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N-cycling in tropical ecosystems: Implications of gross nitrification rates on N2O emissions in rainforests of Northeastern Australia

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Abstract

By using the barometric process separation technique (BaPS) for determination of gross nitrification rates in soils for a set of intact soil cores taken on the Atherton Tablelands, Australia, it could be shown, that (i) gross nitrification rates are strongly correlated to soil temperature, and (ii) that simultaneously determined N_2O-emissions depend heavily on nitrification. Measured rates of gross nitrification rates in these tropical rain forest sites were up to 20 fold as compared to nitrification rates in temperate forest soils. Based on our results it can be conducted, that the annual N-turnover rate via nitrification is up to 1500 kg N ha^{-1} in the tropical rainforest soils of northeastern Australia.

Introduction

On the global scale tropical rainforests are one of the main natural sources for atmospheric N_2O (IPCC 2001). As the production and emission of N_2O is tightly linked to the N-turnover via mineralisation, nitrification and denitrification, a detailed understanding of these microbiological processes is essential. In 1999, Ingwersen et al. presented a new approach to determine gross nitrification rates in undisturbed soil cores, the BaPS technique. So far, gross N-turnover rates were solely determined by the ^{15}N-isotope pool dilution technique (Davidson et al. 1990; Barraclough 1995) using a gas chromatograph-mass spectrometer. Besides high costs, and time consuming experiments, homogenous distribution of labelled ^{15}N, change of substrate availability and disturbance of soil structure are some problems associated with the ^{15}N-isotope pool dilution technique (e.g. Davidson et al. 1990, 1992; Hart et al. 1994; Barraclough 1995; Stark and Hart 1997; Neill et al. 1999). In comparison to ^{15}N pool dilution technique, BaPS has a similar sensitivity and accuracy but the advantage, that no labelled material has to be added to the soil (Ingwersen et al. 1999; Breuer et al. 2001).

Materials and Methods

Experimental design and set-up

The BaPS methodology is based on the observation that in a gas tight, isothermal system containing an intact soil core, main changes in air pressure are due to the microbial processes of respiration (pressure neutral, if coefficient of respiration [RC] is equal to 1.0), nitrification (net consumption of O_2 – pressure decrease), denitrification (net CO_2 and N-gas production – pressure increase) and the non-biological process of CO_2 dissolution into soil solution. Hence the total pressure change ($\Delta n/\Delta t$) inside the system is composed of the net changes of O_2 ($\Delta O_2/\Delta t$), CO_2 ($\Delta CO_2/\Delta t$) and the production of gaseous N-compounds via denitrification ($\Delta N_xO_y/\Delta t$) (Fig. 1). Inverse balancing of the total gas balance finally allows to calculate gross nitrification rates (Ingwersen et al. 1999).

