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DISSOLVED ORGANIC CARBON CONCENTRATIONS ALONG CARBON AND WATER TABLE GRADIENTS IN RAISED BOGS IN LOWER SAXONY (GERMANY) UNDER GRASSLAND

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SUMMARY

Drainage and land use change have altered the carbon cycling of peatlands. Although losses of dissolved organic carbon (DOC) may be an important part of the carbon balance, there is only sparse data on DOC in raised bogs. Thus, we measured DOC concentrations in the soil- and groundwater at six grassland sites with different hydrological conditions, land use intensities and peat properties. Measured DOC concentrations span a wide range (21-604 mg l^{-1}). Groundwater level and the associated land use intensity as well as the peat degradation status show a clear impact on DOC concentration patterns.

KEY WORDS: carbon losses, agriculture, bog hydrology, water chemistry

INTRODUCTION

Peatlands cover around 5% of Germany's land surface. Over 90% of the German peatlands have been drained for agricultural use. The drainage of these ecosystems causes the emission of large amounts of greenhouse gases (GHG; Höper, 2007) and accounts for 4-5% of the German GHG emissions (UBA, 2010). To determine emission factors for GHG fluxes from German peatlands, the joint research project "Organic Soils" started in 2009 (http://www.organische-boeden.de). Dissolved organic carbon (DOC) losses can contribute, for example, up to 12% to the annual net ecosystem exchange in an ombrotrophic bog (Fraser *et al.*, 2001). Drivers for measured DOC concentrations in soil- and groundwater are hard to identify, because many different drivers (e.g. temperature, ionic strength, water content, substrate composition) and processes such as sorption and desorption on the mineral phase as well as formation and decomposition of DOC interact (Moore, 1998). Around 76% of the raised bogs in Germany are located in Lower Saxony (BGR, 2003). Our aims are to improve the knowledge on DOC cycling in bogs and bog relicts used as grassland and to complete the carbon budget of these sites. We focus on grassland as this is the major land use category for bogs in Lower Saxony (47%, BKG, 2010). Here, we aim to determine the effect of soil organic carbon (SOC), groundwater level, and land use intensity on the DOC concentrations in the soil- and groundwater.

MATERIAL AND METHODS

Study sites

For our study, two peatlands in Lower Saxony, the bog "Ahlenmoor" near Cuxhaven and the bog relict "Großes Moor" near Gifhorn were chosen. Both areas are part of the project "Organic Soils" and thus GHG fluxes are also determined at those sites where we measure DOC and water fluxes. Hence, site names were adopted from teams measuring GHG fluxes.

The Ahlenmoor near Cuxhaven is characterized by a mean annual temperature of 9.1 °C and average annual precipitation of 850 mm (2008-11, Steinau, DWD). The Ahlenmoor still has a peat layer of up to 6 m (Schneekloth, 1971). Our sites within the Ahlenmoor were chosen to study differences in land use intensities, which are associated with strong differences in the groundwater level (Table 1). The intensive grassland site AM1 is dominated by *Lolium perenne* (L.) and is mown up to 5 times a year. The extensive grassland site AM2 is dominated by *Juncus effusus* (L.) and various grasses and is mown only once a year. The vegetation of the natural site AM6 mainly consists of *Sphagnum spp.*, but *Eriophorum angustifolium* (HONCK.) and *Drosera rotundifolia* (L.) are also present.

The Großes Moor near Gifhorn has a mean annual temperature of 9.4°C and a mean annual precipitation of 663 mm (2008-11, Wittingen-Vorhop, DWD). Intensive peat cutting and, partially, deep ploughing in the past have lead to a high variability of SOC and peat layer thickness. At our study sites, a shallow amorphous peat layer of around 30 cm overlies coarse sand. At present, the sites are used as extensive sheep pastures. The sites in the Großes Moor were chosen to determine the effects of small scale variability of SOC concentrations and water table depth (Table 1). The study sites are characterized by low SOC concentrations and medium water table depth (GM2), low SOC concentrations and high water table (GM3) and high SOC concentrations and a high water table (GM6). The vegetation mainly consists of *Juncus effusus* (L.) and various grasses, whereas *Sphagnum spp.* is only present at GM6. Site names and their classification depend on the GHG measurement setup of Leiber-Sauheitl (Abstract No. 201/219). Vegetation, land use intensity and groundwater level of GM2 and AM2 are comparable, but the soil organic carbon (SOC) concentrations and the peat layer thickness are much higher at AM2 (Table 1).

