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Environmental impact assessment of wood ash utilization in forest road construction and maintenance — A field study

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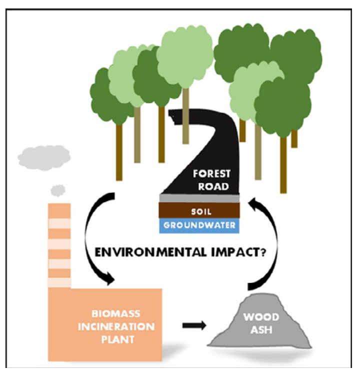
HIGHLIGHTS

- Leaching water concentrations from forest roads built with 15% wood ash differed between sites and type of ash applied.
- Heavy metal solubility was mostly driven by changes in metal oxide solubility and/or by increased availability of competing or complexing anions.
- Results indicate environmental safe use of wood ash in forest road construction if ash and site specific requirements are met.

GRAPHICAL ABSTRACT



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ABSTRACT

The ever increasing use of wood material as fuel for green energy production requires innovative, environmentally safe strategies for recycling of the remaining wood ash. Utilizing wood ash in forest road construction and maintenance to improve mechanical stability has been suggested as a feasible recycling option. To investigate the environmental impact of wood ash application in forest road maintenance, a two-year field experiment was conducted at two Austrian forest sites (Kobernausserwald (KO) (soil pH 5.5) and Weyregg (WE) (pH 7.7)) differing in their soil chemical properties. Two different ashes, one produced by grate incineration (GA) and the other by fluidized bed incineration in a mixture with 15 vol% burnt lime (FBA), were incorporated in repeated road sections at a 15:85% (V/V) ash-to-soil rate. Leaching waters from the road body were collected and analyzed for 32 environmentally relevant parameters over two years. Upon termination of the experiment, sub-road soil samples were collected and analyzed for ash-related changes in soil chemistry. Even though a larger number of parameters was affected by the ash application at the alkaline site (WE), we observed the most pronounced initial increases of pH as well as Al, As, Fe, Mn, Ni, Co, Cu, Mo, and NO_2^- concentrations in leachates beneath GA-treated road bodies at Kobernausserwald due to the lower soil buffer capacity at this site. Despite the observed effects our results indicate that, when specific requirements are met (i.e. appropriate ash quality, sufficient soil buffer capacity below the road body, and single time-point ash incorporation within several decades), wood ash application in forest road construction is generally environmentally acceptable.

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1. Introduction

With increasing focus on energy production from renewable sources, incineration of wood material became increasingly popular over the last decades. Especially countries with large forest cover, such as Austria and Sweden, have high interest in advancing wood incineration technologies. However, despite the benefit of wood being a renewable resource with a CO_2-neutral energy budget, significant amounts of combustion residues (i.e. wood ash) are produced during the incineration process of which the majority is currently deposited on landfills, often at high costs. In 2010, about 128,000 t of wood ash were produced in Austria, of which 49,000 t were disposed of in Austrian landfills (Umweltbundesamt, 2012). Treating ash as a waste product increases occupation of landfills and imposes costs on the incinerator often rendering biomass-based energy production economically unfeasible. If significant amounts of wood ash were recycled in an ecologically acceptable way, both the bioenergy industry and society would benefit (Obernberger and Supancic, 2009).

When designing environmentally acceptable recycling strategies, chemical properties of wood ash have to be considered. During the combustion process the majority of organic material is oxidized to CO_2 and NO_X and released into the atmosphere, while most of the inorganic material is transformed into solid oxides forming the remaining ash. Inorganic compounds mainly derive from the constituents of the plant, including essential plant nutrients such as Ca, K and Mg. Returning these nutrients to the forest ecosystem would be beneficial. However, contaminants like Cd, As, and Pb taken up by the plant or deposited on the plant surfaces (e.g. Steinnes, 1995; Steinnes et al., 1992) well as micronutrients (e.g. Ni, Cu, Cr, Co, Zn), that become toxic at high concentrations also accumulate in different ash fractions. Another critical feature of the ash is its high alkalinity. Due to the high content in alkali carbonates wood ash behaves similarly to a liming agent (Pitman, 2006). The liming effect can benefit the soil, as it might counteract acidification and thus prevent leaching of cationic nutrients or contaminants whereas anionic species might by mobilized (Sharifi, et al., 2013). Depending on the extent of changes in soil solution chemistry, pronounced changes in soil pH may also have an undesirable effect leading to increased leaching of pollutants and nutrients.

The EU waste framework (Directive 2008/98/EC) sets up a hierarchy of waste treatment options, preferring prevention, reuse and recycling over disposal. Following this reasonable principle there have been several attempts to reuse wood ash and to develop legal frameworks for wood ash recycling (Gori et al., 2011). Due to the high amount of bioenergy produced from wood material, the Scandinavian countries are pioneers in investigating ways to make wood ash an economically valuable product. Utilization of wood ash as a soil ameliorant dates back to 1935 in Finland (Hakkila, 1989). In Sweden, research on returning wood ash to forests has been conducted since the 1970s (Pitman, 2006). Returning nutrients to the forest soil is highly wanted but due to the ash features mentioned above, the direct application of wood ash as a fertilizer/liming agent is legally limited to high-quality ash at rates of just a few tons per hectare. In Austria, for instance, it is recommended by the Consulting Committee for Soil Protection to apply a maximum of 2 t ash per hectare every 20 years with special focus on the Cd content of the applied ash (Stangl, 2011). In some countries, including Austria, wood ash is also used as liming agent in agriculture or as an additive for compost production. Again, application rates are strictly regulated and quantities of ash being recycled trough composting are small and rather negligible from a pure economically point of view. Apart from directly returning wood ash to the environment, the construction industry could potentially use a large portion of the produced wood ash for building roads and landfill surfaces or as an amendment in concrete. Its low density and high bearing capacity would make ash suitable for various uses. However, for a wide range of wood ash recycling options there are still several impediments to be overcome. Besides the mostly unexplored environmental impact, there is also a lack in awareness of producers and potential end-users, as well as missing legal regulations (Ribbing, 2007a; van Eijk et al., 2012). Also the variety in combustion procedures and burning material leads to considerable differences in the composition of the ashes and

Table 1
Total concentrations (acid digestion with HF) and other characteristics of the grate ash (GA) and fluidized bed ash (FBA) used in the forest road test trials at two different Austrian forest sites. FBA was always used as a mixture of 85% FBA and 15% burnt lime.

	GA	FBA	85% FBA + 15% burnt lime
	Total measured concentrations		Theoretical concentrations[a]
	[mg kg^{-1} DW]		
Al	47700	18900	16065
As	11	9.4	8.0
B	86	82	70
Ba	641	713	606
Ca	17600	64700	n.a
Cd	1.1	1.3	1.1
Co	15	3.2	2.8
Cr	76	17	14
Cu	70	46	39
Fe	27400	3940	3350
K	24700	48800	41500
Mg	21000	7760	6600
Mn	3090	1350	1150
Mo	1.4	0.49	0.41
Na	5420	3070	2610
Ni	56	12	10
P	2910	2960	2520
Pb	10	14	12
Se	0.70	0.50	0.43
V	67	9.8	8.3
Zn	161	301	256
Other characteristics			
pH	12.7	11.7	12.6
EC [μS cm^{-1}]	9460	1460	10000
DOC [mg kg^{-1} DW]	19	11	8.6
Density [g cm^{-3}]	0.94	n.a	1.5

[a] Theoretical concentrations were calculated assuming the burnt lime consists of CaO only and the density of ash and burnt lime is the same.