The performance of horizontal subsurface flow constructed wetlands with respect to nutrient removal for on-site wastewater effluent

L.W. Gill, N. O'Luanaigh
Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin 2, Ireland.
(email: gilll@tcd.ie, noluanai@tcd.ie)

Abstract
Two horizontal subsurface flow wetlands were constructed on separate sites in Ireland – one to provide secondary treatment and the other to provide a tertiary treatment for single house domestic effluent. A comprehensive analysis over three years provided a robust characterisation of the internal dynamics of the systems with respect to N and P removal. The removal of Total N was only 29% and 30% in the secondary and tertiary treatment wetlands respectively and revealed a drop off in performance over time with a higher release of org-N during summer periods. ^{15}N stable isotope studies confirmed that 35% of the ammonium from the septic tank was passing straight through the process without taking part in any biogeochemical processes. However, the study showed that influent N in both wetlands was being biologically assimilated into organic nitrogen (biomass or plants) and then released again as soluble ammonium — so-called nitrogen "spiraling". Removal of Total P in the wetlands averaged 45% and 28% respectively. The results also showed that if the annual above ground stem matter was completely removed it would only account for 8.4% and 1.3% of the annual total P-load to the respective wetlands. Accordingly the effluent PO_4-P concentrations were still found to be >5 mg/l on average.

Keywords: ^{15}N stable isotope; nitrogen; on-site wastewater; phosphorus; reed bed

INTRODUCTION

The most common type constructed wetland in use in Northern Europe is the horizontal subsurface flow (SSF) reed bed which has been shown to be consistently good in the removal of BOD, suspended solids (SS) and pathogenic organisms (Vymazal, 2002; García et al., 2003). Nutrient removal in such systems however, has proved to be more variable due to the complex interaction of numerous parameters such as water chemistry, climate (air temperature, solar radiation, humidity and precipitation), pollutant concentrations and vegetation, each of which has its own annual cycle, causing changes in nutrient supply, uptake or release of chemical substances and biological activities of micro organisms and plants (Kadlec, 1999). Total nitrogen (TN) removal rates reported for these systems for example, have ranged from high removals of over 90%) to removals as low as 11%. Equally, SSF reed beds generally do not remove high amounts of P from wastewater. A summary of the performance efficiency of such wetlands in a range of European countries showed mean total phosphorus (TP) removals of between 26.7 and 61.4% (Vymazal, 2002). N and P removal in wetland systems is complicated by seasonal and stochastic variability in system responses and temporal factors relating to the detention of nutrients within the large internal wetland storages. The N residence time, for example, will vary markedly (and likely to be far greater than the water detention time) depending on how many times it has been "parked" and recycled in various active or passive storage compartments during its passage through the wetland. Similarly, the fate of P and its cycling in constructed wetlands can be considered with respect to interactions between several compartments, including water, plants, microbiota, sediment/litter and media. Field experience suggests P removal by macrophyte uptake and subsequent harvesting is not a sustainable mechanism and will only account for a small percentage (< 5%) of the total phosphorus (TP) removed (Brix, 1994; Healy and Cawley, 2002).

METHODS

Two horizontal SSF wetlands were designed and constructed on-site for analysis of their performance over the first 3 years of operation. The first wetland (RB1), provided secondary treatment of domestic septic tank effluent (STE), while the second (RB2) operated as a tertiary treatment system following pre-treatment in a rotating biological contactor (RBC). RB1 had a plan area of 15 m^2 with *Phragmites australis* planted whilst RB2 had a plan area of 4 m^2 and a mixture of *Typha latifolia* and *Iris pseudacorus* planted. Both beds were sealed with impervious butyl rubber liner and filled with washed limestone gravel of 5-15 mm diameter. Measurement of wastewater production on both sites across the duration of the monitoring period was achieved by using a tipping bucket flow-gauges (Unidata, Australia) and water samples at the reed bed inlet and outlet points were collected on average once every 2 to 3 weeks intermittently over the monitoring period using portable samplers. Laboratory analysis comprised testing all samples for COD, ammonium (NH_4-N), nitrate (NO_3-N), nitrite (NO_2-N), total nitrogen (TN) and PO_4-P. In addition, a ^{15}N stable isotope tracer study was carried out on both reed beds using labelled ammonium chloride, $^{15}NH_4$-N (98% ^{15}N, Cambridge Isotope Laboratories). During the summer of the third year of operation, representative samples of the reeds in RB1 (*Phragmites australis*) and RB2 (*Typha latifolia* and *Iris pseudacorus*) were collected in order to quantify the level of P-uptake by the macrophytes. The dried biomass samples were then weighed and then phosphorus extraction was carried out using the acid digestion method. The P concentrations were subsequently measured in a Varian ICP.

