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Effects of degree of peat decomposition, loading rate and temperature on dissolved nitrogen turnover in rewetted fens

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ABSTRACT

Rewetting of drained fens with NO_3^- enriched water from agricultural watersheds has been proposed as a valid strategy to reduce NO_3^- load of water courses although their role as dissolved nitrogen (DN) sinks remain unclear because the export of reduced nitrogen forms (NH_4^+, DON) may exceed NO_3^- removal. A laboratory experiment was conducted to investigate the importance of temperature, nitrogen load and the degree of peat decomposition on the role of rewetted fens as DN sinks. Different peat substrates of one degraded drained fen in NE Germany were incubated under stagnant water conditions. Two degrees of peat decomposition (Highly decomposed: HD; Moderately decomposed: MD), two nitrogen loads (Low nitrogen, LN, 40 kg N ha^{-1} yr^{-1}; High nitrogen, HN, 140 kg N ha^{-1} yr^{-1}) and two incubation temperatures (20 °C and 5 °C) were examined. Moreover, net N mineralisation and N microbial immobilisation were also estimated to gain useful insights on the role of the considered factors over processes involved on DN turnover. Under all scenarios considered in this study, fen rewetting was shown to be a valid strategy to recover the function of fens as DN sinks, although large variability on the retention efficiency was observed (~15–75%). N load increased NO_3^- (LN: 7.9 ± 1.0 mg N m^{-2} d^{-1}; HN: 19.3 ± 3.1 mg N m^{-2} d^{-1}) and DN (LN: 5.1 ± 0.8 mg N m^{-2} d^{-1}; HN: 16.5 ± 2.4 mg N m^{-2} d^{-1}) removal, even though the depletion of the added NO_3^- by organic matter decomposition took place only at the peat surface. Peat decomposition strongly influenced DN turnover due to differences in the size of the mobile organic carbon (C) (HD: 132 ± 7 mg C g^{-1} dry matter (DM); MD: 68 ± 2 mg C g^{-1} DM) and N (HD: 9.3 ± 0.5 mg N g^{-1} DM; MD: 2.8 ± 0.1 mg N g^{-1} DM) pools. As a result, NO_3^- removal, net N mineralisation, N microbial immobilisation and NH_4^+ export were higher for highly decomposed peat. In addition, a higher incubation temperature increased NO_3^- removal rates (20 °C: 18.6 ± 3.0 mg N m^{-2} d^{-1}; 5 °C: 8.5 ± 1.7 mg N m^{-2} d^{-1}). Moreover, DN removal was much higher at 20 °C (20 °C: 14.9 ± 2.6 mg N m^{-2} d^{-1}; 5 °C: 6.7 ± 1.6 mg N m^{-2} d^{-1}), but lower than NO_3^- removal rates underpinning the importance of N mineralisation. The results from our study should be considered prior to restore degraded fens. Removing the highly decomposed peat layer, which has been proposed as a method to reduce nutrient release in rewetted fens, can hamper the N removal potential to some extent, especially at high N loading rates.

1. Introduction

Low-nitrogen availability is a distinctive characteristic of natural temperate fens (Bedford and Godwin, 2003), and their lower temperatures and waterlogged conditions slow organic matter decay rates. As a result, N accumulates in peat as refractory organic matter in the long-term, avoiding eutrophication of downstream aquatic ecosystems. As a calculation example, NE Germany fens have the potential to accumulate 4.4–11.9 kg N ha^{-1} y^{-1} (Gelbrecht et al., 2001), accounting for 28–75% of N export to the Baltic Sea from the Schleswig-Holstein region (15.7 kg N ha^{-1} y^{-1}; Trepel and Palmeri, 2002). In Western Europe and North America, low nitrogen availability and slow organic matter decay rates have been impaired by anthropogenic disturbances (Verhoeven et al., 1996; Venterink et al., 2002; Bedford and Godwin, 2003; Van Diggelen et al., 2006), decreasing the potential of fens to remove N. Fens were artificially drained for centuries, resulting in the aeration of superficial peat layers (Holden et al., 2004). It substantially increases N mineralisation and N availability (Martin et al., 1997; Munchmeyer et al., 2000; Venterink et al., 2002, 2009; Keller et al., 2004). Moreover, drainage has counteracted the role of fens as buffer zones for agricultural diffuse pollution in areas where N inputs through hydrological flow paths clearly exceed those in

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natural conditions (Trepel and Kluge, 2004; Montreuil and Merot, 2006; Kieckbusch and Schrautzer, 2007). Hence, anthropogenic disturbances turn a low N availability system into a system with N surplus both from internal and external sources. Under such conditions, N exports increase as dissolved compounds through hydrological flow paths [nitrate (NO_3^-), ammonium (NH_4^+), dissolved organic nitrogen (DON)] and gaseous N losses (NO_2, N_2) (Martin et al., 1997; Holden et al., 2004; Kieckbusch et al., 2006). Furthermore, due to aerobic peat mineralization carbon (C) losses and microbial N immobilisation increases provoking lower peat C:N ratios in drained fens (Yefimov and Tsarenko, 1993; Augustin et al., 1997; Bridgham and Richardson, 2003; Ruckauf et al., 2004).

