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IMPACT OF WOOD- AND PEAT-ASH APPLICATION ON THE POST-FERTILIZATION ELEMENT CONCENTRATIONS OF BIRCH IN A CUT-AWAY PEATLAND

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SUMMARY

The impact of wood- and peat-ash application on the post-fertilization element contents in birch leaves and roots were studied in a cut-away peatland. Six treatments of wood-ash, peat-ash, biotite or Forest PK-fertilizer were used in different mixtures and quantities corresponding to 50 kg ha^{-1} of phosphorus. Ten years after the fertilization, the foliar phosphorus concentrations of birch were on an adequate level, whereas the sufficiency of potassium and boron for the planned 30 years' rotation is uncertain. We found also that even if the cadmium concentrations remained low both in roots and leaves of birch, the dissolution rate of different heavy metals in ash, and their uptake and accumulation in different parts of plants varied considerably.

KEY WORDS: afforestation, *Betula pubescens* Ehrh., heavy metals, roots, shoots

INTRODUCTION

Recycling of wood- and peat-ash as a forest fertilizer has been studied extensively in recent decades, mainly in Finland and in Sweden. Apart of nitrogen (N), ash contains all the elements required for plant growth. Thus ash is suitable for N-rich peatlands where tree growth is usually limited by availability of phosphorus (P) and potassium (K), sometimes also boron (B). Wood-ash is reported to increase tree growth in peatlands drained for forestry and the influence is reported to last up to 50 years or more (Moilanen *et al*., 2002). In afforested cut-away peatlands both wood- and peat-ash are proved to be suitable for the initial fertilization (Huotari *et al*., 2007; 2008; 2009; 2011), but the later effect and duration of ash-fertilization are not well known.

In addition to the valuable mineral nutrients, ash contains also heavy metals, e.g. aluminium (Al), copper (Cu), zinc (Zn), lead (Pb), manganese (Mn), cadmium (Cd), nickel (Ni). Some of these metals (e.g. Mn, Cu and Zn) are essential trace elements for plants, but some (e.g. Pb and Cd) are harmful or even toxic to organisms even in relatively small quantities. Because of its severe toxicity and relatively high mobility, Cd is considered to be the most harmful heavy metal in ash.

The post-fertilization effects of ash application on the element concentrations in plants vary among different plant groups and species (Huotari *et al*., 2011). The levels of Cd and other harmful heavy metals have, however, remained at a low level in the above-ground parts of plants despite the ash application (Moilanen *et al*., 2006; Huotari *et al*., 2011). On the other hand, the post-fertilization heavy-metal concentrations may also vary between the-above-ground and below-ground parts of plants as reported for tree seedlings under laboratory conditions (Österås *et al*., 2000).

Ash application is found out to increase the concentrations of exchangeable and total Cd in peat substrate (Pihlström *et al*., 2000). Thus, it is possible that instead of shoots, the Cd taken up by plants accumulates into roots. However, the impact of ash application on the heavy metal levels in the roots of birches has not been studied earlier in peatlands. For these reasons we studied the effect of ash-fertilization on the element (Al, B, Ca, Cd, chromium (Cr), Cu, iron (Fe), K, Mg, Mn, natrium (Na), Ni, P, Pb, sulphur (S), Zn) concentrations in the leaves and roots of 10 years old downy birch. Here we represent the preliminary results concerning some of the most common growth limiting nutrients (K, P, B) and some heavy metals (Al, Cd, Pb).

MATERIALS AND METHODS

The experimental field was established in 2000 on a cut-away peatland located in Northern Ostrobothnia (64°44´N, 25°16´E, 45 m a.s.l.), in Finland. Detailed experimental design is previously published (Huotari *et al*., 2007; 2008; 2009; 2011). In May 2001 the following six fertilization treatments were applied: 1) unfertilized, 2) wood-ash 7.9 t ha^{-1}, 3) mixed-ash 6.3 t ha^{-1} (wood-ash 3.9 t ha^{-1} + peat-ash 2.4 t ha^{-1}), 4) peat-ash 4.8 t ha^{-1}, 5) peat-ash 4.8 t ha^{-1} + biotite 1.5 t ha^{-1} and 6) Forest PK-fertilizer 0.5 t ha^{-1}. The doses of the fertilizers were adjusted corresponding to 50 kg ha^{-1} of P, as recommended for peatland forests (Paavilainen and Päivänen, 1995).