RESULTS AND DISCUSSION

The efficiency of N-removal in RB1 appears to have been limited by both slow rates of mineralisation, with only about half of the Org-N fraction converted to NH_4-N and little nitrification owing to the predominant anoxic environment of the bed. No discernible pattern with regard to seasonal nitrogen removal could be observed although removals were at their highest during the first year of reed bed operation. The results of the ^{15}N stable isotope tracer study carried out during April and May on RB1 are plotted on Figure 1 against the parallel results from the RWT tracer to indicate the HRT. The results showed that the NH_4-N was not naturally enriched with respect to $\delta^{15}N$ values passing through the reed bed which indicates that much of the influent NH_4-N from the septic tank was passing straight through the reed bed without being taken up in any biologically mediated reactions. However, the lag and then distinct rise in the $\delta^{15}N$ values for the suspended org-N fraction shows that some of the NH_4-N had been biologically assimilated into organic nitrogen (biomass or plants). The tail on the NH_4-N trace may be indicative of the NH_4-N that has been taken into organic form and then released again as soluble NH_4-N – an example of so-called nitrogen "spiraling".

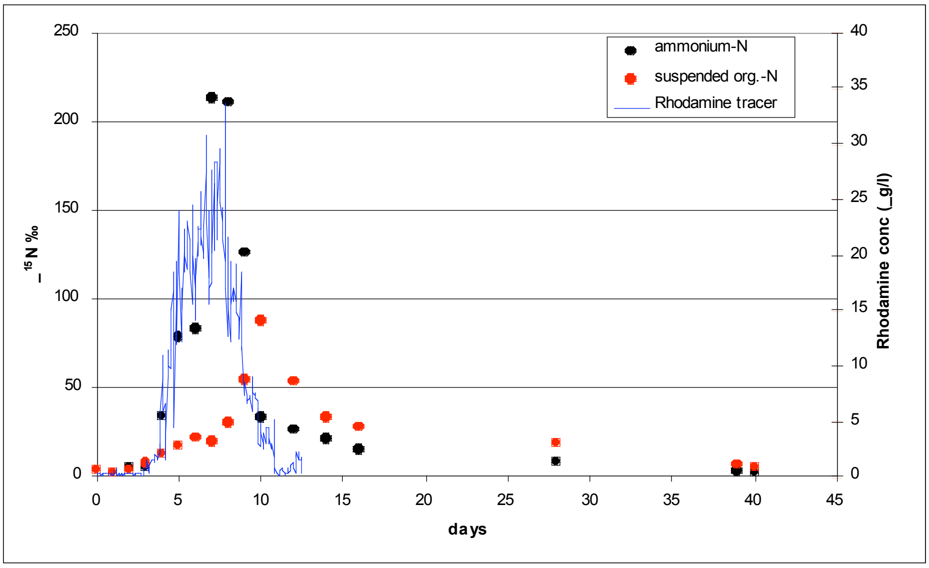

Figure 1. ^{15}N values for RB1 nitrogen fractions and RWT tracer.

The TN load removal (41%) in RB2 was poor especially given that the effluent from the RBC was partially nitrified. On a seasonal basis the rates of denitrification were slightly reduced during the colder months, probably due to minimal nitrogen assimilation occurring at this time, a decrease in the release and mineralisation of Org-N and consequently a reduction in nitrification and denitrification rates.