As a consequence of eutrophication, ecosystem structure and functioning are severely impaired (Bobbink et al., 1998; Holden et al., 2004). Currently, public awareness on the conservation and restoration of anthropogenically altered fens has increased (Zak et al., 2011). Fen restoration is based on rewetting drained areas to slow organic matter decomposition by recovering high water tables, thus recovering peat forming conditions. Rewetting has also been adopted as a valid strategy in agricultural watersheds in order to reduce diffuse NO_3^- pollution (Trepel and Palmeri, 2002). However, it has been shown that N mineralisation is not significantly lowered by rewetting (Venterink et al., 2002; Van Dijk et al., 2004). DON and NH_4^+ export may take place (Stepanauskas et al., 1996; Davidsson and Stahl, 2000; Lenz and Wild, 2001), decreasing the efficiency of rewetted fens as dissolved nitrogen (DN) sinks. Moreover, NO_3^- retention in rewetted fens has a high spatial and temporal heterogeneity (Silvan et al., 2005; Kieckbusch et al., 2006; Tiemeyer et al., 2007), which must be understood. Assuming that denitrification is the main process for NO_3^- removal in rewetted fens (Jansson et al., 1994; Ruckauf et al., 2004), NO_3^- removal efficiency largely depends on carbon and NO_3^- availability (Davidsson and Stahl, 2000; Spieles and Mitsch, 2000). Carbon availability in turn will depend not only on the mobile organic C peat fraction, but also on its quality. Therefore, the degree of peat decomposition must be considered; since anthropogenic desiccation alters organic matter quality as much as it affects the labile organic C pool and its potential for further decomposition (Turetsky, 2004; Laiho, 2006; Glatzel et al., 2008). In this regard, the humic substances content and aromacity can serve as indicators of dissolved organic matter (DOM) biodegradability (Kalbitz and Geyer, 2002; Qualls and Richardson, 2003; Sachse et al., 2005; Glatzel et al., 2008). Moreover, the N loading rate will determine the NO_3^- availability, influencing the DN turnover as shown for other types of wetlands (Spieles and Mitsch, 2000). However, little is known regarding the degree of peat decomposition and the N loading rate that promotes either NO_3^- limited or C limited NO_3^- removal in rewetted fens. Finally, the role of temperature must be evaluated due to its underlying seasonal influence. Temperature alters the kinetics of biogeochemical reactions or decomposition rates as drivers of DN turnover in fens (Updegraff et al., 1995; Augustin et al., 1998; Keller et al., 2004).

In NE Germany about 10% of the area was covered by fens in the past, although at present more than 95% of fen areas are drained or have suffered from lowered ground water tables within their catchment (Zak and Gelbrecht, 2007). Currently, part of this area has been rewetted to re-establish their function as nutrient sinks (~20,000 ha in the state of Mecklenburg-Vorpommern). Although NO_3^- retention has been achieved by performing such a strategy in NE Germany, conditions for rewetted fens to become DN sinks remain unclear and largely depend on NO_3^- retention efficiency compared to DON and NH_4^+ release (Kieckbusch and Schrautzer, 2007; Richert et al., 2000; Zak and Gelbrecht, 2007). In this paper, the effects of the degree of peat decomposition, N loading rate and temperature over DN turnover in rewetted fens were evaluated by performing a laboratory incubation experiment. Moreover, N mineralization and N microbial immobilisation were also estimated to gain useful insights on the role of the considered factors over processes involved on DN turnover. Peat was obtained from one drained fen in the Mecklenburg-Vorpommern region where rewetting using nitrate-enriched ground water is planned. By performing the experiment, we aimed to answer the following two questions: 1) How do peat quality, N loading rate and temperature influence nitrogen turnover in rewetted fens?; and 2) Which conditions are necessary for rewetted fens to become DN sinks? Results of our experiment could be used by managers to implement strategies to restore these wetlands by rewetting with nitrate-polluted water in order to improve water quality in downstream aquatic ecosystems.

2. Methods

2.1. Sampling site

The sampling site "Kleiner Landgraben" (about 600 ha, latitude 53°40′ N, longitude 13°18′ E) is situated about 140 km north of Berlin in the valley of the River Tollense in Mecklenburg Vorpommern (NE Germany). The climate is continentally influenced with 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 of meteorological stations in Trollenhagen and Neubrandenburg, 7 km or 10 km south of the sampling site). 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-intensive agricultural use began in the 19th century and land-use change to pastures and grassland was intensified by a complex dewatering system in the mid-1970s. The change to an increasingly intensive agricultural land-use created species-poor grasslands with tremendous peat losses and shrinking of the soil surface for several decimetres. The natural vegetation consisting of mesotrophic brown moss-sedge reeds (*Caricetalia davallianae*) has almost completely vanished. Additionally, the peat from varying depths has been degraded to different degrees as determined by the "von Post scale" (Puustjärvi, 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.

2.2. Peat sampling and experimental design

After removing the upper 10 cm soil layer or the grass sod, respectively, ca. 90 dm^3 of HD peat (sampling depth: 0.1–0.3 m) and ca. 90 dm^3 of MD peat (sampling depth: 0.5–0.7 m) were collected at one plot in the study site in February 2010. Samples were pooled in plastic containers and homogenised by hand mixing for several minutes in the laboratory. Freshly cut roots were removed. For each peat type, six mesocosms (0.4 × 0.3 × 0.3 m) were filled with about 20 dm^3 of homogenised peat resulting in a layer of ~15 cm deep. The porewater was sampled by means of dialysis chambers, so-called peepers (Hesslein, 1976). At each mesocosm, two different dialysis chambers were installed. The first type was a rechargeable composite sampler that consists of one chamber sampler (~0.05 L) installed in the peat up to 10 cm deep (Zak and Gelbrecht, 2007). This sampling technique allows for nondisturbed monitoring of dissolved substances in the porewater over several months. The second type was a profile sampler that consists of 20 vertically spaced chamber samplers (every 1 cm),