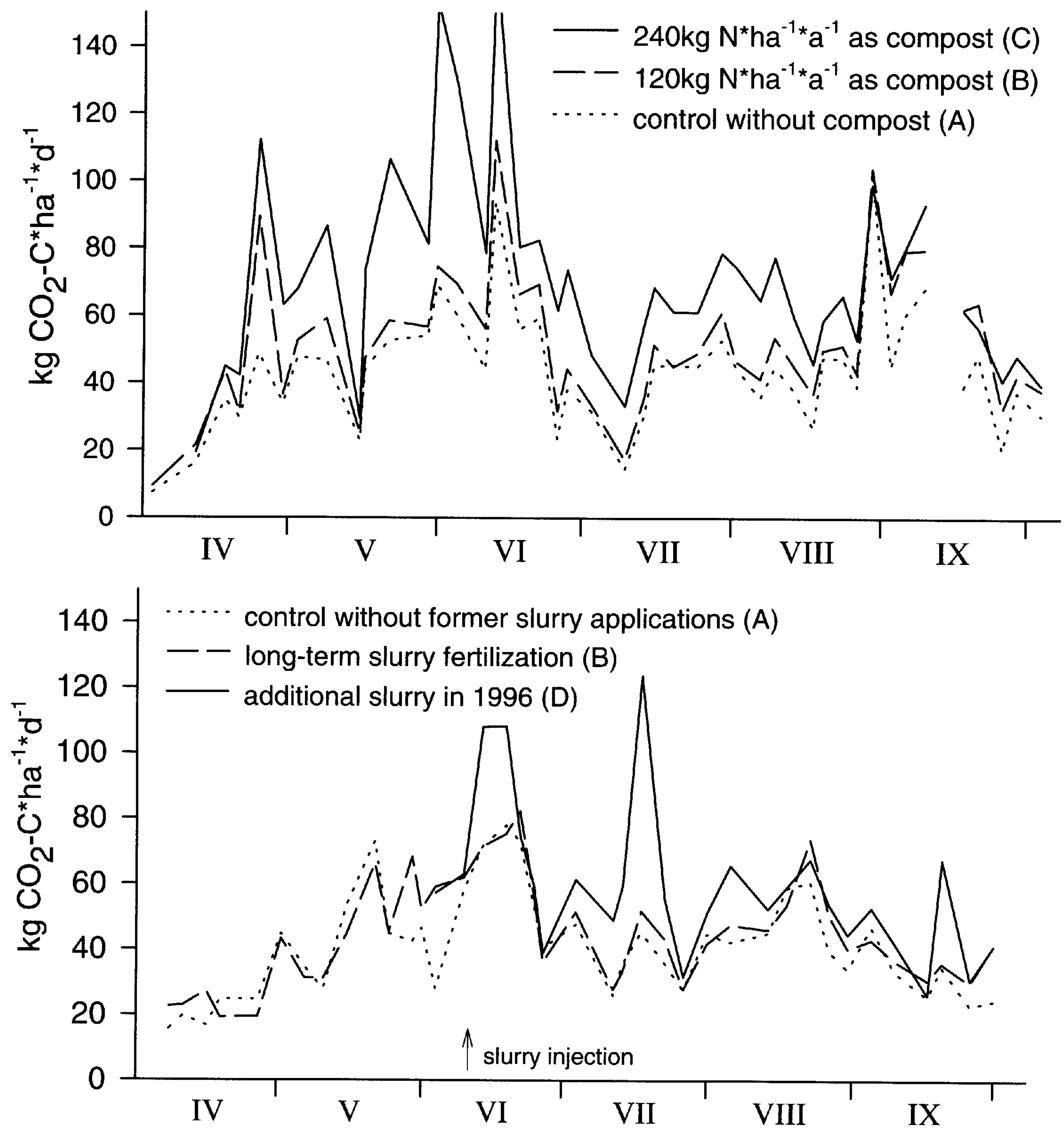


Figure 2: *Annual course of the CO_2-emissions from field experiments 031 (above) and 034*
Abbildung 2: *Jahresgang der CO_2-Abflüsse von den Feldversuchen 031 (oben) und 034*

In the case of field experiment 031 the phase of high N_2O-fluxes started from the middle of April to early June (figure 4) with the sowing of oats combined with fertilizing (30 kg $N*ha^{-1}$ calcium ammonium nitrate). Heavy rainfall in the middle of May resulted in the maximum peak. Rapidly growing plants exhausted the nitrate pool of the soil (figure 3), the next heavy rainfall in the middle of July consequently caused no N_2O-peaks by denitrification. August- and September-peaks appeared after wetting of just cultivated soil. Every kind of tillage creates new surfaces at the soil aggregates, thus opens nutrients for the microbiology and pushes the microbial turnover.

