

Heavy metal leaching from forest roads reinforced with fly ash

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Related studies and presentations

- “Fly ash for forest road rehabilitation” FORMEC 4.10-8.10.2015, Linz, Austria
- “Increased fly ash utilization — value addition through forest road reconstruction” FEC, 16.-19.4.2018, Rotorua, New Zealand

Original scientific paper

Fly Ash in Forest Road Rehabilitation

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Abstract

Finland's forestry and biomass production is seeking novel uses for the fly ash deriving from biomass conversion. There are numerous possibilities for using fly ash in civil engineering including road construction. The increase in biomass production has created more interest for using ash in forest roads. However, no established methods for the rehabilitation of forest roads exist yet. Hence, this research aims to find a suitable construction method that involves using ash that provides adequate bearing capacity. It involved building on test road sections: two of them were reference sections without fly ash. The study examined the effect of four different rehabilitation methods on the bearing capacity of roads. Measurements were made once before and four times after the rehabilitation. The measuring devices included a light falling weight deflectorometer (LFWFD), a dynamic cone penetrometer (DCP) and a conventional falling weight deflectorometer (FWD). Two of the rehabilitation structures were 50 and 25 cm thick fly ash layers. The other two were 15 and 20 cm thick layers made of fly ash and aggregate in different mixing ratios. In all cases, the constructed layers were peened with aggregate. Statistical comparison showed that the bearing capacity of the rehabilitated road sections had improved compared to the reference sections. The recorded bearing capacities after rehabilitation (during spring thaw in 2012, 2013 and 2014) were about the same as before rehabilitation in summer 2011. Based on this study, fly ash can be recommended as an option for forest road rehabilitation.

Keywords: forest road, rehabilitation, fly ash, bearing capacity

1. Introduction

Increasing utilization of biomass is increasing the quantity of produced ash. The wood and peat burning processes of the forest industry are producing a significant amount of ash, about 600,000 tonnes of the ash produced in Finland annually is wood- and peat-based fly ash (Emission 2006). The total annual production of ash in the country is about 1.5 million tonnes. There are 52 power plants around Finland, which produce at least 1000 tonnes of fly ash each year (Tilvääkäntäminen Iäkijärvi 2012).

Ash utilisation is divided roughly evenly between earthworks, landfills and fertilizers or other use (Ojala 2010). The growing ash production necessitates finding sensible ways of utilizing ash. Increased utilization can bring several benefits and there are many potential ways of using fly ash. As a fertilizer, it increases timber growth in forests (Mollanen et al. 2005) and agricultural field crops (Patterson et al. 2004). It can be used as a construction material in road building reducing

the need of natural stone resources (Edil and Benson 2007) or as a filler in concrete (Wang et al. 2008). Ash is no longer considered waste from the energy and forest industries point of view. On the contrary, ash is nowadays a by-product that can be used in various ways. Yet, there are obstacles to expanding ash utilization. In spite of the above mentioned possibilities of use, a remarkable amount of ash ends up in landfills. From the economic point of view, it is important to minimize the amount of ash going to landfills, because the dumping charge has lately been raised to €58 per tonne.

Ash is not as stable a material as mineral soil. Ash can be separated into fly ash and bottom ash based on particle size. The properties of fly ash from wood and peat vary widely depending on the fuel used, the burning process and the combustion gas filtering technique (Koppiaväli et al. 2009). Two features need to be taken into consideration when planning the use of ash: its content of environmentally harmful heavy metals and its technical properties. Ash has been used in the

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ARTICLE

Increased fly ash utilization — value addition through forest road reconstruction

Tommi Kaakkurivaara and Heikki Korpenen

Abstract: Increasing forest biomass utilization is increasing the need to discover more applications for fly ash to avoid dumping charges. Our study concentrates on defining the work phases of reconstruction work and estimation of construction costs for a method using biomass based fly ash. Cost calculations were carried out for two mixed structures of fly ash and aggregate, two uniform structures of fly ash, and a conventional aggregate structure, where construction material volumes were calculated per kilometre for each structure. Our study defined suitable machines and their production per hour for different work phases. Cost calculation equations were formed for the used machines and the transportation of construction materials. Our study showed that building a 200 mm thick uniform layer of fly ash was the best alternative for minimizing construction costs. However, building a 300 mm thick uniform layer of fly ash was the best alternative for minimizing dumping charges.

Key words: forest road, reconstruction, cost estimation, fly ash structure, rehabilitation.

Résumé: L'utilisation croissante de la biomasse forestière accroît le besoin de découvrir plus d'applications qui utilisent les cendres volantes afin d'éviter des frais de déchargement. Le but de notre étude est de définir les phases de travaux de reconstruction et l'estimation des coûts de construction pour une méthode où on a utilisé les cendres volantes issues de la biomasse. Les calculs des coûts ont été effectués pour deux structures où les cendres volantes et agrégats ont été mélangés, deux structures uniformes de cendres volantes, et une structure traditionnelle d'agrégats, où les volumes de matériaux de construction ont été calculés par kilomètre pour chaque structure. Notre étude a permis de déterminer des machines appropriées et leur productivité par heure pour différentes phases de travail. Des équations de calcul des coûts ont été établies pour les machines utilisées et pour le transport des matériaux de construction. Notre étude a montré que construire une couche uniforme de cendres volantes de 200 mm d'épaisseur était le meilleur moyen de minimiser les coûts de construction. Cependant, construire une épaisseur uniforme de 300 mm de cendres volantes était la meilleure solution de réduire les frais de déchargement. [Traduit par la Rédaction]

Mots-clés: route forestière, reconstruction, calcul des coûts, structure de cendres volantes, recyclage.

