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The effect of environmental contamination on plants, with special regard to the role of reed in root zone wastewater treatment system

PhD thesis

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INTRODUCTION

During the last decades in the framework of environmental protection and water quality protection the control of municipal and industrial waste sources has been getting into the focus of attention. Due to this phenomenon new sophisticated wastewater treatment technologies were developed and at the same time cheaper, energy saving solutions appeared, which are easy to operate and maintain. Today biologists and ecologists need to work together actively to solve the problems of wastewater treatment.

In addition to the protection of the environment by the year 2015 Hungary has to meet the European requirements regarding wastewater collection and treatment.

My research work is also important as the elimination and the accumulation of elements and nutrients have not been examined for such a long time in a similar system. Collecting and analysing the results helps the examination of the changes taking place in the system, thus the operation can be controlled, long-term changes can be described and assessed, and basic information can be provided for the planning, operation and maintenance of such systems.

OBJECTIVES OF THE RESEARCH

During my research work I examined the wastewater, the soil and the plant together in a root zone system used to treat municipal wastewater. I focused on the role of reed (*Phragmites australis* (Cav.) Trin. ex Steudel) in nutrient and element accumulation and in the process of purification. The result of the wastewater and soil samples provided fundamental information concerning the nutrient and element accumulation of the soil, and helped the analysis of the changes appearing during the purification processes.

The place of the research was Szügy. Choosing this settlement made it possible to compare the two treatments (reed beds and filter beds without plants), previous information (quantity and quality parameters, other documents) regarding the operation of the system was available, and a well-matured plant community was needed to make the examinations with the reed.

The objectives of my research work were the followings:

» To examine the change of the quality of the wastewater flowing through the system, to describe the purification process with special regard to the quality of the purified water.

  In order to examine the change of the quality of the wastewater flowing through the system I took water samples at six points of the system. Determining the concentration of the parameters investigated the purification process could be described and the purification efficiency of the parameters could be calculated. The regular monthly sampling ensured the examination of the seasonal changes of the quality of the wastewater, that is the comparison of the summer and winter concentration values and purification efficiencies.

- To describe the element accumulation in the soil and plants of the root zone treatment system in Szügy.

  I examined the rate of the accumulation of the different nutrients and elements in the soil of the reed beds and the different plant parts (root, rhizome, stem, leaf) compared to the concentrations measured in the wastewater. I also investigated the influence of the seasonal changes, the changes of the accumulation of the different plant parts during the vegetation period and compared the accumulation rate of the nutrients and elements of the different plant parts.

- To compare the element and nutrient accumulation of natural reed habitats and plant communities with that of the reed beds and plant parts in Szügy.

  I examined how the concentration difference measured in the water/wastewater is reflected in the concentration values measured in the sediment/soil and in the different plant parts. It helped to understand how plants live in an environment where the element and nutrient concentrations are much higher than in their natural habitat.

- To compare the operation of the reed beds and the non-vegetated filter beds.

  My work also included whether the seasonal changes have any influence on the concentration values measured in the purified water flowing into the natural receiver and on the purification efficiency of the vegetated and non-vegetated filter beds.

- To compare the purification efficiencies calculated with mass flows and concentration values.

MATERIAL AMD METHODS

The place of the research was Szügy (1450 inhabitants) where a root zone wastewater treatment system with a 100 m³/day capacity has been in operation since 1994. The purification process involves the following units: chemical pre-precipitation, Imhoff tank, reed beds (parallel with them there are two non-vegetated gravel beds), septic tank (not in use) and a small reed pond for final NH_4-N removal.

The reed beds are isolated from the surrounding soil with waterproof foils, consist of several gravel and sand layers and receive settled wastewater. The wastewater flows through the filter beds vertically. The water is distributed and collected by perforated pipes and the purified wastewater flows into a natural stream.

During the research period (from May 2000 until April 2002) – at the same time as soil samples – wastewater samples were also collected monthly for 24 months from the following six points: raw wastewater /1/, settled wastewater /2/, water flowing out from the gravel beds /3/, water flowing out from the reed beds /4/, water flowing into the lake /5/ and water getting into the receiver /6/. Concentrations of the following parameters were measured in the samples: Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Sr, Ti, V, Zn, NO_3-N, NH_4-N and total N.