Field experiment 034 was cropped with silage maize in the end of April and simultaneously fertilized (30 kg $N*ha^{-1}$ calcium ammonium nitrate). Rainfalls subsequently created N_2O-peaks (figure 4) till the nitrate pool in the soil was exhausted at the end of June (figure 3). Without any cultivating or fertilizing, N_2O-emissions remained low until October (harvesting). One extreme N_2O-peak appeared at treatment D as a result of slurry injection. It nearly doubled total N_2O-emission from the plot compared to treatment B (table 3).

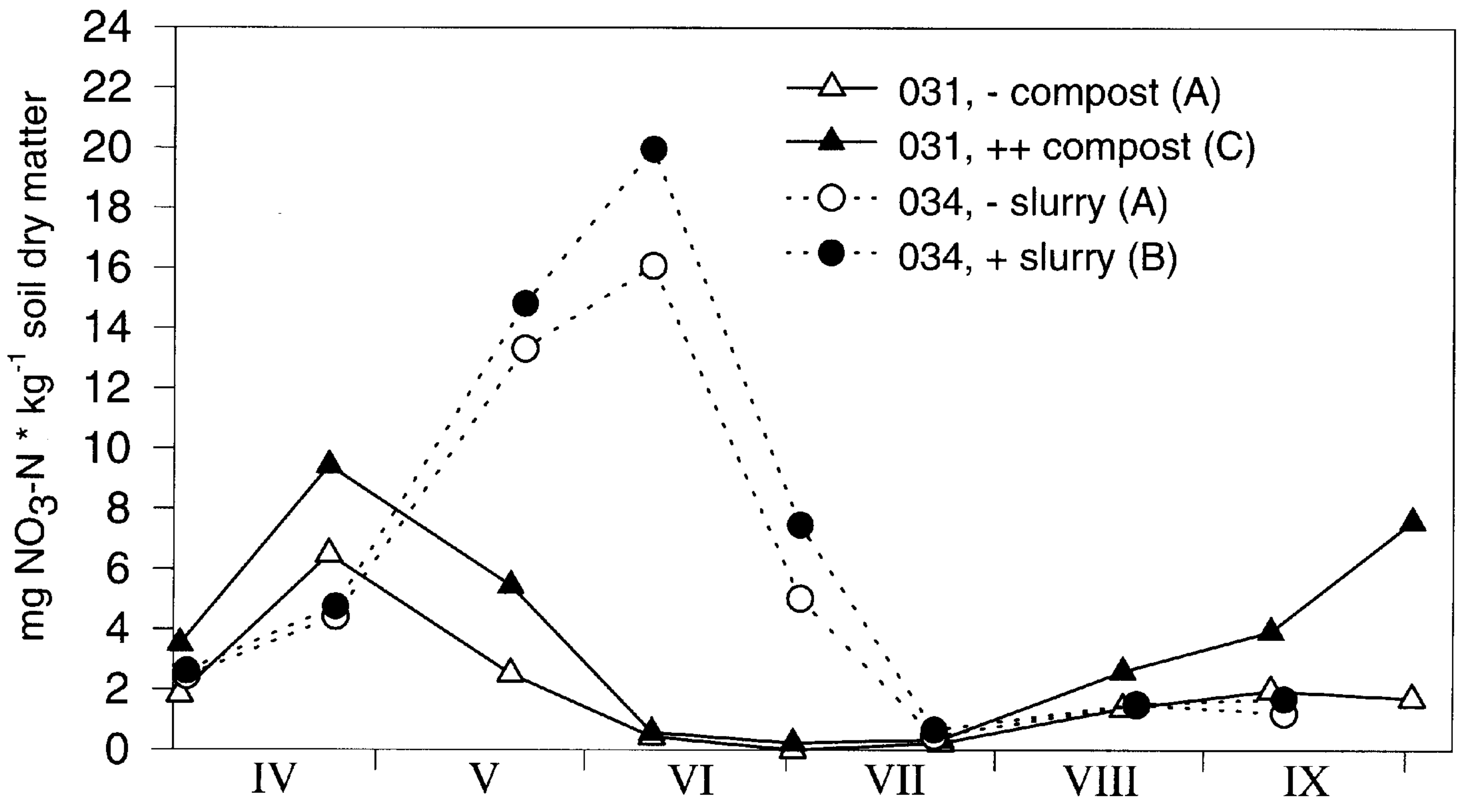


Figure 3: *Course of topsoil nitrate contents at the field experiments 031 and 034 from April to September 1996*

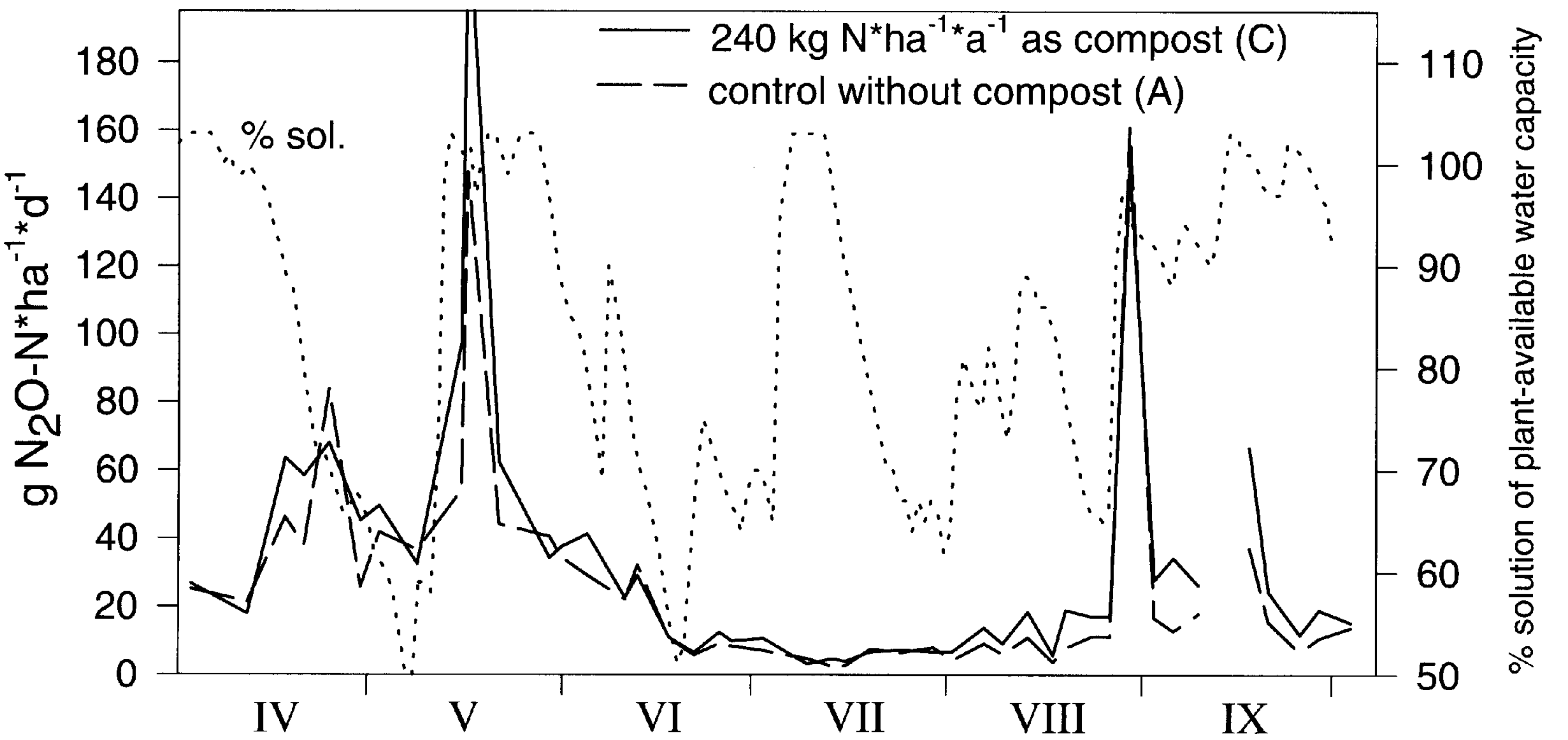
Abbildung 3: *Zeitlicher Verlauf der Nitratgehalte in den Oberböden der Feldversuche 031 und 034 im Zeitraum von April bis September 1996*

