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SPATIAL AND TEMPORAL VARIABILITY OF EXTRACTABLE INORGANIC NITROGEN IN THE TOPSOIL OF GERMAN PEATLANDS

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SUMMARY

Extractable inorganic nitrogen (N_{min}) is used as indicator for the fertilisation demand, nitrogen leaching risk and nitrous oxide emissions from soils, but a comprehensive data set for peatlands and other organic soils is missing. Here, we present a part of a data set from 61 sites covering all important land use classes and organic soil types in Germany. As expected, the N_{min} content of fen sites is higher than that of bog sites. The groundwater table amplitude and the C:N ratio are promising scaling variables for NO_3-N, while driving factors for NH_4-N seem to be more difficult to identify.

KEYWORDS: peatland hydrology, management, nitrous oxide

INTRODUCTION

Extractable inorganic nitrogen (N_{min}) is frequently used as an indicator for the nitrogen leaching risk (Köhler et *al*., 2006) and for fertilization recommendations in agriculture (e.g. MELFF MV, 2004). Furthermore, it may be an explanatory variable for nitrous oxide emissions from soils (Smith et *al*., 2003). However, little is known about the N_{min} contents and dynamics of different peatlands and other organic soils. When intending to develop regionalisation methods for nitrous oxide emissions or leaching risks for these soils, regionalisation approaches for the N_{min} content might be needed as a first step. Furthermore, finding driving parameters for N_{min} on a finer temporal scale might offer insights into the nitrogen cycling of peatlands. Thus, we are compiling N_{min} data from 61 different sites comprising intensive and extensive grassland and arable land, but also re-wetted, forested and mined peatlands all over Germany. In this paper, we will exemplarily present data of 6 sites from two peatlands with contrasting soil properties.

MATERIALS AND METHODS

The project “Organic soils” aims at the improvement of spatial data sets and emission factors for calculating CO_2, N_2O and CH_4 fluxes from organic soils in Germany (www.organische-boeden.de). Greenhouse gas (GHG) fluxes are measured in eleven study areas which cover a wide range of land use classes and soil types (Table 1). Soils in the study areas do not only comprise fen and bog peat, but also low carbon organic soils (LCOS). These soils are defined as organic soils according to the IPCC guidelines (IPCC, 2006), but not according to the German definition of peat (AG Boden, 2005) and have, roughly, at least 12% soil organic carbon (SOC) in the upper 20 cm. As part of the GHG monitoring programme, soil samples (0-20 cm) were collected fortnightly for two years and analyzed for calcium-chloride extractable ammonium (NH_4^+) and nitrate (NO_3^-) (VDLUFA, 1991). At all sites, the water table depth (WTD), meteorological data, soil water content, soil properties and management data are available.

Table 1: Number of study sites on different land use classes and organic soil types in the N_{min} data set of the project “Organic Soils”. Land use class-soil type combinations shaded in grey are included in this study

	Bog	**Fen**	**LCOS**	**Sum**
Arable land	2	4	5	**11**
Intensive grassland	1	6	4	**11**
Extensive grassland	4	7	10	**21**
Forest	4	5	1	**10**
Re-wetting	3	2	-	**5**
Other land use	3	-	-	**3**
Sum	**17**	**24**	**20**	**61**

Table 1 shows the whole range of sites covered by our study. As an example, two sites from the Ahlenmoor (AM) and four sites from the Dümmer (DM) will be analyzed in detail. These sites include the most important land use class for organic soils in Germany – grassland – on all three soil types. The Ahlenmoor is a bog complex with a deep peat layer, high SOC concentrations and low pH values. Site AM1, an intensive grassland, is fertilized and mown up to five times a year. Site AM2 is used as extensive grassland, which is mown only once a year and receives no fertilization. In contrast, the Dümmer area is dominated by fen peat (DM1 and DM2) and LCOS (DM3 and DM4). DM1 and DM3 are used as arable land, while extensive grassland can be found at DM2 and DM3.

RESULTS AND DISCUSSION

Figure 1 shows the annual average N_{min} content of the six sites. In all cases, the inter-annual variability was low, probably due to the fact that neither year was climatically extreme. At the Dümmer considerably higher N_{min}-contents were measured. While the intensity of the grassland use is highest at AM1, the C:N ratio of 26 at both sites in the Ahlenmoor is much higher than at the Dümmer (12-19) and does not favour N mineralization. Furthermore, the Dümmer area is fed by nutrient-rich groundwater. Comparing the same land use class on different soil types, the average N_{min} contents of the fen and LCOS sites are comparable in the case of extensive grassland (DM2 and DM4), while the lowest N_{min} content was measured at the bog (AM2). In the case of arable land, slightly higher N_{min} contents were found at the LCOS sites.

