Wastewater Treatment and Other Research Initiatives with Vetiver Grass

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Abstract: This paper described the role of substrate (soil) with respect to the type of macrophytes (plants) planted in the wastewater treatment in Horizontal Subsurface Flow (HSSF) Constructed wetlands (CWs). Wastewater parameters investigated include Nutrients: Phosphorus (Total Phosphorus, Ortho Phosphorus) and Nitrogen species (Total Kjeldahl Nitrogen (TKN Test)=(NH3-N + organic-N) and NH_3-N) from the Maturation Waste Stabilization Ponds (WSP) effluent, which receives wastewater mainly of domestic nature from the University main Campus of Dar es Salaam, aimed at removing these species. Others were: BOD, COD, TSS and heavy metals from industrial effluents particularly from textile mills as well as physical parameters such as: EC, Temperature and pH. The three substrates were used: murram, granite and limestone; all locally available and of size range: 4-8 mm and the two macrophytes used were: vetiver grass (*Vetiveria zizanioides*) and common reeds (*Phragmites mauritianus*). Six HSSF CW cells packed with different substrates each and planted with different macrophytes, operated in parallel were used. Four cells received wastewater from the Maturation Waste Stabilization Ponds: The first cell was filled with murram and planted with vetiver grass (cell A). The remaining three cells were each filled with granite, murram and limestone respectively and planted with *Phragmites mauritianus* plants (cells B, C and D). The two other cells each of 1:0.6:0.3 m dimensions were used for industrial effluents treatment. One cell planted with Vetiver grass and another one with *Phragmites mauritianus*, both packed with limestone soil. The field experimental set-up was situated near the Waste Stabilization Ponds at the University of Dar es Salaam.

The major findings of this study:

Vetiver grass performed better than *Phragmites mauritianus* in removing of pollutants. For instance It was found from the treatment plant that: the organic removal (BOD) was on average 61.85% and 67.47% and COD of 37.9% and 46.2% for *Phragmites mauritianus* and Vetiver grass respectively. Compared with various reporters it was concluded this removal to be good.

Key words: *Vetiveria zizanioides*, *Phragmites mauritianus*, Wastewater, Constructed Wetlands, Pollutants

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1 INTRODUCTION

1.1 Background

Untreated wastewater usually contains among other contaminants, nutrients, mainly nitrogen and phosphorus that can stimulate the growth of aquatic plants, which in turn results in various environmental pollution related problems. For this reason, the treatment of wastewater is not only desirable but also necessary. Treatment is necessary to correct wastewater characteristics in such a way that the use or final disposal of the treated effluents can take place in accordance with the rules set by the relevant legislative bodies without causing an adverse impact on the receiving water bodies.

In Tanzania effluents coming from textile mills is a major problem. Wastewater from textile mills is discharged into the receiving water bodies on which the community depends for different uses such as washing, irrigation and other domestic activities.

Research on Constructed Wetlands (CWs) is ongoing at many sites around the world. CWs provide an additional treatment to the effluent from secondary treatment in order to polish the effluent from secondary systems like waste stabilization ponds. This additional treatment, usually referred to as tertiary treatment often involves the removal of Nitrogen and Phosphorus compounds, plant nutrients associated with eutrophication. Further treatment may be required to remove additional suspended solids, dissolved inorganic salts and refractory organics (Peavy *et al*., 1985).

Constructed wetlands are used to remove pollutants from wastewater. The performance of such wetlands to remove pollutants from wastewater can be improved by using suitable substrates (Hammer, 1989). From the standpoint of wastewater treatment, certain plant and / or substrate combinations appear to be more efficient in constructed wetland treatment systems, and others may be more tolerant of high pollutant concentrations.

Wetlands have individual and group characteristics related to plant species present and their adaptations to specific hydrologic, nutrient, and substrate conditions. Because of this, a variety of plant species are used in constructed systems. Wetland plants often grow in oxygen-poor substrates. Despite their ability for short-term anaerobic respiration, they grow best when oxygen is available for respiration.

2 LITERATURE REVIEW

2.1 Role of Vegetation

Plants in waste water systems have been viewed as storage compartments for nutrients where nutrient uptake is related to plant growth and production.

Emergent plants utilize their roots to obtain sufficient nutrients from interstitial water. Emergent plants are often grown in gravel beds to stimulate uptake and create suitable conditions for the oxidation of the substrate, thereby improving the ability of the system to treat wastewater. Free-floating species have roots with numerous root hairs and can successfully obtain nutrients from the water column. Submerged plants use nutrients from both the water column and substrate.

