The effect of harvest period on the total uptake of metals by willows and poplars

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Abstract

The development and evaluation of environmental technologies for the removal of metals from contaminated soils is a high priority research. Results from pot experiments showed sufficient extraction capacity by several plants, fast growing trees becoming due to their easy biomass valorization among the most required. The evaluation of pot experiments in field conditions is lacking. Field experiments were set up on anthropogenically medium contaminated soil by Cd and Pb in 2008 and 2009 to evaluate the remediation potential of harvested mature trees and to take into account autumn harvest containing trunks, twigs and leaves as well. The results showed that first harvest after four years was about three fold lower than the second one after another two years. The metal contents in trunks and twigs adversely correlated with the yield. Biomass yield was more important for the metal removal, the remediation factor reached up to 1 % in the second harvest in case of Cd and willow, for Pb was negligible 0.001 % for both plants. Autumn harvest including leaves showed twice more higher Cd removal than winter one in case of willows, differences for Pb were lower for both plants.

Keywords: Cadmium, Lead, Phytoextraction, Field experiment, Remediation factor

1. Introduction

Environmentally friendly remediation methods can help with the improvement of contaminated sites. The importance of development of promising technologies to decontaminate soils is increasing (Melo *et al*. 2008). Phytoextraction, belongs among techniques removing contaminants from the soil, accumulating them in above ground biomass, and removing them from the field with the harvest. This technique can continually remove metals and offer final solution therefore is really challenging (Wenzel *et al*. 1999). Many plant species have been tested for their sufficient element uptake and the ability to accumulate elements in their aboveground biomass. According to our former experience (Vysloužilová *et al*. 2003a; Vysloužilová *et al*. 2003b; Fischerová *et al*. 2006), among plants suitable for phytoextraction of metals belong fast growing trees, mainly several species of willows and poplars. They are able to take up metals and translocate them to the aerial parts, they grow relatively fast and their roots are able to intensively penetrate upper soil layers (Lonardo *et al*. 2011). They showed promising results at weakly and medium contaminated soils (Jensen *et al*. 2009). Produced willows and poplars biomass can be easily used for energy production (Pulford and Dickinson 2006). Phytoextraction potential of *Salix* and *Populus* clones has been tested in several pot experiments with Cambisol moderately contaminated with 5.46 mg Cd kg^{-1}, and 956 mg Pb kg^{-1} revealed that *Salix dasyclados* was able to accumulate more cadmium than lead. Up to 41 mg Cd kg^{-1} was found in willow twigs whereas *Populus trichocarpa* prefer to take up more Pb up to 17.3 mg Pb kg^{-1}. Total metal uptake express as Remediation factor (RF) of both trees was similar to highly recommended hyperaccumulating plants (Fischerová *et al*. 2006). Vysloužilová *et al*. (2003a) confirmed high phytoextraction potential of willow clones in pot experiments in moderately contaminated soil. Within three years *Salix smithiana* was able to remove by above ground biomass more than 20% of total Cd amount at medium contaminated soils but very low amount at heavily contaminated one. Phytoextraction effectiveness is more often tested in pot and laboratory experiments, but their results can show only theoretical phytoextraction potential of trees, because they are usually annually harvested including leaves, they are planted in limited volume of soil, properly treated and regularly watered. Longer field tests are lacking. Maxted *et al*. (2007) performed four years field experiments with *Salix* clones. The best clones removed within the whole period up to 15–20% of the available soil Cd content. The main objectives of the presented study were i) to evaluate accumulation ability of Cd and Pb by willow and poplar clones at the harvests of four and six years trees after set up of field experiment ii) to compare the controversial autumn harvest including leaves with traditional winter one where only wood was removed from the field.

2. Material and Methods

The first part of field experiment was established in April 2008 on multi-risk elements (RE) contaminated agricultural soil in Podlesí (49°42'24"N, 13°58'32"E), near the town of Příbram, 58 km south of Prague. The mean soil pH_{H2O} was 5.66 and pH_{KCl} 5.27. Major contaminants were

