Journal of Environmental Management 143 (2014) 44–53

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

The effects of salinization on aerobic and anaerobic decomposition and mineralization in peat meadows: The roles of peat type and land use

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ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form
27 March 2014
Accepted 13 April 2014
Available online 16 May 2014

Keywords:
Peat soils
Decomposition
Mineralization
Salinization
Climate change
Subsidence

ABSTRACT

Peat soils comprise a large part of the western and northern Netherlands. Drainage for agriculture has caused increased soil aeration which has stimulated decomposition and, hence, soil subsidence, currently amounting to 1–2 cm/yr. River water is supplied to these peat areas in summer to prevent drying out of the peat soils. Saltwater intrusion and evaporation make this surface water slightly brackish during drought periods. In addition, brackish seepage can surface more easily during such dry periods. We performed an incubation experiment in which the effects of salinization on aerobic decomposition and mineralization of shallow peat samples and anaerobic decomposition and mineralization of deep peat samples were studied. We considered four different types of peat samples: peat sampled in agricultural peat meadows and in nature reserves, originally formed under either eutrophic or oligotrophic conditions. The aerobic decomposition was approximately reduced by 50% after salinization, whereas the anaerobic decomposition rates remained unchanged. Remarkably, the response to salinization did not differ between the peat types and land uses. Ammonium concentrations increased while nitrate concentrations decreased after salinization, probably as a result of reduced nitrification. Especially in the oligotrophic peat, ammonium concentrations increased substantially. Phosphate concentrations increased, possibly caused by changes in desorption and adsorption processes due to higher ion concentrations. DOC concentrations decreased in the brackish samples due to precipitation. Furthermore, the eutrophic peat samples showed increasing sulfate concentrations, both in oxic and anoxic incubations, which was attributed to pyrite oxidation. Independently of salinization, nitrification rates were higher in the agricultural, fertilized, peat soils. In conclusion, while salinization might reduce subsidence rates, it will have adverse effects on water quality.

1. Introduction

Peat meadows and associated shallow waters comprise a major part of the land area of the Netherlands. These peat areas have been formed in the course of the Holocene, when wet conditions prevailed and decomposition of organic material was impeded. Large parts of the Dutch peatlands have been in contact with seawater during their formation regularly. The geological events of transgression, periods in which the sea found its way onto the land surface due to relatively fast sea level rise, and regression, periods with a retreat of the sea, caused layered patterns of clay and peat, especially seen near the river mouths. In these landscapes, eutrophic fen peat was formed near rivers and in groundwater seepage areas, while oligotrophic bog peat developed in other areas. Since their reclamation for agriculture in the 13th–16th centuries, drainage for agricultural use has resulted in enhanced peat decomposition rates. Among the consequences of the drainage are soil subsidence (Schothorst, 1977), greenhouse gas emissions (Berglund and Berglund, 2011; Best and Jacobs, 1997; Blodau and Moore, 2003; Limpens et al., 2008; Van den Akker et al., 2008) and surface water pollution (MNP & RIVM, 2002; RIVM, 2009).

In the past 50 years, water levels in the Dutch peat meadow areas have been drawn down even more to facilitate intensive dairy farming, resulting in land subsidence rates up to 1–2 cm/yr (Janssen, 1986; Querner et al., 2012; Schothorst, 1977). During dry summers, which are a concern to water boards, additional water originating from rivers or lakes has to be supplied to the peat areas

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http://dx.doi.org/10.1016/j.jenvman.2014.04.009
0301-4797/

to prevent drying out of the peat soils and limit enhanced decomposition due to more aerated conditions. However, during prolonged summer droughts, which are expected to become more frequent with climate change, the river water has a poor quality and may become slightly brackish because of saltwater intrusion and evaporation (Satijn and Leenen, 2009). Supplying this water to peat areas causes external salinization. Apart from surface water salinization, groundwater is also prone to become more saline due to climate change, so-called internal salinization. Due to water deficiencies in summer and other causes such as drainage, subsidence and sea level rise, the upward groundwater seepage pressure increases relative to the downward pressure of surface waters and shallow aquifers. In some peat areas, this seepage is brackish because the groundwater is in contact with marine sediments (De Louw et al., 2011).

