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A novel alum-sludge based constructed wetland system to reduce pollution effects of agricultural run-off: First results.

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Abstract

This paper is a research brief highlighting the development of a novel alum sludge based constructed wetland system, aimed at reducing the pollution effects of agricultural run-offs. Alum sludge is a by-product of drinking water treatment plants where aluminium sulphate is used as coagulant. The alum sludge cakes were used as the main support matrix in the constructed wetland system, having been shown to have a greater capacity to retain contaminants, especially phosphorus, through sorption phenomena, ionic exchange and other physico-chemical processes. The dewatered alum sludge cakes proved beneficial in enhancing and sustaining phosphorus removal in the system, while the removal of organics is thought to be enhanced by the tidal flow mechanism employed. Overall removal of 82.3 $\pm$ 3.5% (BOD_5) and 85.5 $\pm$ 2.1 % (COD) were achieved in the system

Introduction

Agricultural runoff refers to surface water leaving farm fields because of excessive precipitation, irrigation, or snowmelt. The potential for pollution of surface waters from such agricultural run-off is widely recognized (IWA, 2000; Paul and Eunice, 2002). Reducing pollution by intensive but conventional treatment of the land by conservation practises can be difficult, costly and impracticable (IWA, 2000). In view of the economic pressures confronting farmers nowadays and lack of technical and financial resources for conventional wastewater treatment facilities, effective but affordable systems are needed. Such systems should be aimed at reducing pollutants concentrations before reaching the waterways.

Owing to the seasonal variation of the pollutant loads and hydrology, constructed wetlands (CWs) or systems that incorporate wetland values have been suggested to be best suited to the treatment of agricultural run offs (IWA, 2000). However, CWs designed for agricultural run-off treatment differ in several significant ways from those used for wastewater treatment. Such CWs aimed at reducing pollutant concentration in agricultural run-off before reaching the waterways, should be capable of treating high nutrient and organic levels and handling shock loads. However, it is widely recognised that most CWs systems have poor nutrient (P) removal capacities, except specialised substrates with significant sorption capacity are used. In response to this, a novel CWs, using dewatered alum sludge as the main substrate and incorporating the tidal flow

mechanism is being developed. Alum sludge refers to the by-product of water treatment plants that use aluminium sulphate as coagulant. In most places, it is regarded as a "metal hydroxide waste"of no value. Its disposal is highly regulated and costly but recent researches have shown that the sludge can be beneficially used to enhance phosphorus removal (Yang et al., 2006). Consequently, its integration into the novel CWs would serve to enhance phosphorus removal. In addition to this, the surface area of the sludge can constitute a support for microbial population growth in the CWs and also act as support for macrophyte development. On the other hand, a tidal flow strategy, which involves periodical filling and draining of the CWs matrices, was employed to facilitate enhanced oxygen transfer into the system. This strategy has been demonstrated to beneficially enhance oxygen transfer, particularly in vertical flow CWs (Sun et al., 2006). It is believed that, by enhancing oxygen transfer into the CWs in this non-mechanical way, significant reduction of the high level of organics commonly found in agricultural wastewater can be achieved. This paper presents very briefly, results from an on-going pioneering research effort aimed at reusing alum sludge (dewatered cakes) as a CWs substrate in a tidal vertical flow CWs, to reduce pollutant concentration (especially phosphorus (P))and organic matter, in agricultural run-off.

Materials and Methods

Dewatered alum sludge cakes were collected from the dewatering unit of a 400Ml/d capacity (ultimate capacity) water treatment plant located in South-west Dublin, Ireland. The plant uses aluminium sulphate as the primary coagulant. The 'as sampled' sludges were analysed using Inductively Coupled plasma Atomic Emission Spectrometer (ICP-AES, IRIS Advantage), TOC-V CSH (Shimadzu), Fourier Transform-Infrared (FT-IR, EQUINOX-55), X-ray diffractometer (XRD, D/max-3C) and Scanning Electron Microscope (SEM, JSM-6700F). Detailed results of the characterization tests have been published and can be found in Yang et al., (2006).

