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Fate of phosphorus in two constructed wetlands receiving treated wastewater: contributions of free water, soil and plants retention

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Abstract: Constructed Wetlands receiving treated wastewater (CWtw) have recently become attractive in France under the perception that they would increase water quality of the WWTP effluent. This study focuses on the fate of phosphorus (P) in 2 pilot-scale CWtw after 2 years of operation considering the 3 components: water, soil and plants. P mass balance was estimated by measures of water balance (inflow outflow and infiltration), flow composite samples, grab samples, water in soil, deposits, soil and plants samples. When considering inlet/outlet an efficiency of 83% and 39 % P removal was observed respectively in M1 and M2. Since the plant uptake was of 15-25 % of total P removal in both systems, the remaining fraction was either retained in the soil or infiltrated. Removal of P by harvesting of aboveground biomass is relevant in that case because of a lightly load system and confirms the need for a harvesting per year to avoid the release of up to 7 kg of P.

Keywords: Mass balance; Phosphorus; Treated wastewater

***Session .. –** Case studies or Wetlands improvement: nutrients removal*

Introduction

Constructed Wetlands receiving treated wastewater (CWtw) are systems downstream of Wastewater Treatment Plants (WWTPs) before the receiving water bodies. They have recently become attractive in France under the perception that they increase water quality of the WWTP outlet. More than 500 systems are in operation with a multitude of configurations and expected outcomes.

A 6-year project has been launched and funded by a National Agency to perform the evaluation of 3 sites (full and pilot scales). A comprehensive monitoring was carried out to understand the fate of major pollutants (COD, TN, TP, TSS, etc.) and micropollutants in the different components of these systems: free water, soil and plants. This study will focus on the fate of phosphorus (P) in these 3 components after 2 years of operation.

Material and Methods

Site description

The site, located in southwest France, consists of 6 pilot-scale CWtw. Two of them are Surface Flow CW M1 and M2 (W: 10 m; L: 15 m; H: 0.3 m) built on semi-permeable soil made of a mix of construction by-products and clay. The water depth is between 0.06 and 0.08 m and may vary with the infiltration. Both systems were planted with *Phragmites australis* 6 months before the beginning of the experiment in April 2015. Because of the strong heterogeneity of the soil, the 2 CWtw do not infiltrate to the same extent.

They have been in operation for 2 years and each one received a different type of treated wastewater: M2 from a submerged aerated filter BIOFOR® C (COD = 50 mg/L; no nitrification) and M1 from a second stage of a vertical flow constructed wetland (COD=30 mg/L; nitrification). P was already treated in the WWTP so P concentrations are already low at inlet of M1 and M2 (<1.5 mgP/L).

In this context, inlet and outlet flowmeters for each CWtw and a weather monitoring allow knowing the water balance of each CWtw to determine the infiltration on a daily basis.

Free water sampling

For each CWtw, samplings were made at:

- The inlet and the outlet: four 2-day sampling campaigns with flow proportional composite samples; grab samples every 3 weeks for 2 years
- 0.3 m deep in the soil: the site has also been instrumented with silicon carbide porous suction cups allowing to collect grab samples every 6 weeks for 2 years and 4 composite samples.

With daily hydraulic loads, infiltration and P concentrations, the fraction of P that goes out of the CWtw and in the soil was estimated.

Plants sampling

The plants sampling was performed at each inlet and outlet of CWtw by using quadrats (0.5x0.5 m) in October 2017. Roots, stems and leaves were analysed separately to determine the amount of biomass and P that can be either stored or exported.

Soil and deposits sampling

The soil and accumulated matter (deposits) sampling was performed at the same location than plants samplings at 0.2 m deep. The 2 CWtw do not receive the same kind of treated water which has an impact on organic matter accumulation. Deposits and soil were separately sampled in M2 as there was no deposit in M1.TP was analysed in deposits and soil.

Results and Conclusions

A P mass balance was performed in each CWtw. The contribution of soil and plants for P removal after 2 years of operation was performed on M1 (Figure 1) and M2 (Figure 2).

When considering inlet/outlet an efficiency of 83% and 39 % P removal was observed respectively in M1 and M2. Since the plant uptake was of 15-25 % of total P removal in both systems, the remaining fraction was either retained in the soil or infiltrated. A concentration decrease was always observed between inlet and at 0.3 m deep (in average 0.2 mgP/L for M1 and 0.5 mgP/L for M2) which confirms the substantial sorption of P in the soil. It is supported by the estimation of P accumulated in the soil by measuring its content between the commissioning period and after 2 years of operation. P storage in the soil can be estimated at about 0-7 kg for M1 and 3-7 kg for M2 depending on the sampling location (inlet, outlet, initial state). Since this estimation relies on several hypotheses, it only gives an order of magnitude which highlights the spatial heterogeneity of the soil.