Introduction

Forest road trafficability is essential for successful wood production, which requires an adequate forest road network for on-site delivery of timber harvests. The criterion for technical validity can be decided upon based on the capability of maintaining trafficability throughout the seasons, especially during the spring thawing period. Special attention should be paid to the reconstruction of Finnish forest roads, because their technical conditions often restrict hauling at certain times. The planning and construction of new forest roads are essential becoming more relevant. Reconstruction annually occurs on 3000–4000 km of forest roads in Finland, while the total length of forest roads is approximately 145 000 km. The total costs of forest road construction and reconstruction were approximately €1.4 million in Finland, or equivalent to 12 400 euros per reconstructed kilometre in 2011. Construction cost of a new road are actually slightly higher than those mentioned above, while the reconstruction cost offers a cheaper rate than mentioned. Finnish forest roads were mainly constructed between 1960 and 1990. As a consequence of aging, the service life of forest roads will be expiring soon. The costs of reconstruction are therefore expected to increase in the future (Metsäntaloustieteiden tutkimuskeskus 2014).

Increased fly ash utilization has potential benefits from an economic point of view. Dumping charges have risen sharply in Europe, especially in Finland to €70 per tonne. As a result of rising dumping charges, new applications or methods for utilizing fly ash have become more relevant. One detail of the ash produced in Finland will end up in landfills (Ojala 2010). Our study thus focused on fly ash, which is a by-product of burning wood and peat sources in the power plants of pulp mills. Fly ash biomass is a by-product referred to as fly ash in this paper. The power plants of forest industry and the heating plants of municipalities are the largest sources of ash. The quality of ash is generally decreasing, as a result of growing biomass use. Increased fly utilization (e.g., in forest roads) could achieve economic-financial savings. In addition, fly ash utilization employs carbon-saving and transportation entrepreneurship and saves natural stone resources. The fly ash has several special characteristics. Based on grain size classification it is parallel to soil. The fly ash structure is therefore a non-stone-relevant material with poor bearing capacity. Instead, the fly ash has high bearing capacity, when structure is compared. The fly contains calcium oxide, which contributes due to optimum water content and compaction work (Tilvääkäntäminen Iäkijärvi 2012). For these reasons the technical properties of fly ash differ from natural stone materials.

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First question from audience: how about heavy metals?

Background

- The amount of fly ash which originates from burning of wood and peat has grown to 700 000 tons in Finland (2017)
- Increased forest biomass and peat based fly ash utilization has potential benefits from an economic point of view. Dumping charges have risen lately in Europe, especially in Finland to €70 per ton. As a result of rising dumping charges, new applications or methods for utilizing fly ash have become more relevant.

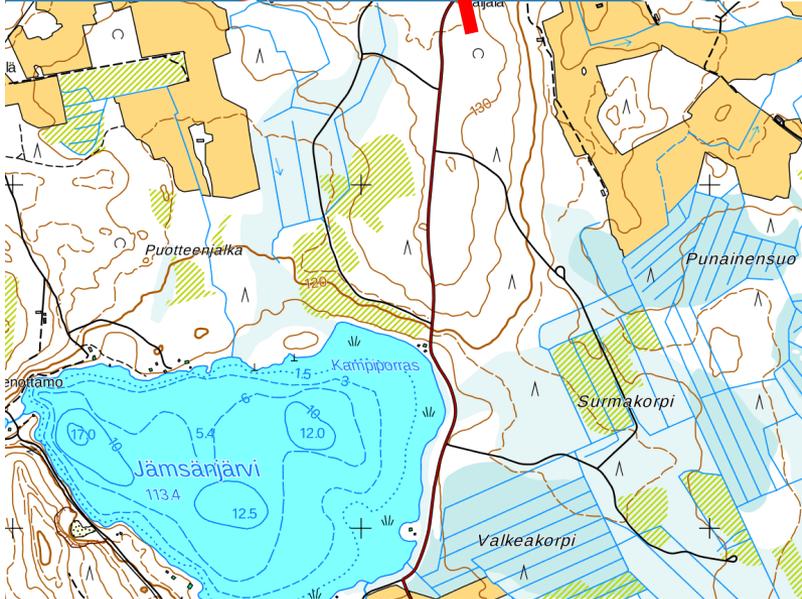
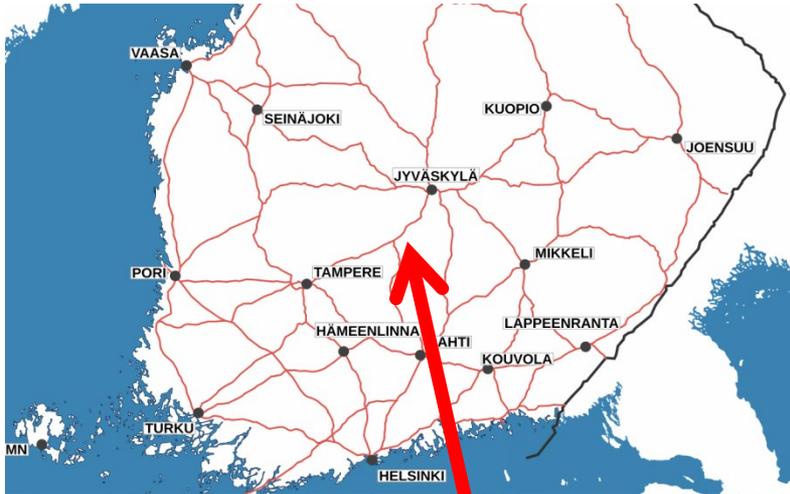
Background

