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Boron in irrigation water and its interactions with soil and plants: an example of municpal landfill leachate reuse

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ABSTRACT

In several countries, leachate is successfully treated by recirculation to the vegetated landfill cover, as it contains several micro and macronutrients for plant growth. However, the proportion and concentration of some parameters can negatively affect the plant growth and soil quality in the case of high leachate input. The presented research discusses B in leachate and its interactions with soil and plants. A ten-month field research was performed on 1.1 ha of the closed and covered municipal solid waste landfill site irrigated with landfill leachate. B concentration was analysed in leachate, landfill soil cover and in plant leaves. Total B concentration in leachate ranged from 0.8 to 3.83 mg/L. Monthly B mass load on the covered landfill site ranged between 0.2 – 1.5 kg/ha. The concentration of bioavailable B in soil cover gradually increased and ranged between <0.5 – 2.75 mg/kg dry weight soil. The average total B concentration in clover leaves was 23.9 mg/kg, in grass leaves 4.5 mg/kg, in the leaves of younger willows in the new part of the landfill cover 41.3 mg/kg and in the leaves of the older willows in the old part of the landfill cover 81.8 mg/kg. Leachate application increased plant growth during the observation period and there were no toxic effects on plant leaves, although B concentrations were higher compared to usual concentrations found in natural environment.

Key words: landfill leachate, municipal solid waste landfill site, boron, willow, irrigation, phytoremediation

IZVLEČEK

BOR V NAMAKALNI VODI IN NJEGOVE INTERAKCIJE S TLEMI IN RASTLINAMI: PRIMER PONOVNE UPORABE IZCEDNE VODE ODLAGALIŠČA KOMUNALNIH ODPADKOV

V različnih državah izcedno vodo uspešno čistijo s pomočjo vračanja na vegetativno prekritje odlagališča, saj vsebuje več mikro in makrohranil za rast rastlin. Pri tem lahko razmerje in koncentracija nekaterih parametrov v izcedni vodi ob velikem vnosu v tla negativno vpliva na rast rastlin in kvaliteto tal. Predstavljena raziskava obravnava B v izcedni vodi ter njegove

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interakcije s tlemi in rastlinami. Deset mesečna erenska raziskava je bila opravljena na 1,1 ha zaprtega in prekritega odlagališča komunalnih odpadkov, ki je bilo namakano z izcedno vodo. Koncentracijo B smo analizirali v izcedni vodi, talnem prekritju odlagališča ter v listih rastlin. Celokupna koncentracija B se je v izcedni vodi gibala med 0,8 in 3,83 mg/L. Masni vnos B na prekritje odlagališča se je gibal med 0,2 in 1,5 kg/ha. Koncentracija biološko razpoložljivega B v tleh je zaradi vnosa izcedne vode postopoma naraščala in se gibala med <0,5 in 2,75 mg/kg suhih tal. Povprečna celokupna koncentracija B v listih detelje je znašala 23,9 mg/kg, v listih trave 4,5 mg/kg, v listih mladih vrb novega dela prekritja 41,3 mg/kg in v listih starejših vrb starega dela prekritja 81,8 mg/kg. Vnos izcedne vode je pospešil rast rastlin v času obdobja opazovanj. Na listih rastlin ni bilo opaziti strupenih učinkov kljub temu, da so bile koncentracije B višje v primerjavi z koncentracijami, ki jih običajno najdemo v naravnem okolju.