Batch adsorption tests have also shown that the dewatered alum sludge cake used has a variable but significant adsorption capacity for P in aqueous solution (Razali et al., 2007). Series of laboratory scale wetland columns were constructed using pyrex tubes, packed with dewatered alum sludge cake with or without washed pea gravel. Results partly presented here are from a unit of these systems, as described in Fig 1. The system was operated in the vertical downflow mode and fed with diluted wastewater from a research farm with a herd size of about 2000 animals. The wastewater, which included rainfall on open areas, was collected from the secondary holding tank of the research farm. Wastewater from the farm is first collected and stored in a central facility from where the wastewater undergoes some form of primary treatment (sedimentation) before being pumped to the secondary holding tank. The wastewater in the secondary holding tank is then subsequently spray-irrigated on open fields, creating a potential risk for pollution of water bodies during run-off from the farm fields. The system was operated in tidal mode consisting of intermittent loading of 4cycles/day, operated using pre-set digital electronic timers. This resulted in a daily hydraulic load of $0.5m^3/m^2.d$

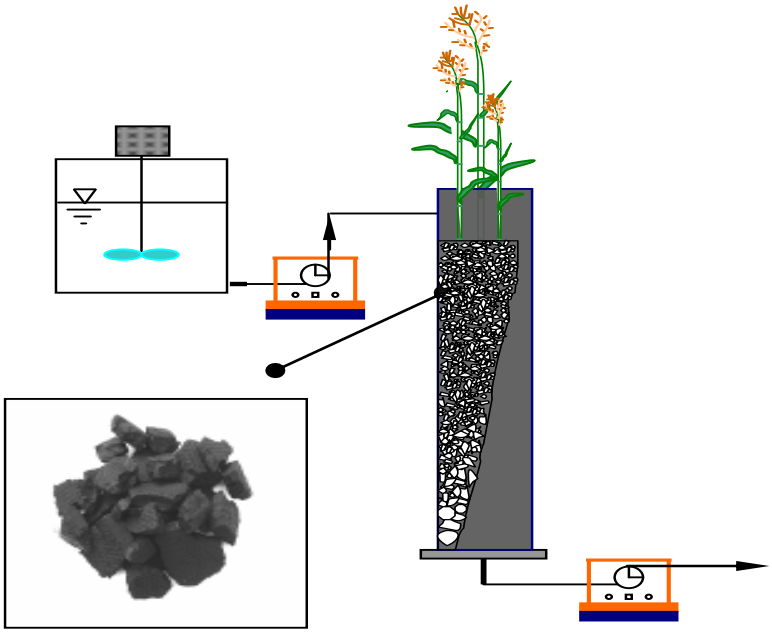

Fig.1.Schematic diagram of the vertical downflow alum sludge based constructed wetland system (dewatered alum sludge cakes shown in inset)

Results

Concentration of pollutants in the wastewater used varied frequently, but averaged 70mg/l (P), 510mg/l (SS), 750mg/l (BOD) and 1150mg/l (COD). The wastewater was diluted with tap water prior to being fed into the lab-scale system. For investigating CWs at such laboratory scales, it is often the usual practise to spike or dilute the source feed to desired concentrations (e.g as in Scholz and Xu, 2002 and Zhao et al., 2004).In this study, a loading of (3.3-10.3) g-P/m^2.d and (35.8-117.7) g-BOD5/m^2.d was used. In comparison to the range of loadings used in similar studies (e.g. Sun et al., 2005), the range of pollutant loading employed here can be regarded as low. However, the hydraulic loading rate used (0.5m^3/m^2.d) is quite higher than the recommended range of 0.025-0.0500.5m^3/m^2.d for vertical flow wetlands (Brix, 1994). Sun et al., (2005) used a hydraulic loading rate of 0.42 m^3/m^2.d in a similar study.

Performance results are briefly presented in Fig 2, 3 and 4. It is well known that in most gravel based CWs, P removal is often poor and in most cases, substantial P removal occurs only after system maturation. This is because in such systems, biomass uptake accounts for a significant part of phosphorus removal in such systems. Therefore, phosphorus removal prior to biomass saturation is often poor. However, performance results obtained from the alum sludge based constructed wetland system indicates that significant P removal was obtained in the system even during the initial stages of operation, and before the development of active biomass (See Fig 2). This highlights the beneficial inclusion of the dewatered alum sludge cakes in the wetland system. Both reactive phosphorus (RP) and soluble reactive phosphorus (SRP) were efficiently removed from the system. Based on preliminary data obtained (not shown), the initial

removal of the carbonaceous substrates could be attributed to filtration while improved removal was obtained gradually as the system stabilized. However, removal of organics was considerably significant in the system even at increased loadings (corresponding to increased influent concentration) (Fig 3). A plot of relationship between loading and removal rates for BOD_5 suggests a trend of increasing removal rate with increasing loading rate (Fig 4).