- The situation of ash utilization in forest road construction and rehabilitation has changed recently in Finland. At the beginning of 2018, the same environmental permission procedure covers both the forest roads and public roads
- How about environment aspects? Ash may contain several heavy metals, e.g. Cu, Cd, Cr, Mn, Hg, Ni and Zn, which are toxic in high concentrations

Objectives

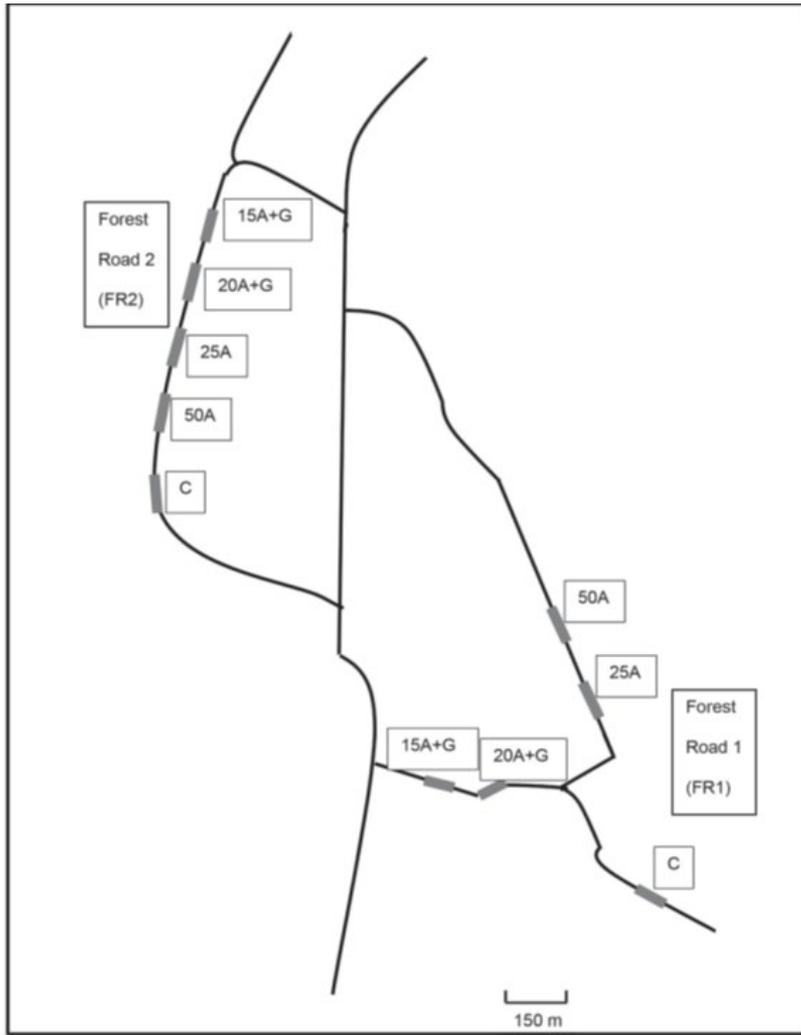
- The aim of this study was to determine the water quality related to the concentrations of dissolved heavy metals and barium (Ba)
- We hypothesized that possible dissolution of heavy metals and Ba from ash layers would be evenly distributed phenomena and similar in all locations from the ash containing road since the homogenous ash layers were constructed inside the forest roads.

Study location



- Experimental area near Jämsä, central Finland.
- Vegetation; Boreal, Forest land; wetlands and upland mineral soils
- Mean annual precipitation 636 mm
- Mean effective temperature sum 1333 degree days
- Mean growing season length 170 days