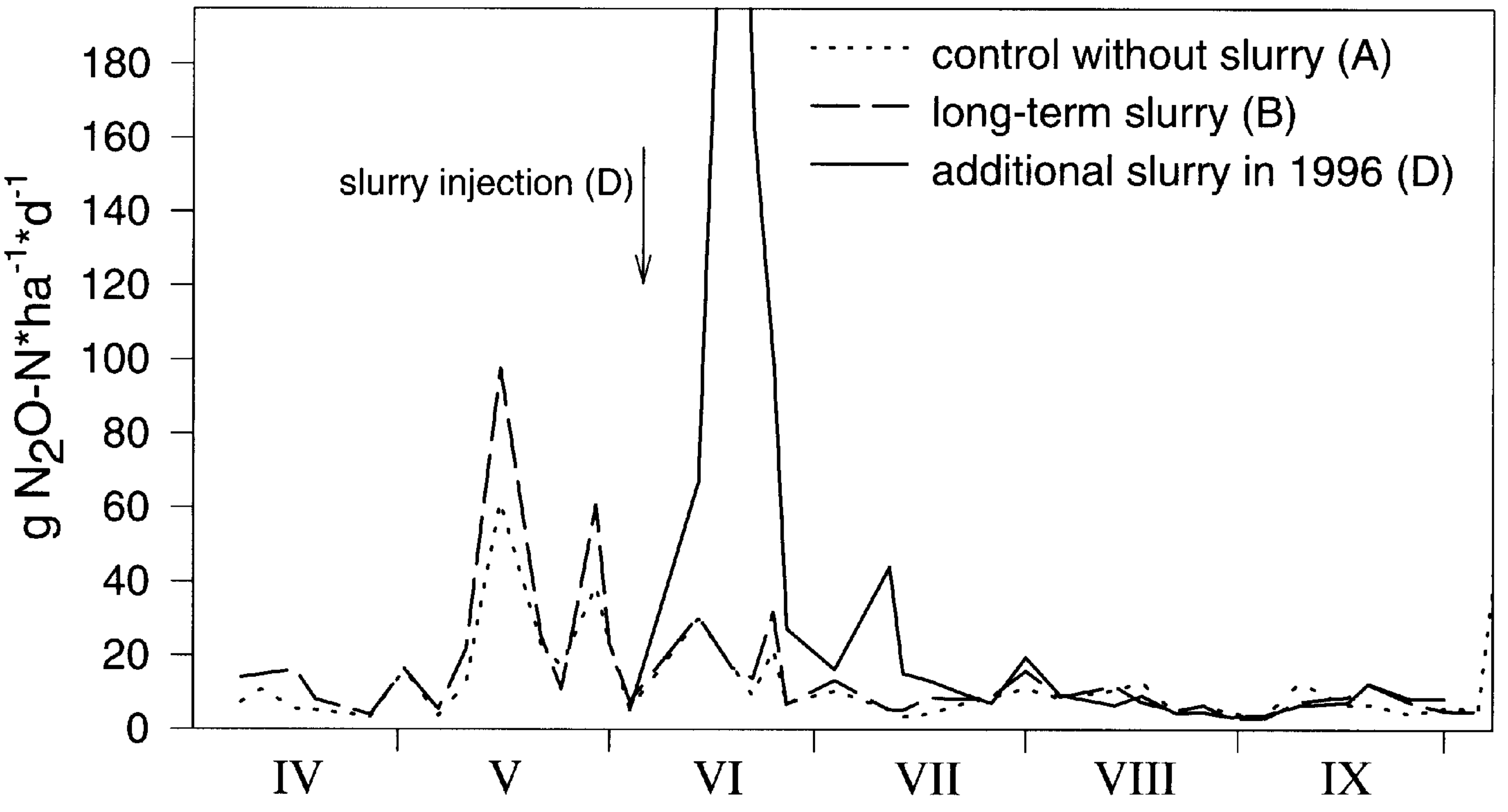
The poor promoting effects of long-term organic fertilizing, perceptible by these field experiments but statistically not ensurable , are probably based on enhanced microbial turnover and the elevated nitrate pool. The effect appears modestly compared with the differences between neighbouring fields of different cultivation (031/oats - 034/silage maize) and with the results of delivery of mineral nitrogen on or into the soil. The temporal pattern of tillage and N-fertilizer application together with climatic conditions evidently determines the order of annual N_2O-losses of an agricultural field. To minimize N_2O-losses, timing and amount of N-fertilizer applications are a more promising starting point than any consideration about C- and N-enrichment of soils.

