Purification performance of the FWS constructed wetland in biotope area over three years

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Abstract

The effluent from the combined household wastewater treatment facilities used in unsewered areas of Japan is generally high in N and P. In Japan, environmental quality standards for Zn pollution were enacted recently because of the toxicity of Zn to aquatic ecosystems. In 2004 a fallow paddy field at the Koibuchi College of Agriculture and Nutrition was converted into a surface-water-flow constructed wetland (500m^2) to clean the effluent from the combined household wastewater treatment facility of a dormitory (100 residents) before discharge to a pond. We evaluated N and P removal efficiencies and the fate of Zn in the wetland from February 2006 to March 2009. Wetland influent contained an average of 20.9 mg/L total N and 2.01 mg/L total P. In the effluent from the wetland, average total N concentration was 11.3 mg/L and average total P was 0.98 mg/L. Average Zn concentration decreased from 0.046 in the influent to 0.027mg/L after passing through the wetland. The constructed wetland system was effective for removing not only nutrient salts but also Zn from secondary treated domestic wastewater. N, P and Zn removal mechanisms are discussed in terms of the material balance and the first order reaction model.

Key Words

Constructed wetland, nitrogen, phosphorus, zinc, *Zizania latifolia,* first-order rate cosfficient.

Introduction

In areas of Japan where no sewerage systems have been constructed, domestic wastewater is usually treated by combined household wastewater treatment facilities (these facilities include primary and secondary treatment processes). Effluent from these kinds of systems generally contains relatively high levels of nitrogen (N) and phosphorus (P). Environmental quality standards for zinc (Zn) pollution were enacted recently in Japan because of the toxicity of Zn to aquatic ecosystems. The water quality standard for Zn in rivers and lakes is 0.03 mg/L, and the wastewater quality standard is 2 mg/L. Wastewater from a dormitory at the Koibuchi College of Agriculture and Nutrition in Ibaraki Prefecture, central Japan is treated by a combined household wastewater treatment facility. N and P in the wastewater are not removed sufficiently, although organic matter is well decomposed. The effluent was being discharged into an irrigation ditch that flowed into a pond for agricultural use. Algal blooms sometimes appeared in the pond, and the major nutrient source was considered to be effluent from the dormitory. In recent years, considerable attention has been directed toward constructed wetlands, because of their low cost and ease of operation (Brix 1993; Vymazal 2007; Cooper 2007). In 2004, about 0.2 ha of fallow paddy field at the college was converted into a biotope containing a 0.05-ha surface-water-flow constructed wetland to clean the effluent from the dormitory before discharge to the pond, as well as to educate students on environmental issues. Because the zone is surrounded by rice fields and because it was to be managed as a biotope, we chose the indigenous *Zizania latifolia* (wild rice) for the constructed wetland vegetation because of concern that other plants (especially *Phragmites australis* (common reed)) might invade the rice fields and puncture their bunds. We were also concerned that any exotic species used could become weeds.

We had already reported on the N, P and Zn removal efficiencies in the constructed wetland system around a year (Abe *et al.* 2008). In this paper we evaluated removal efficiencies of those pollutants in this wetland over three years by using first order reaction model. We also discussed the influence of temperature on the removal efficiencies.

Methods

FWS constructed wetland in Koibuchi Collage

The constructed wetland is a free-water-surface flow (FWS) type about 500 m^2 in area and 0.1 m deep, planted with *Z. latifolia* at the time of its creation. The wetland soil was Humic Gleyed Andosol. To prevent water from flowing directly to the exit, baffles were installed in the wetland to make the water flow through a circuit (Figure 1). The wetland receives secondary treated wastewater (about 26 400 L/d, or 52.8 $L/m^2/d$ of wetland) from a student dormitory with about 100 residents; there is therefore about 5 m^2 of constructed wetland per dormitory resident. Water purified in the constructed wetland flows through the biotope area, mixes with rice field drainage, spring water, and other water, and then flows out of the biotope zone and into the holding pond.

