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Research papers

Improving the remediation capacity of a landfill leachate channel by selecting suitable macrophytes

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ABSTRACT

To assess the remediation capacity of a leachate channel, we monitored basic environmental parameters such as bathymetry, leachate, and soil characteristics and vegetation coverage. Based on our results, we designed a series of experiments to determine the most suitable remediating plant species for sustainable wastewater treatment. We found that adaptability to water depth may be a prime driver of reduced remediation capacity. Large portions of the leachate channel were deeper than the maximum tolerance range of many candidate emergent macrophytes, resulting in only 16% total vegetation coverage. Among tested species, *Typha angustifolia* showed the most promising potential for remediation, reaching the highest aboveground biomass (3300 g/m^2) and demonstrating maximum concentrations in tissues (34,600 mg/kg of Na, 4013 mg/kg of Mg, 904 mg/kg of P, 639 mg/kg of Mn, 191 mg/kg of Fe and 62 mg/kg of Zn) when grown in leachate filled tank for six months. *Typha angustifolia* also showed greater tolerance of water depth than *Phragmites australis*, which previously was planted in leachate channels. Thus, *T. angustifolia* should be more suitable for the actual water depth of the channel. Additional planting of *T. angustifolia* will improve the vegetation coverage, the total remediation capacity and sustainability of the leachate channel. Considering water depths of target wetlands when selecting remediation plant will improve remediation ability and sustainability of remediation wetlands.

1. Introduction

Sanitary landfilling is one of the most common strategies to manage solid waste (Song and Lee, 2010). But landfills can present environmental problems, especially the containment of leachate, which forms as organic waste decomposes (Jones et al., 2006). With rainfall, leachate percolates through waste, and eventually migrates into the surrounding environment (Foo and Hameed 2009), potentially contaminating the underlying substratum (Lee and Jones-Lee, 1994). Leachate contains hazardous heavy metals and other potentially toxic materials (Jokela et al., 2002). Effective leachate processing thus is a key component of any landfill management strategy. The most widely used and effective leachate purification processes are physicochemical treatments (Deng, 2007) combined with biological treatment by microorganisms (Kargi and Pamukoglu, 2003).

The Sudokwon landfill, in Incheon, South, Korea, is one of the largest leachate processing facilities in the world. Leachate is processed by anaerobic digestion, denitrification/nitrification, coagulation, chemical consolidation, precipitation and discharge (Sudokwon Landfill Site Management Corporation, 2013). During the biological processing, denitrification, odor emission, and release temperature are controlled. The chemical processing entails oxidation and coagulation of waste. However, as in other such facilities, the physicochemical and biological treatment processes used are ineffective at removing heavy metals (Sudokwon Landfill Site Management Corporation, 2013).

Heavy metal and other pollutants can be removed from leachates using absorbents but the methodology is technically challenging and consequently expensive. Thus, other lower cost technologies have attracted interest (Mohan and Gandhimathi, 2009). Constructed wetlands that use plants for purification (i.e., phytoremediation) have emerged as a promising alternative because of their demonstrated capabilities to remove pollutants, their cost effectiveness, and environmental friendliness (Rahman et al., 2016)).

Phytoremediation systems utilize the potential of soil–plant system to degrade and inactivate potentially toxic elements in the leachate (Jones et al., 2006). The Sudokwon Landfill has a leachate channel and connected constructed wetlands for leachate treatment and phytoaccumulation. Reeds (*Phragmites australis*) are planted in the channel and methods for the enhancement of uptake have been developed (Song, 2010). However, phytoremediation only is effective if

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contaminants are drawn toward plant biomass, the extent to which may depend on water depth, availability of nutrients, as well as various physical, chemical, and atmospheric factors (Cunningham and Ow, 1996).

Processes of phytoremediation and phytoaccumulation of landfill leachate are still poorly understood (Kim and Owens, 2010), with studies so far focusing on the establishment of vegetation and remediation capacities. Some researches shows very effective remediation (Guittonny-Philippe et al., 2015) that can be applied for actual leachate or waste water purification. However, as the effectiveness of phytoremediation depends on how plants uptake contaminants in the leachate channel, more ecological research on how candidate plants adapt to varied environments is needed. Problems such as low vegetation cover can develop over time, as is apparent in the leachate channel of the Sudokwon Landfill. We investigated the ecological status and operating condition of this leachate channel by monitoring its topography, leachate condition, soil condition and vegetation coverage. Then we conducted leachate tank experiments to evaluate the phytoremediation capacities of candidate plant species.

2. Materials and methods

2.1. Study site

The Sudokwon Landfill, located in Incheon, Korea (37° 34′ 52″ N, 126° 37′ 29″ E) is one of the largest sanitary landfills in the world, with gross area of approximately 20,000,000 m^2. The landfill produces 6700 tons of leachate per day (Sudokwon Landfill Site Management Corporation, 2013), making it one of the largest leachate processing facilities in the world. The landfill has more than 5 km of leachate channel feeding into buffering wetlands to minimize the impact of the leachate on the sea after emission (Song, 2010). The elevation of the channel at the leachate release point was 6 m above sea level and the elevation of the channel at the end (buffering wetland) was 3 m. The velocity of the channel when measured at 30 cm below surface was under detection limit of the propeller type velocity meter (Kenek, Japan). The average annual temperature and precipitation in this area during the research years (2006–2009) were 12.8 °C and 1234 mm (Korean Meteorological Administration, 2010).