Ključne besede: izcedna voda, odlagališče komunalnih odpadkov, bor, vrbe, namakanje, fitoremediacija

INTRODUCTION

Landfilling is still the most common practice of municipal solid waste disposal. By the percolation of water through the waste, leachate is generated which represents substantial environmental concern (Kjeldsen et al., 2002; Dimitriou et al., 2006; Smith et al., 1999; Bowman et al., 2002; Maurice et al., 1999; Cureton et al., 1991). Environmental risk associated with uncontrolled landfill leachate outflow into the environment is largely attributed to the presence of high ammonium nitrogen levels, a range of organic substances, and of a high ionic strength caused by high concentrations of chloride and sodium. Conventional treatment of landfill leachate comprises co-treatment at municipal wastewater treatment plants or on-site leachate treatment in batch treatment processes, which require high energy and capital inputs and can generate large quantities of by-products. Landfill operators are therefore interested in local natural-based and low-cost treatment systems. In several European countries, Australia and USA, landfill leachate is treated by irrigation of recreational areas (Bowman et. al., 2002), by recirculation to vegetated landfill cover (Maurice et. al., 1999; Cureton et al., 1991) and by irrigation of energy crops (mainly short-rotation willow coppice) on restored parts of landfills or on adjacent arable fields (Dimitriou et al., 2006; Dimitriou and Aronson, 2004; Roseqvist and Ness, 2004; Nixon et al., 2000). Irrigation of leachate provides a mechanism of beneficial reuse of leachate with utilization of micro end macro nutrients from leachate for plant growth. Namely, leachate contains several components used by plants for the generation of biomass like water, macronutrients (N, K, Ca, Mg, and S) and micronutrients like B, Fe, Cu, Cl and Zn. Leachate can be therefore used as a substitute for water and inorganic fertilizers and thus reducing the need for non-renewable natural sources, which are being used for the production of fertilizers, although this *in-situ* phyto and bioremediation is limited by the capacity of the system to accommodate added pollutants. Of a particular concern are usually high concentrations of N and high salinity, especially in arid climates, while heavy metals are usually not of particular concern.

B is the tenth most abundant element in oceanic salts, varying in concentration in seawater from 0.52 mg/L in the Baltic Sea to as much as 9.57 mg/L in the Mediterranean Sea (Argust, 1998). Mean surface water B concentration ranges from

0.01 mg/L to 0.1 mg/L and for most groundwaters, the B concentration lies in the range 0.017 and 1.904 mg/L (Argust, 1989; EPA, 1991). Soil B concentration in general range from 2 to 100 mg/kg.

B presence and concentration in landfill leachate depend on the nature of deposited wastes. The main commercial applications are in the production of glass, textile fibreglass, ceramics, detergents, wood preservation materials, fire retardant materials, plastics, medicines, insecticides, and agricultural fertilizers (Argust, 1998; Sartaj and Fernandes, 2005). In addition, B may be present in other materials used in anthropogenic activities, such as fossil fuel burning. The use of B in the manufacture and the use of products in these industries lead to a wide diffusion of B into the environment through various pathways and ending in waste material also on landfill sites.

B causes problems especially in irrigation water. It is an essential micronutrient for higher plants, with interspecies differences in the levels required for optimum growth. The extent to which B is present in different plants and animals varies a great deal, from <0.07 mg/kg B in animal livers up to as high as 248 mg/kg B in some seaweeds (Argust, 1998). There is a small range between B deficiency and toxicity in some plants (WHO, 1998; Gupta et al., 1985; Sartaj and Fernandes, 2005). Francois and Clark (1979) investigated the B tolerance in 25 ornamental plants of which about 15 were moderately damaged by a B concentration of 2.5 mg/L and severely damaged or killed at B concentration in the irrigation water of 7.5 mg/L. Safe concentrations of B in irrigation water range from 0.3 – 1.0 mg/L for sensitive plants (avocado (*Persea americana*), apple (*Malus domestica*), bean (*Phaseolus vulgaris*)), 1 – 2 mg/L for semi tolerant plants (oat (*Avena sativa*), maize (*Zea mais*), potato (*Solanum tuberosum*)), and 2 - 4 mg/L for tolerant plants (carrot (*Daucus carota*), alfalfa (*Medicago sativa*), and sugar beet (*Beta vulgaris*)) (Keren and Bingham, 1985; Nable et al., 1997). By Ayers and Westcot (1994), there are no restrictions on the use of irrigation water foreseen at the B concentrations <0.7 mg/L, at the concentrations between >0.7 and 3.0 mg/L slight to moderate restriction on the use is set, and at B concentration > 3.0 mg/L severe restriction on the use of irrigation water is foreseen. Reffered to Nable et al. (1997), the present knowledge is insufficient to define precisely the acceptable B levels in a growth medium, but soils containing more than 5 to 8 mg/L of hot H_2O soluble B may require special revegetation considerations. However, many native species are well adapted to B levels in excess of 5 mg/L.

