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PHYTOREMEDIATION OF LANDFILL LEACHATE IN CONSTRUCTED WETLAND

Jaak Truu [1]
Jaanis Juhanson [1]
Mait Kriipsalu [2]
Marit Seene [2]
[1] *University of Tartu, Estonia*
[2] *Estonian Agricultural University, Estonia*

ABSTRACT

The integrated remediation plan of the Laguja landfill, Estonia, includes creation of a constructed wetland for treatment of landfill leachate. A mesocosm experiment was conducted in order to estimate the impact of different plant species on purification efficiency of wetland. The quality of water in mesocosms was monitored during vegetation period. All plant treatments enhanced reduction of organic matter (BOD: 87-96%, COD: ca 30%, TOC: ca 50%) as well as ammonia and total nitrogen in water compared to unplanted control. Presence of plants enhanced biodegradative bacterial abundance and activity as well as metabolic diversity of microbial community in water. Water samples from all plant treatments were characterized by distinct microbial communities as revealed by molecular fingerprinting techniques. Most different from the rest of microbial communities were water samples from mesocosm with plants on floating mats. Our results show that in free-water constructed wetlands with vegetation the purification efficiency is not dependent on plant species, while structure of water microbial community differs due to plant species.

KEYWORDS

Landfill leachate; Microbial community; Phytoremediation

1 INTRODUCTION

Seriously contaminated sites can be found in most countries. An interdisciplinary approach and cooperation between research institutions is required during full-scale remediation works. As common practice in many countries, liquid and solid oily wastes were dumped in municipal landfills until 90ies. When mixed with run-off water, leachate and other liquid wastes, ponds were formed at some of these dump sites. In Estonia, such a landfill is in Laguja, South Estonia. The Laguja municipal landfill is an unlined landfill with an area 17 000 m^2. Municipal and industrial wastes have there been disposed of from the early 1970s. The landfill was closed in 2004 and at that time it contained about 50 000 tons of municipal waste. At the lowermost section of the landfill area there was a shallow pond with a surface area of about one hectare. Fuel tank sediments, bilge water, various kinds of oily waste and oil-contaminated water had been dumped into the pond from 1974 to 1993. The pond received also landfill leachate and surface runoff from the surrounding land. The pond had no outflow. Oily leachate infiltrated into the soil and groundwater, creating an environmental concern.

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The integrated remediation plan of the Laguja landfill consisted of the following phases: (i) removal from the pond and treatment of the oily leachate; (ii) removal and treatment of the oily sediments; (iii) filling two smaller emptied pond sections with inert demolition waste; (iv) profiling and capping of the landfill; (v) creation of a constructed wetland for further treatment of the leachate. During remediation works of the contaminated pond, all of its water as well as sediments were removed and treated on site. All activities, including on-site infiltration of treated water, were carried out within the catchment area, so any water eventually drains back to the pond that was under remediation. Since the pond was planned to developed into a constructed wetland, the closed system was guaranteed. The pond was also designed to remain the recipient for leachate from closed landfill.

As a part of post-closure activities at the landfill, a field-scale test was performed in the purified pond section in order to evaluate its re-vegetation possibilities. The task was not easy: the water level in the pond was relatively high, and the resistance of the plants to moderate water pollution was not confirmed. Cattail, accustomed to live in contaminated environment was saved and stored during the cleanup of the last pond section. These plants were cleaned from excess sludge, and planted to the largest pond section.

The effect of aquatic plants on reduction of organic substances in leachate could be direct mediated via uptake of certain substances (phytoaccumulation or phytoreduction) [1] or indirect. In case of indirect impact plants may enhance bacterial growth through the release of easily degradable organic substances from roots (rhizodegradation), or supplying heterotrophic bacteria with dead plant litter. Plant roots are means for oxygen transport and release into soil and sediments [2]. Plants also create surface for formation of biofilm, that is know to more active than free-living bacteria [3]. Biofilms are also more resistant to toxic effect of pollutants. The aim of current study was to test the effect of different plant treatments and plant species on quality of landfill leachate.