2.2. Experimental design

2.2.1. Leachate channel monitoring

In July of 2006, the 5 km long leachate channel was divided into four areas by vegetation coverage and natural (geographical) features (Fig. S1 in Supplementary materials). Site 1 (from the beginning to 900 m of the channel) had the highest vegetation coverage. Site 2 (from 950 to 1700 m of the channel) was separated from site 1 by a bridge, and had less vegetation coverage. Site 3 (from 1700 to 3000 m of the channel) began where the water depth rapidly deepened at 1700 m point. Site 4 (from 3000 m to the end of the channel) was largely devoid of vegetation.

We set up 12 × 12 m quadrats, with 11 replicates in each site, to examine standing vegetation and vegetation coverage. The quadrat size matched the width of the leachate channel (~12 m). We measured how water depth increased with distance (1, 2, 3 and 4 m) from the channel bank to make Sectional schematic view of the channel. In addition, we measured the maximum water depth at which a major plant species, *Phragmites australis*, could be found in the leachate channel and buffering wetlands. Soil were sampled at the bottom of the leachate channel, excluding litters (debris) on the bottom.

Organic matter (OM), pH, total nitrogen (TN), Na, Fe and Mn contents of soil were recorded, together with the temperature, electro conductivity (EC), pH, Na, Fe, Zn, Mn, Mg, TP, TN and chloride contents of leachate in the channel.

2.2.2. Leachate tank experiment

To test remediation ability and water depth tolerance, on May 14th, 2006, rhizomes (subterranean stem that sends out roots and shoots from its nodes) of several species of macrophytes were collected and planted in pots (36 cm diameter, 40 cm height) that we placed into a water tank (2x5 m) in the landfill. *Phragmites australis* Trin. (referred to as *Phragmites* below), *Typha angustifolia* Bory et Chaub (as *Typha* below), *Phacelurus latifolius* (Steud.) Ohwi (as *Phacelurus* below), *Scirpus tabernaemontani* Gmel. (as *Scirpus* below) and *Zizania latifolia* Turcz. (as *Zizania* below) were selected as test plants. These species were selected because most are common Korean macrophytes and most species were able to collect rhizomes from wetlands within 10 km from the landfill (surveyed in 2005, except *Phacelurus*). *Phacelurus latifolius* is a rather rare species that has not been previously studied for but may be effective for remediation, and rhizomes of this species were collected from wetland in Ansan, Gyeonggi province, where was about 70 km from the landfill.

Before planting, we analyzed the biomass of rhizomes in fields (except for *Phacelurus latifolius*) as a basis for comparison for subsequent measurements. *Typha* had an average of 4500 g (fresh weight) of rhizomes per m^2, and the other species had about 3000 g of rhizomes per m^2. However, considering the effects of stress to rhizomes caused by transplantation, we planted *Typha* at 6000 g per m^2 and other species at 4000 g per $m^{2.}$ Based on the pot surface area, 600 g of rhizomes per pot ware planted for *Typha* and 400 g for the other species (10 replications). Rhizomes were planted 1–2 cm deep in sand within the pots, and the water level of the tank was maintained at −10 cm depth from the surface of the soil (sand) for 2 weeks to allow the rhizomes to adapt. After 2 weeks, the piped water in the tank was drained and leachate, taken just before emission into the leachate channel, was added to 10 cm depth for the first month to facilitate shoot growth and to 30 cm afterward. Leachate in the tank was drained and replaced with fresh leachate every month. The leachate tank was covered with a transparent roof to prevent dilution by precipitation. Plant height, biomass, nutrient contents and possible pollutants including some heavy metal contents were measured after six months.

After the first year of study, *Typha* and *Phragmites* were selected for detailed analyses of effects of water depth. Rhizomes of *Typha* and *Phragmites* were collected in wetlands of the Sudokwon Landfill in early April. Four hundred g of rhizomes were planted in each pot and were placed into tanks filled with leachate immediately after planting. The water level was maintained at 10 cm for 3 weeks to give plants time to emerge and stabilize. Then, one tank was kept at a depth of 10 cm and the other one increased to 40 cm (30 replicates each). Plants were harvested later in October.

2.3. Soil, leachate and plant analyses

2.3.1. Soil characteristics

The soil was dried at 105 °C for 48 h to measure its water content. Its organic matter content was determined by loss on ignition (combustion at 550 °C for 4 h). The pH and electrical conductivity of the soil and compost were determined by using a suspension of the soil sample in water (20 g/30 ml) with conductivity meter (model 33, YSI, OH, USA) and pH meter (model 60, YSI, OH, USA). The soil respiration rate was measured with an infrared gas analyzer (EGM-4, PP-Systems, Hitchin, UK).

2.3.2. Heavy metals and other elements

For plant analysis, we harvested a whole shoot (both stem and leaves) and then grounded with a blender. Then few grams of samples were milled again to get fine powder. One gram of dried and milled soil or plants was pretreated with 60% HNO_3 for 24 h and heated to 80 °C for 2 h. Then, 10 ml of 70% perchloric acid was added and the solution was heated to 200 °C until it became clear. The samples then were filtered with Whatman 44 filter paper and their element contents were