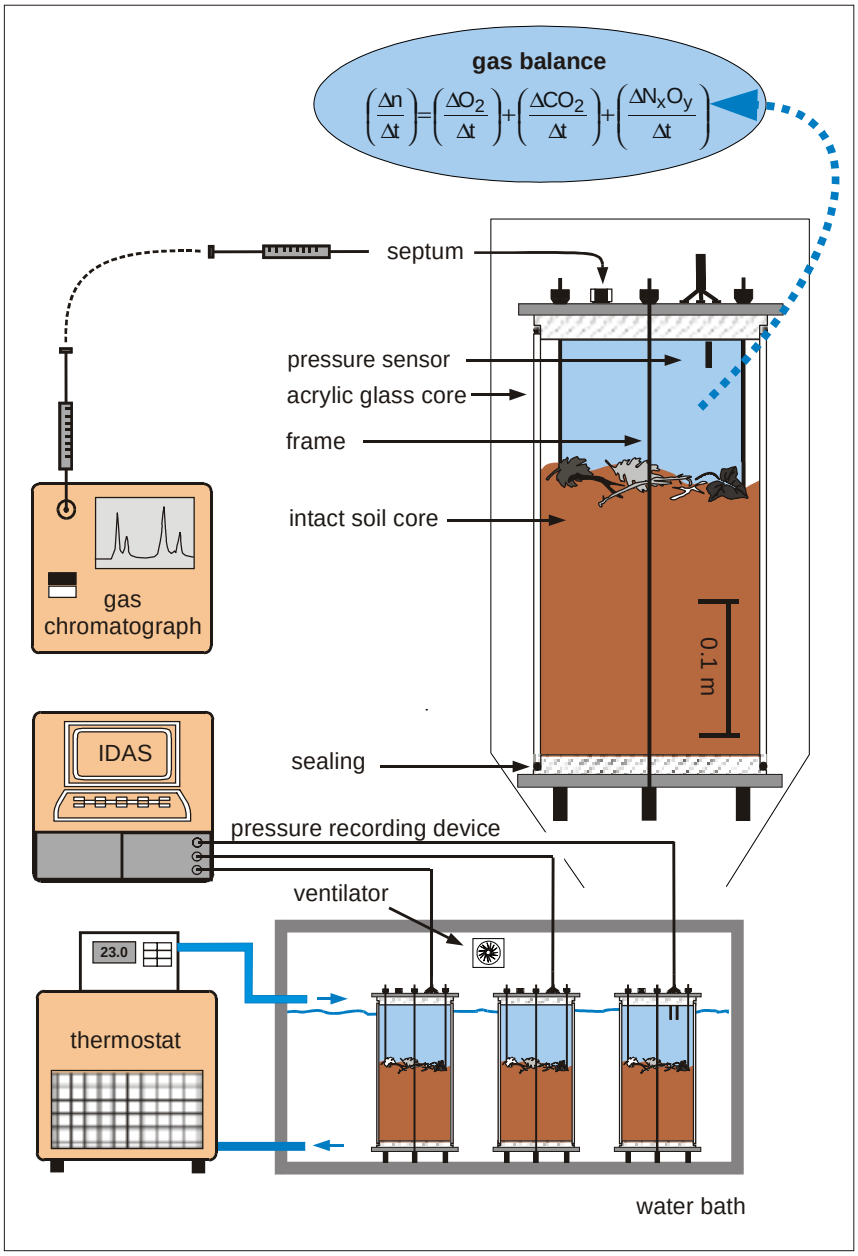

Figure 1: Experimental set-up for the Barometric Process separation technique (BaPS). Determination of gross nitrification rates was performed in three, isothermal incubated, intact soil cores. Gas samples where withdrawn by the use of a syringe and analysed via gas chromatography. Pressure change was recorded using IFU data acquisition system (IDAS). Gas balance was calculated by the determination of O_2, CO_2 and pressure change inside the soil cores.

Soil Sampling and Site Description
At least three replicates of intact soil cores (length 300 mm, diameter 120 mm) were taken close to the sites where N_2O-emission measurements were conducted in 1997 to 1999 (Breuer et al. 2000). Seasonal changes of gross nitrification rates were investigated by sampling soil cores during different hygric seasons (August 1997: dry season; March 1998: wet season; January 1999: transition period from dry to wet season). Soil cores were transported within 4 days after sampling to the microbiological laboratory at IFU. Kauri Creek, Lake Eacham and Massey Creek research sites are located on the Atherton Tablelands, Queensland, Australia (Breuer et al. 2000). The Atherton Tablelands are an elevated plateau with an average altitude of 850 m a.s.l (17 S, 145 E). Soils derived from various parent material: granite (Kauri Creek), metamorphics (Lake Eacham; mainly schist and phyllit) and acid volcanics (Massey Creek; mainly rhyolite). Further details on soil properties and climatic conditions of the sites are given by Breuer et al. (2000).

Results and Discussion

Rates of gross nitrification at all investigated research sites revealed a strong positive dependency on soil temperature (Fig. 2). Furthermore, also N_2O emissions at all sites increased with increasing temperatures, even though the increase was only statistically significant at the Massey Creek site.

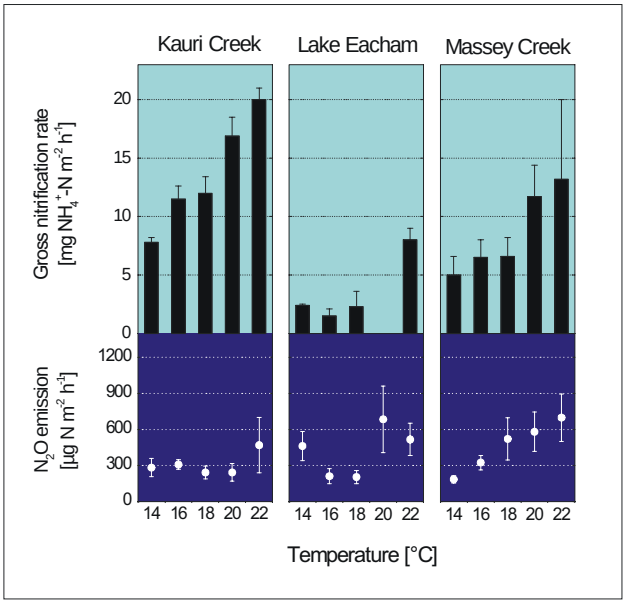

Figure 2: Temperature dependency of N_2O-emission (+/- SE) (lower part) and gross nitrification rates (+/- SE) (upper part) in soil cores taken from three research sites on the Atherton Tablelands, Northeastern Australia.

These observations are in accordance with observations by Ingwersen et al. (1999) who also found that nitrification was positively related to soil temperatures for a temperate German forest soil. Comparable results where found by Davidson et al. (1990, 1992) and Stark and Hart (1997), who showed that gross nitrification rates in warmer summer and autumn times are higher than those in cooler spring and winter season. To expose a general relation between gross nitrification rates and N_2O emission normalized data of all stands were pooled and analysed by regression analysis (highest values for gross nitrification and N_2O emission for each site was set to 1). A significant linear regression with $r = 0.765$ ($p = 0.02$) could be found, supporting the assumption, that N_2O emission are directly dependent on nitrification processes (Fig. 3).