Cd and Pb, pseudo-total (*Aqua regia*-soluble) concentrations of mentioned elements in the top soil were as follows: 7.3 mg Cd kg^{-1} and 1368 mg Pb kg^{-1}. The experimental area was split into individual 8 rows (experimental units), 1.3 metres wide. Each row contained one treatment. Eight replicates with the area of 7.5 x 1.3 m were set for each treatment. Two promising clones, autochthonous *S.* × *smithiana* clone S-218 (hereafter denoted S2) and hybrid clone *Populus maximowiczii* × *P. nigra* J-105, also known as Max-4, (hereafter denoted P1) were selected. Shoots of cuttings were harvested in February 2012 after four vegetative seasons and again in February 2014 after the next two seasons. The second part of field experiment was established in April 2009 on the same site with the same clones. On this part of experiment were also 8 rows with identical experimental design described above. Each row was split into halves (experimental units).). Each replicate covered the area 2.5 × 1.3 m. Eight replicates was set up for every treatment. The first halves of rows were harvested in September (autumn harvest) and all the second halves of rows were harvested in February (winter harvest). For the first time whole plots were harvested after three years in February 2012. For the second time first half of each plot was harvested after two years in September 2013 (leaves and twigs) and second half of each plot was harvested in February 2014 (only twigs). Only the second harvest is presented in this manuscript. The trunks were cut 20 cm above the soil surface. Only in September 2013 leaves were taken off a collected separately. At the others harvests only trunks with twigs were collected, and checked for fresh biomass. Harvested shoots were dried at 60 °C and weighed again. Dry biomass samples were ground using a stainless steel Retsch friction mill (Retsch, Haan, Germany; particle size 0–1 mm). The total concentrations of elements in the biomass of the wood as well in the leaves were determined after dry ashing decomposition procedure using inductively coupled plasma with optical emission spectroscopy (ICP-OES; VARIAN VistaPro, Australia). All statistical analyses were performed using the Statistica 10.0 (www.statsoft.com). All data were checked for homogeneity of variance and normality (Levene and Shapiro–Wilk tests). Collected data did not meet assumptions for the use of analysis of variance (ANOVA) and were thus evaluated by the non-parametric Kruskal–Wallis test. In diagram, clones with the same lowercase letter were not significantly different.

3. Results and Discussion

The results of the first experiment representing differences in biomass development and metal plant accumulation after first four years (2012) of experiments and after another two years (2014). The biomass development in the first four years was significantly lower for both plant species, compare to another two years. The estimated yields of S2 clone was 3.3 and of P1 clone 5.1 t ha^{-1} in the first harvest (2012). The estimated yields of S2 clone was 11.7 and of P1 clone 14.1 t ha^{-1} in the second harvest (2014). The results showed, that for proper biomass yield estimation there is necessary to provide longer term experiments. The biomass growth affected Cd and Pb concentrations in the wood. Both elements were generally less accumulated in the wood harvested in second harvest in 2014 compared to clones harvested in first harvest in 2012 (Fig. 1.). These findings may be explained by "dilution effect" showing limited ability of both plants to accumulate metals under higher biomass production in the second harvest compare to the first one. Presented results are in good agreement with Tinker *et al*. (1981) and Hejcman *et al*. (2010), they also showed that high growth rate of the plant may cause internal decrease of trace elements contents in biomass. The higher Cd concentration was recorded for *Salix* clone S2 in both harvests and conversely the higher Pb concentration was recorded for *Populus* clone P1 (Fig. 1.). This is consistent with results from pot experiments of Fischerová *et al*. (2006).

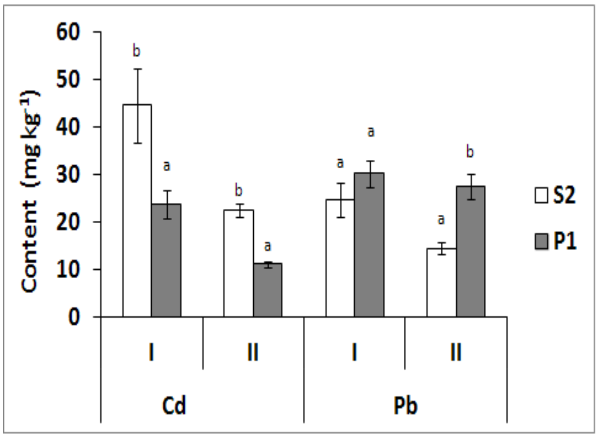

Figure 1. Effect of clone and harvest period on the Cd and Pb contents in twigs of clones *S. smithiana* (S2) and *P. maximowiczii* × *P. nigra* (P1) harvested in first harvest in 2012 (I) and in second harvest in 2014 (II).

The total metal removal represented values taken off from the field by harvests. Even though the Cd and Pb concentrations were higher in first harvest than in the second one, the Cd and Pb total removals were generally higher in the second harvest (Fig. 2.). Amount of Cd removed by willows within first four years was identical with one year removal within the second harvest. The Cd removal by poplars was less promising for both harvests. The same behavior was found in the case of Pb, but the uptake was significantly higher in the case of poplar than willow. Total values of extracted Pb corresponded with Cd, but Pb content in the soil was 30 times higher confirming stronger soil binding of Pb than Cd. Lower Pb removal is clearly seen from Rf coefficients reaching about 0.001 %, but Cd Rf reached almost 1% during second harvest. Our results clearly showed that efficiency of phytoextraction for risk elements by fast growing trees is driven to a large extent by biomass yield. Similar results were also presented by Laureysens *et al*. (2004). The results of the second experiment representing differences between clones harvested in the autumn together with leaves and traditionally in winter to harvest only trunks. Leaves biomass extended total yield by 26 and 30 % in the case of willows and poplars respectively, supporting total removal of metals. Autumn harvested represented the highest content of Cd in willow leaves (Fig. 3).

