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Constructed wetlands for sludge dewatering with high solids loading rate and effluent recirculation: Characteristics of effluent produced and accumulated sludge

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ABSTRACT

Constructed wetlands (CW) have been studied successfully aiming sludge dewatering. Nevertheless, there is still lack of information about some aspects, e.g. can the effluent produced be safely disposed in the environment? What are the options for the post-treatment of that effluent? The main objective of the present study was the evaluation of CW for anaerobic sludge dewatering with medium-high solids loading rate (150 kg total solids.m^{-2}.year^{-1}) and recirculation of the effluent produced (sludge water) into the CW, as an option for its post-treatment. We studied three vertical flow CWs with different macrophytes (*Zizaniopsis bonariensis*; *Cyperus Papyrus*; and *Thypha domingensis*), and 0.8m^2 surface area each. CWs were fed weekly, alternating sludge and sludge water. The system operates in batch more, and hydraulic retention time was set at six days. With recirculation, it was possible to reduce the amount of final effluent produced by evapotranspiration and promote an extra treatment of sludge water, which achieved characteristics for safety disposal in the environment, as such: average COD concentration 137 mgL^{-1}; ammonium nitrogen 5 mgL^{-1}; and phosphorus 2 mgL^{-1}. The average water loses in CWs varied between 24 and 78%. The accumulated sludge did not achieve the standards to be applied in agriculture, especially regarding the pathogen content. However, there was a positive correlation between the reduction of total coliforms and *E.coli* and desiccation of sludge (2-2.5 log units for moisture reduction by 40%). The three macrophytes studied are recommended for sludge treatment wetlands, with higher performances achieved by *Z. bonariensis*, followed by *T. domingensis* and *C. papyrus*. Combining the possibility of applying high organic loading rates and using the own wetland to treat the sludge water was shown to be effective in terms of treatment efficiency and reduction of costs.

1. Introduction

The importance of water, sanitation and hygiene for food and water security is nowadays frequently reported in international discussions. Water pollution is caused largely by inappropriate discharge of wastewater into water bodies. It is well known that faecal sludge has considerably high pollution potential, and its mismanagement is a common reality in many countries, especially in developing countries. When evacuated from septic tanks or pit latrines, faecal sludge contains pathogens and nutrient concentrations 10–100 times higher than domestic wastewater (Kengne et al., 2009).

Constructed wetlands have been studied successfully aiming sludge dewatering. The technology attends developing countries constraints such as low energetic costs and simplified operation. The cost of dewatering 1 ton of sludge in sludge treatment reed beds (STRB) is low and is only about 5–10% of the overall operating cost of traditional methods of sludge dewatering (Kołecka and Obarska-Pempkowiak, 2013).

Uggetti et al. (2011) compared constructed wetlands with other alternatives for sludge management in small communities (<2000 inhabitants), as composting and transportation to wastewater treatment plants. According to the results the CW with direct land application is the most cost-effective and has the lowest environmental impact.

The system of CW for sludge dewatering consists of sealed basins with a filter bed of successive stone layers, gravel and sand fractions, in which macrophytes are planted.

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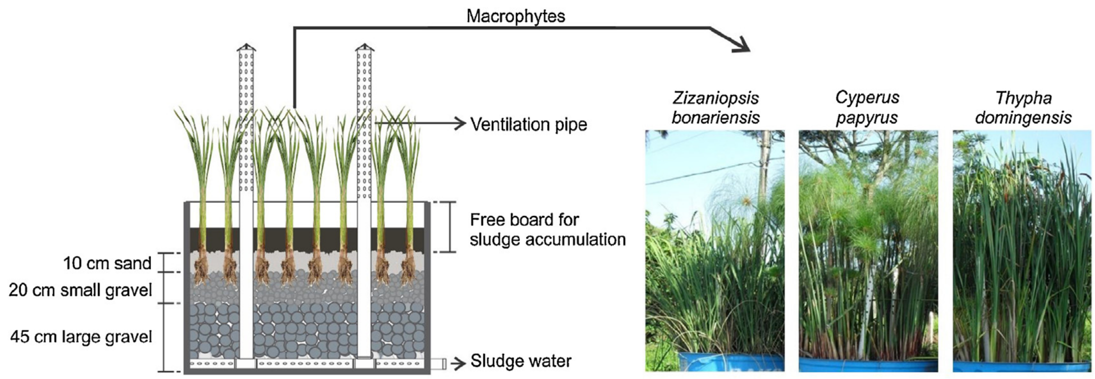

Fig. 1. Pilot-scale scheme of constructed wetlands studied for sludge dewatering.