Soil- and groundwater sampling and analysis

At each study site, nine suction plates (borosilicate glass, 8 cm in diameter) (EcoTech GmbH, Bonn, Germany) were installed in three depths (15cm, 30cm and 60 cm) with three replicates each. For minimizing the disturbance of the natural water flow paths, the suction applied to the plates was chosen according to the tension at the sampling date. Soil tension was measured with tensiometers (UMS GmbH, Munich, Germany) at the same depths. The groundwater table is recorded with a Mini-Diver (Schlumberger Water Services, Delft, Netherlands). Sampling started in May 2011 in the Großes Moor and June 2011 in the Ahlenmoor. It is conducted fortnightly and will continue until May/June 2013. Here, we report on results from May to December 2011. Samples were filtered with a 0.45µm PET membrane filter (Supor450, PALL, Port Washington USA) and stored at 4°C until DOC analysis within the following week using a DimaTOC 2000 (DimaTec, Essen, Germany).

Table 1: Carbon (C) and nitrogen (N) content, C:N ratio, bulk density (BD) within 0-30 cm and 30-100 cm; peat layer thickness, mean water table depth below surface in the year 2011 and land use intensities (int. GL = intensive grassland, ext. GL = extensive grassland) of the study sites in the Ahlenmoor (AM) and Großes Moor (GM); n.d.: values not yet determined.

Parameter	Depth (cm)	AM 1	AM 2	AM 6	GM 2	GM 3	GM 6
C (%)	0-30	44.9	43.5	n.d.	11.3	9.3	47.9
	30-100	46.8	43.4	n.d.	0.4	0.6	3.3
N (%)	0-30	1.5	n.d.	n.d.	0.4	0.4	1.7
	30-100	0.9	0.7	n.d.	0.02	0.02	0.13
C:N	0-30	30	n.d.	n.d.	27	24	28
	30-100	51	60	n.d.	21	24	24
BD (g cm^{-3})	0-30	0.18	0.17	n.d.	1.06	0.97	0.29
	30-100	0.13	0.08	n.d.	1.65	1.91	1.71
Peat layer thickness (m)		3.30	3.40	4.80	0.30	0.32	0.30
Mean water table (cm)		54	31	≈ 0	34	17	18
Land use		int. GL	ext. GL	none	ext. GL	ext. GL	ext. GL

RESULTS

DOC concentrations – differences between the study sites

Fig. 1 shows an overview of the DOC concentrations. They cover a wide range of 21-604 mg l^{-1} in the Großes Moor and 54-539 mg l^{-1} in the Ahlenmoor.

