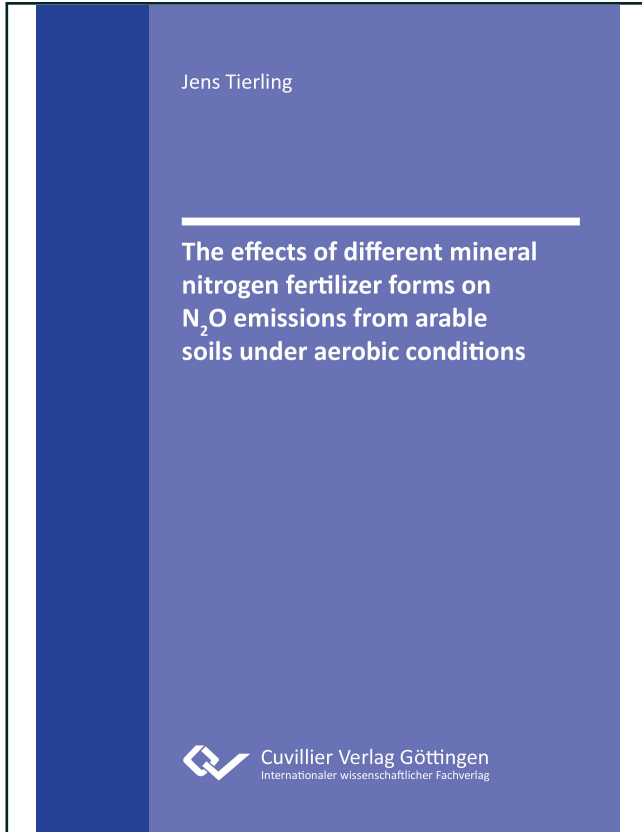




Jens Tierling (Autor)

The effects of different mineral nitrogen fertilizer forms on N₂O emissions from arable soils under aerobic conditions



<https://cuvillier.de/de/shop/publications/7500>

Copyright:

Cuvillier Verlag, Inhaberin Annette Jentsch-Cuvillier, Nonnenstieg 8, 37075 Göttingen, Germany
Telefon: +49 (0)551 54724-0, E-Mail: info@cuvillier.de, Website: <https://cuvillier.de>



1 Abstract

The use of mineral nitrogen (N) fertilizers is an important source of the greenhouse gas nitrous oxide (N₂O). Different N₂O emissions after the application of reduced or oxidized N fertilizer forms can be explained by the predominance of nitrifying or denitrifying environmental conditions. Published studies reported also that urea caused more N₂O emissions than ammonium fertilizers, despite the fact that both N forms are subject to the same process of nitrification.

The mechanisms behind these differences are not well understood. Therefore several incubation experiments were conducted under nitrifying conditions to evaluate the effects of i) two different approaches for measuring N₂O emissions from fertilized soils (flow-through vs. closed chamber), ii) granulated urea and ammonium sulphate on N₂O emissions under aerobic conditions, and iii) soil pH on N₂O emissions after N-fertilization under aerobic conditions. Moreover, N₂O emissions from urea and calcium nitrate (CN) were compared in a field experiment.

It was found that i) N₂O emissions measured with a flow-through chamber system were 3–4 times higher than emissions measured with the static closed chamber method, while obtained N₂O emission dynamics were comparable, ii) nitrite accumulation during nitrification of reduced N fertilizer forms can significantly contribute to N₂O emissions under non-denitrifying conditions, iii) the risk of nitrite accumulation increases with higher soil pH values, iv) the alkalizing hydrolysis of urea promotes nitrite accumulation in soils and thus contributes to N₂O emissions, which explains why urea causes higher N₂O emissions than pure



ammonium forms, especially on soils with low pH values, and v) in an experiment in potato ridges cumulative N_2O emissions from urea were 71 % higher than those from CN, and the main differences between the N forms were explained by nitrification and subsequent nitrite accumulation.

In conclusion, the results indicate that changing from reduced to oxidized N fertilizer forms represents a promising N_2O mitigation opportunity under aerobic conditions.

2 Zusammenfassung

Die Anwendung mineralischer Stickstoff-(N)-dünger ist eine bedeutsame Quelle für das Treibhausgas Distickstoffmonoxid oder Lachgas (N_2O). Unterschiedliche N_2O -Emissionen nach der Anwendung von reduzierten oder oxidierten N-Düngerformen können mit den vorherrschenden Umweltbedingungen (nitrifizierend oder denitrifizierend) erklärt werden. Publierte Studien ergaben aber auch, dass Urea höhere N_2O -Emissionen bedingte als Ammoniumdünger, obwohl diese N-Formen beide der Nitrifikation unterliegen.

Die Gründe für diese Unterschiede sind nicht hinreichend bekannt. Für die vorliegende Arbeit wurden daher mehrere Inkubationsexperimente unter nitrifizierenden Bedingungen durchgeführt, um folgende Fragestellungen zu beantworten: i) Ergeben zwei verschiedene methodische Ansätze zur Messung von N_2O -Emissionen aus gedüngten Böden vergleichbare Ergebnisse (flow-through vs. closed chamber)? ii) Wie wirken sich granuliertes Urea und Ammoniumsulfat auf N_2O -Emissionen unter aeroben Bedingungen aus? iii) Wie wirkt sich der Boden-pH bei N-Düngung auf N_2O -Emissionen unter aeroben Bedingungen aus? In einem zusätzlichen Feldversuch wurden zudem Urea und Kalziumnitrat (KN) miteinander verglichen.