The most common plants utilized are *Phragmites australis* (Hardej and Ozimek, 2002; Nielsen and Willoughby, 2007; Giraldi and Iannelli, 2009; Peruzzi et al., 2009; Bianchi et al., 2011; Stefanakis and Tsihrintzis, 2011; Korboulewsky et al., 2012; Uggetti et al., 2012) and *Thypha* sp. (De Maeseneer, 1997; Panuvatvanich et al., 2009; Stefanakis and Tsihrintzis, 2011; Korboulewsky et al., 2012; Uggetti et al., 2012). In less extent, but also studied are *Echinochloa pyramidalis* (Noumsi et al., 2006; Kengne et al., 2008, 2009), *Cyperus papyrus* (Noumsi et al., 2006; Kengne et al., 2008, 2009; Magri et al., 2010), *Iris pseudacorus* (Korboulewsky et al., 2012) and *Zizaniopsis bonariensis* (Magri et al., 2010; Suntti et al., 2010).

The process for treating sludge in CW consists first in spreading it evenly on the bed surface. After this operation occurs the natural sludge dewatering that may take from 1 or 2 days or weeks, depending on loading and wetland characteristics (Uggetti et al., 2012). So, part of the water content in the sludge (called sludge water, liquid percolate or leachate) is drained through the bed, while another part is evapotranspirated or incorporated in the plants or still as humidity in the medium/sludge. A concentrated sludge layer accumulates on the bed surface through time, and once this layer reaches the wetland capacity, feeding is stopped. The sludge is kept in the bed usually from 2 months to 1 year to improve its mineralization, dewatering and pathogen removal. CW for sludge are normally projected to operate receiving sludge for 10–20 years without removing it from the bed (Nielsen et al., 2014).

During the treatment process as described, the products that need to be managed are the sludge water generated during the feeding period, the accumulated sludge and plants. However there is still lack of information concerning the sludge water, e.g. can the effluent produced be safely disposed in the environment? What are the options for the post-treatment of that effluent?

The sludge water usually contains significantly amounts of nutrients, organic matter and pathogens (Kengne et al., 2013), so it needs extra treatment before disposal. In centralized wastewater treatment plants that have constructed wetlands for sludge dewatering that is not much concern about the sludge water, since it is normally returned to the wastewater plant (Uggetti et al., 2010). Although, in decentralized situations or in plants that receive sludge from emptying septic tanks or pit latrines, the treatment of sludge water can became a problem.

Not many experiences in treating sludge water are reported in literature. Some authors recommend stabilization ponds or constructed wetlands (Koottatep et al., 2004; Cofie et al., 2006; Kengne et al., 2013; Kengne et al., 2014).

In that context, the main objective of the present study was the evaluation of CW for anaerobic sludge dewatering with recirculation of the effluent produced (sludge water) into the sludge layer, as an option for its post-treatment. There was evaluated the characteristics of sludge water produced and accumulated sludge in three CW planted with different macrophytes species. It is believed that the recirculation procedure has high potential application under tropical and sub-tropical climates where the radiation rates and temperatures are higher, making possible to reduce the effluent amount by evapotranspiration, and also promoting an extra treatment of it.

2. Materials and methods

2.1. Study site

The study was conducted in southern Brazil, in the city of Florianópolis (−27°35′48″ latitude, −48°32′57″). Its climate is classified as humid subtropical, with temperatures varying between 28 and 33 °C in the warmest month and 10–15 °C in the coolest, with average annual temperature of 21 °C. The average air moisture is 82% and precipitation stays around 1500 mm per year. The experiment was conducted in the year of 2012 for 9 months, from February to October.

2.2. Pilot-scale unit description

Three vertical flow constructed wetlands (CW) with 0.8m^2 surface area each were studied. CW1 was planted with *Zizaniopsis bonariensis*; CW2 with *Cyperus Papyrus*; and CW3 with *Thypha domingensis* (density of 15 plants.m^{-2}).

The support medium depth of CW was 0.75m, consisting of 0.10 m of coarse sand layer, 0.20 m of small gravel layer, and 0.45 m of large gravel layer. A free board of 0.50 m was projected to allow the dewatered sludge accumulation. The CWs had ventilation pipes (45 mm of diameter) placed vertically on the drainage pipes, extending 1.0 m above the filters surfaces (Fig. 1). The drainage pipes had valves to control the outlet and consequently the hydraulic retention time. CWs were independent from each other, and each outlet was connected to a closed container of 500 L to collect the leachate (called here sludge water).

2.3. Operating conditions and sampling procedures

The system was operated in batch mode, or in cycles as we called here, as following: CWs were fed weekly, alternating anaerobic sludge from a septic tank (load of 150 kgTS m^{-2} year^{-1}) and sludge water (recirculation step).

The sludge loading rate applied is considered medium to high according to references. The common applied loads vary between 10 and 60 kgTS m^{-2} year^{-1} (Uggetti et al., 2010). For achieving the load of total solids, the volume of sludge applied was set at 430 L per each feeding per CW. The volume of sludge water recirculated