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Emission of N_2O, N_2 and CO_2 from soil fertilized with nitrate: effect of compaction, soil moisture and rewetting

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Abstract

Soil compaction and soil moisture are important factors influencing denitrification and N_2O emission from fertilized soils. We analyzed the combined effects of these factors on the emission of N_2O, N_2 and CO_2 from undisturbed soil cores fertilized with $^{15}NO_3^-$ (150 kg N ha^{-1}) in a laboratory experiment. The soil cores were collected from differently compacted areas in a potato field, i.e. the ridges ($\rho_D = 1.03$ g cm^{-3}), the interrow area ($\rho_D = 1.24$ g cm^{-3}), and the tractor compacted interrow area ($\rho_D = 1.64$ g cm^{-3}), and adjusted to constant soil moisture levels between 40 and 98% water-filled pore space (WFPS).

High N_2O emissions were a result of denitrification and occurred at a WFPS $\geq$70% in all compaction treatments. N_2 production occurred only at the highest soil moisture level ($\geq$90% WFPS) but it was considerably smaller than the N_2O–N emission in most cases. There was no soil moisture effect on CO_2 emission from the differently compacted soils with the exception of the highest soil moisture level (98% WFPS) of the tractor-compacted soil in which soil respiration was significantly reduced. The maximum N_2O emission rates from all treatments occurred after rewetting of dry soil. This rewetting effect increased with the amount of water added. The results show the importance of increased carbon availability and associated respiratory O_2 consumption induced by soil drying and rewetting for the emissions of N_2O.
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Keywords: N_2O; ^{15}N; N_2; Denitrification; Soil respiration; Soil moisture; Bulk density; N fertilizer; Rewetting

1. Introduction

Nitrous oxide (N_2O) is a climate relevant trace gas; its contribution to the anthropogenic greenhouse effect has been estimated to 6% (IPCC, 1996). Additionally, it has been shown that N_2O reacts with oxygen radicals in the stratosphere to form nitrogen monoxide, which is involved in the depletion of stratospheric ozone (Crutzen, 1981). Duxbury et al. (1993) and Isermann (1994) estimated that approximately 75% of the global, anthropogenic N_2O emissions derive from agricultural activities. The primary reason for enhanced N_2O emissions from agricultural soils are increased N inputs by mineral fertilizers, symbiotic N_2 fixation, and animal waste application. Nitrous oxide is produced in soils as an intermediate during nitrification and denitrification (Sahrawat and Keeney, 1986; Granli and Bøckman, 1994; Bremner, 1997). Labeling of mineral N pools with ^{15}N enriched nitrogen and measuring the ^{15}N abundance in the emitted N_2O was shown to be a useful tool to determine the contribution of nitrification and denitrification to N_2O emissions from soils (Stevens et al., 1997). According to a model of Davidson (1991), N_2O is primarily derived from nitrification at low and moderate soil moistures with denitrification becoming more important at soil moisture contents greater than 60% water-filled pore space (WFPS) due to a decreased O_2 supply. Soil moisture, soil respiration, soil aggregation, and soil compaction are key factors determining the aeration of soils and the formation of anoxic microsites (Granli and Bøckman, 1994), and these factors may interact and amplify each other in their effect on N_2O emission.

In experiments on potato fields, we observed a significant influence of soil compaction on N_2O fluxes. Soil compaction by tractor traffic strongly increased N_2O emissions;

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whereas soil loosening decreased N_2O fluxes (Ruser et al., 1998; Flessa et al., 2001). We ascribed these results to a change of the macro-pore volume resulting in a restricted or improved availability of O_2 in the soil. However, how soil compaction and soil moisture interact in their effect on N_2O emission remained uncertain, and the extent to which the measured emission rates were influenced by the reduction of N_2O to N_2 was not clear. Additionally, we measured high N_2O and CO_2 in situ fluxes after rewetting of dry soil in midsummer (Ruser et al., 2001). These rewetting emissions did not fit a simple linear correlation model between the gas flux rates and the percentage of water-filled pore space. To obtain more detailed information on how soil compaction, soil moisture and soil rewetting control the production and emission of N_2O, we conducted an incubation study with undisturbed, ^{15}N-fertilized soil cores taken from differently compacted areas (ridge, interrow, tractor-compacted interrow) in a potato field.

