Science of the Total Environment 626 (2018) 228–234

Contents lists available at ScienceDirect

Science of the Total Environment

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

Magnetic mapping of distribution of wood ash used for fertilization of forest soil

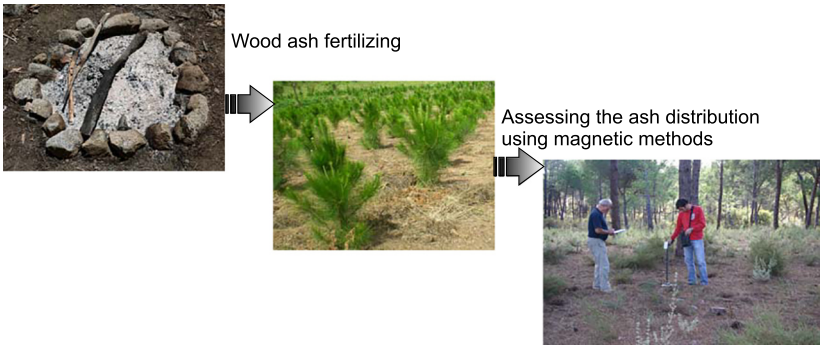
Eduard Petrovský [a,*], Jiří Remeš [b], Aleš Kapička [a], Vilém Podrázský [b], Hana Grison [a], Luboš Borůvka [c]

[a] Institute of Geophysics of the Czech Academy of Sciences, Boční II/1401, 141 31 Prague 4, Czech Republic
[b] Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Kamýcká 129, 165 00 Prague 6, Czech Republic
[c] Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences, Kamýcká 129, 165 00 Prague 6, Czech Republic

HIGHLIGHTS

- Wood ash contains significant portion of ferrimagnetic iron oxides.
- Surface application of wood ash contributes magnetite to topsoil.
- Magnetic methods can be used to observe distribution of the ash applied.
- Suitable geologic, soil and environmental conditions are necessary.
- Lithogenic, pedogenic and technogenic contributions should not mask the ash input.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 November 2017
Received in revised form 10 January 2018
Accepted 10 January 2018
Available online xxxx

Editor: F.M. Tack

Keywords:
Forest soil
Wood ash
Fertilizing
Tree plants
Iron oxides
Rock magnetism

ABSTRACT

The effect of wood-ash fertilization on forest soils has been assessed mainly through geochemical methods (e.g., content of soil organic matter or nutrients). However, a simple and fast method of determining the distribution of the ash and the extent of affected soil is missing. In this study we present the use of magnetic susceptibility, which is controlled by Fe-oxides, in comparing the fertilized soil in the forest plantation of pine and oak with intact forest soil. Spatial and vertical distribution of magnetic susceptibility was measured in an oak and pine plantation next to stems of young plants, where wood ash was applied as fertilizer. Pattern of the susceptibility distribution was compared with that in non-fertilized part of the plantation as well as with a spot of intact natural forest soil nearby. Our results show that the wood-ash samples contain significant amount of ferrimagnetic magnetite with susceptibility higher than that of typical forest soil. Clear differences were observed between magnetic susceptibility of furrows and ridges. Moreover, the dispersed ash remains practically on the surface, does not penetrate to deeper layers. Finally, our data suggest significant differences in surface values between the pine and oak plants. Based on this study we may conclude that magnetic susceptibility may represent a simple and approximate method of assessing the extent of soil affected by wood-ash.

1. Introduction

Wood ash is considered to be a recycling agent that can compensate nutrients removed from the forest ecosystem by the logging of wood and wood biomass (Demeyer et al., 2001; Donald et al., 2005; Hånell

* Corresponding author.
E-mail address: edp@ig.cas.cz (E. Petrovský).

https://doi.org/10.1016/j.scitotenv.2018.01.095
0048-9697/

and Magnusson, 2005; Pitman, 2006; Ingerslev et al., 2011; Omil et al., 2013; Remeš et al., 2016). Attention to the use of ash in forestry has increased considerably in connection with the use of woody biomass for energy purposes (Mead, 2005; Augusto et al., 2008; Norström et al., 2012). Intensive use of forest bioenergy generates vast amounts of ash (Saarsalmi et al., 2012).

The type of burned wood, the combustion process and the site conditions for ash application are important factors for the quality of wood ash. Two types of wood ash are produced in biomass combustion plants - fly ash and bottom ash (Tlustoš et al., 2012). Fly powdered ash is captured from boiler emissions, in cyclone separators, and contains large amounts of nutrients (except N), which are present as dissolvable salts and are rapidly released. In contrast, bottom or boiler ash, usually referred to as mixed wood ash, which is produced in wood fired furnaces, is less reactive and contains lower amounts of heavy metals than fly ash (Santalla et al., 2011; Omil et al., 2013). Positive effects of wood ash in forest soils is based on its high pH, nutrient content (Ca, K, Mg and P), neutralizing capability and potential to increase activity of soil microflora (Huotari et al., 2015). Wood ash contains all the nutrient species a tree needs except for nitrogen (Hånell and Magnusson, 2005). Wood ash therefore does not compensate for deficiency of N, which is known to be the main nutrient limiting growth of forests on mineral soils (Saarsalmi et al., 2012). Thus, wood ash amendments to organic soils most often result in significantly increased forest growth (Hånell and Magnusson, 2005). In mineral soils wood ash should be combined with nitrogen fertilization or applied in the forest stands with Ca, K, and Mg deficiency (Augusto et al., 2008).