Slovenian legislation sets limits for B concentration in the discharge of wastewater into waters (1 mg/L) and public sewage system (10 mg/L) (OG RS, 47/2005). The limit B concentration in drinking water is 1 mg/L (OG RS, 19/2004). The maximum concentration of B in the irrigation water is not defined by Slovenian legislation (OG RS, 84/2005). However, the use of wastewater for irrigation from different sources is not a usual practice in Slovenia, as there are for now satisfactory amounts of surface and underground water. With increased occurrence of summer drought and directions toward recycling and reuse of usable wastes there is a need also in Slovenia to approach toward the possibilities of sustainable use of wastewater sources as a possible reusable nutrients and water sources.

B is one of the most troublesome trace elements in soil management, as it is adsorbed to soil constituents as well as being present in slowly soluble form. B is mainly found in soil in the form either of boric acid (H_3BO_3) or calcium and sodium borates. Irrigation of soil with high B water can lead to the incorporation of B into sites not readily desorbed (carbonate, organic, and free ion portions), which can lead to significant accumulation of B in a period of time on the order of a decade. Continued irrigation with B laden water will exceed the adsorption capacity of the soil and B will accumulate in soil and cause a possible reduction in crop yield (Nable et al., 1997). The primary loss of B from the soil is leaching. Leaching is also the technique used to remove excess B from the surface soil and the root zone, although B leaching is approximately four times slower than sodium (Sartaj and Fernandes, 2005). The situation is therefore more serious in arid and semi-arid environments with low rainfall or where water used for leaching is unavailable.

B absorption by plant roots is affected by various environmental factors, both in the soil and non-soil environments. Important factors influencing B absorption from solution include the initial B content of the soil, the pH of the soil, the type of exchangeable ions present in the soil, the soil organic matter content, the wetting and drying cycles, and the water to soil ratio (Gupta et al., 1985; Romero and Aguilar, 1986; Hu and Brown, 1997). Humidity seems to affect B availability stronger than for other elements, indicating that B insufficiency in plants during drought may be partially associated to the level of B soluble in the water in soil. Studies on B interactions showed that N is the most important as far as its effect on B absorption by plants is concerned (Romero and Aguilar, 1986). Studies showed that B concentrations decreased with increasing quantities of N and that additions of N decreased the toxicity symptoms of B. It seems that B can have positive influence on the absorption of other micronutrients like Zn, Mo, Mn, and Cu (Romero and Aguilar, 1986).

Physiologically, B is considered as an important element for the development of plant tissues (Romero and Aguilar, 1986; Nable et al., 1997). The rapid and specific inhibition of plant growth that occurs upon removal of B is a consequence of two important features of B physiology: the specific structural role of B in the cell wall and the limited mobility of B in the majority of species (Hu and Brown, 1997). As a result of its critical role in expanding tissues and its limited mobility, B has to be supplied continually throughout the life of the plant (Hu and Brown, 1997).

A typical visible symptom of B toxicity is leaf burn – chlorotic and/or necrotic patches, often at the margins and tips of older leaves (Nable et al., 1997). These symptoms reflect the distribution of B in most species, with B accumulation at the end of the transpiration stream (Hu and Brown, 1997; Nable et al., 1997). Tissue concentrations of B can vary considerably; therefore, it is difficult to use foliar analysis for diagnosis of B toxicity (Nable et al., 1997). In species that accumulate B in their leaves, these tissues normally contain about 40 to 100 mg/kg of B dry wt. However, the leaves can contain 250 mg/kg dry wt when B in the soil approaches toxic levels. Leaf concentration of B may exceed 700 to 1,000 mg/kg dry wt in extreme conditions of B toxicity.