The objectives of this study were (i) to determine the effect of different bulk density and soil moisture, the latter including drying and rewetting of the undisturbed soil cores, on the emission of N_2O, N_2 and CO_2 after addition of nitrate fertilizer, and (ii) to determine the contribution of nitrification and denitrification to the N_2O emission.

2. Materials and methods

2.1. Study site

Soil cores were sampled at the Research Station of the FAM Research Network on Agroecosystems in Scheyern, approximately 40 km north of Munich in southern Germany (N 48° 30.0′, E 11° 20.7′). The experimental farm is located in a hilly landscape derived from tertiary sediments partially covered by loess. The mean annual air temperature is 7.4 °C, and the mean annual precipitation is 833 mm. Soil cores were taken from a potato plot (125 m^2) of a crop-rotation trial in October before harvest. The potatoes (*Solanum tuberosum L.*, var. Calla) were planted on May 9th, fertilized with 150 kg N ha^{-1} (ammonium urea solution) on June 10th, and harvested on October 24th. The soil type at the investigated site was a fine-loamy Dystric Eutrochrept. The topsoil had an initial pH value (10^{-2} M $CaCl_2$) of 6.1 and consisted of 23% clay, 55% silt and 22% sand. The bulk density, C_{org} and N_t contents of the three investigated areas (ridge, uncompacted interrow, tractor-compacted interrow) are shown in Table 1. Since the beginning of the FAM project in 1992, conventional farming with shallow tillage has been applied to reduce soil erosion in this undulating landscape. This practice resulted in an accumulation of organic carbon in the upper centimeters of the soil. Due to the ridge cultivation of potatoes, hilling up of this C enriched top soil, resulted in slightly higher C_{org} and N_t contents in the ridge area than in the uncompacted and the compacted interrow areas (Table 1).

2.2. Soil sampling and experimental design

One week prior to the potato harvest, undisturbed soil cores were sampled using stainless steel cylinders of 5 cm in height and an inner diameter of 8.1 cm. In total 60 soil cores were taken from each of the following areas at a soil depth of 0–5 cm: the ridge soil, the uncompacted interrow soil, and the tractor-compacted interrow soil. At the beginning of the incubation experiment, twelve soil cores from each area were used to determine soil bulk density after drying at 106 °C. Based on the mean bulk density of each sampled area we calculated the total pore space assuming a particle density of 2.65 g cm^{-3}. This information was used to adjust moisture content of the incubated soil cores to a specific water-filled pore space. The remaining 48 soil cores from each area were used for the incubation experiment. Gas fluxes (CO_2, N_2O, N_2) were measured from 16 soil cores per area (four moisture levels with $n=4$) and the remaining 32 cores were used to determine soil nitrate concentration and ^{15}N abundance in soil nitrate. The soil cores were air-dried and then they were put on glass plates and sealed at the bottom. At the end of the incubation experiment, bulk density, organic carbon concentration (C_{org}) and total nitrogen content (N_t) of all soil cores were determined ($n=48$).

During the cropping period prior to the soil core sampling, the in situ-measured soil moisture ranged between 35.1 and 70.3% water-filled pore space (WFPS) in the ridge soil and in the uncompacted interrow soil and between 70.2 and 112.2% WFPS in the tractor-compacted interrow soil. This cropping season included heavy precipitation events as well as two periods of severe

Table 1
Mean bulk density, mean C_{org} contents and mean N_t contents of the investigated soil cores from the three differently compacted areas in a potato field (48 replicates each)

Area	Bulk density		C_{org}		N_t	
	g cm^{-3}	SD	%	SD	%	SD
Ridge soil	1.02^a	(0.05)	1.63^b	(0.16)	0.187^b	(0.014)
Uncompacted interrow soil	1.24^b	(0.08)	1.43^a	(0.09)	0.173^a	(0.007)
Compacted interrow soil	1.65^c	(0.07)	1.48^a	(0.07)	0.174^a	(0.010)

Soil cores were taken from the soil depth 0–5 cm. Standard deviation (SD) is given in brackets. Statistical significant differences are indicated by different letters (Student-Newman-Keuls-Test, $\alpha<0.05$).

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