It appears that major contribution from the vegetation in these SSF systems is service of the root/rhizome structure as a substrate for microbial activity and as a limited oxygen source for Nitrification (Reed, 1988). This suggests that, if the plant is expected to play a major role, the depth of the bed should not exceed the potential root development for the plant species selected. Aquatic plants play an important part in supporting the BOD removal processes. Certain aquatic plants pump atmospheric oxygen into their submerged stems, roots and tubers. Oxygen is then utilized by the microbial decomposers attached to the aquatic plants below the level of the water. Plants also play an active role in taking up nitrogen, phosphorus and other compounds from the wastewater. This active incorporation of N and P can be one mechanism for nutrient removal in a wetland. Some of the Nitrogen and Phosphorus is released back into the water as the plants die and decompose. In the case of Nitrogen much of the nitrate nitrogen can be converted to nitrogen gas through denitrification processes in wetlands.

2.2 The Use of Vetiver Grass Wetland for Sewerage Treatment

Vetiver System is a low cost, and extremely effective system for soil and water conservation and stabilization, pollution control, and wastewater treatment. It uses Vetiver Grass, *Vetiveria zizanioides*, for all its bioengineering and conservation applications. The grass is unique and can be used in the tropics and semi tropics, and areas outside the latter (such as California that has a Mediterranean climate) where there are hot summers and winters that do not include permanently frozen soil conditions. The roots of the grass have an average tensile strength of 75 Mpa and improve the shear strength of soil by between 30 and 40%. Engineers liken it to a "Living Soil Nail".

The Esk Shire Council has recently installed a Vetiver Grass System wetland to treat sewerage effluent at Toogoolawah in South East Queensland, Australia. The sewerage treatment plant is situated on a 22-ha site on the northern edge of town. The aim of this scheme was to improve water quality before the effluent discharges to the natural wetlands. The biggest problem with the quality of the effluent is its high nutrient loading, which encourages growth of algae that increases pH and maintains high suspended solids levels that in turn allows the faecal coliform counts to increase. With the recent changes to license conditions imposed by the Environmental Protection Agency, the existing treatment plant no longer complies with the license and so an upgrade of the plant was required Under the existing set up, after treatment by a primary sedimentation process, the effluent is stored in three sewerage ponds, which was designed to discharge the effluent into a swamp area before it overflowed into the local creek. Instead off the above set up, a new and innovative phyto-remedial technology recently developed in Queensland by the Department of Natural Resources and Mines, is being implemented at Toogoolawah. Under the Vetiver Wetland System, the effluent is being treated in two stages:

- Preliminary treatment of the pond effluent in situ by floating pontoons placed in the ponds, and by vetiver planting around the edges of the three sewerage ponds.
- Main treatment by vetiver wetland, once the affluent exits the sewerage ponds it passes through a Vetiver Grass contoured wetlands constructed over 3 hectares of the land.

The Vetiver Grass wetlands have been constructed in rows following the contours to allow good contact between the grass and the effluent. The Vetiver Grass takes up the water and in particular the grass will remove the nutrients from the water that passes through it, as Vetiver Grass system is very effective in removing nutrient loads, it is expected that once the wetland is properly established there should be no release of sewerage effluent from the treatment plant except in times of heavy rainfall. Any water that passes through the Vetiver Grass Wetlands will then flow into the existing low-lying. Here any remaining nutrients are removed and the amount of effluent is further reduced due to water take up and evaporation. This scheme will provide a large-scale prototype of possible sewerage treatment schemes that can be used throughout western Queensland and other locations where there is plenty of land and where the local government doesn't want to pay for installing and operating high cost solutions (http://www.vetiver.org./TVN_FRONTPAGE_ENGLISH.htm)

2.3 *Vetiveria*

Of the ten species of coarse perennial grasses found in the tropics of the old world that belong to the tribe Andropogoneae, *Vetiveria zizanioides* has proven ideal for soil and moisture conservation.

V. zizanioides (L) Nash (2n=20) Khus; vetiver grass; a densely tufted, awless, wiry, glabrous perennial grass that is a "shy breeder" and is considered sterile outside its natural habitat of swampland. It has no rhizomes or stolons and is propagated by root divisions, or slips. The plant grows in large clumps from a much-branched "spongy" rootstock with erect culms 0.5-1.5 meters high. The leaf blades are relatively stiff, long, and narrow-up to 75 centimeters long and no more than 8 millimeters wide-and although glabrous are “downward rough” along the edges. The lower glume is muriculated. The panicle is 15-40 centimeters long; joints and pedicels, glabrous. Spikelets are narrow, acute, appressed, and awnless. One spikelet is sessile, hermaphrodite, and somewhat flattened laterally with short sharp spines. It has a glabrouscallus, three stamens, and two plumose stigmas. The other spikelet is pedicelled and staminate. Some cultivated forms rarely flower.

Both a xerophyte and a hydrophyte, *V. zizanioides* can withstand extreme drought- perhaps owing to the high salt content of its leaf sap as well as long periods of inundation (up to fourty-five days has been established in the field). It has exceptionally wide pH range, seems to be able to grow in any type of soil regardless of fertility, and has been found to be unaffected by temperatures as low as -9^{o} Centigrade.