In June 2011 nine downy birches (h, 2-3 m) per each fertilization treatment were randomly chosen to determine the nutrient and heavy metal concentrations in the roots and leaves. The entire birches with root lumps (d, 60 cm) were dug up. The roots were separated from the peat and graded into two groups, < 2 mm and 2-10 mm, based on the diameter. One sample of leaves per each tree was collected. All the plant samples were dried, ground to a homogenous powder and digested in HNO_3/H_2O_2 –solution using a microwave oven. Element contents were determined from the solution by ICP-emission spectrometry in the Metla laboratory in Vantaa.

RESULTS

Nutrients

Ten years after the fertilization the P concentrations in birch leaves were highest, about 2 mg g^{-1}, in the areas fertilized using mixed-ash, peat-ash or peat-ash+biotite (Fig. 1). At the same time the foliar P concentrations in the areas fertilized using wood-ash or Forest PK-fertilizer were about 1.7 mg g^{-1} and in the unfertilized area 1.1 mg g^{-1}.

The foliar K concentrations varied from 7.8 to 9.2 mg g^{-1} in the areas fertilized using wood-ash, mixed-ash, peat-ash+biotite or Forest PK-fertilizer (Fig. 1). Meanwhile the foliar K concentration in the area fertilized with peat-ash was less than 7 mg g^{-1}, which was equal to the unfertilized area. The concentration of B in birch leaves was highest (27 mg g^{-1}) in the unfertilized area and smallest (20 mg g^{-1}) in the area fertilized using Forest PK-fertilizer (Fig. 1).

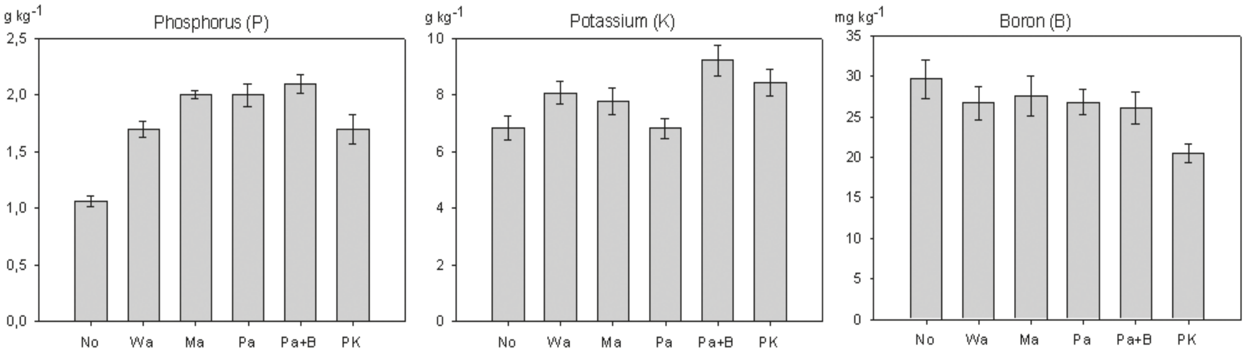

Fig. 1. The concentrations of P (g kg^{-1}), K (g kg^{-1}) and B (mg kg^{-1}) in the leaves of downy birch ten years after the ash application. Treatments: No = unfertilized, Wa = wood-ash, Ma = mixed-ash, Pa = Peat-ash, Pa+B = Peat-ash +biotite, PK = Forest PK-fertilizer. Error bars indicate standard errors of means (n=9).

Heavy metals

Ten years after the fertilization treatments the concentrations of Cd in the leaves and roots of downy birch in all the fertilized areas were lower in comparison to the unfertilized control treatment (Fig.2). Overall, the Cd concentrations were higher in the leaves than in the roots, but the differences were moderate.

The foliar Al concentration of birches was greatest, 50 mg kg^{-1}, in the area fertilized using mixed-ash and smallest, 37 mg kg^{-1}, in the area fertilized using peat-ash (Fig. 2). At the same time the concentration in the unfertilized area was 34 mg kg^{-1}. The Al concentrations in the coarse roots were about 3-6 times higher, and in the fine roots about 12-22 times higher than the concentrations measured in the leaves.

The concentrations of lead (Pb) were below the reliable detection limit (< 0.78 mg kg^{-1}) in majority of the samples. Consequently, these results are not discussed in this context.