The sampling and the determination of element contents of the samples were carried out in accordance with the Hungarian standards (MSZ 1484-3:1998) by using ICP-AES. The KCl soluble ammonium and nitrate-nitrogen content of the samples were determined by distillation (Bremner), while the total nitrogen content was analysed by digestion (BÜCHI 430) and distillation (BÜCHI 322/342 with online titration).

During the research period (from May 2000 to April 2002) soil samples were taken monthly for 24 months. To take soil samples the two reed beds (680 m² each) were divided into 25 25 squares of 4×4 metres, from which 5–5 were selected at random. Samples were taken from 9 points of each square with a soil sampler from the upper 40 centimetre deep layer of the soil. Sampling was done according to the Hungarian standard (MSZ 21410-1) and then the samples were transported in plastic boxes to the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences for further preparation and examination.

After the removal of mechanical pollutants (e.g. gravel, leaves, root and other plant pieces) soil samples were dried at room temperature, ground, sieved and then mixed to be homogenous. Samples prepared for further analysis were stored in paper sacks in a dry place at room temperature. From each soil sample 1,00 g was measured for digestion with nitric acid and hydrogen-peroxide in a microwave equipment (MSZ 21470-50:1998). Then the element and nutrient concentrations (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Sr, Ti, V, Zn) of the samples were analysed by using ICP-AES. The KCl soluble ammonium and nitrate-nitrogen content of the samples were determined by distillation (Bremner), while the total nitrogen content was analysed by digestion (BÜCHI 430) and distillation (BÜCHI 322/342 wit online titration).

Plant samples (whole reed plants) were collected monthly between May 2000 and April 2002 during the vegetation periods (between May and October) from the same sampling places as the soil samples. The plants were washed with tap water and then with distilled water, and their roots, rhizomes, stems and leaves were separated. The organs deriving from 9 plants were mixed before digestion with nitric acid and hydrogen peroxide in a microwave equipment. Then the following parameters were measured in the samples: total N, P, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Sr, Ti, V and Zn.

The preparation of the plant samples (drying, grinding), their digestion (with nitric acid and hydrogen-peroxide in a microwave equipment) were done according to the regulations. The element concentrations of the samples were measured by using ICP-AES, while the total nitrogen content was analysed by digestion (BÜCHI 430) and distillation (BÜCHI 322/342 wit online titration).

The FVA 7 statistical analysis programme and MS Excel were applied to analyse the data, the methods used were two-way ANOVA, F probe, t probe and linear regression analysis.

RESULTS

The new scientific results of my research work can be summarised as follows:

The comparison of the purification efficiencies of the summer and winter periods in the root zone treatment system in Szügy

The purification efficiencies of the summer and winter periods in the root zone treatment system in Szügy did not differ significantly. Based on the concentration values in the case of some of the parameters - Ba, Ca, Fe, Mg, P, Sr and total N - more favourable elimination efficiency was measured in summer. On the contrary the system operated better in eliminating Al, Cu, K, Li, Ti and NH_4-N in the winter. It can be established that in the summer period due to the more intense biological activity, plant growth and development enhanced by the more favourable environmental conditions, the concentration values of most of the parameters were lower in the purified wastewater.

Considering the purification efficiencies of the root zone system in Szügy calculating with the average yearly concentration values it could be seen that the system operated well in the elimination of Al (94%), Zn (83%), Cu (64%), NH_4-N (60%), P (58%), Ba (55%) and total N (52%). In the case of Ti (39%), Fe (32%), K (20%), Sr (5%) and Mg (2%) the operation of the system was less successful, while the effluent was enriched in NO_3-N and Ca.

The accumulation of metals in the root zone treatment system in Szügy

I experienced that metals primarily accumulated in the root of the reed, secondly in its rhizome and in the smallest amount in the stem. Based on my results it could be concluded that the element concentrations of leaf and root could be used more reliably as a bioindicators, reflecting the presence of elements available and their rate of supply.