The effect of reduced mineral fertilization and combined slurry applications on N_2O-emissions was tested at field experiment 053 (figure 4). The first fertilizer application to the winter barley in the middle of March provided high nitrate contents in the soils (lower at treatment C) till the end of April. Saturated soil moisture consequently caused high N_2O-emissions in this period.

Peaks after reduced fertilizing turned out to be smaller. Two later fertilizer applications into the growing cereals produced no lasting increase of the nitrate pool (data not shown). Peaks after heavy rainfall events in May were analogously moderate. Rewetting of the nearly nitrate-free soil in July caused no peak at all. A higher level of N_2O-output was reached after stubble breaking at the end of July, followed by a peak caused from a start fertilization to catch crop cultivation. At treatment D, fertilization was done by slurry incorporation (as much slurry-NH_4-N as mineral N at the other N-fertilized treatments), what resulted in a huge peak, establishing total N_2O-loss in this treatment on a markedly higher level compared to pure mineral fertilization (table 4). Rewetting of dried up soil still rich in nitrate at the end of August was accompanied by similar huge peaks in all treatments.

N_2O-fluxes at field experiment 053 were also measured in 1995. Figure 5 gives a survey of nineteen month of measurement. An outstanding proportion of March/April and August/September to total annual N_2O-loss is expressed. Freezing/thawing cycles in the winter are now reported to be a natural source of high N_2O-emissions (GOODROAD and KEENY, 1984; KAISER et al., 1996).