In this paper we would like to expose the problems of B from landfill leachate in the case of leachate recirculation to the vegetated landfill cover. A ten month field research was performed at the municipal solid waste landfill site at Dobrava near Ormož in the southeastern part of Slovenia. 1.1 ha of the closed and covered landfill site was irrigated with landfill leachate by underground irrigation system placed on 30 cm depth. The landfill site was covered with 1 m soil layer and planted with willows (*Salix sp.*), grass mixture and white clover (*Trifolium repens*). The covered part of the landfill site was divided into two parts according to the landfill closure steps. The first part (old cover) has been planted and irrigated since 2003 and the second part (new cover) since 2004.

MATERIALS AND METHODS

Total B concentration in leachate was monthly analysed from grab samples taken from the reservoir from where leachate had been pumped on the landfill cover. Before the determination of total B concentration in leachate, triplicate samples were wet digested in Kjeldahl flasks using HNO_3 and H_2O_2.

Soil core samples were collected four times per year from 25 evenly distributed spots, separately on the new and old plantation, using the soil probe. The soil cores were taken at the depth of 90 cm and divided into three parts (0-30 cm, 30-60 cm and 60-90 cm). The cores from the same depths were mixed, air dried, sieved through 2 mm sieve and ground to powder. The total B concentration in soil was determined after *aqua regia* (HNO_3:HCl = 1:3) digestion of samples. To evaluate a bioavailable B fraction, the extraction of soil samples in 0.11 M CH_3COOH was performed (Rauret et al., 2000).

Plant samples were collected at the end of the growing season, including leaves of willows, grass and clover. Microwave-assisted total digestion of plant samples was performed by HNO_3:$HClO_4$ = 7:1 extraction (Sastre et al., 2002).

Digested diluted samples of leachate, soil and plants were analyzed with Agilent 4500 series ICP-MS instrument (Babbington nebulizer with Peltier-cooled spray chamber, carrier gas Ar, 1.05 L/min, RF power 1300 W). Standard addition technique (N = 10) was used to avoid matrix interferences. The limit of detection was calculated as a concentration corresponding to three-fold standard deviation (3s, N = 6) of blank determinations. Blanks were subjected to the same digestion procedure as samples.

TraceSelect (Fluka, Buchs, Switzerland) and Suprapur (Merck, Darmstadt, Germany) acids and deionised water (Milli-Q) were used for the preparation of samples, extraction solutions and standard solutions.

The data on precipitation, temperature and potential evapotranspiration were acquired from the nearby weather station at Jeruzalem. The amount of pumped leachate was followed by the pump counter.

Pedologic analyses were performed according to standards: SIST ISO 10390:1996 (pH of soil samples), SIST ISO 14235:1999 (organic metter content), and SIST ISO 11260:1996 (cation exchange capacity - CEC).

RESULTS AND DUSCUSSION

Leachate

From January to October 2005, the concentration of B in landfill leachate recirculated to the planted landfill cover by underground irrigation system ranged between 0.8 and

3.83 mg/L (Figure 1). Varying concentrations of B in landfill leachate are reported, ranging from 0.3 – 63.2 mg/L (Castonguay et al., 1996), 2.6 – 4.0 mg/L from municipal solid waste landfill in Florida (Statom et. al., 2006), 0.05 – 1.1 mg/L from small closed New Zealand landfills and 1.1 – 10 mg/L from large operational New Zealand landfills (Golden Associates, 2002), 10.5 mg/L in average from Ontario landfill (Sartaj and Fernandes, 2005), to up to 64 mg/L from municipal solid waste landfill in Ljubljana, Slovenia (Bulc, 1998). Compared with the data from the literature, leachate from the landfill under consideration was not excessively loaded with B. However, according to the normative values laid down by Decree on the Emission of Substances and Heat in the Discharge of Wastewater into Waters and Public Sewage System (OG RS, No. 47/2005), the values would be exceeded in the case of its discharge into a watercourse (normative W – 1 mg/L), but not if discharged into the sewage system (normative S – 10 mg/L). As leachate was reused and recirculated to the vegetated part of the landfill with an isolated base, there was no discharge of leachate into the environment and, therefore, no pollution of surface and underground waters.

