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How properties of differently cultivated fen soils affect grassland productivity — A broad investigation of environmental interactions in Northeast Germany

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ABSTRACT

This paper describes the impact of drainage and grassland use on selected soil parameters (e.g. organic carbon content, bulk density) of typical fen soils in Northeast Germany and, hence, their influence on grassland productivity. A broad investigation of site conditions has been realized at 23 grassland fields concerning soil properties, vegetation attributes and groundwater dynamics. Collectively selected fields represent characteristic types of grassland management and stages of moorsh-forming process. Concerning the entire sample, site conditions of agriculturally used peatlands vary strongly. Based on that complex data-set, the importance of defined potential impact factors on grassland production is tested and expressed in a linear regression model. Annual yield of the 2011 growing season, as a quantitative parameter of grassland productivity, does not indicate any correlation to site-specific conditions or cultivation strategy. In contrast, energy content as a qualitative measure varies strongly in relation to defined environmental parameters. Model performance is indicated with an adjusted R-square of 0.89 while the main impact factors are annual use frequency, mean summer water table (MSWT), maximum groundwater drawdown (GWmax), and organic carbon content (Corg).

Contents

1. Introduction

Fen soils differ greatly from terrestrial soil ecosystems, since they develop under prolonged water saturation and the correlated absence of oxygen, that both inhibit decomposition of dead vegetation. As a

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result, fen soils are characterised by high accumulation rates of soil organic matter, referred to as peat formation, which is one major classification factor according to the global climate debate (UNFCCC, 2008; IPCC, 2007) and the assessment of soil vulnerability (Fell et al., 2016; Holsten et al., 2009).

Especially the continuous lowering and adjustment of the water table to establish and/or preserve land cultivation causes aeration-induced processes of peat mineralisation, peat subsidence and peat shrinkage (Zauft et al., 2010; Zeitz and Velty, 2002; Ilnicki and Zeitz, 2002; Kasimir-Klemedtsson et al., 1997). As a result, chemical and physical fen soil properties change irreversibly: organic carbon stocks are depleted and oxidised carbon is emitted into the atmosphere (Pohl et al., 2015; Augustin and Herrmann, 2014; Heller and Zeitz, 2012; Drösler et al., 2008; Bellamy et al., 2005; Byrne et al., 2004; Augustin et al., 1996). In addition, bulk densities increase, accompanied by a decline in soil porosity and water permeability (Mueller et al., 2007a). In sum, degradation processes culminate in an annual decrease of peat thickness of 0.5 to 3.0 cm in the temperate zone, depending on land-use intensity and drainage depth (Fell et al., 2016; Junghans et al., 2013; Wallor et al., 2012; Leifeld et al., 2011; Kluge et al., 2008; Nieuwenhuis and Schokking, 1997; Schothorst, 1977). Such changes are typical for all agriculturally used peatlands and principally proceed according to aeration depth and, hence, to water table (Zeitz and Velty, 2002). Intensity of the described processes become apparent in diagnostic soil horizons reflecting earthification or even moorshification of topsoil and aggregation of subsoil, respectively (Zauft et al., 2010; Mueller et al., 2007b; Mueller et al., 2007c; Schwaerzel and Bohl, 2003). Earthification reflects structural changes of the topsoil due to increasing aeration (also termed "moorsh" by Oleszczuk et al., 2008). Earthified peat has a crumbly, grainy structure in the first state of degradation. The ongoing process of degradation then causes a complete loss of soil structure accompanied by strongly hydrophobic conditions of topsoil, which indicates moorshification. The mentioned dynamics of fen soil degradation hereinafter are referred to as "moorsh-forming process" (Zeitz and Velty, 2002).

