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Original Research

The Ecological Potential of *Spiraea van-hauttei* (Briot.) Zabel for Urban (the City of Belgrade) and Fly Ash Deposit (Obrenovac) Landscaping in Serbia

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Abstract

Spiraea van-houttei (Briot.) Zabel has often been used for urban landscaping and for the biological recultivation of ash deposits in Serbia. This study examines its photosynthetic efficiency, water balance, and trace element content in the 'Stara Zvezdara' park in the city of Belgrade, in the fly ash deposits of the 'Nikola Tesla – A' thermoelectric power plant in Obrenovac, and at the Arboretum of Belgrade's Faculty of Forestry. Site-dependent variations were found in the water saturation deficit, photosynthetic efficiency, Cu and Mn concentrations, and leaf damage symptoms. The higher water saturation deficit measured in the city park showed some difficulties in maintaining water balance due to Pb accumulation in leaves and the chlorotic damage caused predominantly by car exhaust pollutants. A photosynthetic efficiency (0.787) within the optimum range indicated the capacity of this species to tolerate the elevated concentrations of pollutants in the city air. However, the low photosynthetic efficiency (0.588) and the deficiency of Cu (2.380μg/g) and Mn (9.550μg/g) that caused leaf wilting indicated that the spiraea would probably disappear from the fly ash deposits in spite of a favourable water balance.

Keywords: city park, fly ash deposits, photosynthetic efficiency, trace elements, water balance

Introduction

Belgrade is a city with many chemical, pharmaceutical and metallic industrial plants located not only in the outlying areas, where there are the large industrial complexes of three coal-electric power plants, but also in the central parts of the city, and this together with heavy urban traffic provides sources for various types of pollutants. The main factors that limit plant growth in the urban environment are high temperatures and drought during the summer, polluted air and soil, as well as soil compaction and physical damage due to human vandalism [1]. According to the reports of the City Laboratory for Human Ecology for 2004, the city of Belgrade was characterized by elevated concentrations of SO_2 (98-172 μg/m^3; the permissible concentration is 50 μg/m^3), NO_2 (51-115 μg/m^3; the permissible concentration is 60μg/m^3), CO (10-18 mg/m^3; the permissible concentration is 3 mg/m^3), and soot (34-121μg/m^3; the permissible concentration is 50μg/m^3), in addition to Pb in particulate matter with concentrations in the range of 50-1704μg/m^2/day (the permissible concentration is 250μg/m^2/day), and Zn in soot deposition with concentrations of 54-2417μg/m^2/day (the permissible

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concentration is 400µg/m²/day). At the same time, the approximate total number of cars passing along boulevards was 41,760 cars/24h.

The 'Nikola Tesla-A' power station in Obrenovac, 30 km southwest of Belgrade, is also a source of pollutants, and the situation has been exacerbated by the creation of certain waste deposits in its vicinity. The creation of fly (80-85%) and bottom ash (15-20%) deposits covering 400ha alongside the Sava River has created unfavourable conditions for plant survival. Plants are simultaneously and continuously affected by the unfavourable physical and chemical characteristics of the ash, together with the adverse microclimatic conditions. Because of the unfavourable moisture, physical and thermal characteristics, primarily caused by the dark-grey colour of the ash and its sandy texture, plant growth on such a substrate may be considered to be under stress conditions. The dry area of the deposit is prone to wind erosion. The major factors that limit plant survival on ash deposit sites are the lack of essential nutrients, mostly N (<0.05%), and available P_2O_5 (0.05-0.2%), a high B content (410µg· g^{-1}), and high concentrations of some potentially toxic trace elements, including Pb, Cd, As, Hg, Mo, Se and Cr, in the ash [2-6].

The intensive and continuous deposition of toxic substances causes disturbances in the physiological processes of plants, visible damage symptoms, the decay of individuals, and even the disappearance of certain species from those sites exposed to pollution. Numerous studies have indicated a high sensitivity of Photosystem II to the effects of heavy metals that directly influence chlorophyll fluorescence through a decrease in the Fv/Fm ratio and chlorophyll decomposition, and indirectly through the inhibition of other physiological processes, which in turn affect photosynthesis [7, 8]. Furthermore, a high sensitivity of Photosystem II to a deficit of essential elements (such as Cu and Mn) at the ash deposit site was noted [4]. Thus, induced chlorophyll fluorescence can provide speedy results for the photosynthetic efficiency screening of different plant species exposed to different environmental stresses. Under heavy metal stress, the relative leaf water content was significantly reduced in different plant species [9, 10].