Test structures

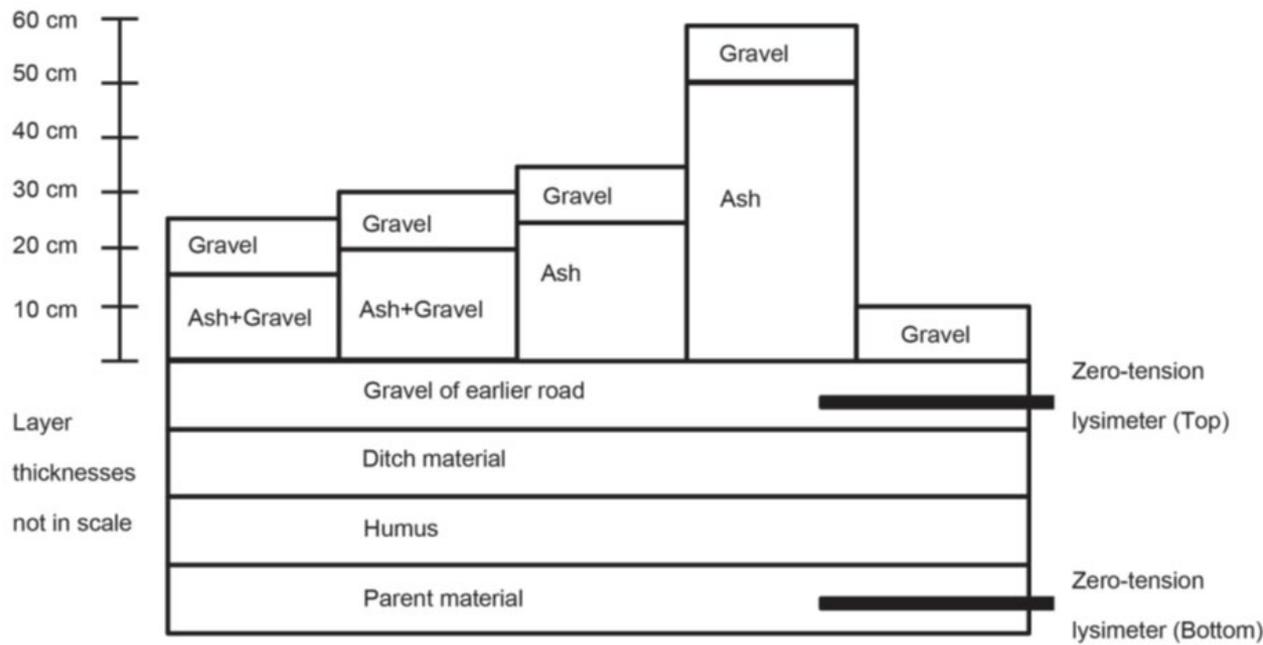


Treatments:

- **C** = control (no ash)
- **15A +G** = 15 cm layer of ash + gravel
- **20A + G** = 20 cm layer of ash + gravel
- **25A** = 25 cm layer of ash
- **50A** = 50 cm layer of ash



Road structure and lysimeters

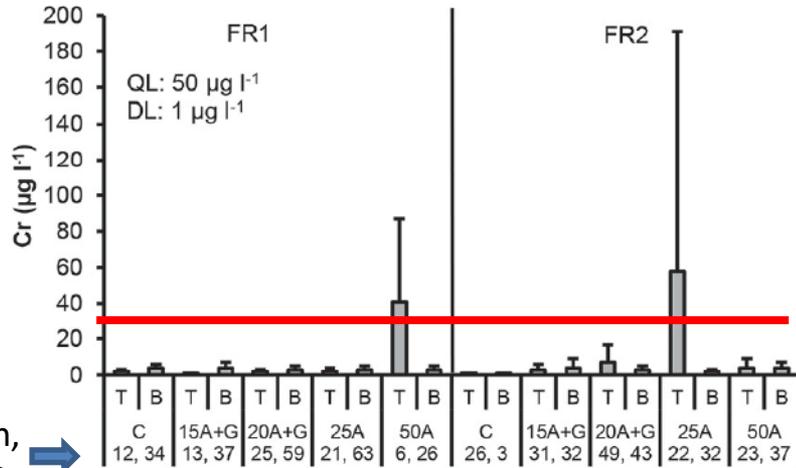


- Percolation water collected by lysimeters ($0,1\text{m}^2$)
- Also ditch water samples collected up and down stream
- Data collecting 2011 – 2014, May–November at about 4-week intervals.

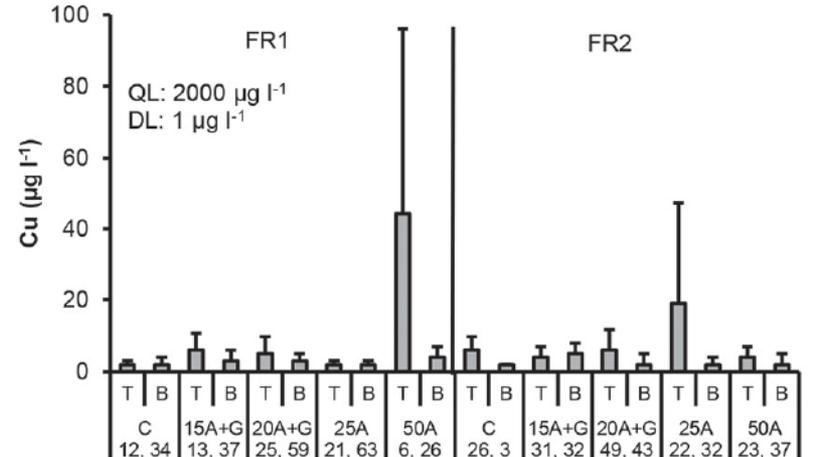
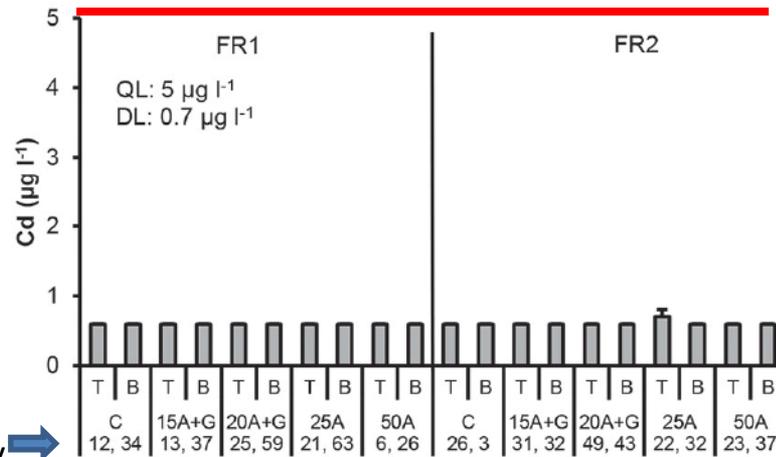
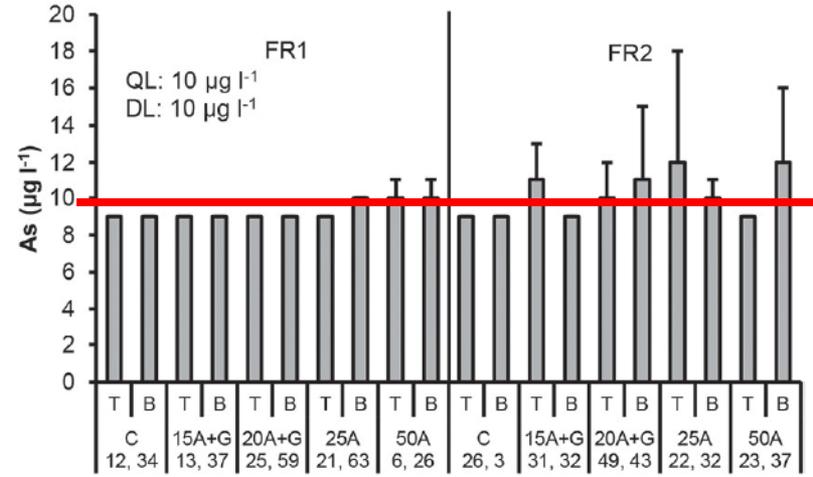
Upper limit concentrations