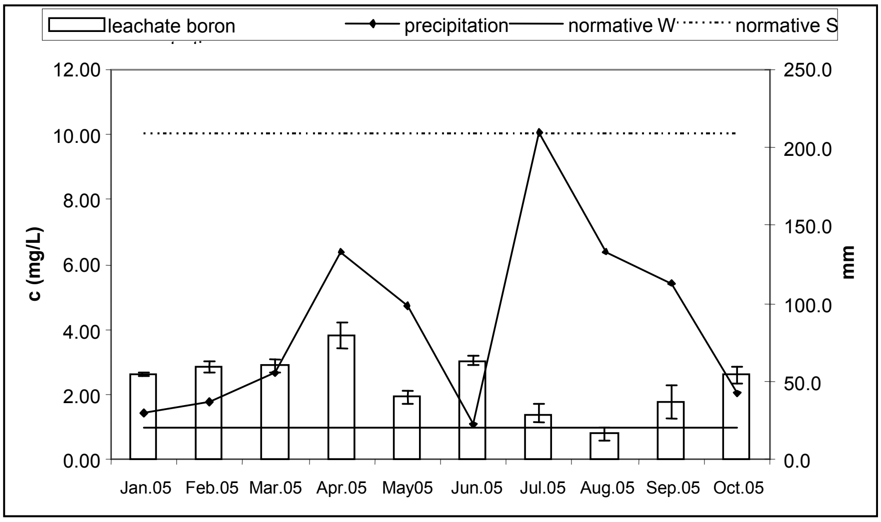

Figure 1. Monthly measurements of B in leachate used for irrigation. Maximum permissible concentration of B in waste water is presented for the outflow into surface waters (normative W) and the sewage system (normative S) (OG RS, 47/2005). Cumulative monthly amount of precipitation (mm) is calculated between monthly leachate sampling intervals.

Comparing the measured concentration of B in leachate and the limit values or safe B concentrations in irrigation water (Keren and Bingham, 1985; Nable et al., 1997; Ayers and Westcot 1994), the water used in this case was at the medium limit level (<0.7 – 3 mg/L). The recommendations cited and the restrictions on B concentration in irrigation water apply to crops and the use of water in dry climates where irrigation water is the main source of water during high water deficit in growing season. In our case, the leachate input represented 28% of total water received by a square metre of surface during the growing season, i.e. from April to September and 37.5% during the monitoring period from January to October 2005, respectively (Figure 2). This means that the actual concentration of B in water was lower, except during the time of high evapotranspiration and water deficit. In the event of longer drought periods, when B concentration in soil solution is higher due to evapotranspiration, according to the literature, the concentration of B in leachate may be toxic to plants. Monthly mass load of B through leachate per 1.1 ha of vegetated landfill site ranged from 0.2 to 1.5 kg/ha or, on average, 0.8 kg/ha (Figure 2). Total mass load during the monitoring period from January to October 2005 was 7.9 kg/ha.