The primary objective of this research was to evaluate the water regime, photosynthetic efficiency, trace element concentrations in leaves, and the morphological symptoms of damage to the Vanhoutte spiraea, *Spiraea vanhouttei* (Briot.) Zabel, at a control site in relation to a site exposed to car exhaust emissions (the city) and an anthropogenically-formed site (the ash deposit). On the basis of this comparison, the ecological potential of the examined species for urban landscaping and biological recultivation of ash deposits was assessed.

Experimental Procedures

The research was carried out during July 2004 at three sites chosen with regard to sources of pollution: the 'Stara Zvezdara' park in the central zone of the city of Belgrade (predominantly exposed to car exhaust pollution), the fly ash deposits of the 'Nikola Tesla-A' power station in Obrenovac, 30 km from Belgrade (an anthropogenically-formed site), and the Arboretum of Belgrade's Faculty of Forestry (established within a zone of a mixed *Quercus frainetto* and *Quercus cerris* forest), located in an area with no direct source of pollution (the control site). At each site, five individuals of the same age (5 years) were chosen and measurements undertaken on them.

Photosynthetic efficiency (Fv/Fm) was determined *in situ* through the method of induced chlorophyll fluorescence of Photosystem II, using a portable Plant Stress Meter (BioMonitor S.C.I. AB, Sweden). Chlorophyll was excited for 2 seconds by actinic light with a photon flux density of 200 and 400 µmol m^{-2} s^{-1}. Prior to measuring the chlorophyll fluorescence, samples were adapted to the dark for approximately 30 minutes in order to maximize the oxidation of the primary quinone electron acceptor pool of Photosystem II and to enable the full relaxation of any rapidly recovering fluorescence quenching. The measuring of the photosynthetic efficiency (Fv/Fm) of the plants was undertaken 15 times at each of the sites (3 times on each of the 5 individuals).

Using measurements of the relative water content (RWC) and the leaf water saturation deficit (WSD) of leaves, an analysis of the plant water balance was performed on the basis of the weight difference between fresh leaves abundant in water and absolutely dry leaves. RWC and WSD values were expressed in percentages. The measuring of the RWC and WSD of the plants was undertaken 15 times at each of the sites (3 times on each of the 5 individuals).

Concentrations of boron, copper, manganese, zinc, lead and cadmium in leaves were also measured. Leaves were collected from the selected individuals and a collective sample originating from each of the research sites was formed. Plant material was dried to a constant weight, 12 hours at 80°C, and then ground and wet digested in a microwave oven (CEM, 39 MDS-2000). Wet digestion encompassed several steps: 0.4 g of plant material, 12 ml HNO_3, and 4 ml H_2O_2 was put into Teflon vessels (ACV – Advanced Composite vessels). The temperature of each sample reached 180 ± 5°C over a 5.5 minute period and was then maintained at 180 ± 5°C for a duration of 9.5 ± 5 minutes (Environmental Protection Agency standards). The concentrations of Cu, Mn, Zn, Cd and Pb were determined through atomic absorption spectrophotometry (Pye Unicam SP9), using a sodium atomic absorption standard solution (Sigma Co.). Boron concentrations were determined using the spectrophotometer method with the aid of curcumin. The detection level of Cu, Mn, Zn and Pb was 0.5 ppm, and B and Cd 0.2 ppm. Concentrations were expressed inµg/g of the dry leaf weight. The concentrations of Cu, Mn, Zn, Pb and B measured at the three sites under investigation were compared between the sites themselves and also with those values obtained from reference literature.

The differences between the city park, the ash deposit and the control site in terms of the photosynthetic efficiency, relative water content and water saturation deficit of the Vanhoutte spiraea were investigated using a one way-ANOVA analysis.

Results

The analysis of the Fv/Fm showed the lower photosynthetic efficiency of *Spiraea van-houttei* in the city park ($p<0.001$) and at the fly ash deposit ($p<0.001$) than at the control site. Likewise, lower vitality ($p<0.001$) of spiraea individuals was found at the fly ash deposit in relation to the city park (Table 1). The mean value of the Fv/Fm measured in the city park (0.787) was lower than the control (0.820), but still within the general optimum range of plant photosynthetic efficiency, whereas the Fv/Fm (0.588) measured at the fly ash deposit was below the optimum range (0.750-0.850) empirically obtained by Bjorkman and Demmig, cited by Pavlović et al. [4].