In Northeast Germany peat formation as a sedentary bedding of organic material is mainly caused by high groundwater levels in the glacial valleys of the landscape (Kühn, 2014), where the extent and duration of water-saturated conditions determine the accumulation rate of organic material. According to site-specific climatic conditions the formation process requires over 10,000 years (Kaiser et al., 2012; Mundel, 2002) and may result in more than ten metre-thick peat accumulation. The federal state of Brandenburg, located in Northeast Germany, was covered by fen soils to an extent of 210,000 ha in the year 1950 (Fell et al., 2016; Bauriegel, 2014). Up to 98% of that has been affected by drainage and cultivation and, hence, by loss of organic material (Luthardt and Zeitz, 2014; Succow, 2001). This has resulted in a decrease of spatial coverage to 165,000 ha (Fell et al., 2016; Bauriegel, 2014). Related to groundwater level and land-use intensity, decreases in carbon storage differ (Heller and Zeitz, 2012; Mueller et al., 2007a; Höper, 2007). Principally, fen soils in Brandenburg are used as grassland, either as extensive or semi-extensive pasture or as intensive forage and hay production for dairy cattle, sometimes combined with subsequent grazing after the last cut. Some very wet grassland sites are cut only once a year in the framework of nature conservation. Extensive and semi-extensive grassland fields are usually not fertilized with inorganic nitrogen. In practise, observed levels and forms of additional nitrogen input vary due to agri-environmental measure. Therefore, decreasing grassland yields and energy contents in forage can be a result of restricted nitrogen application (Čop et al., 2009; Käding, 2006; Kirkham and Tallowin, 1995). Another important relation concerning grassland cultivation strategies on fen soils describes the impact of cutting frequency on the development of dry matter yield. Regardless of the site-specific plant community, reduced cutting frequency leads to increasing grassland yields that show decreased forage quality (Čop et al., 2009; Käding, 2006; Kirkham and Tallowin, 1995).

Grassland productivity and forage quality is as well determined by the site-specific community of plant species, whose development is in turn strongly related to water dynamics and agricultural practise (Käding et al., 2005; Kaiser et al., 2005; Schrautzer, 2004; Schalitz et al., 2002). Hence, modelling of grassland yield is often based simply on the vegetation community or management strategies. Generated changes in fen soil characteristics as well as the natural heterogeneity of fen soils are usually not considered. Käding et al. (2005) present a site and management-dependent model for calculating grassland yields and forage quality for corresponding sites of Northeast Germany. Fens are considered within this model approach solely because of their deviating nutrient and water cycling in comparison to mineral soils. A determination of fen soils with regard to vertical structure (substrate, decomposition rate) and depth of the peat layer is not included in the model, but is essential for assessment of moorsh-forming process and related alteration in grassland productivity. The main driver determining the extent of fen soil degradation is the water regime. In the model by Käding et al. (2005) it is indicated by the water supply levels of Petersen (1952) reflecting the groundwater table below surface in the growing season. A similar approach is offered by Knieß et al. (2010) who recommend the mean summer water table in combination with the lowest annual water table as the main factor controlling the degradation of fen soil properties. The semi-quantitative model introduced by Knieß et al. (2010) covers a variety of potential fen soil types and grassland management systems but does not generate any forecast about yield quality from relevant grasslands. A combined study including a more extensive differentiation of fen soil types, together with a comprehensive analysis of grassland parameters dependent on water regime and grassland management is offered by Schalitz et al. (2002). Their small-scale lysimeter study concentrates on a particular peatland formed by paludification and provides highly site-specific results, which are to some extent transferable under practical conditions.

Due to moorsh-forming process, the number of potential impact factors on site-specific plant development and, hence, grassland yield and forage quality may increase. Besides hydrological conditions and management strategy, pedological parameters, reflecting fen soil degradation, probably influence grassland productivity and may complicate an explicit classification of grassland sites in terms of yield calculation. Hence, the primary aim of the present study is to examine if there are proven interactions between progressive moorsh-forming process, water dynamics, land-use intensity and grassland productivity. In order to detect the extent of the described interactions in relation to representative management strategies, a variety of environmental parameters at representative grassland sites in Northeast Germany were investigated under practical conditions. By following this approach, it should be possible to fill the gap in knowledge regarding the interactions of the most important factors characterising the status of agriculturally used fen soils: water, soil and vegetation.

2. Material and methods

2.1. Experimental design

According to the aim of the present study the investigation under practical conditions was realized in the landscape of five examination sites covered by fen soils located in the German Federal State of Brandenburg. Typically, field studies proceed differently than test areas structured in small-scale block design (Bloch et al., 2014) and data collection and statistical assessment is limited by some factors. To compromise between the scientific rules and the special features of landscape research the experimental design, illustrated in Fig. 1 was introduced.

The examined fen sites developed through different, and partially combined hydrological processes, e.g. terrestrialisation, percolation, paludification and inundation (Succow and Lange, 1984). As a result, the requirements for peat formation varied and particularly peatlands