



Research paper

Elements availability in soil fertilized with pelletized fly ash and biosolids

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ABSTRACT

The aim of the study was to evaluate the impact of combined and pelletized industrial residues on availability and mobility of nutrients and potentially toxic elements in soil, plant growth and element uptake. Plant pot experiments were carried out using soil to which 2% of pelletized residue containing biosolids mixed with either municipal solid waste incineration fly ash (MFA) or biofuel fly ash (BFA) was added. The tests showed that the plant growth did not correspond to the content of available nutrients in fertilised soil. MFA application to soil resulted in elevated concentrations of P (506 mg/kg), As (2.7 mg/kg), Cd (0.8 mg/kg) and Pb (12.1 mg/kg) in soil, lower plant uptake of Al (25 mg/kg) and Ba (51 mg/kg), but higher accumulation of As (4.3 mg/kg) and Cd (0.3 mg/kg) in plants compared to the unamended soil and soil amended with BFA. On average, the biomass of the plants grown in the soil containing MFA was larger than in other soils.

Considering the use of industrial residue mixtures as soil amendments or fertilizers, the amount of added elements should not exceed those taken up by plants, by this preventing the increase of soil background concentrations.

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1. Introduction

Currently, the recycling of industrial residues such as biofuel fly ash, an air pollution control residue from combustion of wood-based fuel and municipal sewage sludge (biosolids) to soil as the source of nutrients is encouraged (Swedish Forest Agency, 2008; Swedish EPA, 2002). However, due to a very high alkalinity of fresh ash (pH ≈ 12), a direct application to soil is not recommended. Application of the powdered residue to soil may lead to phytotoxic effects and suppressed plant growth (Brännvall et al., 2014a). Results of this study showed that powdered residues such as fly ash could be toxic to the plants, especially those fly ashes from the municipal solid waste incineration. Taking into account the results from the previous studies by Brännvall et al., 2014a and Brännvall et al., 2014b industrial residue mixtures (biosolids and fly ashes) have been further treated. It is known that processing of the

residues, e.g. through pelletization, granulation and ageing, might transform the residues into a product that has a lower pH and is easier to handle. Granulated/pelletized residues have a smaller specific surface area compared to powdered ones, which leads to a reduced reactivity and a slower release of constituents (Eriksson, 1998; Larsson and Westling, 1998; Steenari et al., 1998; Nieminen et al., 2005). This is advantageous for the release of potentially toxic elements, which is expected to be smaller than from fresh residues. A slow release of P and N might also reduce the loss of nutrients from the fertilised areas.

The aim of this study was to evaluate the impact of combined and pelletized industrial residues containing biosolids mixed with either municipal solid waste incineration fly ash or biofuel fly ash on availability and mobility of nutrients and potentially toxic elements in soil and their uptake by plants.

Detail characterisation of raw residues and their mixtures was performed are presented in Brännvall et al., 2014b. Also element availability for plants when powdered i.e. not pelletized fly ash and biosolid mixtures were used and are described in Brännvall et al., 2014a. In this paper pelletized residue mixtures as soil fertilizers and element availability for plants is evaluated.

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2. Materials and methods

2.1. Materials

2.1.1. Fly ash

Fresh and dry (without added water) biofuel fly ash from combustion of tree bark was collected from a fluidized bed incinerator in Northern Sweden. Municipal solid waste incineration fly ash was collected from a storage pile in a landfill where the ash was transported from a waste incinerator. The fuel comprised household waste, animal by-products, recycled wood chips, sleepers containing creosote and other solid waste. The sampling of this ash was carried out at two separate occasions.

2.1.2. Biosolids

Dewatered, anaerobically digested biosolids were collected from a storage pile at a municipal wastewater treatment plant in Northern Sweden.

2.1.3. Soil

Forest mineral topsoil (at 10–20 cm depth) collected in Luleå, Sweden, was air dried, homogenized and sieved to a <4 mm fraction prior to the experiment with pelletized residue mixtures. The particle distribution (ISO/TS 17892-4) analysis resulted in 7.1% silt/clay, 38.9 fine sand, 33.1% course sand and 28% gravel (according to Brady and Weil, 2008).

The detail analysis of soil can be found in Nilsson, 2012.

2.2. Preparation of residue mixtures

Biosolids (60% of dw (dry weight)) were mixed with either biofuel fly ash or municipal solid waste incineration fly ash (40% of dw), dried at 50 °C for 48 h and pelletized, called BFA and MFA, respectively, using a vibrating perforated plate (Van Aarsen type CT 20, No 88732, The Netherlands). The size of pellets is 0.5 mm diameter and ~1.2 mm length.

