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Physical properties of forest soils along a fly-ash deposition gradient in Northeast Germany

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A B S T R A C T

This study investigates the effect of predominant historical atmospheric depositions of fly ashes from brown coal power plants on physical properties of forest soils along a deposition gradient (0 to 33.9 km). Studies on physical properties of a pure fly ash show a sand dominated texture, high particle density, (macro-)porosity and saturated hydraulic conductivity as well as a slight water repellency. The enrichment of fly ash particles is more obvious in the forest floor horizons closer to the main emission source, where an increase of air capacity (R^2=0.67) and saturated hydraulic conductivity (R^2=0.53), and a slightly higher particle density is observed, while plant available water (R^2=0.57) and water repellency (contact angle R^2=0.71) decreased. The organic C composition of the forest floor horizons, characterized by organic substances rich in aliphatic groups, which appear to be responsible for the partially extremely high water repellency is not influenced by fly ash accumulation. However, an input of fly ashes into the organic soil layers reduces the water repellency by adding non-hydrophobic mineral compounds. A hierarchical cluster analysis supports the gradual influence of fly ash deposition; sites close to the emission source differ distinctly from sites further away. No impact of fly ash was found for the top mineral horizons.

1. Introduction

The mainly silviculturally used region "Dübener Heide" had been influenced by industrial immissions since the end of the eighteenth century until the middle of the 1990s (Holz, 2007). 18 mio. Mg SO_2 and 12 mio. Mg fly ashes had been exhausted and had accumulated leewards the main emission sources in the forests of the region "Dübener Heide" following the prevailing westerly winds (Neumeister et al., 1991). Forest stands had been damaged mainly by the toxic effects of SO_2 on assimilation processes and on the stomatal functioning. The strongest damages appeared close to the main emission sources; these damages were classified as deposition zones (Lux, 1965). As soil chemical investigations confirm a gradual impact of aeolian immissions within a distance of 8 to 15 km to the main emission sources, a modified zonal classification was used in the project ENFORCHANGE (Makeschin and Fürst, 2007). Close to the main emission source higher pH-values as well as a higher base saturation even in 30 cm soil depth were measured (Koch et al., 2002; Klose and Makeschin, 2003; Klose and Makeschin, 2004; Fritz and Makeschin, 2007).

The impact of fly ash on soil physical properties is mainly discussed for agricultural melioration, as plant available water can be increased or hydraulic properties affected (Gangloff et al., 2000; Pathan et al., 2003; Yunusa et al., 2006). Horn and Taubner (1997) describe Regosols developed from brown coal rust and fly ash on a disposal site in Northeast Germany, which show high porosities implicating high saturated hydraulic conductivities. Kovacs and Mang (2002) investigated ashes from brown coal power plants in Hungary, which also show a high saturated hydraulic conductivity. Soil physical properties of Northeast German forest soils without considerable contamination were under examination by Greiffenhagen et al. (2006) determining hydraulic functions and water repellency and by Buczko et al. (2007) with focus on water repellency. According to these investigations, forest floor horizons feature a very high total porosity, an extremely high saturated hydraulic conductivity and varying wettability values depending on water content and drying history. Furthermore, wettability of forest soils is affected by the amount and by the composition of soil organic carbon. Ellerbrock et al. (2005) emphasize, that soils with a high amount of aliphatic constituents show with respect to their SOC/clay relation a reduced wettability. Forest floor horizons organic C consists of aliphatic alkyl C groups (e.g. lipids and hemicelluloses), O/N-alkyl C functional groups like polysaccharide and proteins, carboxyl groups (e.g. acids, amides) and aromatic aryl C groups like lignin (Kögel-Knabner et al., 1988). Concerning wettability of soils, unpolar long-chained aliphatic alkyl-C groups are supposed to act as hydrophobic components (e.g. Franco et al., 1995, Michel et al., 2001). The chemical composition of forest floors of forest stands which developed on lignite rich mine spoils in Lusatia, Germany indicates the presence of carbohydrates and lignin originating from plant material, while aromatic structures which are characteristic for lignite material where also observed (Rumpel et al., 1998). These

