Project *brief*

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# Thresholds for air pollutants of forest ecosystems (critical loads) – Effect of denitrification and weathering

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- **Continued high demand for denitrification measurements and weathering studies.**
- **High $N_2O$-emissions for disturbed soil samples.**
- **Negligible $N_2O$-emissions for undisturbed soil samples.**
- **PROFILE-modellings show significantly lower weathering rates than compared literature and substrate texture approach (STA).**

## Background and objective

Critical Loads (CL) were established by the Air Convention to counteract the increased nitrogen (N) and sulfur inputs (S) and their harmful impact on forest ecosystems. It determines limits for the deposition of nitrogen and sulfur which require obligatory measures to decrease the emissions and to protect forests against acidification and eutrophication.

The calculation of CL occurs through empirical studies, simple mass balances according to the steady-state-principle or dynamic models which are shown in the Mapping Manual UN/ECE 2017 and the national report.

The processes of denitrification and weathering are of high importance for the calculation of CL and were evaluated in this project.

Denitrification defines the reduction of nitrate ($NO_3^-$) and nitrite ($NO_2^-$) to nitrous oxide ($N_2O$), nitric oxide (NO) and molecular nitrogen ($N_2$).

Hence, the denitrification leads to a loss of nitrogen in the soil and the release of climate-relevant trace gases.

Both the weathering and the deposition are the reproducing forces regarding nutrients. The rate of weathering requires the buffering capacity and fertility of the soil and it is a criterion to assess the material sustainability in forestry. The weathering process is the highest sink for protons in the soil and it significantly influences the sensitivity of an ecosystem to acid inputs.

Both the modeling of the weathering rate and the amount of nitrogen released by denitrification are subject to large insecurities. This also effects the calculation of CL for acidification and eutrophication.

In this project, we evaluated denitrification and the weathering in terms of the CL calculation basis.

## Methods

The denitrification part is composed of a literature study as well as laboratory tests about $N_2O$ and $N_2$-emissions of forest soils. In the literature review we evaluated 325 studies of $N_2O$ emissions and 80 studies of $N_2$ emissions. The focus lies on the following criteria: ecosystems, climate zones, forest types, elevations, air/incubation temperature, precipitation/soil moisture, clay content, pH-value as well as carbon and nitrogen content in the soil.

Soil samples for the laboratory experiments originate from 15 nationwide distributed forest monitoring stations. 250 cm³ soil sampling rings are used for the analysis of $N_2O$, methane ($CH_4$) and $CO_2$ emissions in the laboratory.

The analyses were performed at different levels of soil moisture (70 and 90% WFPS) and soil temperature (5, 15, and 20°C). At the same time, it is differentiated between disturbed and undisturbed samples.

Additionally, the impact of clay content, N-deposition as well as $NO_3^-$ and $NH_4^+$ content on the emissions was investigated by us.

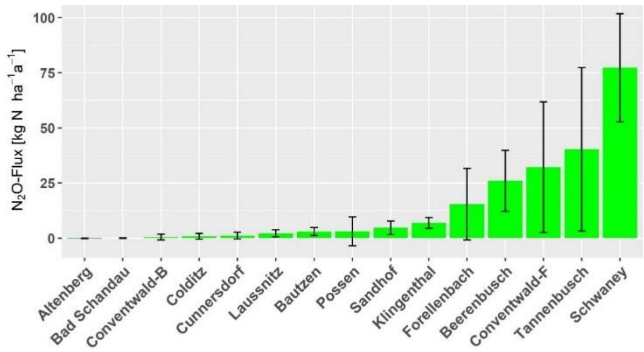


**Figure 1: $N_2O$-Emissions of disturbed soil samples (soil temperature: 20°C, soil moisture: 90 % WFPS)**

For the determination of the weathering rate we used the results from the x-ray fluorescence analysis of the Clay Mineral Consultation from the years 1989 to 2012.
We calculated the reaction of the minerals with the elements of the soil solution with the soil geochemical model PROFILE from Sverdrup and Warfvinge for every horizon separately. Climate data, deposition data, litterfall, element uptake by vegetation, soil parameters and the chemical composition of the soil solution are used for this purpose.