Die Ergebnisse zeigen, dass i) die mit der flow-through-Methode gemessenen N_2O -Emissionen um das 3–4-fache höher waren als mit der closed chamber-Methode, wohingegen die N_2O -Dynamik vergleichbar war, ii) während der Nitrifikation von reduzierten N-Formen die auftretende Nitritakkumulation wesentlich zu den N_2O -Emissionen unter nicht-denitrifizierenden Bedingungen



beitragen kann, iii) die Wahrscheinlichkeit von Nitritakkumulation mit dem pH-Wert zunimmt, iv) die den Boden-pH erhöhende Hydrolyse von Urea Nitritakkumulation und damit N_2O -Emissionen begünstigt, was zu höheren N_2O -Emissionen von Urea im Vergleich zu anderen Ammoniumformen führt, insbesondere auf Böden mit geringen pH-Werten, und v) die N_2O -Emissionen aus einem Kartoffeldamm nach der Düngung von Urea 71 % höher ausfielen als nach der Düngung von KN. Ein Großteil dieses Unterschieds konnte durch Urea-induzierte Nitritakkumulation erklärt werden. Die Ergebnisse deuten darauf hin, dass unter aeroben Bedingungen der Wechsel von einer reduzierten zu einer oxidierten N-Düngerform eine N_2O -Mitigationsoption darstellen kann.



Table of contents

1	Abstract	3
2	Zusammenfassung	5
3	General introduction.....	17
4	Methodological comparison of a “flow-through system“ and the “closed chamber system“ to measure N₂O and CO₂ emissions from soils	26
4.1	Abstract	26
4.2	Introduction.....	27
4.3	Material and methods	29
4.3.1	Flow-through system to measure N ₂ O and CO ₂ emissions from soil (Experiment 1)	29
4.3.2	Closed chamber system to measure N ₂ O and CO ₂ emissions from soil (Experiment 2).....	32
4.3.3	Comparison of the flow-through system and the closed chamber method for measuring N ₂ O and CO ₂ emissions from soil (Experiment 3)	34
4.3.4	Recovery of added gases in the flow-through system (Experiment 4)	36
4.3.5	Recovery of nitrate as denitrification products N ₂ O and N ₂ in the flow-through system (Experiment 5)	36
4.3.6	Gas chromatography	37
4.4	Results	38
4.4.1	Comparison of N ₂ O and CO ₂ emissions measured with the flow- through and the closed chamber system (Exp. 1 and 2).....	38
4.4.2	Influence of the measurement method on N ₂ O and CO ₂ emission rates from soil (Exp. 3)	40
4.4.3	Recovery rates in the flow-through system (Exp. 4 and 5)	42



4.5 Discussion	45
4.5.1 Influence of the measurement system on soil gas emission rates	45
4.5.2 Recovery rates in the flow-through system	47
4.5.3 Influence of the measurement system on soil gas emission dynamics.....	48
4.5.4 Advantages and disadvantages of the two systems	49
4.6 Conclusions	51
5 Emissions of nitrous oxide (N₂O) affected by pH-related nitrite accumulation during nitrification of N fertilizers	52
5.1 Abstract	52
5.2 Introduction	53
5.3 Material & Methods	55
5.3.1 Effect of the N fertilizer form on N ₂ O emissions	55
5.3.2 Effect of nitrite on N ₂ O emissions	57
5.3.3 Effect of irrigation on nitrite concentrations and N ₂ O emissions	58
5.3.4 Effect of soil pH on N ₂ O emissions during nitrification.....	59
5.3.5 Statistical analysis.....	61
5.4 Results	61
5.4.1 Effects of different N fertilizer forms on N ₂ O emissions.....	61
5.4.2 Effect of nitrite on N ₂ O emissions	64
5.4.3 Effect of irrigation on nitrite concentrations and N ₂ O emissions	65
5.4.4 Effect of soil pH on N ₂ O emissions during nitrification.....	67
5.4.5 Relationship between N ₂ O emission rates and nitrite concentrations.....	69
5.5 Discussion	71
5.5.1 Role of nitrite in N ₂ O emissions during fertilizer nitrification.....	71



5.5.2 Effect of soil pH on N ₂ O emissions during fertilizer nitrification	74
5.6 Conclusions.....	77
6 Effects of N fertilizer form on N₂O emissions and nitrite dynamics in a field cropped with potatoes	78
6.1 Abstract	78
6.2 Introduction.....	79
6.3 Material & Methods	80
6.3.1 Experimental setup.....	80
6.3.2 Gas emission measurements	81
6.3.3 Soil moisture and weather	82
6.3.4 Soil analysis.....	82
6.3.5 Statistical analysis.....	83
6.4 Results	83
6.5 Discussion	88
6.6 Conclusions.....	94
7 General discussion	96
8 References.....	102
9 Curriculum Vitae	112
10 Acknowledgements	113