Ususally geochemical methods (e.g., content of soil organic matter or nutrients) are employed in assessing the effect of wood-ash fertilization on forest soils. However, a simple and fast method of determining the distribution of the ash and the extent of affected soil is missing. In this paper we present the use of magnetic susceptibility, which is controlled by ferrimagnetic Fe-oxides, in assessing the fertilized soil in the forest nursery of pine and oak young plants. From the point of view of magnetomineralogy, magnetic properties of soils are examined using concentration of magnetically ordered Fe-oxides, in particular magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3). These minerals are only accessoric in soils, but even minute concentrations control macroscopic concentration-dependent magnetic properties (e.g., magnetization and magnetic susceptibility). In case of absence of ferrimagnetic minerals, magnetic properties of soils are determined by paramagnetic substances, such as poorly crystaline Fe-(oxy)hydroxides or Fe-containing clay minerals (e.g., Pizarro et al., 2007; Jordanova et al., 2011). These often serve as precursors of ferrimagnetic magnetite/maghemite or antiferromagnetic hematite. Present methods and devices are able to detect even very low concentrations of magnetite/maghemite in soils (Jordanova, 2016). According to Dearing (1999), 0.1% of magnetite in hypothetical soil contributes 85.4% of the total susceptibility (of 5.855×10^{-7} m^3/kg).

Magnetic susceptibility is the primary parameter used either in-situ or in the lab with the aim to assess the concentration of magnetite/maghemite. It offers wide range of applications. For example, it has been used widely for mapping soils and other biocarriers polluted by atmospherically deposited dust (Magiera and Strzyszcz, 2000; Moreno et al., 2003; Hanesch et al., 2007; Kapička et al., 2008; Wang, 2013). Magnetic susceptibility along with other magnetic parameters, reflecting type, concentration and grain size of Fe-oxides, has been used to study the degree of weathering of basement rock and pedogenesis (Maher et al., 2003; Su et al., 2015; Grison et al., 2015, 2016, 2017). Fe-oxides in soils may reveal different land conditions (even historically, e.g., Geiss et al., 2008; Fischer et al., 2008; Hyland et al., 2015), fires (Oldfield and Crowther, 2007; Roman et al., 2013), soil degradation and erosion (Royall, 2001; Jordanova et al., 2014; Kapička et al., 2015), etc.

In the present study, we applied magnetic susceptibility in order to investigate soil fertilized by wood ash, in particular we estimate the spatial and vertical extent of fertilization under pine and oak young plants in comparison with intact soil. Moreover, as a first step we present magnetic properties of the used wood ash, which provide arguments for the use of magnetic mapping in the field for this specific purpose.

2. Materials and methods

The study was carried out in territory of the Doksy Municipal Forests Ltd. (Central Bohemia Region, about 60 km north of Prague), which is located in Natural Forest Area No 18 - North Bohemian Sandstone Plateau and Bohemian Paradise, at sites of natural pine forests (Fig. 1a). The forest is about 100 years old, the area is flat and free of artificial irregularities. The experimental forest stand is classified according to the Czech forest ecosystem classification (Viewegh et al., 2014) as acidic Beach oak (*Fageto-Quercetum acidophilum*), the altitude being 280 m a.s.l. The plantation is on flat or on very gentle slope, the soil type is according to the Czech taxonomic soil classification system Arenic Podzol (Němeček et al., 2008). Four soil pits (example is shown in Fig. 1b) in the original pine forest revealed horizons summarized in Table 1.

The research plots were established after the harvesting of mature pine stands (Fig. 1a) by the end of 2010, followed by mechanic soil preparation. After the harvesting, four plots were prepared according to the wood debris and slash (logging residues) processing as follows:

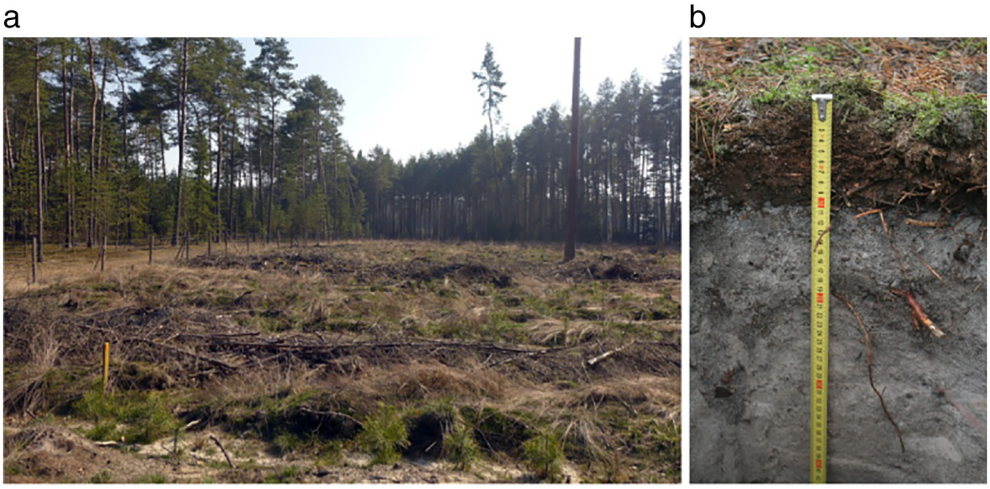


Fig. 1. a) General picture of the tree plantation, b) vertical profile of the intact forest soil nearby.