There was no difference between the control site and the fly ash deposit site (ns) in terms of the RWC and WSD, but an unfavourable RWC and WSD was measured in the city park in relation to the control ($p<0.001$), Tables 2 and 3. Differences in the RWC and WSD between individuals from the city park and the ash deposit were found ($p<0.001$) (Tables 2 and 3).

The boron concentration at all sites varied from 18.0µg· g^{-1} measured in the city park through to 28.4µg/g at the fly ash deposit (Table 4), which is within the normal range for plants. According to Kabata-Pendias and Pendias [11], the toxic effect of B is noted in concentrations above 50 µg/g (Table 5).

The Cu concentration was 14.00µg/g at the control site, while a lower content of 7.95µg/g was measured in the city park (Table 4). Both concentrations were within the normal range for plants. However, at the fly ash deposit only 2.38 µg/g of Cu was found, which is considered a deficit in terms of Cu concentration [11] (Table 5).

Similarly, the Mn concentrations in leaf tissue samples at the control site (240.0µg/g) and the urban site (120.8µg/g) were within the normal range, but there was a deficit of Mn at the ash deposit site, only 9.55µg/g (Table 4). Con-

Table 1. Photosynthetic efficiency (Fv/Fm) of *Spiraea van-houttei* from control site, the city park and fly ash deposit (mean value with standard deviation in parentheses).

Site	Fv/Fm	Control site	City park	Fly ash deposit
Control site	0.820 (±0.009)	-	***	***
City park	0.787 (±0.018)	***	-	***
Fly ash deposit	0.588 (±0.038)	***	***	-

ANOVA, n = 15, M (SD), ***$p<0.001$

Table 2. Relative water content (%) of *Spiraea van-houttei* from control site, the city park and the fly ash deposit (mean value with standard deviation in parentheses).

Site	RWC (%)	Control site	City park	Fly ash deposit
Control site	96.780 (±2.891)	-	***	ns
City park	84.950 (±8.250)	***	-	***
Fly ash deposit	94.923 (±3.320)	ns	***	-

ANOVA, n = 15, M (SD), ns-no significant; ***$p<0.001$

Table 3. Water saturation deficit (%) of *Spiraea van-houttei* from control site, the city park and the fly ash deposit (mean value with standard deviation in parentheses).

Site	WSD (%)	Control site	City park	Fly ash deposit
Control site	3.220 (±0.989)	-	***	ns
City park	7.200 (±3.310)	***	-	***
Fly ash deposit	2.797 (±1.792)	ns	***	-

ANOVA, n = 15, M (SD), ns-no significant; ***$p<0.001$

Table 4. Trace element concentrations in *Spiraea van-houttei* leaves from control site, the city park and the fly ash deposit.

Site	B (µg/g)	Cu (µg/g)	Mn (µg/g)	Zn (µg/g)	Pb (µg/g)	Cd (µg/g)
Control site	24.00	14.00	240.00	17.50	-	-
City park	18.00	7.95	120.80	21.75	3.55	-
Fly ash deposit	28.40	2.38	9.55	20.07	2.38	-

Table 5. Trace element concentrations in fly [a]ash, [b]soil and [b]plants.

	B (µg/g)	Cu (µg/g)	Mn (µg/g)	Zn (µg/g)	Pb (µg/g)
[a]Fly ash	410	225	812	125	126
[b]Soil	1-467	1-323	7-9200	3-770	1.5-286
[b]Plants:					
Deficiency range	5-30	2-5	10-30	10-20	-
Normal range	10-100	5-30	30-300	27-150	5-10
Excessive or toxic range	50-200	20-100	400-1000	100-400	30-300

[a] From Simonović (3), [b] From Kabata-Pendias and Pendias [11]

centrations in the range of 10-30μg/g (11) are considered a deficit for plants (Table 5).

The Zn concentration varied within a narrow range, from 17.5μg/g at the control site and 20.07μg/g at the ash deposit, to 21.75μg/g in the city park (Table 4). There was a deficit of Zn at all the sites. The normal range is 27-150μg/g [11] (Table 5).