Even though Cr, Ni and V were not detectable in the wastewater, they accumulated in the root, the rhizome, the stem and the leaf as well. Cd and Co were only detectable in the underground plant parts, while Pb was found only in the root.

I established that the root accumulated Mn with four, Fe, Al, Ti and Zn with three, while Li, Mg and Sr with two orders of magnitude higher concentrations than it was measured in the wastewater. The rhizome accumulated Mn with four, Fe and Ti with three, Al and Zn with two, while Li, Mg and Sr with one order of magnitude higher concentrations than it was measured in the wastewater.

In the stem the largest concentration difference was measured in the case of Mn. In the cases of Fe, Ti and Zn the concentration values were higher with two orders of magnitude than those of the settled wastewater, while for Al, Li, Mg and Sr the concentration difference was one order of magnitude.

I found that the leaf also accumulated Mn with four orders of magnitude higher concentrations compared to that of the settled wastewater. In the cases of Fe the concentration values were higher with three orders of magnitude, for Mg, Sr, Ti and Zn with two, while for Al and Li the concentration difference was one order of magnitude.

I established that the soil accumulated Al and Fe with four, Mn and Ti with three, Cr. Li, Mg, Ni, Sr and Zn with two, while Cu with one order of magnitude higher concentrations than it was measured in the wastewater. Cd and Cr was detected in the soil in similar concentrations than in the root.

Examining the relationship between the concentrations of the elements in the wastewater and the soil I experienced that in the case of Ba, Ca, K, Mg and V the linear regression relationship was statistically proven, while for the concentrations of Al, Cu, Fe, Mn, Na, P, Sr, Ti, Zn, NH_4-N, NO_3-N and total N the same relationship could not be observed.

It could be concluded that in the case of the major part of the parameters examined - Al, Ba, Cd, Co, Cu, Fe, K, Na, P, Sr, Ti and V - the linear regression relationship between the concentration values measured in the soil and in the root could be proven statistically (α=0.05). In the case of similar number of parameters the same relationship could be seen between the values of the soil and the rhizome (Al, Ca, Cd, Cu, K, Li, Mg, Na, P, Sr, Ti, V and Zn), and between those of the soil and the stem (Ba, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Sr, Ti and V) (α=0.05). In the case of some elements (Al, Ca, Cu, Fe, Mg, Sr and Zn) the linear regression relationship was statistically proven between the values of the soil and the leaf (α=0.05).

Comparison of the element and nutrient accumulation of natural reed habitats and plant communities with that of the reed beds and plant parts in Szügy

Comparing my results with those of the clean and contaminated shores of Lake Balaton it was established that the concentration values of Ca, K, Na, P, NH4-N and Zn in the waster/wastewater were one order of magnitude higher in the root zone system. In the case of Mg and Sr the concentration values were nearly equal. As far as the NO_3-N, Fe and Cu contents of the water/wastewater were concerned no difference occurred in the order of magnitude of the concentration values.

Comparing the results of the sediments of Lake Balaton with those of the soil of the filter beds in Szügy it was established that the soil of the filter beds had higher concentrations of Ca, Mg, Na, P, Mn and Cu by one order of magnitude, while in case of K and Fe the difference was two orders of magnitude and considering the total nitrogen supply of the soil it was three orders of magnitude. As far as Sr and Zn are concerned there was no real difference between the soils.

Comparing the concentration values of the soil with those of the settled wastewater it can be seen that the accumulation of Al and Fe in the soil was four orders of magnitude higher, while that of Mn and Ti, that of Cr, Li, Mg, Sr and Zn, and that of Cu was three-, two- and one order of magnitude higher.

Based on present measurements and the data obtained from natural reed habitats it can be stated that in case of several elements (Ca, K, Na, P) the order of magnitude measured between the concentration values of the wastewater/lake water were also observed in the soil/sediment. Although the order of magnitude of differences in concentration values measured in the wastewater/water was not detectable for Cu and Fe, a two-order of magnitude difference was observed in the concentration values of the soil/sediment.