V. zizanioides does not produce seeds that germinate under normal field conditions. *V. nigritana* (the Nigerian species) does seed, but the seedlings are easily controlled (Grimshaw, 2000).

Studies on the aquatic plants found in water bodies known to receive effluent from the mines have shown high concentrations of heavy metals like copper, lead, zinc and cadmium in these plants. A variety of emergent, floating and submergent macrophytes have been used in heavy metal removal studies. In the emergent group, *Phragmites mauritianus* and *Typha latifolia* have been used extensively. Although *Vetiver grass* has not been used for this kind of work, it was the plant that was chosen for this study for the following reason:

For a plant to be useful for agriculture and biological engineering and accepted as safe, it should have as many as possible of the following characteristics:

- It should exhibit xerophytic and hydrophytic characteristics if it is to survive the forces of nature. Vetiver grass, once established, is little affected by droughts and floods
- It should have a deep penetrating root system, capable of withstanding tunneling and cracking characteristics of soils. The roots should penetrate vertically below the plant to at least 3 meters
- It should be capable of growing in extreme soil types, regardless of nutrient status, pH, sodicity, acid sulphate or salinity, and toxic minerals. This includes sands, shales, gravels, mine tailings, and even more toxic soils.
- It should be capable of developing new roots from nodes buried by trapped sediment, and continue to grow with the new ground level, to eventually forming natural terraces.
- It should be totally free of pests and diseases and should not be an intermediate host for pests or diseases of any other plants
- It should be easily cheap and easy to establish as a hedge and easily maintained by the user at little cost
- It should be easily removed when no longer required.

Vetiver grass has all these characteristics. *Phragmites mauritanus* has the following characteristics:

- Has extensive roots and rhizome system and therefore provides a good room for the attached microbial growth, which enhances biodegradation of organics.
- Has highest oxygen transfer capacity hence can grow well in a water logged basin due to their large internal air spaces for transportation of oxygen to roots and rhizome
- It is locally available

However, plant uptake for pollutants accounts for only a small fraction of the pollutant removed.

3 MATERIALS AND METHODS

3.1 Substrate Material

The substrates employed in this study were murram (pumice) soil, granite and limestone. The murram was collected from Uchira village about 15 km from Moshi – Dar es Salaam high way (Tanzania). The granite was collected from Pongwe Quarry as the main source in Tanzania. The gravel size ranges between 4 – 8 mm. Both substrates were analysed for their metal content.

3.2 Macrophytes

Macrophytes used were *Phragmites mauritianus* (commonly known as reeds) and *Vetiver* grass. Transplanted rhizomes of *Phragmites mauritianus* and *Vetiver* grass were used.

3.3 Constructed Wetland Cells

Six HSSF CW cells packed with different substrates each and planted with different macrophytes, operated in parallel were used.

- Four concrete cells of size 150 cm x 30 cm and a depth of 60 cm received wastewater from the Maturation Waste Stabilization Ponds: the four cells were planted with macrophytes of equal density but different species The first cell was filled with murram and planted with vetiver grass (cell A). The remaining three cells were each filled with granite, murram and limestone respectively and planted with *Phragmites mauritianus* plants (cells B, C and D). Each cell was fitted with perforated pipes inserted at a distance of 37.5 cm apart. These pipes provided sampling points within the cell.
- The two other cells each of 1:0.6:0.3 m dimensions were used for industrial effluents treatment. One cell planted with vetiver grass and another one with *Phragmites mauritianus*, both packed with limestone soil.

The field experimental set-up was situated near the Waste Stabilization Ponds at the University of Dar es Salaam.

4 RESULTS AND DISCUSSION

4.1 Nitrogen Species

The results for ammonium-Nitrogen (NH_3-N) removal for the different cells, is shown in Fig. 1 below. The cell A with *vetiver* grass showed an NH_3-N removal of about 25% while the cell with *phragmites* showed removal of about 32%.

The removal of organic-N concentration was observed during the whole sampling period (with zero data in the second sampling date) in both cells.

Fig. 1 Cells layout

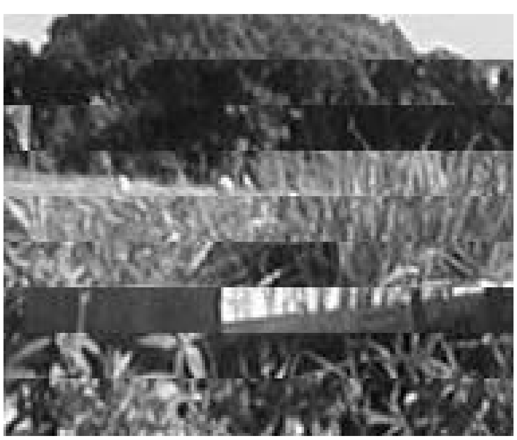

Fig. 2 Vetiver cell (Plants after 1 year)

Removal of organic nitrogen (org-N) was significantly better in cell A (with vetiver grass) than in cell C (phragmites). About 83.8% of org-N was removed in the vetiver grass cell compared to 55.3% in the phragmites cell (Fig. 2). The difference between the two performances indicated that, vetiver grass offered high efficiency by about 28.5% better than *Phragmites macrophytes*.