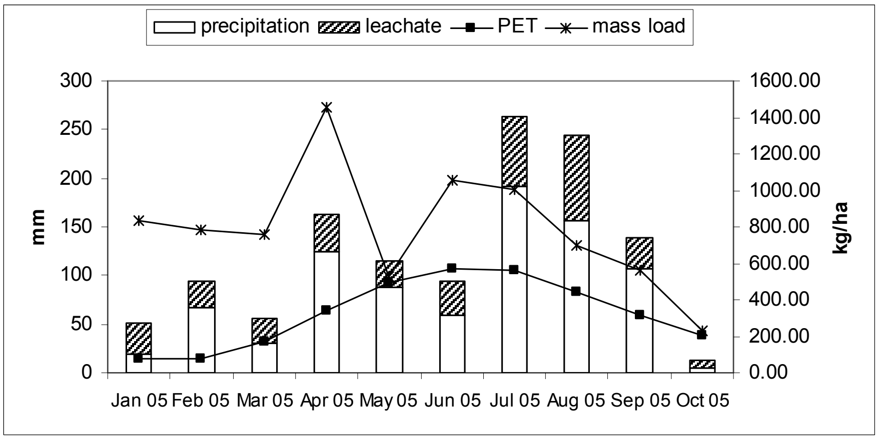

Figure 2: Cumulative monthly amount of B mass load (kg/ha) with leachate irrigation, monthly amount of precipitation (mm) and leachate water (mm) irrigated on 11,000 m^2 of planted area with potential evapotranspiration (PET, mm).

Soil

Only part of the total quantity of metals in soil may be considered bioavailable, labile, mobile and potentially toxic. To determine easily soluble metal fractions available to plant uptake, water and electrolyte solutions, e.g. acetic acid, were commonly used (Rauret et al., 2000). Soil water solution is prepared to estimate the proportions of metals that can be transferable into water and therefore easily available to plants. Solutions with acetic acid are prepared to estimate the proportions of metals not easily water soluble, but bioavailable as plants excrete similar compounds which increase metal solubility. In our research, total and acetic acid extractable (bioavailable) B concentrations in soil cover samples were measured.

The results of measurements of total and bioavailable B concentrations showed that all B in soil was in bioavailable form (the difference between total and bioavailable B concentration of the same sample was in the range of analytical error), so only the results of bioavailable B determination are represented (Figures 3 and 4). At first sampling in January 2005, only bioavailable B concentration in upper soil layer (0-30 cm) of the new cover exceeded the LOD (0.5 mg/kg). During this period, the amount of precipitation was much lower than the amount of leachate recirculated to the planted landfill cover (Figure 2). At the second sampling, bioavailable B concentrations in all soil samples were below LOD in spite of continuous irrigation of the soil cover with leachate. Obviously, due to precipitations, the leaching of B in the first part of the year was sufficient to keep B concentration at such a low value. From the third sampling in August 2005, bioavailable B concentrations began to increase and thus higher B concentrations were measured on the new cover. Higher soil B concentrations in the new cover could be explained by lower plant uptake and lower evapotranspiration. Willows on the new cover were less developed than willows on the old cover where they reached the height of 2 m. Beside this, the average B concentration in the willow leaves of the old cover was higher than the B concentration of the willow leaves on the new cover. Predominant vegetation on the new cover were grasses and white clover. Referred to Reinmann et al. (2001), birch and willow are very successful in supplying themselves with major (S, P, K, Ca and Mg) and minor (B, Cu and Zn) nutrients, where plant/soil bioaccumulation ration for B in willow leaves reached 6.4. As can be seen from Figures 3 and 4, the concentration of bioavailable B on the new and old cover decreased with depth. As the irrigation system was placed on the 30 cm depth, the higest B concentration was therefore expcted to be on the depth between 0 and 60 cm and the lowest on the depth of 90 cm.