Measured parameter	Density (kg l ⁻¹)	Quality limit (QL)	Source
<i>Heavy metals</i>			
Arsenic (As)	5.72	10 µg l ⁻¹	Finlex (2001)
Cadmium (Cd)	8.65	5 µg l ⁻¹	Finlex (2001)
Cobalt (Co)	8.90	1 µg l ⁻¹	Lahermo et al. (2002)
Copper (Cu)	8.96	2000 µg l ⁻¹	Finlex (2001)
Chromium (Cr)	7.19	50 µg l ⁻¹	Finlex (2001)
Lead (Pb)	11.35	10 µg l ⁻¹	Finlex (2001)
Molybdenum (Mo)	10.22	70 µg l ⁻¹	Lahermo et al. (2002)
Nickel (Ni)	8.90	20 µg l ⁻¹	Finlex (2001)
Zinc (Zn)	7.13	3000 µg l ⁻¹	Finlex (2001)
<i>Earth alkaline metal</i>			
Barium (Ba)	3.59	700 µg l ⁻¹	WHO (2011)

Concentrations in percolation water



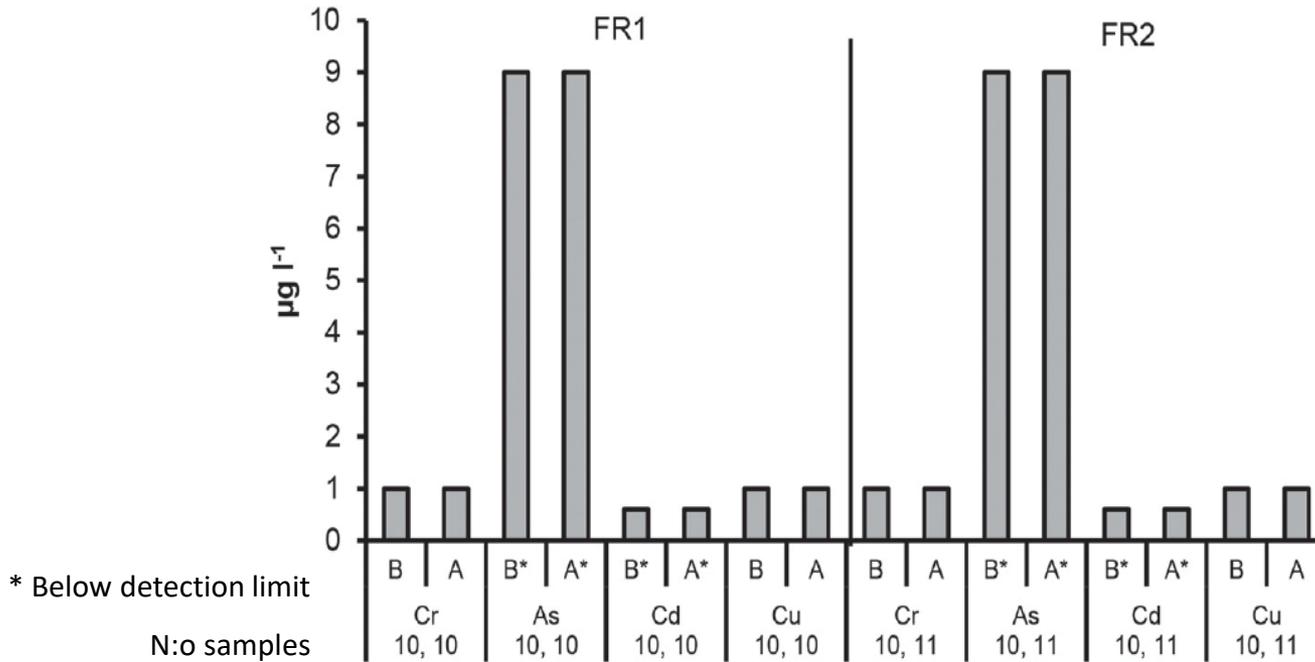
Mean,
std. Dev.