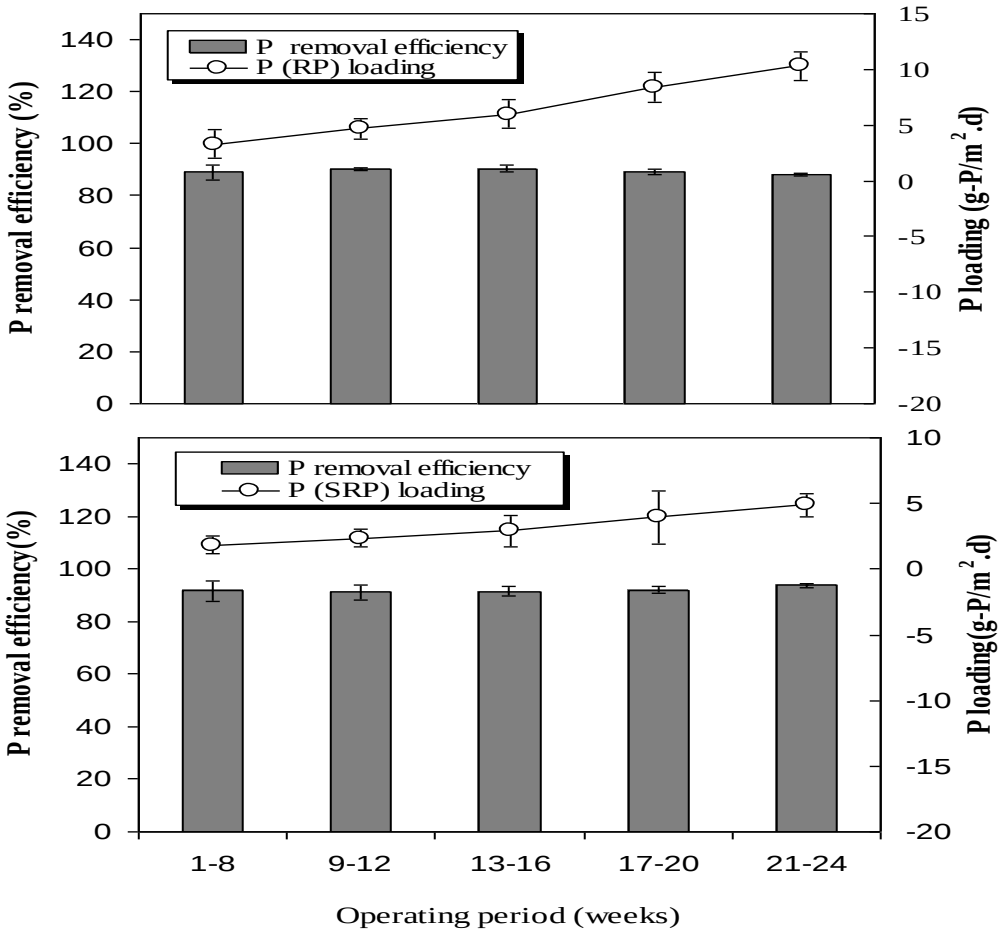

Fig 2. Loading and removal efficiency for soluble reactive phosphorus (SRP) and reactive phosphorus (RP) in the lab-scale vertical downflow wetland