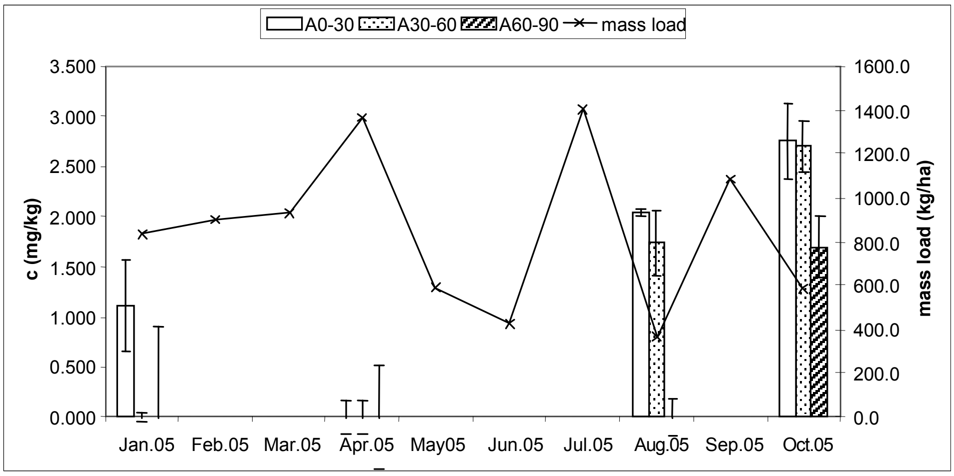

Figure 3: Time variation of bioavailable B concentration (mg/kg) in three soil layers (0–30, 30–60, 60–90 cm) on the new landfill cover (A) with monthly B mass load (kg/ha) calculated between monthly leachate sampling intervals.

Within the soil system, a variety of mechanisms exist that will influence the resistance time of B within the soil. These include the relative demand for B from plant life within the soil, the amount of rainfall either washing B out of the soil profile or adding B to it, the action of clays acting as adsorption/desorption sites for B, temperature, organic matter and soil pH (Argust, 1998; Sartaj and Fernandes, 2005). The pH of soil is one of the most important factors affecting the B availability in soil and plants (Romero and Aguilar, 1986), with higher availability to plants with decreasing pH. The pH of our soil samples were not changing considerably during the measuring period and it varied from 7.2 to 7.6, indicating that pH did not have an important role in the B uptake by plants. The second important factor, which affects B availability, is the soil texture (Romero and Aguilar, 1986). In the soils with fine texture (clay), larger quantities of B soluble in hot H_2O were found than in soils with coarse texture, indicating that B is adsorbed in clay particles. However, the soil with high adsorption capacity will maintain lower B concentration in soil solution. In coarse textured soil low in clay and low in organic matter, B is highly mobile and a subject to leaching losses. Increasing of B concentration in soil samples in our case indicates an important influence of adsorption of B onto soil particles. The soil on the covered part of landfill consisted of 56% of silt fraction, 23% of clay fraction and 21% of sand fraction with the CEC amount from 16.5 to 24.7 cmol/kg, which enabled

B adsorption. On the other hand, the organic matter content of soil was low and varied from 0.6 to 1.2 and therefore not contributing to additional B accumulation.

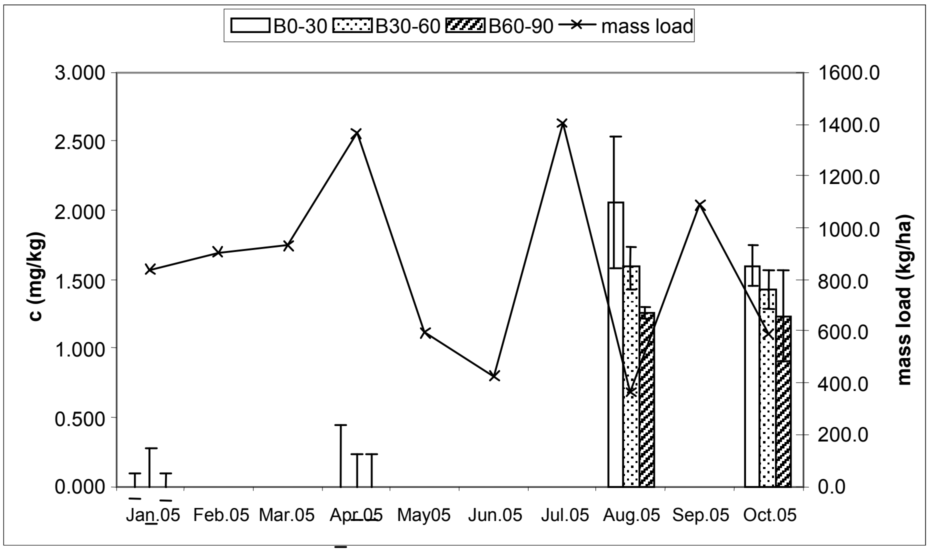

Figure 4: Time variation of exchangeable B concentration (mg/kg) in three soil layers (0–30, 30–60, 60–90 cm) on the old landfill cover (B) with monthly B mass load (kg/ha) calculated between monthly leachate sampling intervals.