Mean,
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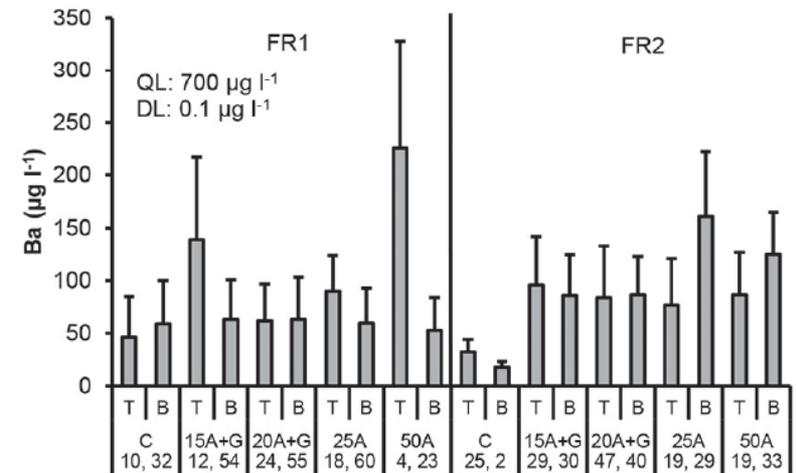
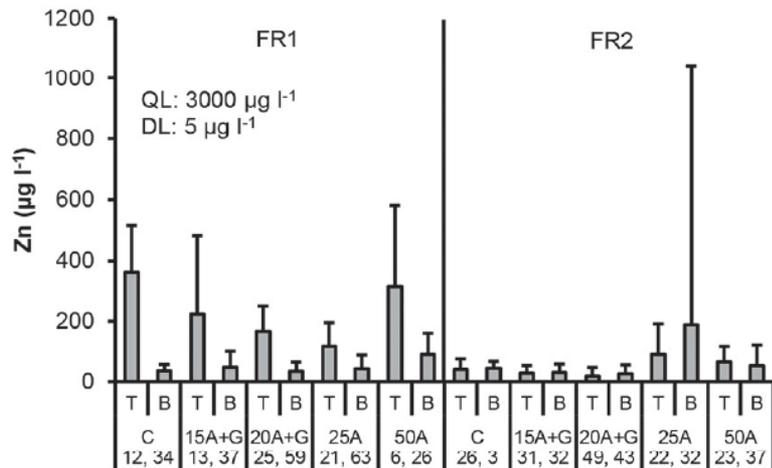
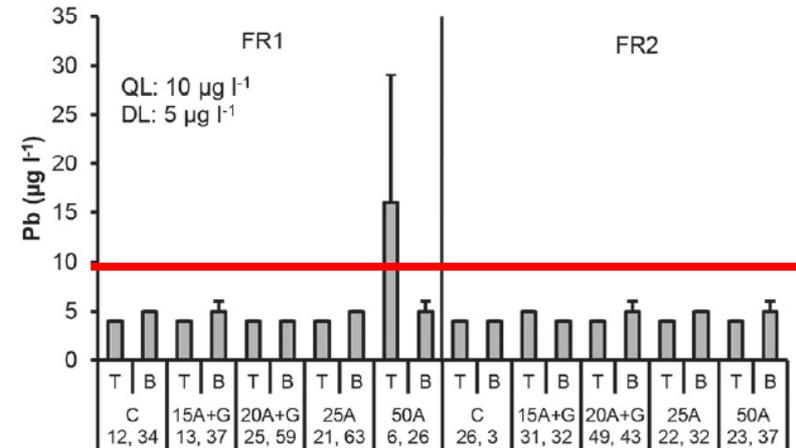
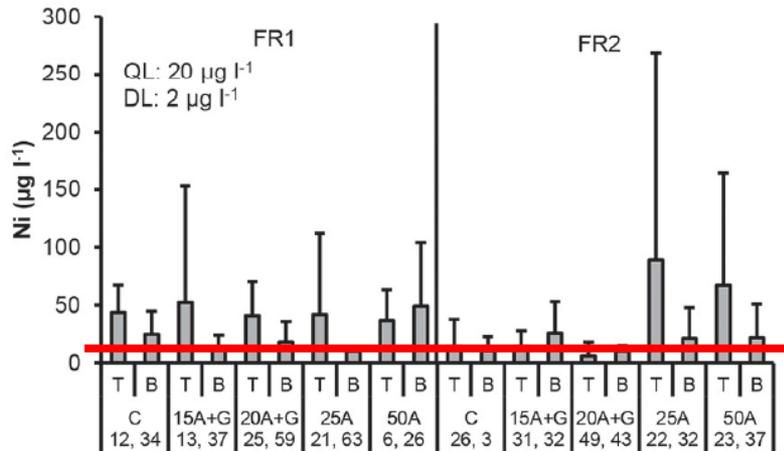
- QL = quality limit, DL = detection limit of analytical equipment.