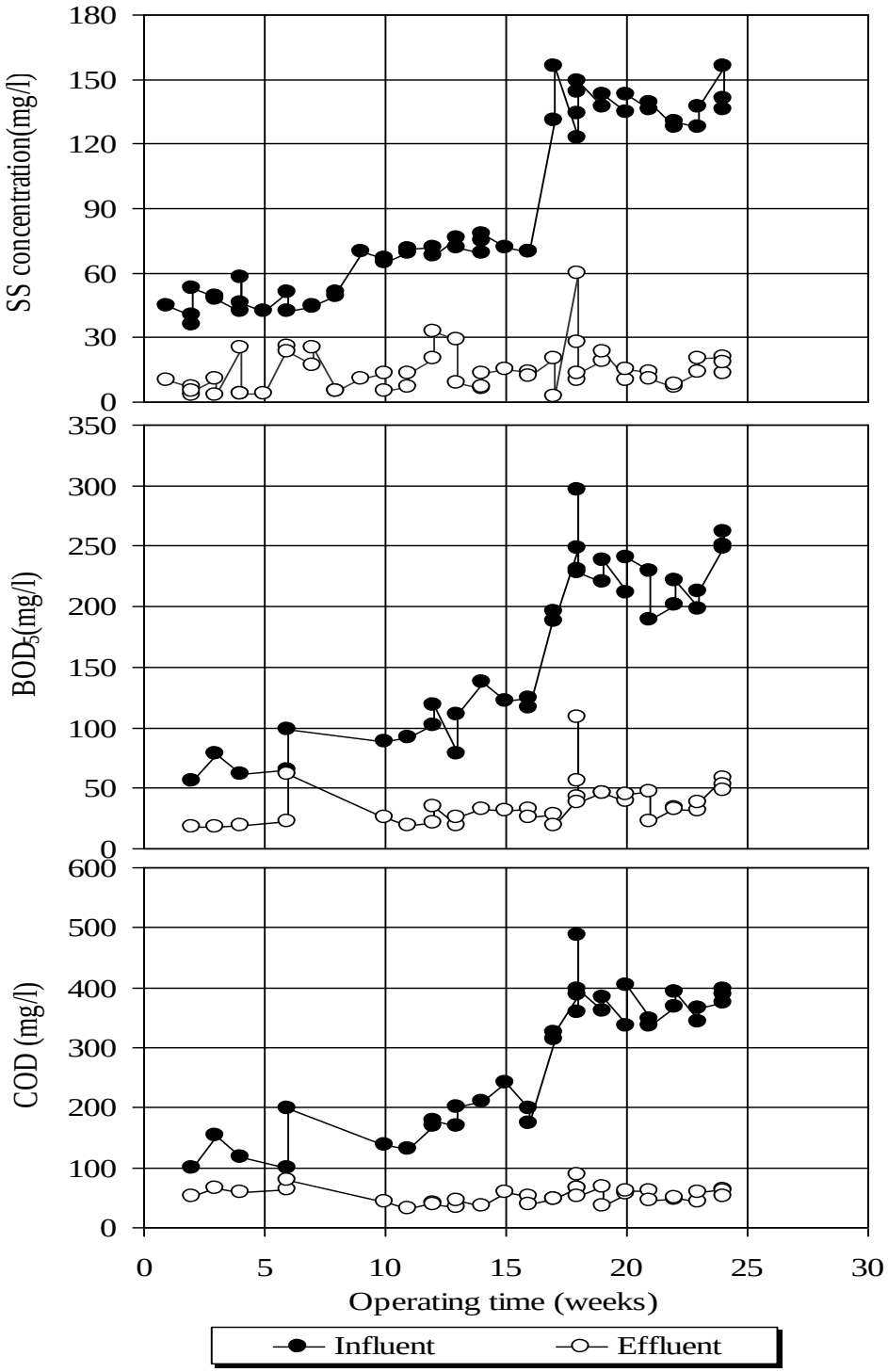

Fig 3.Performance results and trends for suspended solids (SS), BOD_5 and COD in the lab-scale vertical downflow wetland