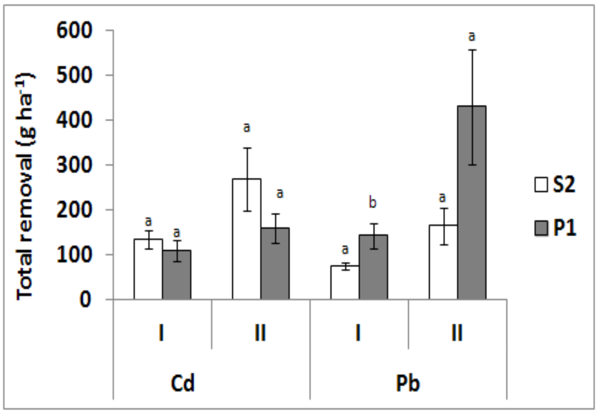

Figure 2. Effect of clone and harvest period on the Cd and Pb total removal by twigs of clones *S. smithiana* (S2) and *P. maximowiczii* × *P. nigra* (P1) harvested in first harvest in 2012 (I) and in second harvest in 2014 (II).

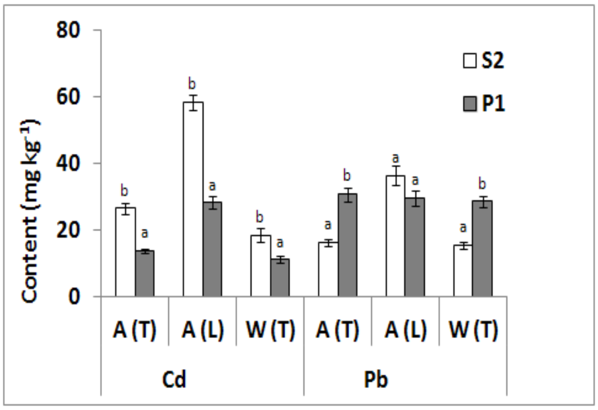

Figure 3. Effect of clone and harvest term on the Cd and Pb content in twigs (T) and in leaves (L) of clones *S. smithiana* (*S2*) and *P. maximowiczii* × *P. nigra* (P1) harvested in autumn (A) and in winter (W).

Leaves of both willow and poplar clones contained twice higher Cd than twigs. This trend is in good agreement with the previous results obtained for different Salix and Populus clones in pot experiments by Bedell *et al*. (2009) and in the field trial by Hu *et al*. (2014). Leaves accumulation of lead was also highest in the case of willows, poplars leaves and twigs accumulation was comparable. The metal accumulation by trunks and twigs was similar to previous experiment. Clone S2 accumulated in twigs more Cd than clone P1, but the lead accumulation was opposite higher at P1, fort both elements the differences were significant.. Relatively low differences between Pb accumulation in twigs and leaves of poplar can be explained by low mobility of this element. It was found, that Pb accumulated mainly in the bottom part of plants, especially in roots. Pb was bound on cell walls due to good affinity to galacturonic acid (Połeć-Pawlak *et al*. 2007; Seregin and Kozhevnikova 2008). Metal accumulation in twigs in autumn and winter harvests were comparable for both plants. Shoots of both clones removed higher amounts of Cd and Pb from soil in autumn harvest than in winter harvest (Fig. 4.). This was not caused just by high Cd and Pb contents in leaves and their reasonable yield, but also primarily higher yield of biomass in autumn harvest than in winter one. The total dry yield of S2 clone was 24.1 and of P1 clone 17.7 t ha^{-1} in the autumn harvest (September 2013) and 17.0 and 12 t ha^{-1} in the winter harvest (February 2014) respectively, calculated from 2 growing seasons after the last harvest

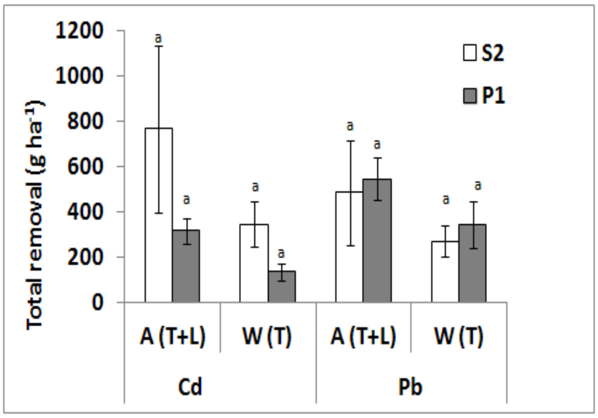

Figure 4. Effect of clone and harvest term on the Cd and Pb total removal by twigs (T) and leaves (L) of clones *S. smithiana* (*S2*) and *P. maximowiczii* × *P. nigra* (P1) harvested in autumn (A) and in winter (W).

Due to mentioned differences in total biomass yield, the phytoextraction in the autumn harvest was twice more successful than in winter harvest in the case of Cd for both willows and poplars (Fig. 4). The Pb phytoextraction showed similar trend but the differences between autumn and winter harvests were lower. The autumn harvest has several limitations. The early performed autumn harvest may lead to sprouting new shoots before winter, freezing of immature shoots and low accumulation of storage substances. This could have negative consequences for wintering and grow of clones in the next year (Mrnka *et al*. 2010). The late autumn harvest is affected by substantial fall the soil and the risk of wintering of stumps is relatively .of leaves causing decreasing removal of metals from the soil and the risk of wintering of stumps is relatively high.

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