## Results

The comparison of the $N_2O$-literature review shows further need of denitrification measurements. The main share of the reviewed studies was made more than 10 years ago and does not meet the required quality standards for their measurement methods. In frequent cases the duration of the studies has been too short or the measurement intervals have been too large to receive significant results and comparisons.
Comparing the studies according to the classified criteria, the lack of studies for individual variables is noticeable, such as the clay content of > 62,5 % (only 2 studies).
The laboratory analysis about soil degassing only showed significant $N_2O$ emission results for disturbed soil samples with the treatment of 20°C and 90 % WFPS (Figure 1). In this case, the $NO_3$ content in the soil showed a significant positive influence on $N_2O$ emissions. This becomes especially clear at the sites Conventwald in the Black Forest near France as well as Tannenbusch and Schwaney in North Rhine-Westphalia near the agriculturally intensive regions in the Netherlands (Figure 1). The emissions of the disturbed samples can be considered as the maximum potential of emissions. For the usage of undisturbed samples, as they appear naturally, the $N_2O$ emissions are less than 1 kg N $ha^{-1}a^{-1}$.
The $CO_2$ emissions do not show any correlation to the $N_2O$ emissions. They are in the typical range of $CO_2$ emissions of forest soils in temperate climate.
For $CO_2$ and $CH_4$ emissions, no correlation to the parameters clay content, nitrogen deposition, and $NO_3$ and $NH_4$ content can be observed. All sites show a significant $CH_4$ uptake for disturbed and undisturbed samples.
The calculation of the weathering rate shows that there are no significant differences for acid parent material (weathering class 1, n=59) for soils with a rough texture (clay <°18°mass-%), as well as for neutral and alkaline parent material (weathering class 2, n=20).
The calculation of the weathering rate shows that the rate of weathering is increasing with its class (VW). For soils with a coarse texture and acidic (VW=1) or intermediate parent rock (VW=2) the median is way lower than the substrate-texture-approach. The main share of soils investigated are assigned to weathering classes 4 and 1 which are more than 70 %. The results for the weathering rate of fine or very fine texture are not significant as it is based on only 5 investigated forest soils.

For the soils of weathering classes 1 to 4 and 6, K-feldspar, plagioclase and illite provide the largest proportion of minerals (67-83 %) in the weathering rate. The proportion of illite increases with increasing weathering class, while the proportion of K-feldspar decreases. In soils of weathering class 5, pyrobole and in weathering rate 20 calcite and dolomite provide the highest proportion of minerals in the weathering rate.

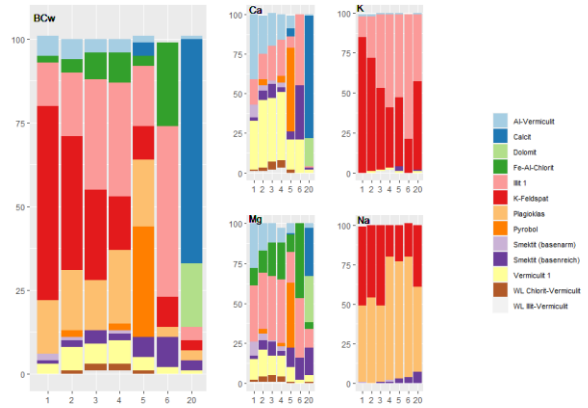


**Figure 2: Results of weathering rate modelling with PROFILE**

## Recommendations

The studies have shown that further investigations and measurements are needed to gain more significant results. For further research we recommend:

- Measurements of $N_2O$ and $N_2$ emissions have to be conducted under unique conditions and requirements as well as specifying the measurement and site conditions.
- Studies on denitrification must be extended to organic soils, as high N losses are to be expected here compared to mineral soils, especially in the degraded state.
- Further calculations with three independent methods for estimating the weathering rate.

## Further Information

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