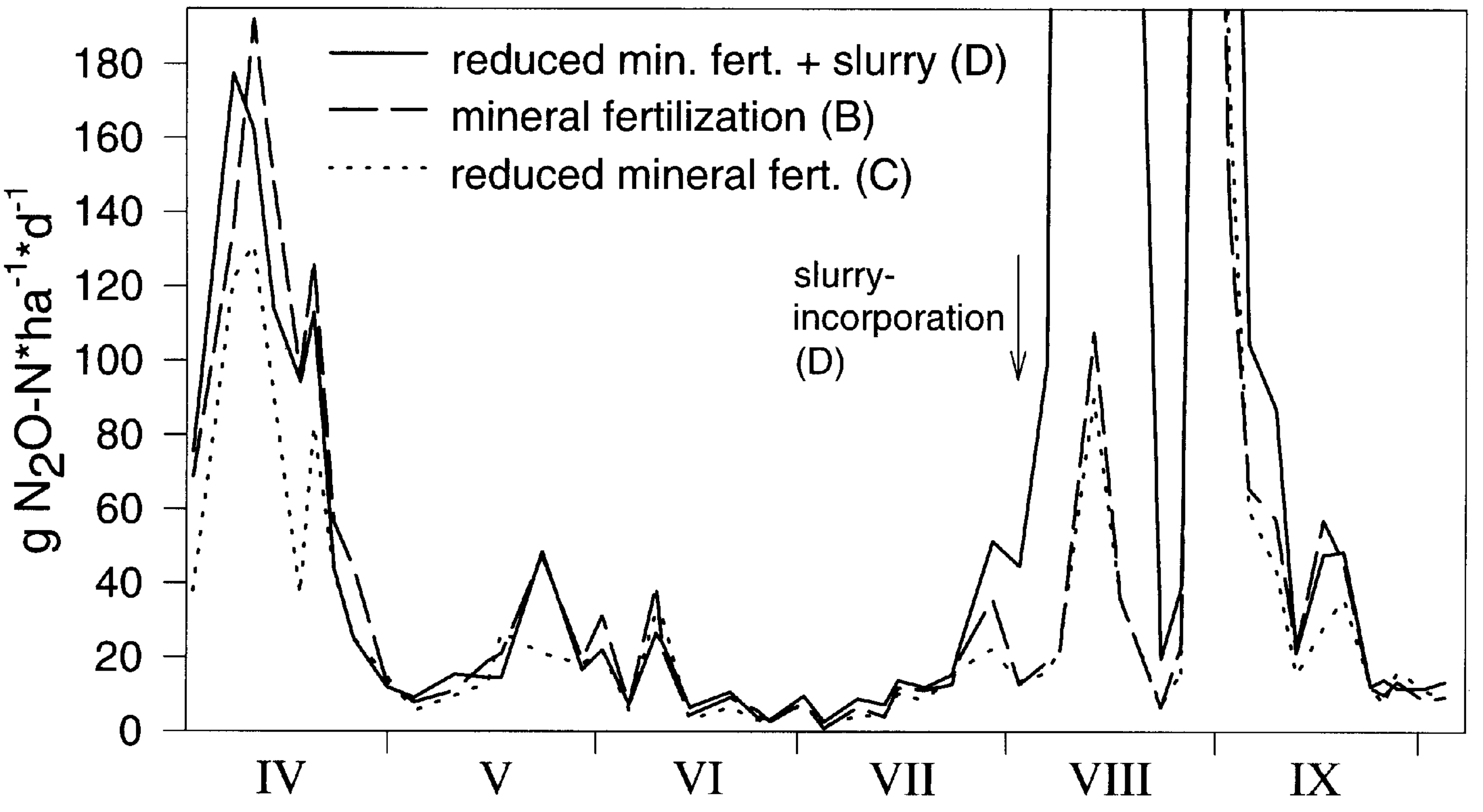


Figure 4: *Course of the N_2O-emissions at the field experiments 031 (above), 034 (middle) and 053 (below) from April to September 1996*

Abbildung 4: *Zeitlicher Verlauf der N_2O-Abflüsse von den Feldversuchen 031 (oben), 034 (Mitte) und 053 (unten) im Zeitraum von April bis September 1996*