Removal of P in RB1was found to be on average 45%. Freundlich and Langmuir isotherms were produced in the laboratory for the pea gravel media used (see Figure 2) which indicated that the gravel would have been expected to become fully saturated with respect to P after 2 years under the effluent loading it experienced. However, the temporal variations of PO_4-P effluent concentrations showed the same pattern as the influent values and no indication that the bed was becoming saturated up to the end of the trial. A strong linear correlation between PO_4-P surface loading and removal suggested a consistent removal of P throughout the bed and that plentiful adsorption sites were still available after 3 years of monitoring. The results of the analyses of the reed stems and roots at the end of the third year of operation showed that the total P mass in the *Phragmites australis* reeds (stems and roots) in RB1 only accounted for 10% of the total mass of P removed (2.50 kg) over the operation of this secondary reed bed. Also, if the annual above ground stem matter was completely harvested, it would equate to just 8.4% of the annual total P-load to the reed bed.

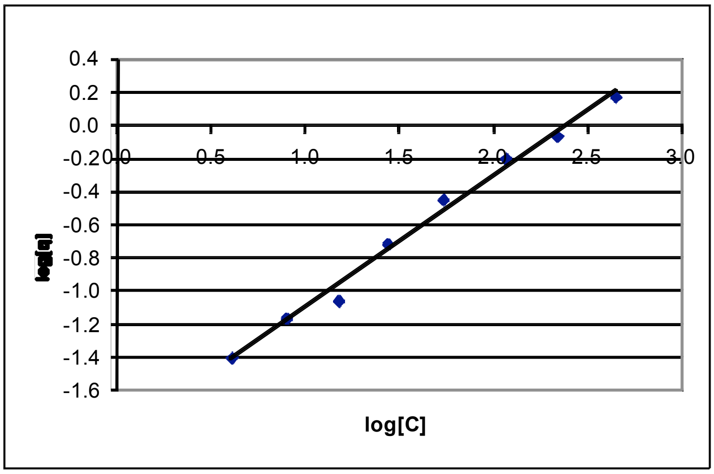

Figure 2. Langmuir isotherm for limestone gravel used as media in reed beds.

An average P-load removal of 22% through RB2 was less than half the rate achieved by the secondary treatment reed bed RB1 owing to the reduced surface area for adsorption and a greater average HLR. The results of the analyses of the *Typha latifolia* and *Iris pseudacorus* samples taken from RB2 showed that a total P mass in the living roots and stems only accounted for 1.3% of the P-load over the monitoring period.

CONCLUSIONS

N removal was found to be poor across both SSF reed beds, with only 29% removal of TN across the secondary treatment bed and 41% removal across the tertiary treatment bed on average. Removal of P in the secondary treatment bed was found to be more than double the removal achieved across the tertiary treatment bed due to a combination of reduced surface area for adsorption and a greater mean HLR. There was no indication that the reed beds had become saturated with respect to P adsorption even though laboratory studies on the gravel media would indicate that they should have reached their limit. Further investigations in the P-uptake study revealed that the total P in the stems and roots of the reeds equated to only 10% of the total P removed in the secondary treatment reed bed and only 1.3% of the P-load in the tertiary treatment bed over the duration of the beds' operation. Hence, annual harvesting of the stems should not be considered to be a significant sustainable long-term method to control phosphorus.

REFERENCES

Brix, H. (1994). Constructed wetlands for municipal wastewater treatment in Europe. In: Mitsch, W.J. (Ed.), Global Wetlands: Old World and New. Elsevier, Amsterdam, The Netherlands, pp. 325–333.

García, J., Vivar, J., Aromir, M. & Mujeriego, R. (2003). Role of hydraulic retention time and granular medium in microbial removal in tertiary treatment reed beds. Wat. Res., 37, 2645–2653.

Healy, M. & Cawley, A.M. (2002). Wetlands and aquatic processes – nutrient processing capacity of a constructed wetland in western Ireland. J. Environ. Qual., 31, 1739-1747.

Kadlec, R.H. (1999). Chemical, physical and biological cycles in treatment wetlands. Wat. Sci. Technol., 40, 37–44.

Vymazal, J. (2002). The use of subsurface constructed wetlands for wastewater treatment in the Czech Republic: 10 years experience. Ecol. Eng., 18, 633–646.