Ditch water



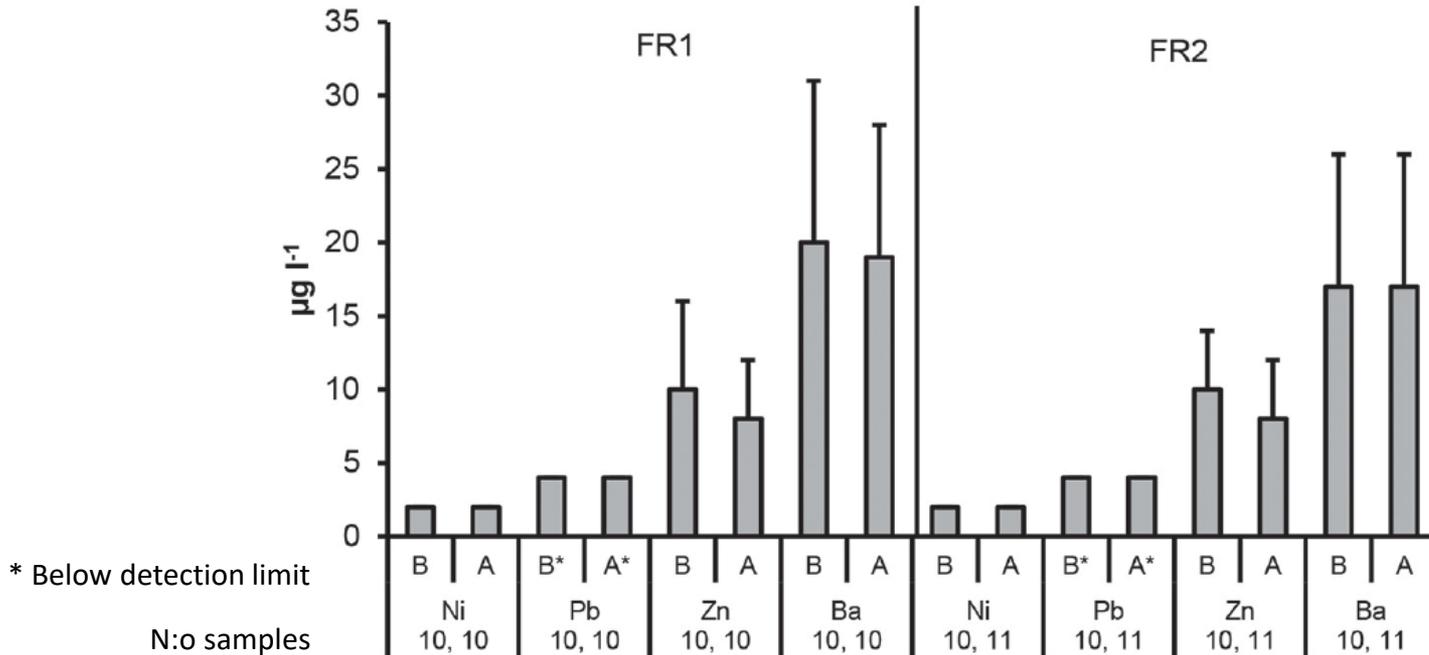
- collected before (B, no ash effect) and after (A, incl. possible ash effect) the ditch crossed the experimental forest road containing ash layers (FR1, FR2).

Concentrations in percolation water



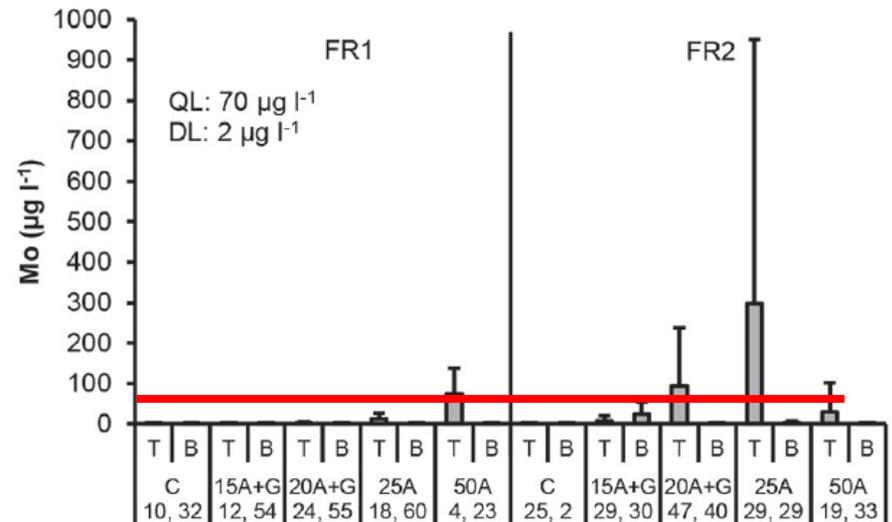
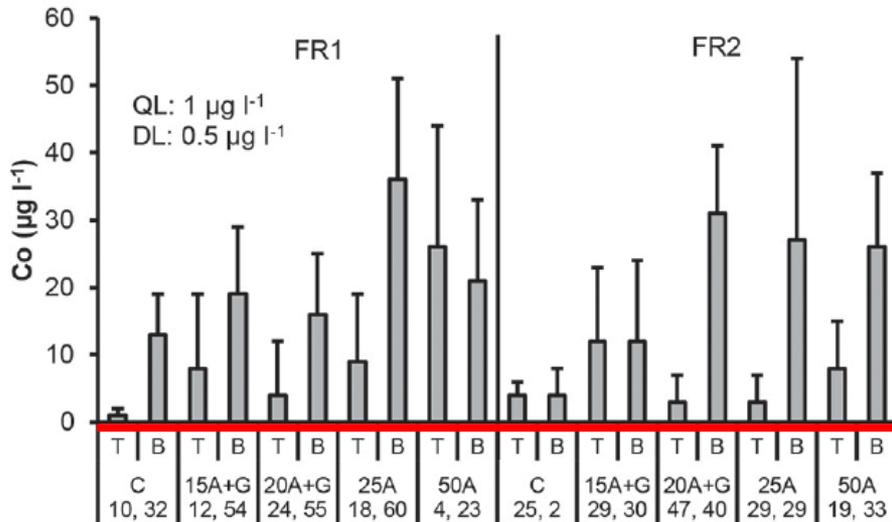
- QL = quality limit, DL = detection limit of analytical equipment.