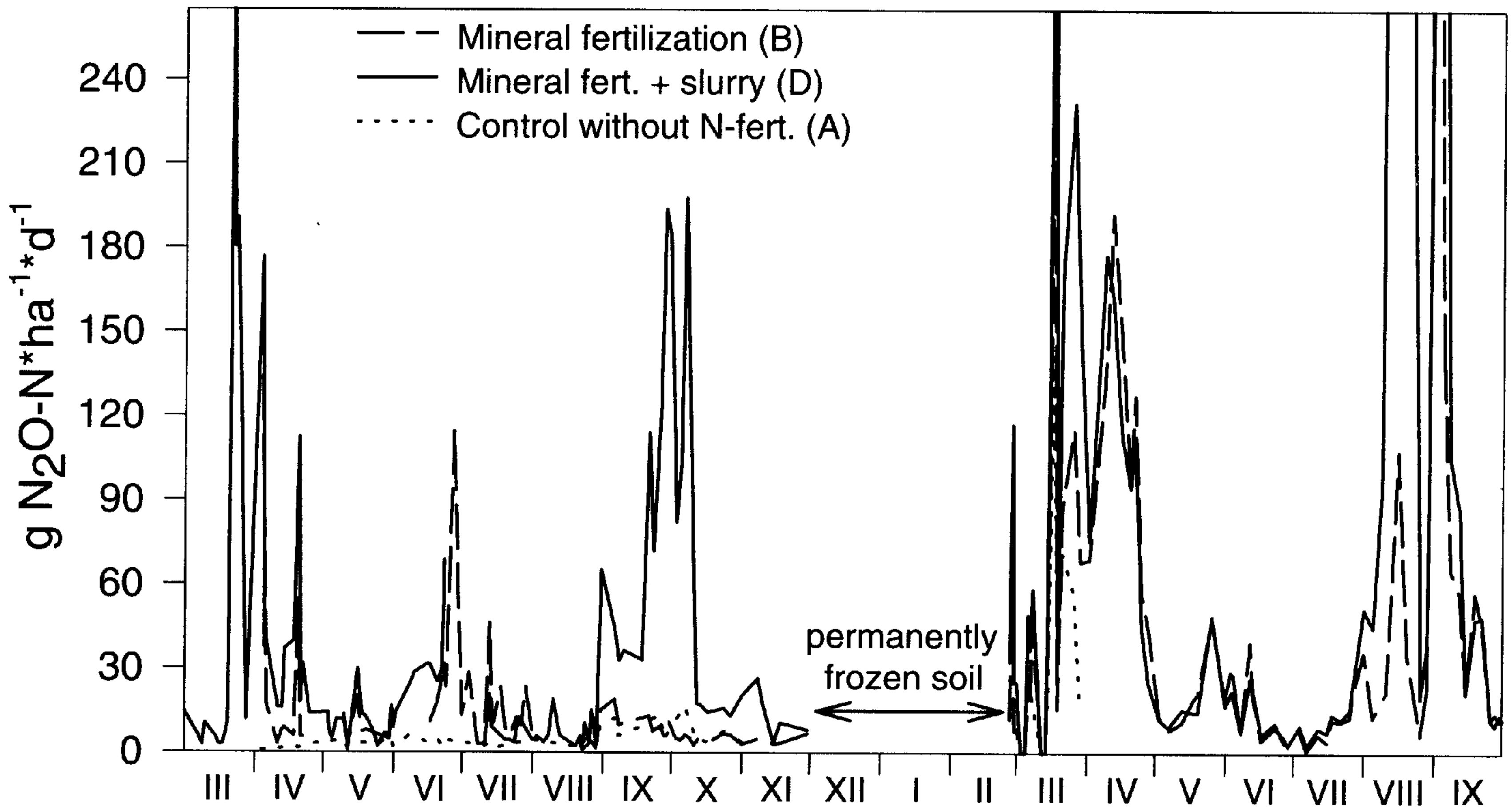


Figure 5: N_2O-emissions at field experiment 053 from March 1995 till September 1996
Abbildung 5: N_2O-Emissionen des Feldversuchs 053 von März bis September 1996

In the presented trial, even the control plot without N-fertilization emitted high amounts of N_2O under such circumstances (March, 1996), whereas its emissions remained very low during the rest of the year. Spring emissions increased rapidly after the first fertilization. From the position of minimizing N_2O-emissions, loading the nitrate pool of the soil for young plants, which are unable to take up nutrients rapidly, has to be designated as a mistake. Furthermore the risk of NO_3-leaching is implied. The huge peak at treatment D in IX/X 1995 was a consequence of slurry incorporation to straw decomposition. In the treatments, that have been measured in both years, N_2O-losses were higher in 1996 than in 1995 because of longer periods of high soil moisture (table 4).

Table 4: Total N_2O-losses at field experiment 053, summed over different spaces of time ($kg\ N_2O\text{-}N*ha^{-1}$)
Tabelle: Gesamte N_2O-Abflüsse vom Feldversuch 053, aufsummiert über verschiedene Zeiträume ($kg\ N_2O\text{-}N*ha^{-1}$)

	Control (A)	min. fert. (B)	reduced min. fert. (C)	reduced min. fert. + slurry (D)
Σ IV '95 - IX '95	0,8	3,0	< 3,0	7,3
Σ IV '96 - IX '96	-	5,5	3,3	13,8
Σ IV '95 - III '96	2,5	5,4	-	11,9

Conclusions

The results of the field experiments permit the following statement: C- and N-enrichment of agricultural soils by organic fertilization cannot be equated with a new order of N_2O-emissions at a site. A promoting effect on N_2O-output is detectable, but its dimension appears to be small compared to the effects of mineral nitrogen fertilization. The extent of N_2O-emissions from our fields was determined by the temporal pattern of tillage and N-fertilizer application connected with climatic conditions. Therefore, a general avoidance of C- and N-enrichment of soils is not necessary from a position of minimizing N_2O-emissions. Regarding the existing promoting effect, an excessive enrichment is not permittable. N-removal by crops is an important tool to protect the environment from forced problems of N_2O-emissions and NO_3-leaching. Discontinuation of agricultural production on fields with enhanced soil fertility has to be avoided.