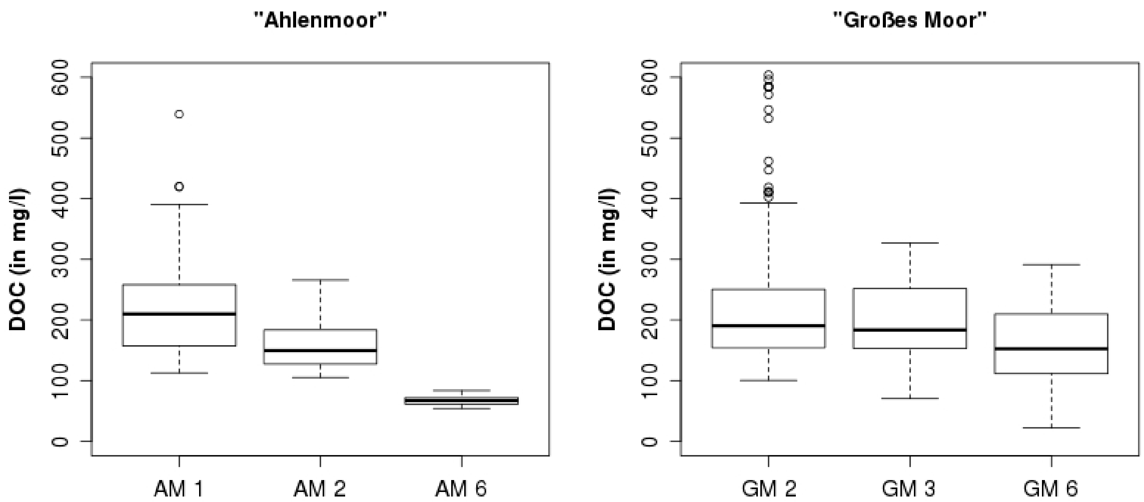

Figure 1: DOC concentrations per site (all depths and replicates) at the Ahlenmoor (AM1: n=110; AM2: n=108, AM6: n=101) and the Großes Moor (GM2: n=130; GM3: n=151, GM6: n=148) for the sampling period June-December 2011 Central crossbars represent the median, the boxes the 75th and 25th percentile and the circles extreme values.

In the Ahlenmoor DOC concentrations reflect land use intensities. The lowering of the water table with increasing land use intensity led to increased DOC concentrations. At the intensive grassland (AM1) where the mean water table is lowest the highest DOC concentrations were measured. In contrast, at the natural bog – where the groundwater table was near the surface during the whole sampling period – the lowest DOC concentrations were determined (Fig. 1).

Study sites at the Großes Moor show in general only minor differences. If a heavily disturbed peat relict layer is present, differences of the average groundwater level will lead only to minor differences in the DOC concentrations as shown by the comparison of GM2 and GM3. The high number of outliers at GM 2 is caused by a suction plate in 30 cm depth. The reasons for these values are still unknown. Surprisingly, the lowest DOC concentrations were measured at the site (GM6) with the highest SOC concentrations and stocks (Tab. 1). Even in the coarse sand (60 cm), the DOC concentrations in the Großes Moor were higher than in the natural bog (AM6). Concentrations measured at GM2 and GM3 under extensive grassland are in the same range as at the much dryer intensive grassland site (AM1) in the Ahlenmoor.

DOC concentration - depth profiles at the Ahlenmoor

DOC depth profiles were different at the sites in the Ahlenmoor (Fig. 2). Changes in land use intensity combined with a decreasing mean water table changed DOC concentration patterns with depth as well. DOC concentrations in all depths were highest at the intensive grassland site (AM1), whereas at the natural site (AM6) DOC concentrations were lowest in all depths. At the natural site, where all suctions plates were in the saturated zone during the whole sampling period, no trend with depth can be found. DOC concentration and their variability are quite similar. In contrast, depth profiles at AM1 and AM2 show a clear pattern. The lowest concentrations at AM1 and AM 2 were measured at 60 cm depth which was saturated at most sampling dates. With increasing distance to the mean groundwater table, both the DOC concentrations and their variability increase. Hence, the highest DOC concentrations and highest variability occur in 15 cm depth at AM1.