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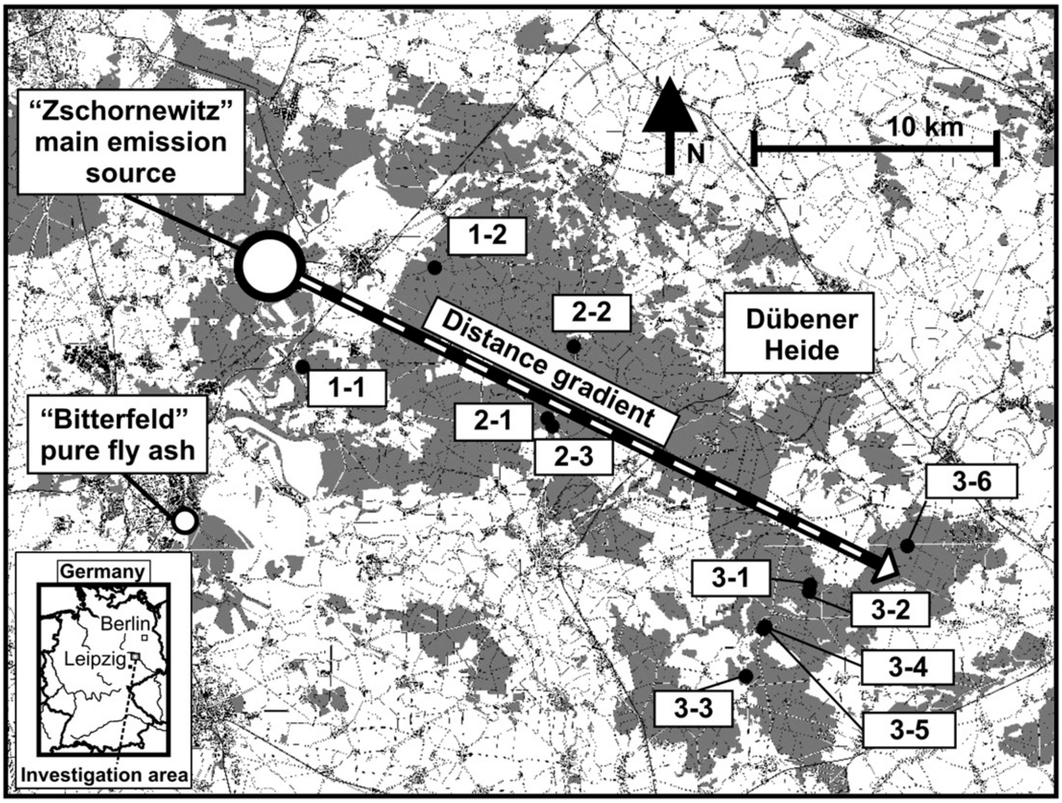

Fig. 1. Location of the investigation area "Dübener Heide" in Northeast Germany, of the investigated forest sites along a distance gradient (description in Table 1) and of the pure fly ash site in Bitterfeld (preposition 1: minor distance and previously very strongly or strongly damaged forest stands; 2: medium distance and previously moderately damaged forest stands; 3: major distance and previously mainly minor damaged forest stands).

lignite material compositions show a distinct dominance of aromatic as well as aliphatic carbon species, while ash from lignite fired power plant contains primarily highly aromatic groups, as aliphatic components are lost largely by combustion. Wettability of fly ash and fly ash enriched forest soils should be affected by its organic carbon as well as by the inorganic minerals of the fly ash, which have hydrophilic properties (Tschapek, 1984).

This study presents physical properties of eleven forest soils, which are sited along a fly ash deposition gradient, and a pure fly ash as a reference substrate. The investigated forest sites represent typical soil types and forest stands in this region. Especially the forest floor horizons play an important role in the water balance of forest soils; their soil physical properties however are insufficiently studied. Hence, aim of this study is, (1) to characterize soil physical properties (particle density, bulk density, pore size distribution, saturated hydraulic conductivity and hydrophobicity) of a pure fly ash, of forest floor and top mineral horizons; (2) to determine the chemical composition of the organic C of the pure fly ash and of forest floor horizons at different distances to the main emission source as an important factor for wettability; and (3) to identify the impact of fly ash deposition on these properties along a distance gradient.

2. Materials and methods

2.1. Study area

The region "Dübener Heide" is part of the North German lowlands located between the rivers Elbe and Mulde leewards the industrial region "Bitterfeld-Wolfen" and its former largest brown coal power plant in "Zschornewitz" (Fig. 1). It is a landscape characterized by meltwater sands and terminal moraines (Kainz, 2007). The area is mainly used by forestry with dominating stands of beech (*Fagus sylvatica*) and pine (*Pinus sylvestris*). The mean annual temperature is 9.1 °C with a mean annual precipitation of 546 mm. Arenosols and Podzols (according to WRB, 2006) derived from glacial sand while gleyic properties dominate soils affected by groundwater and stagnic properties on sites with water logging. All soils have a fibri-folic horizon as organic layer. Table 1 outlines the investigated sites with respect to the previously forest stand damages according to Lux (1965) and to the classification of the project ENFORCHANGE. Preposition "1" in the site-names means, that these sites are located at a minor distance to the main emission source "Zschornewitz" with "very strongly or strongly damaged forest stands", preposition "2" means a medium distance and a "moderately damaged forest stand" and preposition "3" that the location is sited at a major distance having mainly "minor damaged forest stands". The forest damages had derived from the toxic effects of SO_2 and other toxic emissions, which had not only been exhausted by the main emission source in

Table 1
Description of the investigated forest sites in the region "Dübener Heide" (preposition 1: minor distance and previously very strongly or strongly damaged forest stands; 2: medium distance and previously moderately damaged forest stands; 3: major distance and previously mainly minor damaged forest stands)

Site in Fig. 1	*Distance to main emission source/km*	*Soil group (WRB, 2006)*	*Stand*
1-1	4.2	Arenosol	Pine/oak
1-2	7.5	Arenosol	Pine
2-1	14.9	Arenosol	Beech
2-2	14.9	Podzol	Pine/beech
2-3	15.2	Arenosol	Pine/beech
3-1	29.6	Arenosol	Pine
3-2	29.6	Arenosol	Beech
3-3	30.2	Podzol	Pine/beech, oak
3-4	30.2	Arenosol	Beech/oak
3-5	30.4	Podzol	Pine
3-6	33.9	Cambisol	Pine