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The effect of rewetting drained fens with nitrate-polluted water on dissolved organic carbon and phosphorus release

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ABSTRACT

Restoration of peatlands has been found to mitigate eutrophication due to the high and long-term capacity of peatlands to reduce nitrate (NO_3^-) fluxes. However, altered peat composition and/or contamination of the water used for rewetting can promote the release of dissolved substances, resulting in serious biogeochemical constraints on achievement of restoration goals. Elevated dissolved organic carbon (DOC) release can alter the turnover of organic matter in rewetted fens and adjacent aquatic ecosystems. Increasing availability of soluble reactive phosphate (SRP) can significantly elevate primary productivity, stimulating eutrophication and associated problems. We conducted a laboratory study to evaluate the effect of rewetting long-term drained fens with NO_3^- polluted water on DOC and SRP release. The effects of peat decomposition, NO_3^- loading rate and temperature were considered. Different peat substrates from one degraded, drained fen in northeast Germany were incubated under stagnant, inundated conditions. Two levels of peat decomposition (high and moderate), two NO_3^- loads (40 kg N ha^{-1} y^{-1} and 140 kg N ha^{-1} y^{-1}) and two incubation temperatures (20 °C and 5 °C) were studied. Peat types were characterized by means of a sequential chemical extraction procedure to estimate the size of the DOC and SRP mobile pools. It was shown that peat decomposition controlled SRP and DOC release due to significant differences in mobile C and P pools. Low temperature slowed the rates of microbiologically mediated processes involved in SRP and DOC turnover. To some extent, the effect of temperature modified the effect of peat decomposition. Due to complete NO_3^- removal at the peat surface layer (<1 cm), NO_3^- load did not influence SRP and DOC production in the peat, but did impact their release at the peat-water interface. Our study found that when highly decomposed peat is incubated at 20 °C under low nitrate conditions, a substantial amount of DOC is released. Similarly, SRP release only occurred under those same conditions. Results from our experiments provide insight into the potential release of DOC and SRP that could occur in rewetted fens.

1. Introduction

Anthropogenic activities have approximately doubled the input of available nitrogen (N) to the Earth's land surface (Galloway et al., 2008; Gruber and Galloway, 2008; Schlesinger, 2009), with the rate of change increasing dramatically in recent decades. Increased nitrogen fluxes have been described to cause severe eutrophication problems in freshwater and marine ecosystems throughout the globe (Howarth et al., 1996; Rabalais et al., 1996; Boesch, 2002; Cabezas et al., 2009), and N has been proposed as the limiting factor for the eutrophication of marine ecosystems (Howarth and Marino, 2006). Although the importance of phosphorus (P) and N as ultimate cause for eutrophication of freshwater lotic and lentic ecosystems is a subject of debate (Schindler et al., 2008; Sterner, 2008), several current and pending water protection policies in Europe, the USA and Canada are designed to reduce N fluxes in order to reduce eutrophication. Because some aquatic systems, such as peatlands, have a high and extended capacity to reduce nitrate (NO_3^-) fluxes, wetland restoration should be enhanced (Lamers et al., 2002a; Verhoeven et al., 2006). However, altered peat composition and/or pollution of peatland inflow water can promote the release of dissolved substances when degraded peatlands are inundated. Inundation reduces oxygen availability and lowers the redox state, and so promotes the reduction of oxidized forms. This characteristic might impose serious biogeochemical constraints on achieving restoration goals (Lucassen et al., 2004; Lamers et al., 2006; Zak and Gelbrecht, 2007; Smolders et al., 2010). At moraine landscapes in northern Europe, inundation of drained fens (minerotrophic peatlands) with nitrate-contaminated agricultural runoff is an effective strategy to restore degraded fens and reduce NO_3^- fluxes (Trepel and Palmeri, 2002; Kieckbusch and Schrautzer, 2007). In this paper, we evaluate the effects of this

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rewetting strategy on releases of dissolved organic carbon (DOC) and soluble reactive phosphorus (SRP).

The release of DOC from peatlands is important because any change in DOC fluxes will result in a significant regional redistribution of terrestrial carbon (C) (Limpens et al., 2008). Artificial drainage of peatlands has been found to increase DOC production by stimulating aerobic decomposition of organic matter, which impairs the role of peatlands as atmospheric carbon sinks (Holden et al., 2004; Worrall et al., 2007). The functioning of adjacent aquatic and marine ecosystems can be modified if DOC surpluses are exported from drained peatlands (Freeman et al., 2001; Tranvik and Jansson, 2002; Sachse et al., 2005) due to the influence of DOC on productivity, biogeochemical cycles and attenuation of visible and UV radiation (Pastor et al., 2003). In addition, DOC impacts water quality in terms of color, taste, safety and aesthetics, primarily by altering the acid-base and metal complexation characteristics of soil and stream water (Worrall et al., 2003). Raising water tables in drained peatlands has been proposed as a way which might temporally decreases DOC production by decreasing C mineralization rates (Worrall et al., 2007). However, previous research has shown that rewetting can actually stimulate DOC production (Kalbitz and Geyer, 2002; Zak and Gelbrecht, 2007; Waddington et al., 2008). When rewetting is accomplished using water from agricultural runoff, the effect of an influx of NO_3^- must be evaluated since it provides an external electron acceptor which could alter the breakdown of organic matter and DOC turnover (Smolders et al., 2006; Alewell et al., 2008; Limpens et al., 2008).

