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SUSTAINABILITY OF WATER AND SANITATION SYSTEMS

Phosphorus removal in macrophyte based treatment

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EUTROPHICATION OF SURFACE water bodies due to high nutrient loads is a global concern. In Uganda, proliferation of the water hyacinth (*Eichhornia crassipes*), and blue-green algae along the shores of Lake Victoria may be an indicator. The inefficiency of existing sewage management systems would greatly affect the lake's ecosystem save for wetlands which are reported to have waste water purification capacity (e.g, Taylor, 1991; Breen, 1990; Muthuri,*et al*, 1989; Chale, 1989;), through nutrient depletion and pathogenic die-off. Capacities, performances and responsible processes are however still indefinite and a subject of study.

Results of a six months' model-study on phosphorus uptake capacities by *cyperus papyrus* indicate that papyrus vegetation can effectively remove as much as 10.6 mg P m^{-2} d^{-1}. In floating papyrus, subjected to frequent flushing and not attached to sediments, there are indications of a sustenance requirement of at least 2 mg P/L. Levels in excess of 30 mg P/L seem to ultimately affect proper plant growth.

Background

Over 70% of Uganda's industrial and urbanized towns are within catchment areas of its many surface water bodies. These towns depend on the water for multiple socio-economic and public health functions including water supply, fishing, navigation and waste water disposal. The last function however has increased stresses on water resources when increasing quantities of pollutants are discharged into them. Mugidde (1993), for example, reported changes in phytoplankton species and macrophytes in L. Victoria, attributable to water quality, and in particular, nutrient changes.

The inefficiency of most waste water management systems, and total absence in some cases, is likely to greatly affect this aquatic ecosystem save for the many fringing wetlands existing between the communities and sewer outfalls. Examples in Uganda include: Nakivubo swamp, Kampala; Nabajjuzi swamp, Masaka; and Kirinya swamp in Jinja. These wetlands, with*Cyperus papyrus* as the dominant vegetation, have the capacity to remove nutrients from waste water as it flows through them by either plant/microbial uptake,chemical precipitation, adsorption onto sediments, or loss into atmosphere (denitrification). Moreover, compared to extended conventional systems that would effectively remove nutrients, these systems are cheaper, need minimum maintenance, can be operated by non-skilled personnel and require minimum energy.

Whereas nitrogen can be lost to the atmosphere through denitrification, phosphorus is a more conservative nutrient whose removal can only be the other mechanisms outlined above. The capacity of sediments to retain phosphorus is however limited and wetlands can actually export it (Gehrels and Mulamoottil, 1989). Microbial uptakes are also limited under anaerobic conditions in wetlands. It is therefore believed that phosphorus can only be effectively removed by papyrus harvesting. However, the rates and amounts of P that plants can effectively remove from waste-water, optimum concentrations and frequency for harvesting which will ensure wetland sustainability are not certain and are a subject of related studies under IHE-Delft, in the Netherlands.

The overall objective of this study was to assess the capacity of papyrus wetlands to control phosphorus related eutrophication in order to better understand and promote this technology.

Specifically, the study aimed at:

1. Experimentally determining the P removal capacity of *Cyperus papyrus*.

Figure 1. Map of Nakivubo wetland and Inner Murchison Bay of Lake Victoria, showing field sampling sites (1 to 3)

2. Assessing the effect of increased nutrient loads on uptake and plant growth rates.
3. Relating total P uptake by experimental plants to results of Nakivubo swamp in Kampala and estimating the swamp's capacity to receive higher pollution levels.

Methodology

i) Experimental set-up

Two clones (one rhizomatous and the other seedling) of young floating *Cyperus papyrus* plants were planted in each of 10 pots on one of the open terraces of the Faculty of Technology, Makerere University. The pots were once a week fed with waste water, from the end of Nakivubo channel (see site 2, figure 1), in which varying nutrient levels based on phosphorus concentrations and an N:P ratio of 10:1 were added. The P and N sources were $NaH_2PO_4.2H_2O$, KNO_3 and $(NH_4)_2SO_4$. P concentrations used were 0.5, 2, 4, 8, 30 and 50 mg P/L. The remaining 4 pots consisted of a blank (only raw waste water) and duplicates for the 0.5, 4 and 30 mg P/L nutrient levels respectively. All 10 pots were fed with a uniform surplus carbon source (sucrose) so that this element, which is abundant in the natural swamp is not limiting. The plants were left in the open to experience nearly similar environmental conditions as field plants about 6 Km away.

Raw water was collected once a week, analyzed for total P and kept at 4^{o}C for < 48 hours. A three weeks' stabilization period was allowed for the plants to re-establish themselves prior to measurements.

ii) Sample collection and analysis:

At the end of each week, water samples were taken from each pot for immediate total P determination. In addition, electrical conductivity and pH were measured using appropriate WTW probes. Feed water was then replenished to re-establish the different P levels.

Table 1. Initial and some 7th week results

Water samples for similar measurements were also taken from the Bugolobi sewage treatment plant effluent, end of Nakivubo channel (the major feed into the wetland) at the inlet point into the study wetland and at the Inner Murchison bay - swamp interface (sites 1 to 3 on Figure 1).