Measurements

The volume of wastewater inflow was measured with an integration flow meter. The effluent water volume was calculated as the sum of inflow and rainfall minus evapotranspiration. Because the ground water level is high in the biotope area, water leaching is considered to be negligible. For convenience, the typical rate of evapotranspiration from a Japanese paddy field was substituted for that from this constructed wetland. The water quality was analysed weekly from April 2006 through March 2009. Inorganic N and PO_4-P were measured by ion chromatography (IC7000, Yokogawa). Total N (TN) and total P (TP) concentrations were measured with an autoanalyser (TRAACS 2000, Bran +Luebbe) after potassium persulphate and sodium hydroxide digestion. To measure acid-soluble Zn concentration, water samples were adjusted to pH 1 with nitric acid just after sampling. To measure dissolved Zn concentration, water samples were filtrated with 0.2µm membrane filter. Zinc concentration was measured with an inductively coupled plasma optical emission spectrometer (Vista-Pro, Varian). The aboveground parts of Z. latifolia growing over an area of 1m^2 were harvested at 5 points in the constructed wetland. Samples were dried at 80C for 3 days and then milled to fine powder. The N concentration was measured with NC analyzer (SUMIGRAPH, Sumika Chemical Analysis Service). After acid digestion of the powder, the P concentrations were measured by autoanalyzer and the Zn concentration by inductively coupled plasma optical emission spectrometer

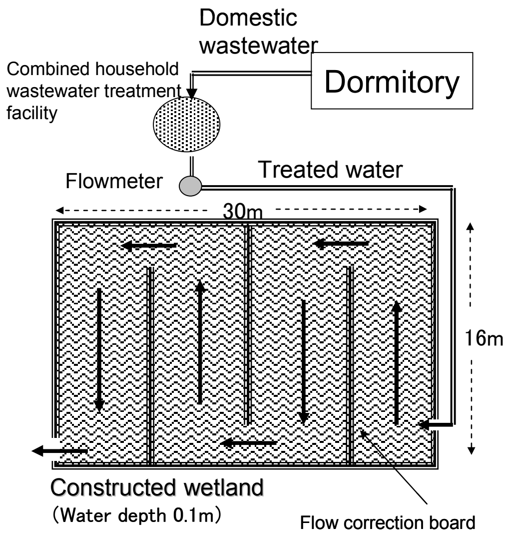

Figure 1. FWS constructed wetland in biotope area in Koibuch College.

Results and discussion

Figure 2 illustrates the concentrations of TN, TP and acid-soluble Zn concentration (in 0.1 mol/L HNO_3 solution) in the influent to, and effluent from, the constructed wetland. Table 1 shows average concentrations of N, P and Zn compounds in the influent to, and effluent from, the constructed wetland.

TN, TP and acid-soluble Zn in the influent were removed effectively by the constructed wetland system. On average, the influent to the wetland (i.e., the effluent from the wastewater treatment facility) contained 20.9 mg/L TN and 2.01 mg/L TP. In the effluent from the wetland, average TN concentration was 10.3 mg/L (46% reduction) and the average TP concentration was 0.98 mg/L (51% reduction). The average acid-soluble Zn in the influent was 0.046 mg/L. Acid-soluble zinc was almost the same as total zinc: the slope of the linear regression between total and acid-soluble Zn concentrations was 0.959, quite close to 1 (Abe *et al.* 2008). Therefore, the fate of acid-soluble Zn was considered to reflect total Zn behaviour. The average acid-soluble Zn concentration in the effluent was 0.027 mg/L (41% decrease). Our findings indicate that the constructed wetland system effectively decreased the Zn concentration in the secondary treated domestic wastewater to below the water quality standard level. Most studies of heavy-metal treatment in constructed wetland systems have examined heavily contaminated wastewater from mine drainage and industry (Mays and Edwards 2001). In contrast, our results indicated that a constructed wetland planted with *Z. latifolia* was useful for treating wastewater with a low Zn concentration; the system decreased the Zn concentration to a level that was unlikely to have negative effects on the aquatic organisms downstream.

The influent to the wetland contained 10.8 mg/L NO3-N, 8.5 mg/L NH_4-N and 1.5 mg/L organic + particulate N. These values indicated that organic compounds were decomposed successfully in the combined household wastewater treatment facility (Table 1). Inorganic N, PO_4-P and dissolved Zn was removed mainly by the constructed wetland system. The organic + particulate N, P and particulate Zn concentration hardly decreased while the effluent was passing through the wetland; therefore, the major mechanism of N, P and Zn removal in the wetland appears to be plant uptake and/or physicochemical reactions, rather than precipitation of particulate N, P and Zn.