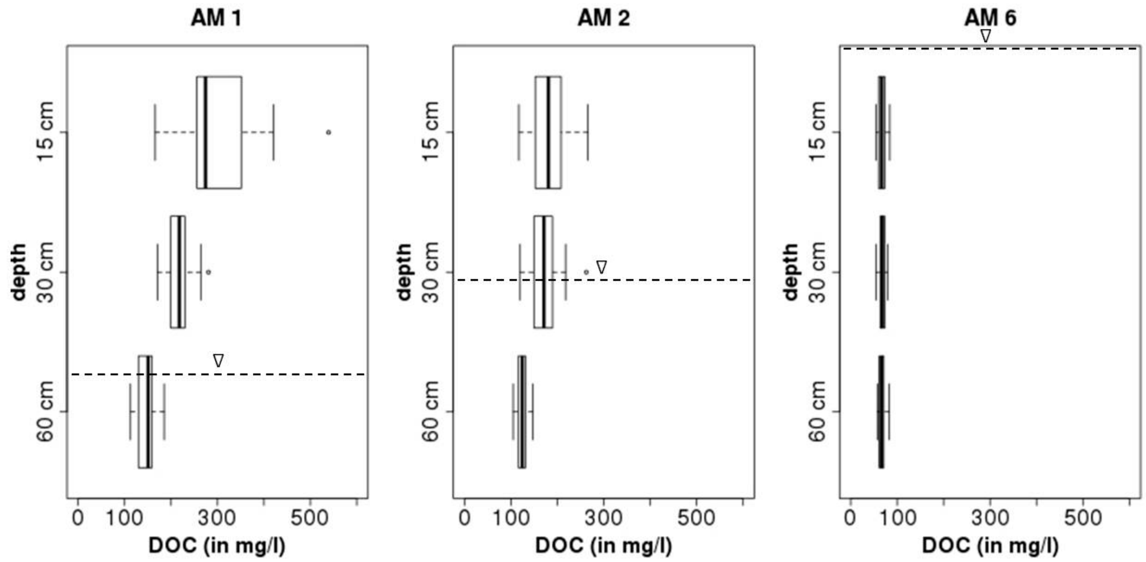

Figure 2: DOC concentrations per depth (3 replicates) of the sites in the Ahlenmoor (AM1: n=37, 35 and 38, AM2: n=36, 35 and 37, AM6: n=34, 34 and 33). Central crossbars represent the median, the boxes the 75th and 25th percentile and the circles extreme values. The dashed line shows the mean water table during the sampling period June-December 2011.

DISCUSSION AND CONCLUSIONS

DOC concentrations in temperate and boreal fens and bogs as reviewed by Schwalm and Zeitz (2011) were commonly between 20-100 mg l^{-1}, seldom exceeded 200 mg l^{-1} and were thus much lower than our values. DOC concentrations over 600 mg l^{-1} were also reported by

Glatzel (2003) for a block-cut peatland in Québec, who noted that these were some of the highest DOC concentration ever measured in peatlands.

At the Ahlenmoor, the effect of the groundwater table and the associated land use intensity is very clear. This disturbance increases both the DOC concentrations and their variability in the order intensive grassland > extensive grassland > natural bog. Lowering the water table combined with an increased aeration leads to an enhanced mineralization of the upper peat layer and an enhanced DOC production, while DOC losses (consumption or leaching) did not increase to the same degree. Generally, the impact of drainage is measurable up to at least a depth of 60 cm, where DOC concentrations from the intensive grassland were twice as high as under natural conditions even though this part of the profile remained saturated at most sampling dates. Within one single bog land use intensity and associated water table depth are suitable indicators for DOC concentration patterns. This does, however, not apply to bogs with different development, land use history and therefore peat quantity and quality (e.g. GM2/GM3 vs. AM1).

In contrast, small scale variability of SOC and groundwater level as investigated in the Großes Moor, lead so far only to minor differences in the DOC concentrations. Whereas Kalbitz and Geyer (2002) could show that fens with higher SOC contents have higher DOC concentrations, in the study area Großes Moor, the site with the highest SOC content showed the lowest DOC concentrations. This may be due to the fact that at GM2 and GM3 the original peat structure is destroyed not only by degradation processes, but also by deep ploughing. The same reason could explain higher DOC concentration at GM2 compared to AM2, an otherwise comparable site with higher SOC concentrations. The high DOC concentrations measured in the Großes Moor indicate that the degradation process of the amorphous peat layer is not yet finished. However, it remains to be subject of further investigations which processes lead to the release of such huge amount of DOC. In this study area, possible differences due to different water table depths seem to be overridden by the effects of the highly disturbed peat layers. Furthermore, the results already show that organic soils which cannot be classified as peat still have to be considered when identifying areas with potentially high DOC losses.

As a next step, we will include the effects of pH, ionic strength, water content and flow direction on the DOC concentrations and model the soil water fluxes to calculate DOC losses.

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