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Effect of plant species on sludge dewatering and fate of pollutants in sludge treatment wetlands

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ABSTRACT

Plants are assumed to play a central role in sludge treatment wetlands (STWs) by preventing clogging, favouring dewatering and improving sludge mineralisation. However, few comparative studies have been made to assess the influence of plants presence or species on the treatment of sludge in STWs. Therefore, the aim of this study was to evaluate the effect of three plant species on sludge dewatering and mineralisation, and on the general fate of water and pollutants in STWs. The experimental setup consisted of mesocosm sized STWs planted with monocultures of *Phragmites australis*, *Typha angustifolia* and *Scirpus fluviatilis*, in addition to an unplanted control, each in duplicate. The mesocosms were fed with settled fish farm sludge for three summers, and the effect of plants was assessed according to the percentage of pollutants per mass of dry sludge (pollutant content), in addition to a mass balance analysis of pollutants in the STWs.

Results revealed that the standard method for assessing STW efficiency (i.e. sludge pollutants content) is inadequate when comparing the subtle effect of plant species and that a mass balance analysis should be used instead. Mass balance showed that pollutants were mainly retained within the sludge cake, while the rest was considered trapped inside the STWs or mineralised. Only a small percentage of pollutants was discharged at the effluent (from <0.1% to 5% of total pollutants input). Plant species had a distinct effect on pollutants, which differed according to the sampling location in the STWs. At the outlet, pollutant removal was more efficient in the planted system and was significantly different according to plant species. In the sludge cake, contrary to common assumptions, STWs planted with *T. angustifolia* and *S. fluviatilis* had generally higher sludge cake volume, mass of organic matter, nitrogen and phosphorus, when compared to the unplanted control. This was attributed to the presence of plant litter in the sludge cake, which mitigated mineralisation. In contrast, STWs planted with *P. australis* resulted in the highest reduction in sludge volume and were the most efficient for sludge dewatering and mineralisation of organic matter in comparison to other species and the unplanted control. A fraction of the nitrogen and phosphorus was also sequestered in plant tissues, which represented close to a quarter of the nitrogen input by the sludge in *P. australis* STWs. This study shows that the presence of plants and the choice of plant species is an important factor that affects sludge dewatering and mineralisation, but also the general fate of water and pollutants in STWs. Further studies should be done in a full size STW to validate the finding obtained in this mesocosm experiment.

1. Introduction

Sludge treatment wetland (STW) is a phytotechnology specialised in the reduction of sludge volume, by the means of dewatering and mineralisation process. Plants are thought to play a central role in STWs, by preventing clogging, favouring dewatering and improving mineralisation of the sludge (Nielsen, 2007). They are assumed to enhance dewatering through plant transpiration and by creating drainage tunnels within the sludge layer through the movement of stems and roots (Nielsen, 2003). Furthermore, aeration from the tunnels as well as oxygen transfer from the plant to the rhizosphere are considered to favour microbial processes responsible for the mineralisation of the sludge cake (Uggetti et al., 2010).

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Although plants constitute a key element of this technology, few studies have tested the influence of plants or plant species on the dewatering and mineralisation of the sludge. Essentially all studies comparing planted to unplanted STWs were conducted using *Phragmites australis*, sometimes with contradictory findings. The presence of *P. australis* has been shown to enhance sludge volume reduction, with 3–8% less volume in planted systems compared to unplanted controls (Edwards et al., 2001; Stefanakis and Tsihrintzis, 2012). *P. australis* can similarly favour dewatering, with an average of 2–6% more total solids content (TS) in the sludge cake compared to unplanted control (Edwards et al., 2001; Stefanakis and Tsihrintzis, 2012). However, a study by Liénard et al. (1995) measured no TS difference between the sludge cake of planted and unplanted STWs. Sludge mineralisation was higher in planted systems, with 3–6% less total volatile solids content (TVS) per TS in the sludge cake (Liénard et al., 1995; Stefanakis and Tsihrintzis, 2012), yet one study measured no difference (Edwards et al., 2001). A lower percentage of nutrients has generally been found in the sludge cake of planted STWs, with 1–6% less total Kjeldahl nitrogen content (TKN) and 0.3–3.5% less total phosphorus content (TP) per TS (Liénard et al., 1995; Stefanakis and Tsihrintzis, 2012). Little attention has been given to the effect of plant species in STWs. To date, the single study comparing the effect of plant species on the dewatering and mineralisation of sludge revealed no significant difference between *P. australis* and *Typha* sp. in terms of volume reduction, chemical oxygen demand (COD), TS, TVS, TKN and TP removal (Uggetti et al., 2012). However, the significance of any effect of plant presence or particular species in STWs is difficult to assess, since these experiments were conducted without replicated units. Variance for each treatment is therefore unknown or, if presented (spatial or temporal sub-sampling of the same STW units), it is usually too large to allow a clear interpretation.