2.3. Soil fertilization

2.3.1. Soil mixtures

800 g of air-dry soil and soil mixed with 2% pellets (BFA or MFA) were placed in plastic pots (of 1 l volume) in triplicates. Soil without fertilisers (unamended soil) was used as a control. The pots were sown with 1 g of a grass seed mixture composed of 90% grass and 10% herb species and is intended for re-vegetation of sandy, nutrient deficient soils. The detailed composition of the mixture is given in Kumpiene et al. (2007). The pots were placed under artificial light for 12 h on–12 h off illumination regime and were kept at a temperature of 14 ± 1 °C holding constant soil moisture level by manual irrigation with distilled water. After five weeks, the pots were placed under natural light and kept at ca 23 °C in order to promote plant growth.

2.3.2. Soil pore water

Soil pore water was collected at the beginning of the experiment (first sampling – 1st) and 7 weeks later just before harvesting the plants (second sampling – 2nd) using the Rhizon soil moisture samplers (Eijkelkamp, the Netherlands) in acid-washed, vacuumed 100 ml glass bottles. The pH and EC were measured immediately after sampling in small aliquots of the samples. The remaining samples were stored refrigerated at 4 °C prior to element analysis.

2.3.3. Plants

The plant shoots were harvested after 7 weeks for biomass measurements and element concentration analysis. The plants

were washed with double distilled water, dried for 72 h at 60 °C, weighed for dry mass determination, then ground using a stainless steel grinder and analysed for chemical elements by the accredited laboratory ALS Scandinavia.

2.4. Evaluation methods

2.4.1. Sequential chemical extraction

Bulk soil (Soil B) was carefully separated from the rhizosphere soil (Soil R) and air-dried prior to the sequential extraction. Six steps were applied for element fractionation in 1 g of the bulk and rhizosphere soil samples according to the procedure described in (Brännvall et al., 2014b). In brief, the following fractions were extracted: Fraction (I): Exchangeable, using NH₄OAc adjusted to pH 6.5 with acetic acid (HOAc); Fraction (II): Bound to carbonates (acid-soluble), using NaOAc adjusted to pH 5.0; Fraction (III): bound to poorly crystalline Fe(III) oxyhydroxides (reducible), using NH₄-oxalate adjusted to pH 3.0; Fraction (IV): bound to crystalline Fe–Mn oxides (reducible), using NH₂OH–HCl in 25% (v/v) HOAc adjusted to pH 2; Fraction (V): bound to organic matter and secondary sulphides (oxidizable), using 30% H₂O₂; and Fraction (VI): Residual fraction (non-soluble), using aqua regia (HNO₃:HCl, 1:3 v/v).

2.4.2. Analytical methods

Concentrations of elements in the pore water and extracts were measured by inductively coupled plasma optical emission spectroscopy (ICP-OES, Perkin Elmer Otima 2000 DV). Chloride (Cl⁻), phosphate (PO₄⁻) and sulphate (SO₄²⁻) content was determined spectrophotometrically (AACE Quattro, Bran + Luebbe, Germany). Total N in solid sample was analysed by the accredited laboratory ALS Scandinavia according to ISO 11261 method. The total element concentration in soil was calculated from the sequential extraction analysis by summing all 6 fractions of each element. The pH and EC of Soil B and Soil R soil was measured in 1:2.5 v:v soil-deionised water suspensions after 30 min equilibration.

2.4.3. Acid neutralization capacity (ANC)

ANC was determined by taking 0.5 g of ash suspended in 55 ml of de-ionized water and titrated with 0.1 M HCl, while stirring until the end-point pH 3 was reached. A TitroLab system (Radiometer

Table 1

Properties of pellets made of biofuel fly ash mixture with biosolids (BFA) and MSWI fly ash mixture with biosolids (MFA).

	BFA	MFA
TS (%)	77.2 ± 0.5	74.1 ± 0.3
pH	7.90 ± 0.03	7.70 ± 0.02
EC (mS/cm)	2.60 ± 0.04	7.30 ± 0.03
Macronutrients (mg/kg)		
Ca	62,300 ± 3400	76,000 ± 1700
K	13,100 ± 300	17,800 ± 300
Mg	9300 ± 500	9700 ± 200
N	13,800	16,700
P	21,300 ± 600	21,500 ± 1500
S	13,000 ± 600	19,900 ± 800
Trace elements (mg/kg)		
Cr	98.0 ± 4.4	218 ± 9
Cu	185 ± 14	854 ± 42
Fe	22,000 ± 600	25,100 ± 1000
Mn	2968 ± 211	807 ± 24
Ni	54 ± 2	66 ± 1
Zn	1063 ± 104	8584 ± 411
Potentially toxic elements (mg/kg)		
Al	41,700 ± 1400	51,300 ± 2600
As	126 ± 13	255 ± 5
Cd	5.9 ± 0.4	76.2 ± 2.4
Pb	42.0 ± 3.6	1815 ± 98

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