2 MATERIAL AND METHODS

2.1 Experiment setup

Four plastic tanks with the size of one cubic meter were sunk into the pond. One tank was left un-vegetated as a control; common cattail (*Typha latifolia)* was planted in second tank, common reed (*Phragmites australis)* into third, and various types of shallow water plants, e.g. mare's tail (*Hippuris vulgaris),* flote grass *(Glyceria fluitans), and* floatingleaved pondweed *(Potamogeton natans)* were planted on supporting structure floating on the water in fourth tank. Such an approach with floating mat would allow ignoring the relatively high water level fluctuations in the pond, and providing stabile living environment for such plants. All of the tanks were hydraulically isolated from the pond water. Experiment was established in the beginning of August 2004, and water samples from tanks and pond were collected in October same year. Water samples were subject to chemical and microbiological analyses. Pond water chemical parameters measured are listed in *Table 1*.

Table 1. Pond water chemical parameters in August and October 2004.

Parameter	Unit	August	October
pH	mg/l	8.5	7.79
BOD_7	mg/l	72	15
NH_4	mgN/l	8.4	13
NO_3	mgN/l	0.02	0.85
N_{tot}	mg/l	36	29
PO_4	mgP/l	0.85	1.6
P_{tot}	mg/l	2.6	2.1
COD	mg/l	500	370
TOC	mgC/l	320	204

2.1 Microbiological methods

Number of heterotrophic aerobic bacteria was enumerated by the spread plate method in triplicate on R2A agar (Difco). The number of phenol-degrading bacteria was determined in triplicate sets on M9-salts agar plates supplemented with trace elements and phenol (2,5mM). The heterotrophic activity and diversity of microbial community was measured using Biolog EcoPlates (Biolog, Inc.). Microbial DNA was extracted from water samples with UltraClean Microbial DNA Isolation kit (Mo Bio Laboratories, Inc.). Bacterial community structure was assessed with primer pair 338f-GC/518r [4]. A denaturating gradient gel electrophoresis (DGGE) system DCode (Bio Rad, Inc.) was used to separate the amplified gene fragments. DGGE gels were digitized and banding pattern analysed using cluster analysis.

3 RESULTS

All plant treatments enhanced reduction of organic matter (BOD: 87-96%, COD: ca 30%, TOC: ca 50%) as well as ammonia and total nitrogen in water compared to unplanted control. In case of unplanted control the reduction of BOD was 27% and COD 8%, respectively. Both ammonia nitrogen and concentration of phosphate phosphorus decreased remarkably (85-95%) in planted mesocosms, while concentration of nitrate increased from zero to values around 0.7 mg l^{-1}. Mesocosm with floating plants exhibited largest reduction of both total and phosphate phosphorus.

Figure 1 shows the ordination of water samples from mesocosms. Three planted mesocosm samples cluster together on plot, while unvegetated mesocosm sample differs from the rest of the samples. The plot indicates that main shifts in water chemical parameters have been in same direction in all cases, but the changes have been largest in vegetated mesocosms. The effect of plant species on water chemical parameters was small compared to difference between planted and unplanted tanks.

Presence of plants enhanced biodegradative bacterial abundance and activity as well as metabolic diversity of bacterial community in water. The number of aerobic heterotrophic bacteria was in the range $9x10^6$ – $2.3x10^7$ CFU ml^{-1}, without clear difference between treatments. Number of phenol degrading bacteria was highest in case of floating plants ($9x10^4$ CFU ml^{-1}) and lowest in mesocosm without vegetation ($1.5x10^4$ CFU ml^{-1}). Activity of heterotrophic microbial community was 1.3-2.3 times higher in planted mesocosm compared to control as measured with Biolog microplates. Water samples from all plant treatments were characterized by distinct bacterial communities as revealed by molecular fingerprinting technique (*Figure 2*). Most different from the rest of bacterial communities were water samples from mesocosm with floating plants. Water samples from tanks with *Typha* and *Phragmites* clustered together, but the similarity of bacterial communities was less than 60%.