List of figures

Figure 3-1: Atmospheric concentration of N ₂ O between 1800–2014. Data retrieved from EEA (2016).	19
Figure 4-1: Sketch of the flow-through system. A gas mixture of known composition flushes continuously through a sealed PVC soil container and further to a software-controlled 16-port valve, from where the gas stream of each container can be directed to a gas chromatograph.....	31
Figure 4-2: Sketch of the closed chamber system. It consists of a soil container and a chamber made of polypropylen. To measure gas emission rates, the chamber is placed onto the soil container, so that the rubber seal seals the headspace against the ambient air. During enclosure, the headspace air is sampled several times, and the increase in N ₂ O (or CO ₂) concentration is determined.	33
Figure 4-3: Emission rates of N ₂ O (top) and CO ₂ (bottom) for a sandy soil not fertilized (left) and fertilized with 8.2 g N m ⁻² as urea (right) during 21 days of aerobic incubation. Data points are means ± sd (flow-through: n=3; closed chamber: n=6).....	39
Figure 4-4: Emission rates of N ₂ O (top) and CO ₂ (bottom) from a sandy soil after fertilization with 8.2 g N m ⁻² as urea. Treatments on the left were measured with the flow-through (FT) system, treatments on the right with the closed chamber (CC) method. From DOE 11 on (grey area), soil containers from the FT treatment were measured with the CC method (FT-to-CC), and containers from the CC method were measured with the flow-through system (CC-to-FT). Treatments CC and FT were not modified. Data points are means ± sd (n=3).....	42

Figure 4-5: Emission rates of N_2O and N_2 from a loamy silt soil which was incubated under an anaerobic Helium atmosphere for 14 days. The soil's initial nitrate content was 109 mg N kg^{-1} . Data points are means \pm sd ($n=3$). The table on the upper right shows cumulative emissions and the emission factor of the total N losses after 14 days. 44

Figure 4-6: Relative fertilizer-induced emission rates (expressed as relative to the highest emission rate of each treatment) of N_2O (left) and CO_2 (right) from a sandy soil, measured with the closed chamber and the flow-through system. 8.2 g N m^{-2} urea was applied onto the surface as solid fertilizer. Soil columns were then incubated under aerobic conditions for 21 days. Data points are means ($n=3$). Uncertainty estimates were omitted for better clarity (see. Fig. 4-3). 49

Figure 5-1: From top to bottom: Changes of soil ammonium concentration, pH value, soil nitrite concentrations, and nitrous oxide emission rates of a loamy sand soil incubated under aerobic conditions after the application of 8.2 g N m^{-2} either as potassium nitrate (KN), ammonium sulphate (AS), or urea. Plots show mean values \pm sd ($n=6$). 63

Figure 5-2: Effect of nitrite addition on N_2O emission rates from a loamy sand soil incubated under aerobic conditions. The amount of applied nitrite is given above each panel in $\text{mg NO}_2^- \text{-N m}^{-2}$. Values are means \pm sd ($n=3$). 65

Figure 5-3: Relationship between cumulative N_2O emission rates from a loamy sand soil and the concentration of added nitrite solution after six days of aerobic incubation. The solid line indicates an exponential model. Model and residual standard errors are also shown. 65



Figure 5-4: Nitrous oxide emissions from a loamy sand fertilized with potassium nitrate (KN; left) or urea (right) and incubated under aerobic conditions for 18 days. Each plot shows the control treatment (black solid line) in comparison to a treatment that received three events of surface water addition between day 10–12 (grey shaded area). Values are means \pm sd (KN: n=2; Urea: n=3). 66

Figure 5-5: From top to bottom: Soil pH value, soil nitrite concentrations, and N₂O emission rates of two loamy sand soils with differing pH values after surface application of 7.3 g N m⁻² either as ammonium sulphate (AS) or urea. The control treatment (None) received no fertilizer. Both soils were sampled from a long-term liming experiment. N₂O emission rates are smoothed with splines, and individual data points are not depicted to enhance clarity. Points and lines indicate means \pm sd (n=3), the non-fertilized treatments were not replicated. 69

Figure 5-6: Relationship between N₂O emission rates and soil nitrite concentrations for loamy sand soils fertilized with ammonium sulphate (AS) or urea. An ANCOVA model for the sites as categorical effects and soil nitrite concentration as continuous covariate, and a single linear regression model are shown. Confidence and prediction intervals at 95 % confidence level are indicated by dashed and dotted lines, respectively. The first part of the labels refer to the soil's origin (HH = Hanninghof, used in the first three experiments; Alt = Altenhagen, soil from a long-term liming site used in the fourth experiment), the numbers in parentheses indicate the initial bulk pH value. Lastly, the N form fertilized is indicated. The ANCOVA table for a common model for all data is given in the top part of the plot. 70

Figure 6-1: a) Emission rates of N₂O, b) soil moisture in 10 and 20 cm soil depth, and c) daily precipitation on a loamy sand soil