It was observed that for P, K, Mn, Zn and Cu the higher concentrations of the constructed environment surrounding the plant resulted in higher concentration values of the four plant parts (root, rhizome, stem, leaf) analysed. Considering N and Fe the contamination of the environment was reflected in the underground plant parts, while the concentration values were similar in the stems and leaves. As far as the Mg and Sr concentrations of the plants living in natural and constructed habitats are concerned none of the plant parts differed significantly. The Ca content of the rhizome of the reed in the root zone system was lower, while the Na content of all four plant parts was lower as well.

Comparison of the operation of the reed beds and the non-vegetated filter beds

Comparing the purification efficiencies of the reed beds and the non-vegetated gravel beds it was experienced that reed beds operated better in decreasing the concentrations of P, NH_4-N, total N, Zn, Al, K and Li. Considering the whole year or the summer and winter periods separately reed beds operated better as well.

The concentrations of Al, Ba, Fe, Mn, P and Sr in the water flowing out from the non-vegetated filter beds differed significantly in the summer and winter periods. In the case of another group of elements - Ca, Cu, K, Li, Mg, Na, Ti, Zn, NH_4-N, NO_3-N and total N – the change of the season did not affect the concentration values measured in the effluent.

The concentrations of Al, Ba, Ca, Cu, K, Li, Mg, Na, P, Sr, Ti, Zn and NH_4-N in the water flowing out from the reed beds differed significantly in the summer and winter periods. In the case of three elements –Mg, NO_3-N and total N - the change of the season did not affect the concentration values measured in the effluent.

Comparison of the purification efficiencies calculated with mass flows and concentration values

The data and the sampling results of the root zone wastewater treatment system of Szügy show that purification efficiencies calculated by taking into consideration mass and water flows, provide more typical and reliable results on the real operation of the system than those values which are calculated by applying concentration values.

Comparing the mass flows arriving to the reed beds and leaving them it can be seen that the evaporation and purification effect of the reed decreases the mass of the materials transported, which indicates that the reed evaporates water and retains some part of the pollutants. During the summer months there is no water leaving the reed beds, so from the point of view of the receiver the purification efficiency of the system is 100%.

Considering the operation of the entire wastewater treatment system in Szügy it can be concluded that the purification efficiencies calculated by taking into consideration mass and water flows were higher with 15-50% in the case of all the parameters. As far as Ca and Na are concerned the water was enriched in these elements, but when mass flows were applied they demonstrated 45% elimination.

NEW SCIENTIFIC RESULTS

1. Analysing the average monthly concentration values measured at the root zone wastewater treatment system in Szügy I concluded that the purification efficiencies of the system measured in the summer and winter periods did not differ significantly, which means that the operation of the treatment system was not affected considerably by the seasonal changes.

Considering the purification efficiencies of the root zone system in Szügy calculating with the average yearly concentration values it was established that the system operated well in the elimination of Al (94%), Zn (83%), Cu (64%), NH_4-N (60%), P (58%), Ba (55%) and total N (52%).

2. Examining the accumulation of elements and nutrients in the system I established that metals are primarily accumulated in the root, secondly in the rhizome and in the stem in the smallest amount. On the contrary nutrients mainly accumulated in the aboveground parts, the leaf contained them in the largest amount. Based on my results it can be concluded that the element concentrations of leaf and root are the most reliable bioindicators, reflecting the presence of elements and nutrients available in the environment and their rate of supply.

I established that metals accumulated in the roots and rhizome with three or four orders of magnitude higher concentrations compared to the concentrations measured in the wastewater. The high selectivity of ion transportation into the shoot is one of the reasons for the wide ecological amplitude of the reed. The high concentrations in the root refer to selective ion uptake and to effective ion binding on the surface of the roots.

I established that the soil accumulated Al and Fe with four, Mn and Ti with three, Cr. Li, Mg, Ni, Sr and Zn with two, while Cu with one order of magnitude higher concentrations than it was measured in the wastewater. Cd and Cr was detected in the soil in similar concentrations than in the root.