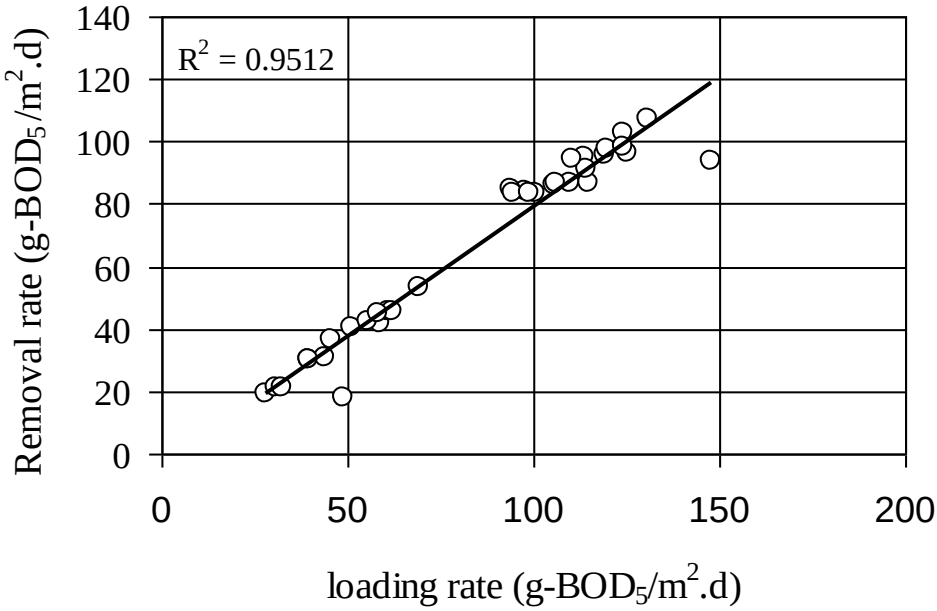

Fig 4 Plot of loading vs. removal rate for BOD_5 in the lab-scale vertical downflow wetland

Discussion

These results have preliminarily shown that dewatered alum sludge can be successfully incorporated into a novel CWs for the purpose of reducing pollutant concentration in agricultural run off. A specific reason for using the dewatered alum sludge is to enhance the reduction of P in such wastewaters. P is particularly noted for its effect on the aquatic environment, especially eutrophication, when discharged above certain threshold concentration into waterways. The dewatered alum sludge is capable of reducing P concentration in such agricultural wastewater before getting into the waterways through run-offs. This is through a ligand exchange mechanism (IWA, 2000, Yang et al., 2006). Despite the periodical increase in influent P concentration (See Fig 2), removal of P was high and sustained throughout the duration of the experiment. This indicates that such use of the dewatered alum sludge cakes could be optimised to enhance P removal, and more importantly to ensure phosphorus removal before biomass maturation. Removal of organics improved steadily with operation time, with removal efficiencies up to 82.3 $\pm$ 3.5% (BOD_5) and 85.5 $\pm$ 2.1 % (COD) achieved in the system. There were slimy coverings on the surfaces of the used sludge as compared to the surfaces of the clean sludge (images not shown), which suggest system maturity, biomass development and reflect the suitability of the system for the growth and activities of microorganisms. Based on the tidal flow concept (Green et al., 1998), a theoretical oxygen supply (TOS) of 137.2g/m^2.d was considered to have been supplied to the system (See Eq. (1)).

The tidal flow concept refers to the rhythmical filling of the constructed wetland matrices with wastewater and then subsequently draining it. This allows for maximum pollutant biofilm contact during the fill stage. As the wastewater is being drained from the system, the draining water acts as a passive pump, which draws in atmospheric air into the matrices, thus replenishing the biofilm with oxygen. Equation (1) is hinged on the knowledge that the volume of air drawn into the wetland matrices will be equal to the volume of the drained wastewater. Therefore, based on the perfect gas equation at 20°C and atmospheric pressure, the theoretical oxygen supply into the wetland column across its surface area was determined according to equation. (1). In comparison with the oxygen demand on the system, the tidal flow strategy can be seen to have the potential to enhance treatment efficiency, with substantial reductions obtained even at higher loadings. Fig.4 illustrates the fairly linear relationship between loading and removal rate for BOD_5 suggesting that with the enhanced oxygen supply of the tidal flow strategy, it may be more feasible to obtain improved performance even at higher loadings. This is however still subject to extensive experimental investigation

$$\mathrm{TOS} = \frac{0.21\left[\frac{\mathrm{O_2}}{\mathrm{Air}}\right] \times 1[\mathrm{atm}] \times 32\left[\frac{\mathrm{g}}{\mathrm{mole}}\right] \times 8\left[\frac{\mathrm{l}}{\mathrm{d}}\right]}{0.082\left[\frac{\mathrm{l} \times \mathrm{atm}}{\mathrm{mol} \times \mathrm{K}}\right] \times 293[^{o}\mathrm{K}] \times 0.0163[\mathrm{m}^2]} = 137.2\ \mathrm{g-O_2/m^2 \cdot d} \qquad \text{Eq.(1)}$$

Conclusions

An attempt was made to incorporate dewatered alum sludge cakes into a novel constructed wetland system aimed at reducing the pollution effects of agricultural run-offs. The system showed excellent removal for P in wastewater while appreciably reducing the organic load in the wastewater. While the excellent removal of P is attributed to adsorbing capability of the dewatered alum sludge, the tidal flow mechanism used enhanced oxygen supply necessary for organic load reduction. Further studies are however still on-going to optimise the development of the system.

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