Total phosphorus was determined by the ascorbic acid method on a Hach DREL2000 spectrophotometer, following potassium persulphate digestion (APHA/AWWA, 1992).

iii)Biomass measurements:

Plant growth was monitored during the study period by fortnightly measurements of shoot dimensions (height and girth at base) and total increase in weight of the plants over time.

Results and discussion

i) Initial conditions

Initial experimental conditions and some supplementary results are summarized in Table 1.

ii) Phosphorus absorption by papyrus

It was observed that P uptake rates were a function of both time and concentrations. In figure 2a, the average daily P uptake was higher during the first 5 weeks and subsequently reduced.

Both figures 2a and 2b also reveal that weekly total phosphorus removal rates from the wastewater were, after the fourth week, almost similar for concentrations

Figure 2a. Average daily total P uptake rate, as a function of initial load.

Figure 2b. Weekly total Phosphorus uptake as a function of time.

Table 2. Potted papyrus phosphorus absorption as %ge of initial load

between 2 and 8 mg P/L. At lower concentrations (1 mg P/L), phosphorus uptake actually ceased after the 5th week, and instead, P was released into the water. P uptake for higher concentrations (30 and 50 mg P/L) were generally higher but also more erratic. The above results for weeks 1 and 6 are elucidated in Table 2. P release for lower concentrations may be attributed to imminent death of plants (see Table 1, week 7) due to limited nutrients compared with competing demands e.g, by algae and other microbes.

The rapid die-off of plants for low P concentrations does not completely tally with field conditions. In the field, papyrus has been seen to grow even in areas where P levels were as low as 0.2 mg/L (pers. obs.). This is due to recycling of nutrients on death of biota (Chale, 1989), leading to localised and sustaining high concentrations. The phenomenon would probably have occured for the pots if roots were not virtually rinsed on a weekly basis, during nutrient replenishment.

iii)Biomass growth rate

Figures 3a to 3d relate to the biomass growth rate as a function of P concentration and time. 3a shows that the daily biomass growth is much higher for the first 4 weeks and reduces to near constant levels thereafter. This compares quite well with uptake rate trends in figure 2a.

Figures 3b, c and d show that there is a steady rise in plant biomass as a function of P concentrations. Optimum and sustainable growth occurs at concentrations of 4 - 8 mgP/L. Table 2 further elucidates this. For 30 and 50 mg P/L however, there appears to be a luxury uptake of P which is not reflected in the biomass growth rate. In fact, some parameters like the girth and total height are seen to be lower, possibly as a result of nutrient toxicity (Reddy and DeBusk, 1987).

Following an extremely dry spell (week 8) in which some plants withered due to excessive evapotranspiration,it was decided to set up an additional pot to monitor P levels and residual volumes for 1 week. The results were used to optimise regular water additions to the pots.

Results after week 8 therefore represent a rejuvenation effort by the plants. To this end, nitrogen levels were boosted for all the pots while P levels remained the same. This is reflected in the results for all concentrations for weeks 9 to 11.

iv) Field results

Results for samples from sites 1,2 and 3 in the field are summarized in Table 3. Turning to Figure 2a again, for

Figure 3a. Average daily increase in plant weight as % of initial weight.

Figure 3c. Increase in total plant girth circumference at base with time

Figure 3b. Increase in plant biomass with time.

Figure 3d. Increase in total plant height with time

Table 3. Field results (see Fig.1. for sample sites)

the ‘optimum’ nutrient levels of 2-8 mgP/L, it can be estimated that stable P uptake is at a rate of 0.5 mg/d. For the experimental buckets of area=0.047 m^2, this corresponds to an absorption capacity of 10.6 mg P/m^2.d. Considering the Nakivubo swamp which has an area of about 1.8 km^2, the allowable daily load is 19.1 kgP/d. For an average flow of about 80,000 m^3/d, the optimum concentration that should flow to the swamp for total removal should be under 0.24 mg P/L.

From these results, if all other variables are ignored, P removal between sites 2 and 3 is equivalent to 0.45 mg/L. If an optimum concentration for papyrus uptake of 0.24 mg P/L is assumed, then about 0.21 is adsorbed onto sediments and peat material. This corresponds to a high percentage of total P removal and hence should not be ignored. A further check on field sediment adsorption / release capacities is recommended.

Conclusions

1. Papyrus plants, even minus a sub-stratum, have the capacity to remove at least 0.5 mg P/m^2.d and hence protect surface waters from eutrophication.
2. A minimum P concentration in the water is required to sustain papyrus growth. In experimental conditions, this corresponded to 2.0 mg/L. Below this, papyrus tends to be out-competed.
3. Low nutrient concentrations lead to papyrus die off and subsequent release of more nutrients. This phenomenon may be responsible for sustenance of plants in areas with low water-phase P concentrations.
4. At P concentrations 30 mg/L, algae and other possible competitors lead to reduced biomass growth. In the field, this could correspond to a much lower nutrient level.
5. The direct relationship between P concentrations and biomass growth rates necessitates regular harvesting of plants to ensure sustained P removal.

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