Ditch water



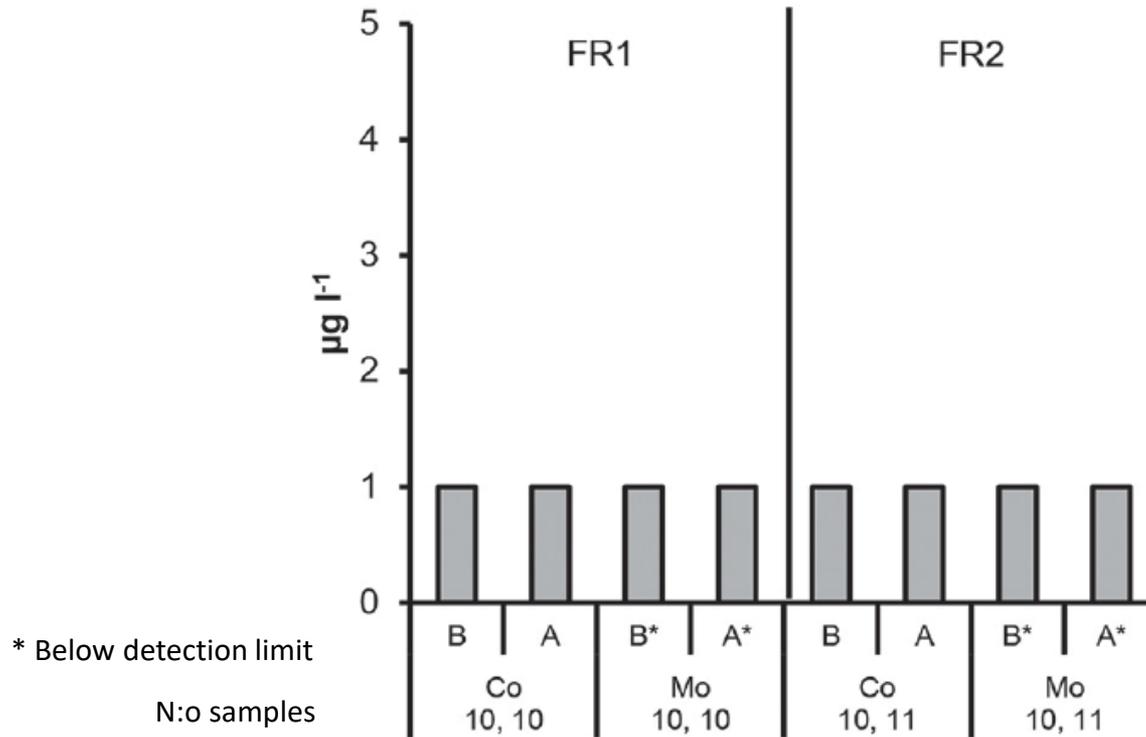
- collected before (B, no ash effect) and after (A, incl. possible ash effect) the ditch crossed the experimental forest road containing ash layers (FR1, FR2).

Concentrations in percolation water



- QL = quality limit, DL = detection limit of analytical equipment.

Ditch water



- collected before (B, no ash effect) and after (A, incl. possible ash effect) the ditch crossed the experimental forest road containing ash layers (FR1, FR2).

Conclusions

- The mean concentrations of all the measured parameters were low in many treatment plots that contained ash, and the mean concentrations decreased in the road structure from the top to the bottom level of the road.
- Some lysimeters close to the ash layer had elevated concentrations of heavy metals (e.g. As, Ni, Mo) and Ba in percolation water, when others necessarily did not.
- The ash containing forest roads did not negatively affect the concentrations of water in ditches that crossed the forest roads.
- The leaching from the forest roads seems to take place from some points from the ash layer and not evenly from the entire ash layer.
- Risk for leaching should be considered if the points with high concentrations are widely spread in the road, and water from these parts is flowing directly to side-ditches and groundwater without percolation through the soil material of the road structure.
- The risk for leaching of heavy metals and Ba seems to be low.

Thank you!

- Further information:
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- Any questions?

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Leaching of heavy metals and barium from forest roads reinforced with fly ash

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Highlights

- Heavy metal concentrations were generally low in percolation and ditch water samples of ash roads, but elevated concentrations were found in some parts of ash roads.
- Risk for heavy metal leaching is negligible if road parts producing high concentrations are rare.

Abstract

The aim of this study was to determine the effect of leaching of heavy metals (Cr, As, Cd, Cu, Ni, Pb, Zn, Co, Mo) and earth-alkaline metal, barium (Ba), on the percolation and ditch water quality from the forest roads that contained ash in the road structures. Water quality was studied in the immediate vicinity below the ash layers as well as deeper in the road structure. Water quality was also determined in the drainage water in ditches that crossed the forest roads. A mixture of wood and peat based fly ash was used in the road structures. The treatments were: 1) no ash, 2) a 15 cm layer of ash/gravel mixture, 3) a 20 cm layer of ash/gravel mixture, 4) a 25 cm layer of ash, and 5) a 50 cm layer of ash. Large variation in the concentrations of Cr, As, Cu, Ni, Pb, Mo and Ba in the percolation water, even within the same treatment, caused difficulties to generalize the results. The concentrations of Cr, As, Ni, Pb, Mo and Ba in water samples were high in some treatment plot lysimeters containing ash compared to the control (no ash). On the other hand, many lysimeters had low and similar concentrations in water samples in the treatment plots containing ash compared to concentrations in the control plots. The ash in the roads did not affect the concentrations in the ditches. The leaching is uneven and seems to take place only from some parts of the ash layer. Risk for leaching is minimal if such parts are not widely spread.

Keywords lysimeter; fly ash; recycling; forest road rehabilitation; environmental impact assessment; low-volume road

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