Table 1. Average concentrations of N, P and Zn compounds in the influent to, and effluent from, the constructed wetland.

Conpounds	Influent (mgL^{-1})	Effluent (mgL^{-1})	Remarks
TN	20.9	10.3	Average during 3 years (n=157)
NO3-N	10.8	5.4	
NH4-N	8.5	4.3	
Org + particulate N	1.5	1.3	
TP	2.01	0.99	Average during 3 years (n=157)
PO4-P	1.42	0.44	
Org + particulate P	0.61	0.54	
TZn	0.37	0.11	Average of selected samples (n=10)
Dissolved Zn	0.27	0.03	
Particulate Zn	0.04	0.07	

Figure 3 illustrates the material balance of the constructed wetland during the period from April 2007 to March 2008. Yearly loading to the wetland was 335 g/m^2 for TN (0.92 $g/m^2/d$) and 33 g/m^2 for TP (0.09 $g/m^2/d$). The removal amount was 131 g/m^2 for TN (0.36 $g/m^2/d$) and 17.0 g/m^2 for TP (0.05 $g/m^2/d$)., giving percentage removal rates of 39.2% and 50.8%, respectively. Thirty eight g N and 5.4 g P had accumulated in the aboveground parts of *Z. latifolia* per 1 m^2 of the wetland. As a proportion of the yearly removal by the constructed wetland system this amounted to 29.0% of the N and 32.2% of the P removed. Yearly Zn loading was 0.560 g/m^2 (0.0 15 $g/m^2/d$). The yearly Zn removal amount was 0.367 g/m^2 (0.001 $g/m^2/d$), and the percentage removal rate was 65.5%. The amount of Zn accumulated in the aboveground parts of Z. latifolia corresponded to 8.5% of the Zn removed by the constructed wetland system over a year.

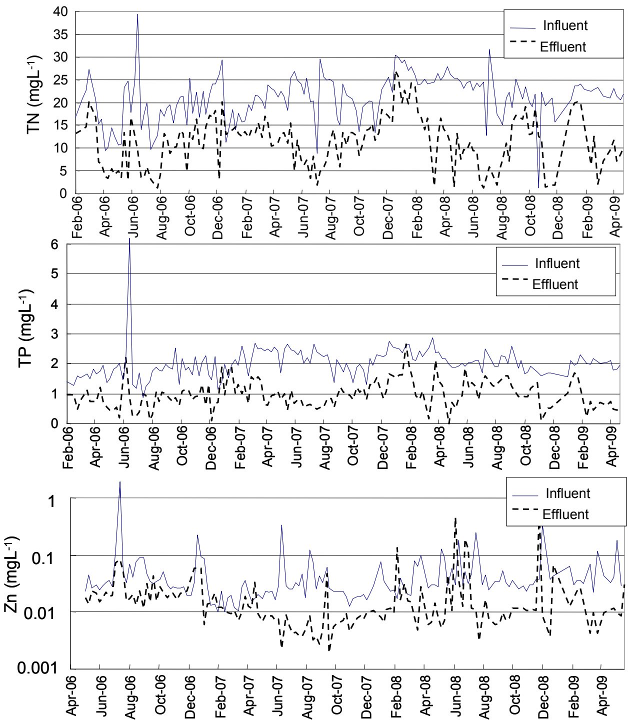

Figure 2. TN, TP and acid-soluble Zn concentrations in the influent to, and effluent from, the constructed.wetland.

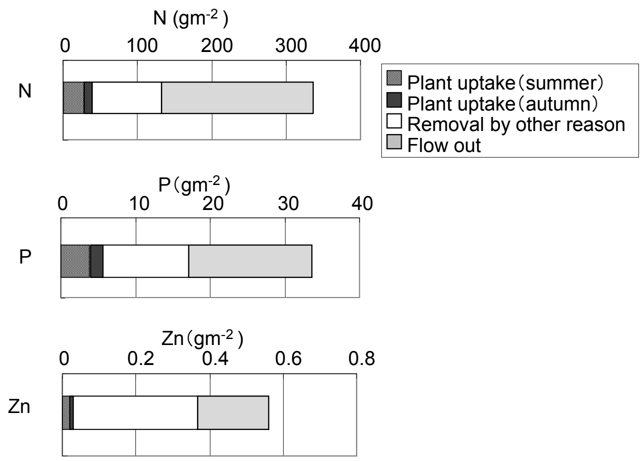

Figure 3. N, P and Zn balance during the period from April 2007 to March 2008.