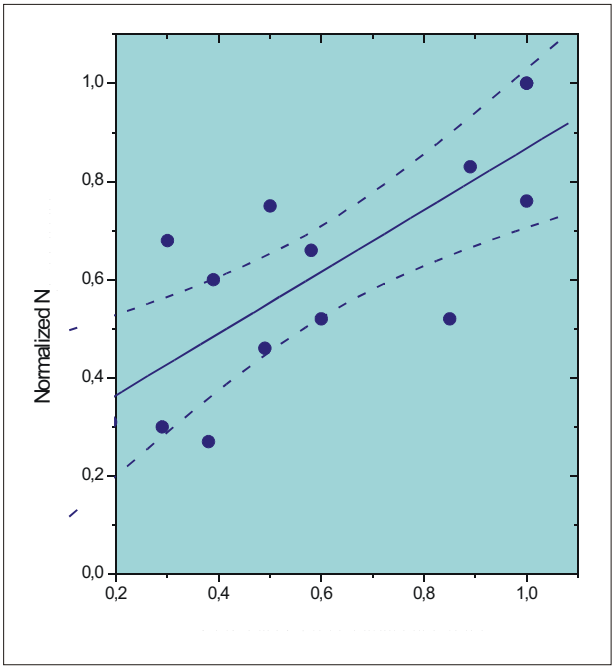

Figure 3: Correlation and regression between normalized gross nitrification and normalized N_2O-emission rates. Normalization was performed to compare data from different sites. Highest value in each case was set to 1.

Overall lowest gross nitrification rates were found during dry season, when low soil moisture presumably limited nitrification. Highest mean gross nitrification rates were found in soil cores from Massey Creek and Kauri Creek site during the transition period from dry to wet season with approx. 27 mg $N\text{-}NH_4^+$ m^{-2} d^{-1}, whereas significantly lower values during this period of time were obtained for the Lake Eacham site with approx. 15 mg $N\text{-}NH_4^+$ m^{-2} d^{-1}. The increase of gross nitrification rates with higher soil moisture conditions is in good agreement with experiments conducted by Davidson et al. (1993), who found drastically increased gross nitrification rates after artificially wetting of soil samples taken from a dry tropical forest site in Mexico. Measured gross nitrification rates at the research sites were up to 20 fold higher than rates of nitrification as determined by others e.g. in temperate forests soils (Breuer et al. 2001). Based on the results of gross nitrification measurements it can be conducted, that approx. 600 kg N ha^{-1} (Lake Eacham site) to 1500 kg N ha^{-1} (Kauri Creek and Massey Creek site) are nitrified annually. One explanation for the differences in gross nitrification rates between the research sites might be the narrower C/N ratio and the higher organic C content of Kauri Creek and Massey Creek compared to Lake Eacham site (Breuer et al. 2001). The general picture of seasonal and spatial variation in gross nitrification rates is also reflected in the seasonal and spatial pattern of N_2O emissions at the different sites (Breuer et al. 2000), i.e. significant higher N_2O emission in all seasons at Kauri Creek and Massey Creek site as compared to lower N_2O emissions at Lake Eacham site. By plotting N_2O emissions versus gross nitrification rates, Breuer et al. (2001) revealed a positive dependence of N_2O emissions with gross nitrification rates (Fig. 4), even though an outlier superposed a significant regression.

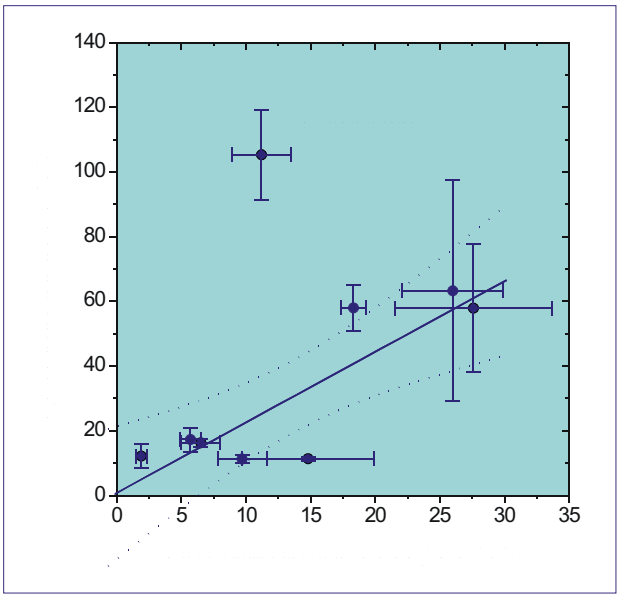

Figure 4: Dependence of gross nitrification rates (in intact soil cores) and N_2O-emissions (field measurements) between 1997-1999 at Kauri Creek, Lake Eacham and Massey Creek. Significant correlation only valid if outlier Kauri Creek 03/98 is excluded (y = 0.9+0.0022 x; r^2 = 0.750; p = 0.005).

A validation and an improvement of these findings should be achieved if gross nitrification rates are measured at the same time when N_2O emission measurements are conducted in the field.

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