Long-term draining and agricultural use of peatlands increase the release of organic-bound P, converting it in to more mobile fractions, and thereby raising the mobilization potential (Schlichting et al., 2002; Zak et al., 2008). The release of SRP from such increased mobile fractions may promote eutrophication in rewetted fen areas and their adjacent aquatic ecosystems. SRP availability in rewetted fens has been found to be up to three orders of magnitude higher than in pristine fens (Zak et al., 2004). Fen rewetting can stimulate SRP release as a result of processes like hydrolytic particulate organic matter cleavage, fermentation and/or reduction of Fe(III)-hydroxides. Moreover, SO_4^{2-} inputs via the rewetting water must be considered due to SO_4^{2-} potential to stimulate internal eutrophication, that is SO_4^{2-} mediated P mobilization. Under anaerobic conditions SO_4^{2-} and Fe reduction lead to sulphide production, FeS_x formation and mobilization of Fe-bound SRP (Lamers et al., 2002b; Zak et al., 2009). High NO_3^- loads in the rewetting water can prevent SRP release by buffering the redox potential of the rewetted peat, and decreasing Fe-(III)-hydroxide reduction rates (Lucassen et al., 2004). Furthermore, NO_3^- supply via rewetting can decrease SO_4^{2-} reduction rates and, therefore, internal eutrophication (Lucassen et al., 2004). Indeed, NO_3^- addition has been proposed as a valid method to reduce phosphate release from lake sediments and prevent therefore eutrophication (Andersen, 1982; Sorensen, 1982; Jensen and Andersen, 1992; McAuliffe et al., 1998; Schauser et al., 2006). However, SRP release will be neither promoted by rewetting nor suppressed by nitrate at rewetted fens if redox insensitive P-binding sytems (e.g. $Al(OH)_3$ or microbial decomposition of organic matter play an important role (Hupfer and Lewandowski, 2008). The imbalance between external P sedimentation and the P binding capacity of anoxic sediments must be also taken into account when performing studies in rewetted fens with important sediment inputs from the catchment (Hupfer and Lewandowski, 2008).

In northeast Germany about 10% of the area was historically covered by fens, although at present more than 95% of fen areas are drained or have suffered from lowered ground water tables within their catchment. Currently, part of this area has been rewetted to re-establish the fen's function as NO_3^- sinks (ca. 20,000 ha in the Mecklenburg-Vorpommern region). In the current investigation, we used laboratory studies to evaluate the effect of rewetting with NO_3^--polluted water on DOC and SRP release. In order to gain a better understanding of the impacts, the influence of peat decomposition, NO_3^- loading rate and temperature were assessed. Peat decomposition must be considered because it controls the size of the mobile DOC and SRP peat fractions (Kalbitz and Geyer, 2002; Smolders et al., 2006; Zak et al., 2010). Moreover, porewater and peat Fe:SRP ratios can be affected by the degree of peat decomposition and therefore potential SRP release (Zak and Gelbrecht, 2007; Geurts et al., 2008). Because the NO_3^- loading rate controls the NO_3^- supply, it also exerts a strong influence on DOC and SRP turnover due to the role of NO_3^- as an electron receptor. Temperature increases accelerates organic matter decomposition (Updegraff et al., 1995; Davidson and Janssens, 2006), thereby influencing DOC production and the release of SRP due to microbially-mediated decomposition processes. Temperature can also affect diffusive transport of porewater compounds to the surface.

2. Material and methods

2.1. Study area

The sampling site, "Kleiner Landgraben", is situated about 140 km north of Berlin in the Tollense River valley in Mecklenburg Vorpommern (northeast Germany). The site covers approximately 600 ha, and is located at latitude 53°40'N, longitude 13°18'E. The area has a mean annual precipitation of 523 mm and a mean annual temperature of 7.9 °C. The mean daily temperature is 0.0 °C in January and 17.5 °C in July (data from 1980 to 2010 obtained from meteorological stations in Trollenhagen and Neubrandenburg, 7 km and 10 km south of the sampling site, respectively). According to Joosten and Clarke (2002), the studied fen can be classified as a carbonate rich riparian mire system consisting of spring mires at the valley edge, wider percolation mires dominated by groundwater flow, and a strip of flood mires along the main ditch of Kleiner Landgraben. Drainage for peat extraction and low-intensity agricultural use began in the 19th century. Land use conversion to pastures and grasslands was intensified by a complex dewatering system developed in the mid-1970s. The change to an increasingly intensive agricultural land use created species-poor grasslands with a substantial loss of peat and subsidence of the soil surface by several decimetres. The natural vegetation of mesotrophic brown moss-sedge reeds (*Caricetalia davallianae*) has almost completely vanished. Additionally, the peat at various depths has been degraded to different degrees, as determined using the "von Post scale" (Puustjaervi, 1970). The upper horizon is highly decomposed (HD) (~0.3 m at the sampling site), followed by moderately decomposed (MD) or slightly decomposed peat up to a maximum depth of 3.4 m. The effect of degree of decomposition on the different C and P pools has been previously described (Zak et al., 2008).

2.2. Peat sampling and experimental design

Further details on peat collection and experimental design are provided in Cabezas et al. (2012). Briefly, experimental mesocosms (0.4 m × 0.3 m × 0.3 m; n = 12) were filled with two different peat types (20 dm^3; ~15 cm): HD (n = 6) and MD (n = 6). Two different types of dialysis chambers, so-called "peepers" (Hesslein, 1976), were set in each mesocosms. The first was a rechargeable composite sampler, which is a one-chamber sampler (~ 0.05 L), placed in the peat up to a depth of 10 cm depth (Zak and Gelbrecht, 2007). The