The presence of Pb was not detected in leaves from the control site (Table 4). The measured values from both the ash deposit site (2.38μg/g) and the city park (3.55μg/g) were within the normal range for plants (5-10μg/g; [11]) (Table 5).

The presence of Cd was not detected in any of the plant material samples.

Damage symptoms of leaves were not detected at the control site, while symptoms of chlorotic damage in the form of spotty light yellow, reddish-brown or dark brown chloroses were present in the city park, and leaf wilting was observed at the fly ash deposit.

Discussion

Spiraeas as valued elements of green areas are highly ornamental shrubs. *Spiraea van-houttei* (Briot.) Zabel grows rapidly, is soil tolerant, prefers sunny locations, is considered highly resistant to urban and industrial pollution, and is often used for planting in Belgrade's parks and for the biological recultivation process at the ash deposit in Obrenovac.

The lowest photosynthetic efficiency (0.588) was measured in the Vanhoutte spiraea at the ash deposit site when compared to the control site and the city park. The low vitality of individuals from the ash deposits indicated the presence of photo-inhibitory damage. A narrowing of the range and deviation from the optimum values occurs in conditions of exposure to one or more stress factors at a site. At the ash deposits, plants are affected by the unfavourable physical and chemical substrate properties, adverse microclimatic conditions, and pollution. These unfavourable conditions are limiting factors, impeding the normal development of basic physiological processes, such as photosynthesis [4]. In addition to its adverse chemical effects, ash endangers plants mechanically due to its abrasive effect. The deposition of fly ash particles on leaf surfaces acts as a physical barrier that decreases the availability of active photosynthetic radiation, thus altering the ability of leaves to absorb it. As a consequence, the temperature on leaf surfaces increases. In the hot, dry summer period, plant leaves at ash deposit sites can become overheated, which affects the course of normal photosynthesis and other biosynthetic processes [4]. The vitality of individuals from the city park was lower in relation to the control, but still within the referential values [4], which implies their ecological potential for overcoming the limitations of such a habitat.

There was no difference in the RWC and WSD between the control site and the fly ash deposit site; however, differences between the control site and the city park, and the fly ash deposit site and the city park were found. The favourable water balance of this mesophytic species at the ash deposit site is a result of the periodic watering of the deposit to prevent ash dispersion (due to management of the ash deposit). In our opinion, this species has a high adaptive potential to use the relative humidity of the air (the ash deposit site is located alongside the Sava River) to compensate for the deficit of water in the ash. The higher water saturation deficit measured in the city park indicated some difficulties in maintaining the water balance. This could be the result of chlorotic damage, which leads to uncontrolled water loss from leaf tissues, and of Pb accumulation in leaves (3.55μg/g). Sharma and Shanker Dubey [12] found that Pb lowers the level of compounds that are associated with maintaining cell turgor and cell wall plasticity, and thus lowers the water potential within the cell. In spite of the leaf damage and water saturation deficit, photosynthetic efficiency is within the optimum range, which indicates that the ecological potential of the examined species is well-coordinated with the ecological potential of an urban site characterized by elevated concentrations of pollutants.

All the analyzed elements were characterized by high concentrations in the fly ash, but by normal (B and Pb) or deficit concentrations (Cu, Mn, Zn) in spiraea leaves, indicating that these elements accumulate on a major scale during the combustion process, but are not readily taken up by plants. For example, the binding of Cu by soils is related to the formation of organic complexes and is highly dependent on soil pH, and the overall solubility of both cationic and anionic forms decreases at about pH 7 to 8 [11]. The pH value of the ash at the 'Nikola Tesla-A' deposit is 7.7 to 7.9 [3]. Normal concentrations of Cu in plant tissues range from 5 to 30μg/g (Table 5). Deficiency symptoms appear when the Cu concentration in leaves is $<5\mu g \cdot g^{-1}$ [11]. The concentration of Cu in spiraea leaves from the ash deposit site was 2.38μg/g. Such a deficiency caused leaf wilting, which is, according to Kabata-Pendias and Pendias [11], a damage symptom of a Cu deficit.

In spite of the favourable water balance, a low photosynthetic efficiency was measured predominantly as a result of the deficit of Cu, Mn and Zn. Such low vitality showed that the ecological capacity of the species examined is not coordinated with the ecological potential of the ash deposit site, indicating that the spiraea will probably disappear from that site in the near future.

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