N, PO4-P and acid soluble Zn concentration in the wetland decreased with distance from inlet (data not shown). Then assuming that inorganic N, PO4-P and acid soluble Zn concentration were reduced by first order reaction and water flow in the wetland was plug-flow, first order areal rate coefficient (k) was calculated by the following equation. Ln(C/Co) =-k/q, where C is the effluent concentration, Co is the influent concentration, k is the first order areal rate coefficient, and q is the hydraulic loading rate (q=Q/A). The rate coefficient for inorganic N reduction was well correlated with temperature. It indicated that N was removed mainly by biological reaction like denitrification. On the contrary, k for PO4-P and acid soluble Zn reduction did not change synchronously with temperature. It indicated that P and Zn were removed mainly by physicochemical reaction. Taken together, our results suggest that N was removed mainly by denitrification and partly by plant absorption, and that P was removed mainly by adsorption to soil particles and partly by plant absorption. Our results also suggested that Zn was removed mainly by physicochemical reactions, such as by adsorption to soil particles and organic matter in the constructed wetland.

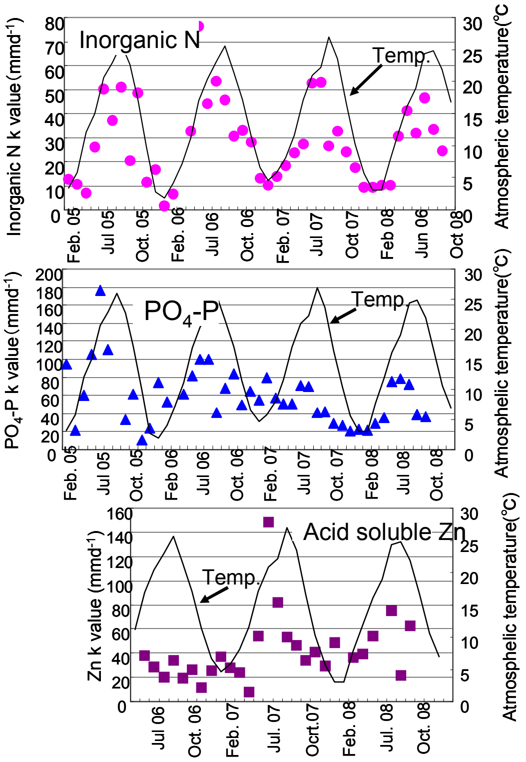

Figure 4. Changes in first order rate coefficient (k) for inorganic N, PO_4-P and Zn reduction.

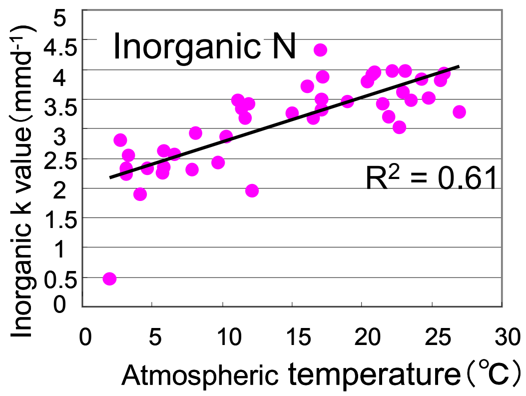

Figure 5. Relationship between first order rare coefficient (k) for inorganic N reduction and atmospheric temperature.

Conclusion

The FWS constructed wetland planted with *Zizania latifolia* was effective for removing not only nutrient salts but also dissolved Zn from secondary treated domestic wastewater over three years. The material balance in the wetland and the analysis on the first order rate coefficient for N, P and Zn reduction suggested that N was removed mainly by denitrification and partly by plant uptake, P was removed mainly by adsorption to soil particles and partly by plant uptake and Zn was removed mainly by adsorption to soil particles and organic materials.

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