3. Comparing my results with those of the clean and contaminated shores of Lake Balaton I concluded that in case of several elements (Ca, K, Na, P) the order of magnitude measured between the concentration values of the wastewater/lake water were also observed in the soil/sediment. Although the order of magnitude of differences in concentration values measured in the wastewater/water was not detectable for Cu and Fe, a two-order of magnitude difference was observed in the concentration values of the soil/sediment.

Analysing and comparing the plant samples of the natural and contaminated habitats I observed that in the case of P, K, Mn, Zn and Cu the higher concentrations of the more polluted environment surrounding the plant resulted in higher concentration values of the four plant parts (root, rhizome, stem, leaf) analysed. Considering N and Fe the contamination of the environment was reflected in the underground plant parts, while the concentration values were similar in the stems and leaves. As far as the Mg and Sr concentrations of the plants living in natural and constructed habitats are concerned none of the plant parts differed significantly. The Ca content of the rhizome of the reed in the root zone system was lower, while the Na content of all four plant parts was lower as well.

4. The results of the comparison of the purification efficiencies of the reed beds and the non-vegetated filter beds of the root zone wastewater treatment system in Szügy proved that reed beds operated better in decreasing the concentrations of P, NH_4-N, total N, Zn, Al, K and Li. Considering the whole year or the summer and winter periods separately reed beds operated better.

5. The data and the sampling results of the root zone wastewater treatment system of Szügy showed that purification efficiencies calculated by taking into consideration mass and water flows, provide more typical and reliable results on the real operation of the system than those values which are calculated by applying concentration values, as due to its evaporation and purification effect the reed decreases the mass of the materials transported considerably.

I demonstrated that the purification efficiencies calculated by taking into consideration mass and water flows were higher with 15-50% in the case of all the parameters. It proves that the pollution of the environment (receiver) is much less than it is thought.

CONCLUSIONS AND RECOMMENDATIONS

The results of the wastewater, soil and plant samples taken in the root zone system in Szügy provide fundamental information regarding the operation of the system that can be used in the case of other ones.

The results justify that reed can be well applied in constructed wetlands as it has a high element and nutrient accumulation capacity, and due to its high evaporation ability, oxygen and surface providing capacity it affects the purification processes favourably. During the research it was also proven that reed beds operated better than non-vegetated filter beds in the elimination of the different elements and nutrients.

The more favourable and more reliable purification efficiencies calculated by taking into consideration mass and water flows also prove the viability of constructed wetlands, and show that such systems contaminate the environment less than it is thought. It is important to mention that longer hydrological measurements needed to provide more precise calculations.

Monitoring systems should be installed at constructed wetlands. It would be fundamental to measure regularly at least the concentrations of the basic water quality parameters (BOI_5, KOI_{Cr}, TSS, NH_4-N, TN, PO_4-P, TP) in the influent and effluent. Collecting and analysing the results would help the examination of the changes taking place in the system, thus the operation could be controlled, long-term changes could be described and assessed, and basic information could be provided for the planning, operation and maintenance of such systems.

I think it would be important to carry on further research on the effect of climatic and microclimatic conditions, such as temperature, precipitation, evaporation, etc. It would be interesting to see if these factors have any influence on the physical, chemical and biological processes taking place in the system.

The present results prove that the examinations of the material transport and accumulation processes and the role of the plant should be carried on in the future. Plants play an important role in constructed wetlands, a well-developed plant community has many positive effects. It would be also useful to analyse the element concentrations of the soil/sediment by applying other chemical analytical methods.

It is also needed to talk about the financial questions. The installation of the monitoring systems is of primary importance, as without preliminary data and information it is impossible to construct a well operating system. On the other hand the installation and operation of a monitoring system is too expensive for the authorities of small settlements, so it should be financed by the state.

Data and information provided by the monitoring systems would assist the planning, operation and maintenance of such systems and the overview and change of the present subsidy system and regulations, which is vital from the point of view of the wastewater treatment of smaller settlements.

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