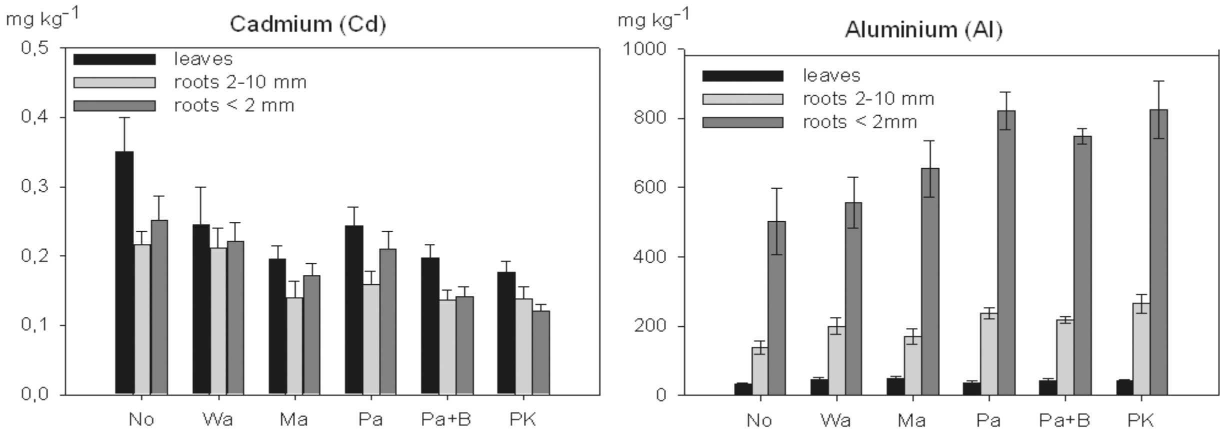

Fig. 2. The concentrations (mg kg^{-1}) of Cd and Al in the leaves and roots of downy birch ten years after the ash application. Treatments: No = unfertilized, Wa = wood-ash, Ma = mixed-ash, Pa = Peat-ash, Pa+B = Peat-ash +biotite, PK = Forest PK-fertilizer. Error bars indicate standard errors of means (n=9).

DISCUSSION

In the fertilized areas, the birches of dense energy-wood stand were on average 2-3 m high and indicated no visible nutrient deficiency symptoms, whereas the sporadic birches on the unfertilized area were mainly stunted. We found that the foliar P concentrations of 10 years old birches in all the fertilized areas were on the level that is estimated to be adequate for the growth of birches (Reinikainen, 1967). Meanwhile, the P concentrations in the unfertilized area were about 30 % smaller than the values reported for birches suffering from severe P shortage (Hytönen and Kaunisto, 1999), which confirms the poor availability of P in cut-away peatlands.

Only the treatments using peat-ash + biotite or Forest PK-fertilizer had increased the foliar K concentrations of birches above the estimated deficiency limit (<7-8 g kg^{-1}) for the growth of birches in drained peatlands (Sarjala & Kaunisto, 2002). Even though downy birch leaves are reported to display no visible chlorosis until the K concentration is as low as 3.9 g kg^{-1} (Reinikainen, 1967), K may be a limiting factor for tree growth within the planned 30 years rotation time of this energy-wood stand. Since K is reported to be easily released from wood-ash, a large proportion of available K may have already leached from the site. On the other hand, both the content and solubility of K in peat-ash is usually low (Nieminen *et al*., 2005), which may explain the relatively poor effect of peat-ash on the K concentration in birch leaves. Also the amounts of applied K varied considerably among the fertilization treatments, since the doses of the fertilizers were adjusted corresponding to 50 kg ha^{-1} of P.

Ten years after the fertilization the foliar B concentrations in all the fertilized areas were smaller than in the unfertilized area, indicating that the birches may already suffer from B deficiency. We found also that the foliar K, B and P concentrations of birch had decreased in all the treatments as compared to the values measured six years earlier (Huotari *et al*., 2011). Thus, enrichment of ash-fertilizers or additional fertilization treatments may be needed to ensure adequate nutrient levels for the planned rotation time. However, since no valid threshold values for the P, K or B deficiency of downy birch are available for Finnish conditions, the sufficient nutrient levels of birches grown for energy-wood in dense stands need to be defined.

Our results proved that the dissolution rate of different heavy metals in ash, and the heavy metal uptake and accumulation in different parts of plants varied considerably. The Al concentrations in the roots were considerably higher than in the leaves, indicating that the Al taken up by birches accumulates into roots. Furthermore, the Al concentrations in birch leaves in the ash-fertilized areas were about 4-6 times higher, and in the unfertilized and PK-fertilized areas 2-3 times higher than the concentrations measured six years earlier (Huotari *et al*., 2011). Surprisingly, the concentrations of Cd in birch roots were slightly smaller as compared to the leaves, despite the ash application. In addition, the foliar Cd concentrations were only half of those measured six years earlier (Huotari *et al*., 2011). Owing to the high liming capacity of ash, the ash-induced decrease in Cd accumulation may be a long-term phenomenon (Moilanen *et al*., 2006). Thus, to predict the influences of ash fertilization on heavy metal cycling in forest ecosystem, long-term studies on the element concentrations in different parts of the plants, and on the rates of dissolution of different ash products are needed.

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