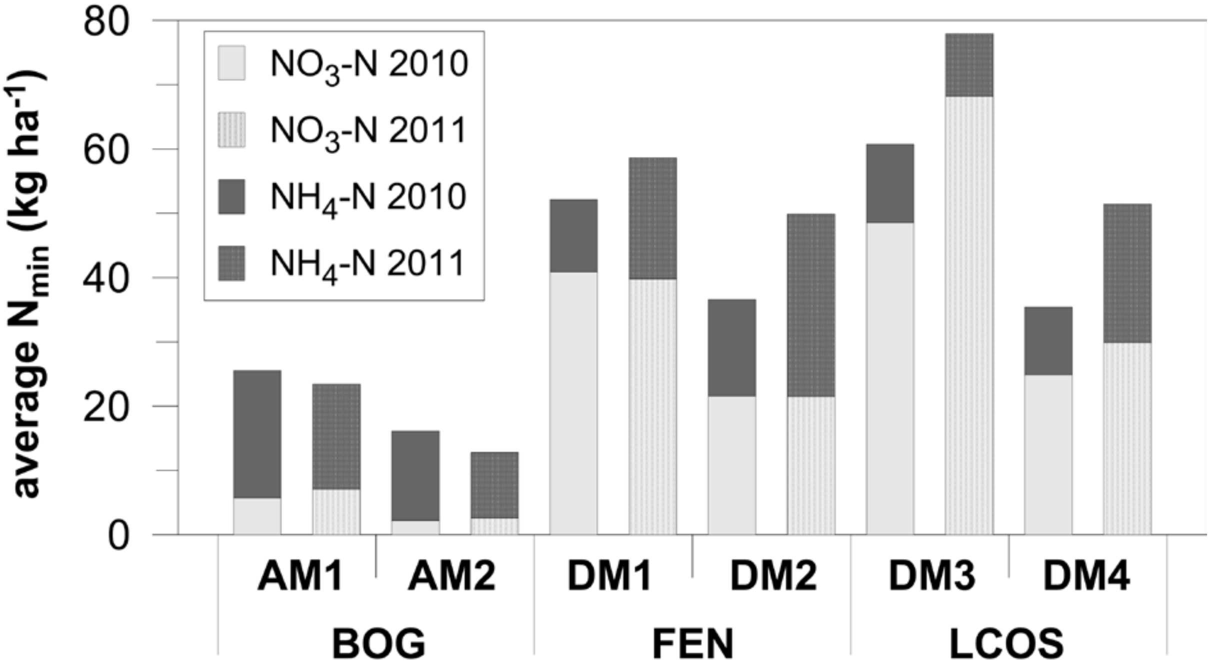

Figure 1: Average N_{min} content of the soils (0-20 cm) at the study areas Ahlenmoor (AM) and Dümmer (DM). LCOS: low carbon organic soil.

With the exception of DM2 in 2011, NO_3-N is the larger fraction of N_{min} at the Dümmer sites, while in the Ahlenmoor, NH_4-N is dominating. The average water table depths at AM2 and DM1 and DM2 are comparable (0.31, 0.30 and 0.28 m), while the WTD at AM1 is even lower (0.63 m). Thus, oxygen supply seems not to be the limiting factor for nitrification in the Ahlenmoor, but rather the pH value. Comparing the fen peat and LCOS, the dryer LCOS sites DM3 and DM4 have a higher fraction of NO_3-N which is available for denitrification. Taking into account that the LCOS sites have an average WFPS of 70% as opposed to 77% at the fen sites, nitrous oxide formation conditions seem to be favourable at these sites (Davidson, 1991). Thus, these soils need to be taken into consideration when discussing both gaseous and aqueous N fluxes from organic soils.

Table 2 shows the average annual N_{min}, NH_4-N and NO_3-N contents of the six sites together with some potential driving factors. Although data is limited, linear regression shows clearly influences on NO_3-N (and, consequently, on N_{min}), but not on NH_4-N. Although there is some correlation between WTD descriptors and NH_4-N, these are not statistically significant. Hopefully, including more sites into the analysis will allow to identify better controlling variables such as the C:N-ratio or the pH value.