The deposit sampled in M2 is most likely coming from frequent biofilm discharge of WWTP (biofilter) upstream. The analysis shows that deposits contribution for P on M2 is about 8-9 kg but as long as the biofilm discards happened when there was no sampling, the overall amount of P entering M2 was most probably underestimated.

P uptake from plants was evaluated to 3-5 kg (M1) and 4-7 kg (M2) after 2 years of operation, based on analysis performed after a harvesting at the end of the first year. This corresponds to measured P concentrations from 15 to 34 gP/m^2 and includes roots, stems and leaves. If the harvestable biomass is only considered, P concentrations are in the range of 6-18 gP/m^2 which are within the reported ranges of 0.01-19 gP/m^2 for the amount of harvestable P in aboveground biomass (Vymazal et al., 1999).

A large fraction of P accumulated in the soil of each CWtw, the predominant mechanism remaining unknown. Plants uptake seems large compared to the amount of P entering M1 and M2 this confirming the need for a harvesting each year to avoid releasing P in the CWtw.

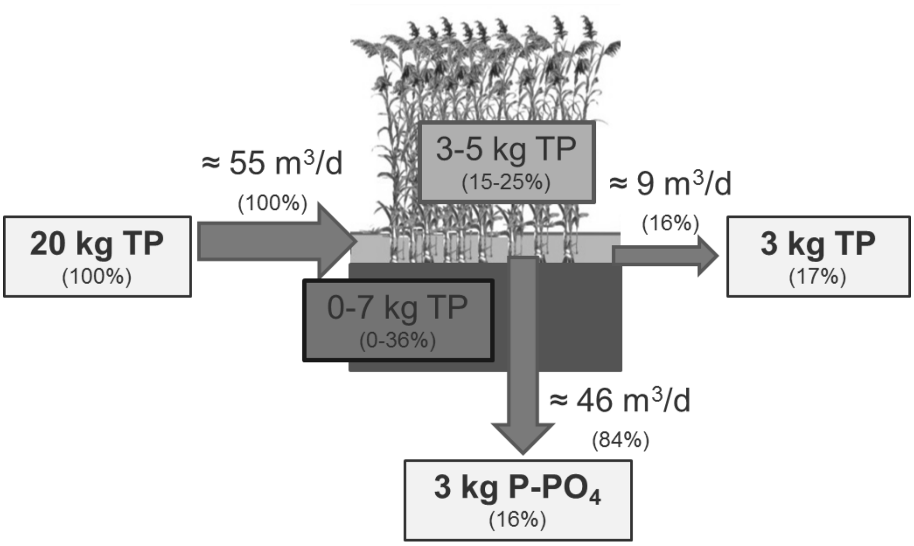

Figure 1 Phosphorus mass balance on M1 with contributions (%) of water surface, deposits, soil and plants after 2 years of operation

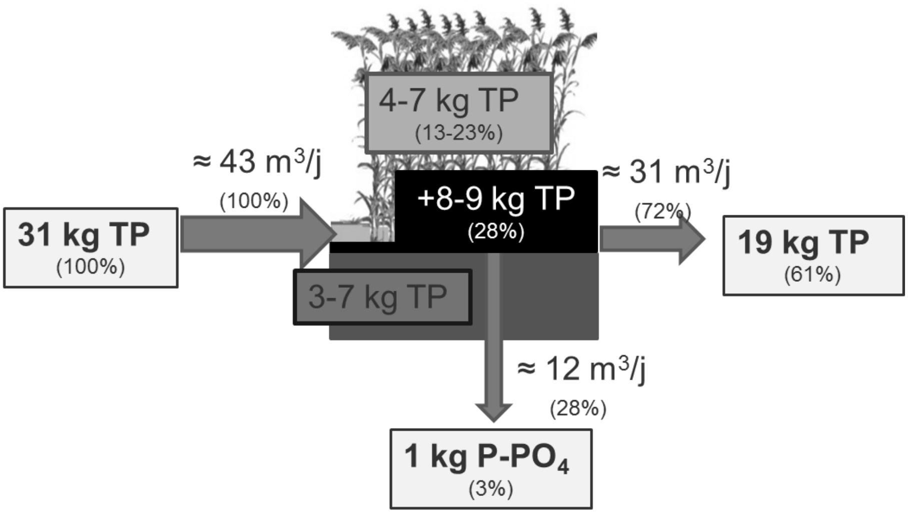

Figure 2 Phosphorus mass balance on M2 with contributions (%) of water surface, deposits, soil and plants after 2 years of operation

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