Plants

The average B concentration in clover leaves was 23.9 mg/kg, in grass leaves 4.5 mg/kg, in the leaves of younger willows in the new part of the landfill cover 41.3 mg/kg and in the leaves of the older willows in the old part of the landfill cover 81.8 mg/kg. On natural sites, B concentration in the leaves of different plants varies considerably. Bargagli (1998) states the following typical B concentrations (mg/kg dw) in the leaves of different plants: apple tree 27, peach tree 2, spinach 37.6, citrus 21, tomato 33.3, *Lolium perenne* 6.2, *Taraxacum officinale* 10, *Robinia pseudoacacia* 15, wheat 4.9, barley 9. Reimann et al. (2001) measured on average 15.9 mg B/kg dry wt on 23 samples of willow leaves (*Salix* sp.) in the area of 1,500,000 km^2 in northern Europe, whereas Alker et al. (2002), after three years of irrigation by leachate, measured the B concentration in willow leaves of between 11.3 – 44.6 mg/kg, while the concentration in control plants, which were not watered by leachate, ranged from 5.0 to 11.7 mg/kg. In our case, the B concentrations in grass and willow leaves were higher in comparison with the concentrations under natural conditions (Bargagli, 1998; Reimann et al. 2001). Compared with Alker et al. (2002) results, higher B concentrations were measured in the leaves of the older willows in the old part of the landfill. Moreover, our measurements were carried out in September, at the end of the growing season, while Alker's data refer to the measurements made in August. In their research, Alker et al. (2002) found out that irrigation by leachate from the municipal landfill enhanced the plant growth as compared with the part, which was irrigated only by water, and the part where no water was added. The findings of our research were the same. The introduction of leachate into the soil of landfill cover resulted in a more vigorous growth of vegetation and faster burst into leaf in spring in comparison to ruderal vegetation growing next to the landfill on the soil of the same composition as of the landfill cover layer. Also, there were no visible symptoms of leachate toxicity on leaves, such as chlorotic or necrotic patches. This finding indicates that the measured higher B values in leaves were not toxic to plants.

Figure 5: B concentration (mg/kg) in the leaves of white clover (*Trifolium repens*), willow (*Salix sp.*) and the grass mixture irrigated with landfill leachate.

During the monitoring period, the identified increase of B in soil contributed to better supply of the soil with B. In the event of further increase in B concentration in soil, could lead to the possibility of toxicity; for that reason, there is a need for longer monitoring of changes in B concentration in the soil and plants. In addition, leachate is a complex mixture of organic and inorganic substances. Therefore, the plant uptake of B does not depend only on the concentration of bioavailable B in soil solution, but also on the interaction with other leachate components.

CONCLUSIONS

During the ten-month monitoring period, the use of landfill leachate with B concentration at the medium limit level, applicable to the irrigation water in agriculture (Ayers and Westcot, 1994), did not have negative effects on the growth of landfill cover vegetation consisting of grass mixture, white clover and willows. However, there was a distinctive trend of an increased concentration of bioavailable B in the soil as well as increased B concentration in plant leaves as compared to the typical B concentrations in plants on natural sites. Because of the identified increasing trend in B concentration the monitoring is being continued to identify long-term change dynamics of B in soil cover and plants. Considering the high intake rate of B by willows, there is a possibility of efficient removal of B by regular cutting of vegetation, as the removal of B from leachate by traditional methods is difficult. Thriving of plants at higher B concentrations indicates that less severe restrictions regarding B concentration in irrigation water are necessary for planting of ligneous vegetation than for crops in temperate climates.

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