The pollutant content of sludge gives only the ratio of pollutants per solids, but not the specific mass of pollutants accumulated within the sludge cake of the STW. This can be a significant bias when comparing subtle differences between treatments, since at the same ratio (e.g. 30% TVS/TS) planted STWs could have a proportionally lower mass of TVS and TS per surface than the unplanted STW, but still result in the same pollutant content. Therefore, the effect of plants in STWs could be better assessed using a mass balance analysis, which gives the amount of water and pollutants retained in the sludge cake, sequestered in the plant, transformed or discharged at the outlet. Water balance analysis of STWs planted with *P. australis* has shown that a large proportion is eliminated through evapotranspiration (58–84%), most of the rest being discharged at the outlet (13–41%), and only a small fraction being retained in the sludge cake (1–4%) (Begg et al., 2001; Stefanakis and Tsihrintzis, 2011). Water balance analysis of STWs planted with *Typha angustifolia* found a lower percentage of water loss through evapotranspiration (42%), with the remaining water considered discharged at the outlet (58%) (Panuvatvanich et al., 2009). In STWs planted with *T. angustifolia*, total solids were retained mainly in the sludge cake (38–52%), with only 11–12% present at the outlet and the rest unaccounted for (36–50%) (Koottatep et al., 2001). Another study found that nitrogen was mainly retained in the sludge cake (55%), a very small portion was sequestered in *T. angustifolia* tissues (0.2%), and the rest was discharged at the outlet (13%) or unaccounted for (13%) (Panuvatvanich et al., 2009). None of these studies reported a comparative analysis of mass balance between plant species under similar experimental conditions. Consequently, the effect of plants species on the fate of water and pollutants in STWs remains inconclusive.

The aim of this work was to evaluate the effect of the presence of plants and specific plant species on sludge dewatering and mineralisation, and to determine the fate of water and pollutants in

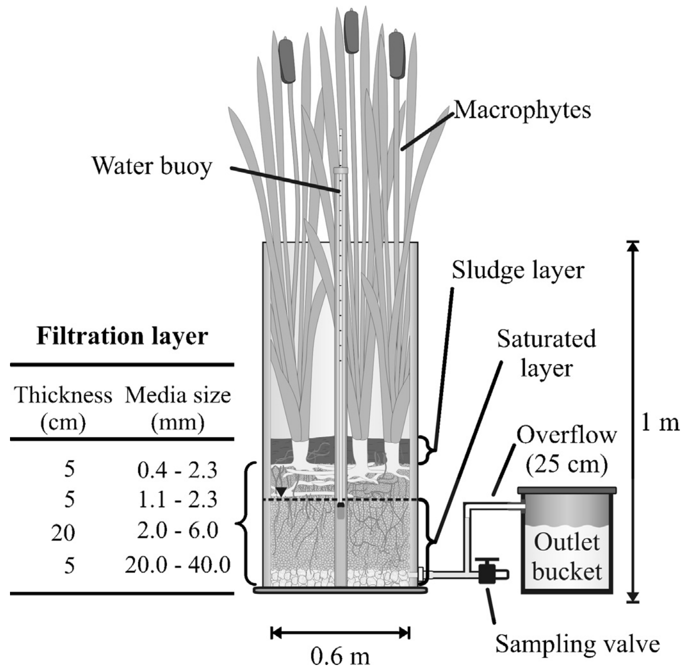

Fig. 1. Cross section of the mesocosm showing the granular size of each filtration layer.

sludge treatment wetlands. The experiment was conducted over three summers in mesocosm sized STWs planted in monoculture of *P. australis*, *T. angustifolia* and *S. fluviatilis*, and compared to an unplanted control, all in duplicates. The experimental STWs were not completely drained, and a saturated layer was retained at the bottom of the wetland to favour evapotranspiration and pollutants removal. The experimental systems were fed with concentrated fish farm sludge, and the performance was evaluated by the efficiency of sludge dewatering and mineralisation, as well as by mass balance analysis.

2. Materials and methods

2.1. Experimental design

The experiment was conducted in a field located at the Montreal Botanical Garden (Quebec, Canada), which has a semi-continental climate with warm, humid summers and very cold winters. The mean monthly temperature reaches a maximum of 20.9 °C in July and a minimum of −10.2 °C in January. Average annual precipitation is 979 mm (22% as snow), and the growing season lasts for about 195 days, from mid-April to mid-September (Environment Canada, Climate Normals 1971–2000). The experimental setup consisted of mesocosm-sized sludge treatment wetlands (cylindrical shape; height: 1 m; diameter: 0.6 m), each composed of 4 filter layers of different granular sizes (see Fig. 1 for details). Contrary to conventional STWs, the experimental mesocosms were not completely drained, and a saturated layer was retained by placing an overflow at 25 cm from the bottom. All water coming out from the overflow was recovered in an outlet bucket for sampling. Each mesocosm was planted with a monoculture of *P. australis*, *T. angustifolia*, *S. fluviatilis* and a fourth remained an unplanted control. All STWs treatment were in duplicate for a total of 8 mesocosms. A randomized block design was used for distributing the plant species among the mesocosms.