Discussing risks for N_2O-losses, the beneficial influence of a suitable organic fertilization on soil structure has to be taken into consideration. Well drained and aerated soil diminishes denitrification activity.

To minimize N_2O-emissions from agricultural fields, other starting points are more promising, for example reduction of N-fertilization to young plants. As long as a weather forecast for longer periods is impossible, an optimal pattern of N-fertilizer applications cannot be given. Likewise there is no certainty if several smaller doses of N always result in a lower N_2O-loss than one high application or the reverse. A simple but effective option is the use of ammonium-fertilization combined with nitrification inhibitors (MOSIER et al., 1996, MC TAGGART et al. 1997).

Concerning the difficult question about optimal slurry utilization, high N_2O-emissions after slurry incorporation favour non-spreading, NH_3-volatilization-braking overground deposition for example in the form of bands between growing plants. On the other hand, these bands likewise emit high amounts of N_2O and volatilize still a considerable proportion of their NH_4-content. Injection or incorporation of slurry completely reduce NH_3-volatilization, but entail also heavy N_2O-losses. Considering the importance of the trace gas losses both application techniques have to be recommended. C-reduced slurry (by anaerobic fermentation or separation) lead as well to reduced NH_3-volatilization as to lower N_2O-fluxes irrespective of application technique (DOSCH and GUTSER, 1996). Application of organic fertilizers with a lower content of mineral nitrogen like composts (0-10 % of total N) or manure (10-20 % of total N) imply less problems about both N_2O-emissions and short-term NO_3-leaching.

An option for a strong reduction of N_2O-losses is Organic Farming without any mineral fertilization (KILIAN et al., 1997). Concerning every land utilization system with reduced yields, it is a political question to look at absolute N_2O-emissions or alternatively at N_2O-emissions per unit of produced food. Agricultural production without any N_2O-emission is impossible. N_2O-peaks created by freezing/thawing cycles are completely unavoidable and neither tillage nor fertilization can be reduced at will.

Summary

The effect of C- and N-enrichment of agricultural soils by long-term organic fertilization was tested using three field experiments about different fertilizing strategies with organic components. Beside increased microbial activity and N-mobilisation a promoting effect on N_2O-release was found. The order of this effect appeared modestly compared to the direct, immediate effects of applied mineral nitrogen from organic or mineral fertilization. Total N_2O-losses were determined by the temporal pattern of N-fertilization, cultivation and the climatic conditions. The decisive attribute of organic fertilizers about their liability to increase N_2O-emissions was their content of mineral or rapidly mineralizable nitrogen.

Zusammenfassung

A. KILIAN, R. GUTSER and N. CLAASSEN: *N_2O-emissions following long-term organic fertilization at different levels (N_2O-Emissionen als Langzeitwirkung unterschiedlich intensiver organischer Düngung)*

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Anhand dreier Feldversuche wurde die Wirkung einer C- und N-Anreicherung von Ackerböden durch langjährige organische Düngung auf die N_2O-Emissionen untersucht. Neben erhöhter mikrobieller Aktivität und N-Mobilisierung fand sich auch eine erhöhte N_2O-Abgabe.

Die Größenordnung dieses Effektes erscheint jedoch als zweitrangig im Vergleich zur direkten, sofortigen Wirkung der Zufuhr von mineralischem Stickstoff durch mineralische oder organische Düngung. Das zeitliche Muster von Bodenbearbeitung, N-Düngung und Witterung war entscheidend für die Gesamthöhe der N_2O-Verluste. Wichtigster Parameter für die Beurteilung organischer Dünger hinsichtlich ihrer Fähigkeit, N_2O-Verluste zu erhöhen, ist daher ihr Gehalt an mineralischem oder rasch mineralisierbarem Stickstoff.

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