Table 2: Pearson's correlation coefficient *r* between NO_3-N, NH_4-N, N_{min} and potential driving factors. Correlation coefficients shaded in grey are significant at p=0.05. WTD – water table depth, q – volumetric water content, T – temperature, SOC – soil organic carbon, N – nitrogen, decomposition – decomposition of the peat (von Post scale). All soil parameters refer to a depth of 0-20 cm

	NO_3-N	**NH_4-N**	**N_{min}**
$WTD_{average}$	0.35	-0.22	0.29
$WTD_{minimum}$	0.24	-0.41	0.13
$WTD_{maximum}$	0.60	-0.35	0.51
$WTD_{amplitude}$	0.64	-0.31	0.58
$\Theta_{average}$	-0.76	0.23	-0.72
$WFPS_{average}$	-0.26	0.10	-0.24
Annual precipitation	-0.77	-0.24	-0.86
Average T_{air}	0.76	0.25	0.85
Average T_{soil}	0.74	-0.04	0.75
Frost days	-0.60	-0.37	-0.72
SOC (%)	-0.77	0.18	-0.74
SOC stock	0.01	0.27	0.08
Nt (%)	-0.71	0.23	-0.69
N Stock	0.57	0.16	0.63
C:N	-0.75	0.06	-0.76
pH	0.57	0.27	0.66
decomposition	0.81	-0.04	0.82

The water table effects on NO_3-N are especially interesting as not the average WTD, but the maximum water table and the amplitude are positively correlated with NO_3-N. While the maximum water table depth shows the depth which is aerated at least once a year, a higher amplitude indicates that a larger part of the soil profile is repeatedly drained and re-wetted. Such changing conditions may enhance mineralization (Martin et *al*., 1997).

Counterintuitively, the N content is negatively correlated with NO_3-N and N_{min}. This can be explained by the LCOS which have low N concentrations but relatively high N stocks due to a higher bulk density. C:N ratio, in contrast, seems to be a more promising scaling parameter, as it is not only correlated to the NO_3-N and N_{min} content, but is also a good indicator for nitrogen cycling. Climatic factors seem to have a large influence as already shown in a study in Lower Saxony (Schweigert et *al*., 2004). However, more study areas need to be included into the regression analysis, as, at the moment, climatic factors clearly distinguish between the comparatively dry and warm Dümmer area and the cooler and wetter Ahlenmoor. The differences between these study areas can be simply explained by the soil types, but bogs also occur in the Dümmer region and *vice versa*. Overall, these limited results give rise to optimism that developing an empirical model for annual N_{min} data will be possible.

As extensification is frequently proposed as a measure to reduce nitrogen leaching and GHG emissions, the comparison of intensive and extensive grassland under otherwise comparable conditions such as AM1 and AM2 is of especially interesting. The average N_{min} content and the fraction of NO_3-N were higher at the intensive site during both years (Fig. 1). In Figure 2, the temporal variability at these sites is shown in detail. The temporal pattern of NO_3-N, NH_4-N and total N_{min} is complex at both sites. For example, it is difficult to distinguish between N peaks caused by hydro-meteorological conditions and by fertilization: In some cases, fertilizer application led to an N_{min} peak at AM1. However, after the second fertilizer application date (July 2010), the unfertilised site AM2 shows a similar N_{min} peak as AM1 which points to mineralization during this dry spell. Similarly, it is unclear what caused the NO_3-N peak at AM2 in December 2010. Furthermore, dry conditions and fertilizer application frequently coincide during summer. This co-correlation between different factors – temperature being another example – is a general problem with such data, but by including more sites into the analysis, we hope to be able to unravel some of the complexity.