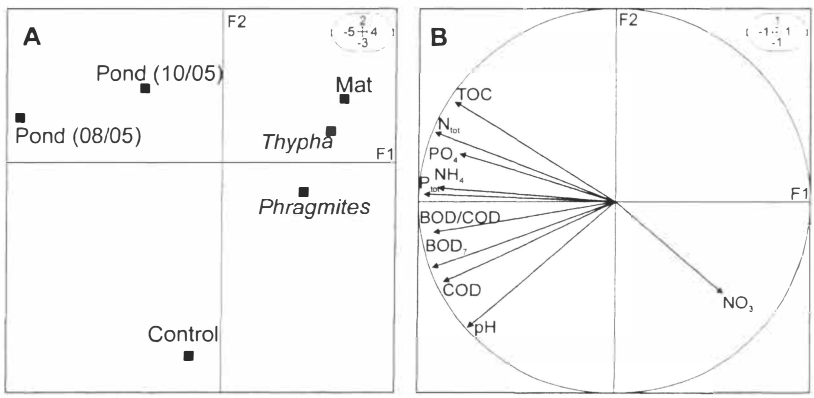

Figure 1. Principal component analysis based on water chemical parameters. Two first principal components (F1 and F2) account for 72.5% and 14.4% of overall data variation, respectively. Plot A shows ordination of water samples with respect to first two principal components. Plot B presents correlation of water chemical variables with first two principal component axes.

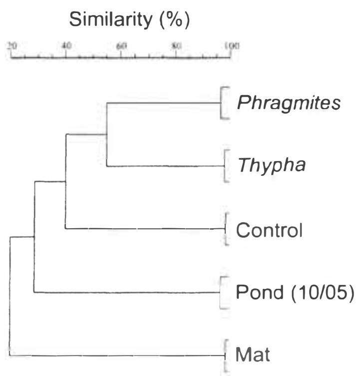

Figure 2. Cluster analysis of bacterial communities based on denaturating gradient gel electrophoresis (DGGE) fingerprints. Shown are two parallel measurements.

4 DISCUSSION

Alternative extensive low cost treatment methods based on different types of constructed wetlands for on-site treatment of landfill leachate have been used as a part of integrated purification system successfully in many cases [5, 6]. It is not reasonable to compare retention values obtained in this experiment with actually working systems, as it was not continuous flow system. In our experiment number of aerobic heterotrophic bacteria in mesocosms was several magnitudes higher than typically recorded in landfill leachate [7], which could be partly the result of better aeration of leachate in pond as well as due dilution effect. The increase of phenol-degrading bacteria abundance in planted mesocosms could be associated to better removal of recalcitrant organic substances in leachate. It has been shown in lab experiments that helophytes enhance the removal of xenobiotics in sand-bed reactors [8]. The effect of rhizodeposition from aquatic plants on bacterial degradation of xenobiotics is stronger for more recalcitrant compounds [9]. Plants also stimulate nitrification and denitrification in vicinity of roots in sediment [10]. Our data indicate indirectly that nitrification and denitrification activity was increased in planted mesocosms. The effect of plants on these processes may be complex, involving in addition to release of root exudates and better aeration near roots, reduction of water toxicity to nitrifying bacteria due increased number of biodegrading bacteria within microbial community. Also, immobilization of nitrogen into plants and microbial biomass should be taken into account. Contribution of plants to uptake of nitrogen may be most significant in case of floating plants, but further experiments are needed to support this conclusion. The outcome of comparison of bacterial community structure based on DGGE fingerprints between treatments suggests that plant species has effect on formation of bacterial species composition in water. Many different factors may influence the composition of bacterial community in wetland, but studies of soil bacterial communities have shown that plants exert highly selective effect on bacterial community in rhizosphere [11]. Further research is needed to explore changes within functionally important bacterial groups during phytoremediation of landfill leachate.

6 CONCLUSIONS

In free-water constructed wetlands with vegetation the purification efficiency is not dependent on plant species, while structure of microbial communities differs due to plant species. Floating plants on supportive structure could be used to enhance purification efficiency when water is too deep for submerged plants.

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