Although peat areas had locally been influenced by brackish water during their formation (Bakker and Van Smeerdijk, 1982), questions have been arising about the effects of the recent summer salinization on peat decomposition and mineralization (Lamers et al., 1998; Smolders et al., 2006). The supply of more brackish river water and internal salinization both cause higher ion concentrations with a chemical composition reflecting sea salt. This composition characteristically has a high sodium, chloride and, to a lesser degree, sulfate concentration. Generally, a sudden increase in salinity will impede decomposition as the increase in osmotic value can pose a stress to microorganisms (Laura, 1974; Pathak and Rao, 1998; Setia et al., 2010). However, there are salinity-resistant Archaea, Bacteria and Eucaryota which can accumulate salts or osmolytes to adjust their osmotic potential; nonetheless, such mechanisms demand energy (Oren, 1999) and carbon mineralization efficiency becomes lower (Setia et al., 2011). Hence, a higher salinity, often expressed as the concentration of chloride ions, is expected to hamper both aerobic and anaerobic decomposition rates. Sulfate salts, on the other hand, can stimulate anaerobic decomposition because sulfate is one of the alternative terminal electron acceptors (TEAs). When studying the effect of salinization on decomposition rates, understanding the role of terminal electron acceptors (TEAs), that can be present both in the pore water and in the soil, is crucial. In aerobic conditions, oxygen functions as the terminal electron acceptor. Alternative TEAs under anaerobic conditions, in the order of declining thermodynamic yields, are nitrate (NO_3^-), manganese (Mn^{4+}), ferric iron (Fe^{3+}), sulfate (SO_4^{2-}), and ultimately CO_2 which leads to CH_4 production (Rydin and Jeglum, 2006). Adding electron acceptors such as sulfate to anaerobic peat soils can therefore lead to the shift from methanogenesis, an anaerobic slow process, to sulfate reduction, which is a faster process (Canavan et al., 2006; Capone and Kiene, 1988). In inundated salt-affected soils, sulfate reduction is known to be one of the most important decomposition pathways (Canavan et al., 2006; Jørgensen et al., 2009). Hence, the addition of sulfate might stimulate anaerobic decomposition.

Conflicting results have been reported in the literature on the effects of salinity on nitrogen mineralization in organic matter; literature on the effects of salinity on mineralization of peat soils in particular is scarce. The results of these studies were often dependent on the methodology, in addition to differences between soil types and salt composition and concentration. Ammonification and nitrification can be affected by salinization. Laura (1974) found that nitrogen mineralization increased after salinization as total nitrogen content decreased substantially with higher salt concentrations. In addition, ammonium concentrations increased with increasing chloride salt concentrations while nitrate concentrations decreased, probably as a result of restricted nitrification; this was an experiment in which organic matter was added to a sandy loam soil. Experimental additions of artificial seawater to inundated peat cores resulted in lower nitrification rates (Portnoy and Giblin, 1997). McCLung and Frankenberger Jr. (1987) compared nitrification and ammonification rates in silt loam soils after chloride and sulfate additions and noticed that, while NaCl treatments almost completely stopped nitrification, the same concentration of Na_2SO_4 only resulted in a 27% reduction in nitrification. Ammonification rates also decreased due to salinization, and more due to NaCl addition than due to Na_2SO_4 (McClung and Frankenberger Jr., 1987). Irshad et al. (2005) also found lower ammonification concentrations in salt-amended samples. Their study included the role of fertilization, which is highly relevant in the framework of our study as most of the Dutch peatlands have been intensively fertilized. The concentrations of ammonium and nitrate declined more strongly with increasing salt concentration in samples treated with urea and manure than in the samples without fertilizers. In general, both ion adsorption and mineralization rates are likely to be affected by salinization, with consequences for nutrient release and water quality. Increased ionic strength due to salinization could increase ion release from the peat complex as a result of higher cation exchange. On a longer time span, nitrification might be hampered, which could lead to increased ammonium concentrations; however, when also ammonification is hampered, both ammonium and nitrate concentrations are expected to decrease.

Phosphate and DOC release from the soil complex can be affected by salinization as well. Firstly, sulfate, chloride and phosphate compete for the same anion adsorption sites (Beltman et al., 2000). In addition, sulfide, which is produced when sulfate is reduced, interferes with the iron–phosphorus cycle by reducing iron^{3+} (hydr)oxides and iron^{3+}-phosphates. The insoluble FeS_x that is formed reduces the availability of iron to bind phosphate, thereby increasing phosphate mobility, as reviewed by Smolders et al. (2006). Secondly, the dynamics of Dissolved Organic Carbon (DOC) might also change due to salinization. It has been hypothesized that DOC concentrations in the surface water decrease with salinization because of DOC precipitation (Hruska et al., 2009; Monteith et al., 2007).

In this study, an experiment was performed in order to explore the effects of groundwater and surface water salinization on anaerobic and aerobic decomposition and net N and P mineralization rates of peat in peat meadow areas in the Netherlands. More specifically, we compare the effect of salinization on the aerobic and anaerobic decomposition and mineralization rates of peat differing in origin and land use history in a full factorial comparison. We used eutrophic as well as oligotrophic peat samples, the eutrophic samples consisting of the remains of a *Carex* sp. and *Phragmites* sp. dominated vegetation and the oligotrophic samples of the remains of a *Sphagnum* sp. dominated vegetation. Both peat types were sampled in nature reserves as well as in dairy meadows. Next to water level manipulations, agricultural land use is affecting belowground cycling of carbon and nutrients through inputs of chemical fertilizers and manure, which has led to earthification of the peat and a change in the microbial community (Jaatinen et al., 2008). Although nitrogen addition stimulates the decomposition of easily degradable organic matter, it has been found to hamper the decay of recalcitrant compounds (Craine et al., 2007; Knorr et al., 2005; Mack et al., 2004). *Sphagnum* peat is known for its higher concentration of phenolic compounds and more acidic conditions, which both result in higher resistance against decomposition (Verhoeven and Toth, 1995). This study aims at clarifying the effects of land use and peat type on decomposition and mineralization characteristics as well as their response to salinization.