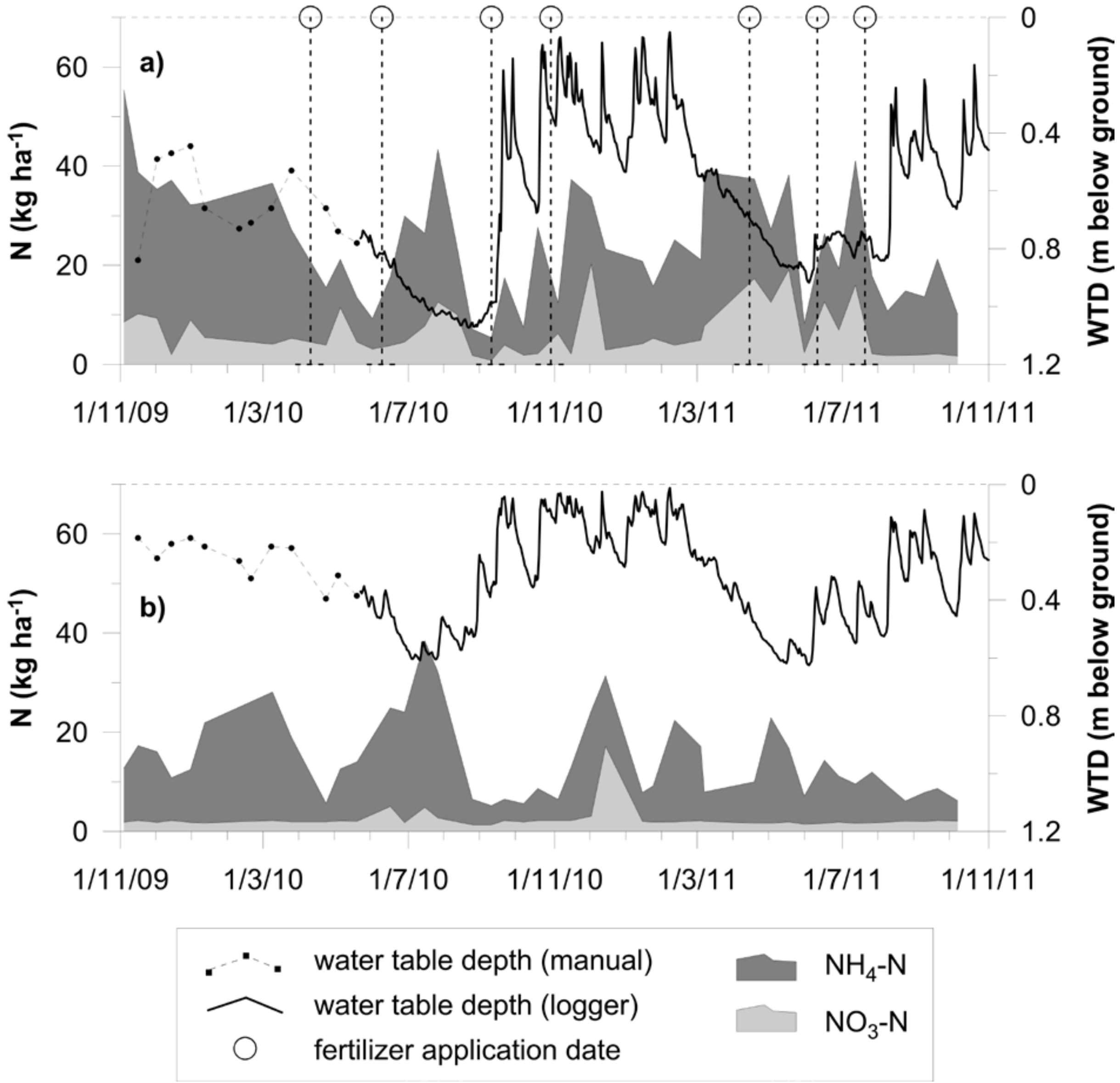

Fig. 2: N_{min} content and water table depth (WTD) at the a) intensive grassland (AM1) and the b) extensive grassland in the Ahlenmoor. Circles represent fertilizer application dates. AM2 is not fertilized.

Overall, in this example the correlation between the two sites is higher than the dependency on any other potential driving variable. Thus, time series analysis will be challenging. One reason for this is the N_{min} data set itself. First, the water content derives from gravimetric sampling and not from continuous logging. Checks (comparisons against neighbouring time series and WTD) were run to ensure that no grievous errors were made and obviously implausible data was removed, but the gravimetric method is still prone to errors due to spatial variability. Second, the bulk density of peat is not constant and thus the use of a single value introduces uncertainty into the calculation of the N_{min} content, especially given the large range of bulk densities of organic soils compared to mineral soils.

CONCLUSIONS AND OUTLOOK

We analyzed N_{min} data from six different sites on different organic soils. Annual averages of NO_3-N are so far easier to explain than those of NH_4-N. Low carbon organic soils (LCOS) show at least as high N_{min} contents as fen peats and should be considered when discussing both nitrous oxide emissions and nitrogen leaching as these soils frequently overlie highly conductive sand. On a finer temporal resolution, analysis is challenging. In future, the full data set of annual values will be analysed with multivariate methods and parameters suitable for regionalization (e.g. the soil type, generalised land use and groundwater level classes) will be derived. This will, together with a map of organic soils and climate data, used for the regionalization of N leaching risk and as an input to N_2O models.

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