Generally, the variation of Nitrogen species concentrations in the influent was largely influenced by the variation in the influent loading of nitrogen as well as organic matter. Also the variation has been contributed by the transformation processes (Nitrogen cycle), taking place within the cells. For instance, the transformation of organic-N into NH_3-N (Mineralization). These transformation processes result into consumption and production of these species continuously in the cell.

Fig. 4 NH_3-N, average removal rates

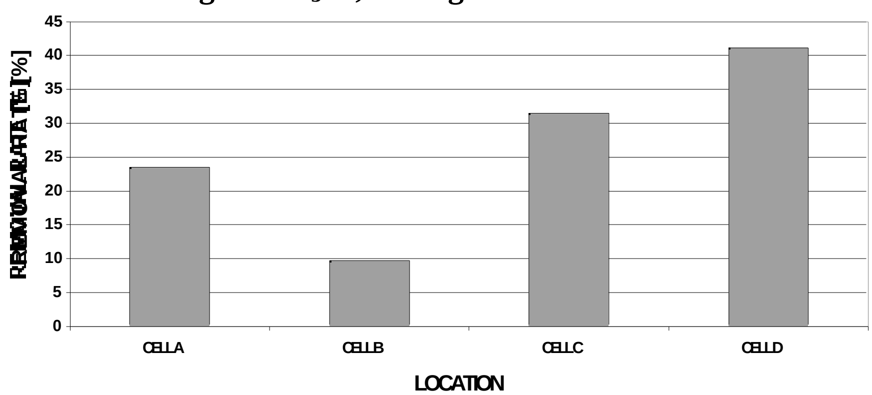

Fig. 5 Organic-N, average removal rates

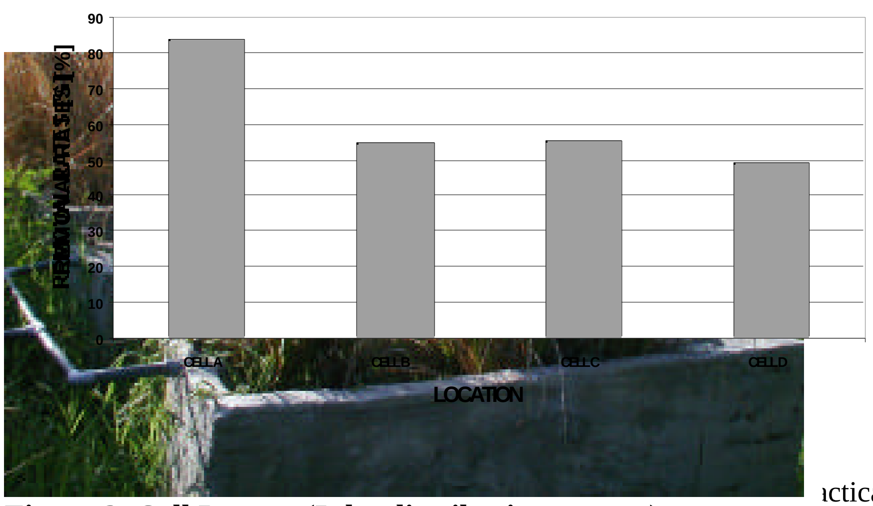

Figure 3. Cell Layout (Inlet distribution system)

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Past studies show that plants contribute very little in phosphorus removal, about 3% (Mng'anya *et al.*, 2001). This in addition to the observed poor development of the plants in the limestone bed suggests removal mechanisms in the bed to be mainly sedimentation of particulate phosphorus aided by good substrate porosity and precipitation followed by the sorption of soluble phosphorus.

Fig. 6 Average Phosphorus concentrations

However, it was observed that:

- The murram-vetiver bed was seen to have developed much faster than the murram-phragmites.
- The murram-vetiver bed suffered frequent clogging during the whole period of sampling, though *vetiver* grass seems to be resistant to this clogging (i.e. no effect observed in its growth) (See pictures below-from Dr. Minja).

4.3 Textile Wastewater Parameters

4.3.1 TSS, COD

It was found that: the cell planted with *vetiver* grass removed 81.42% of the TSS. The cell planted with *Phragmites mauritianus* reduced 79.4% of the TSS. The COD concentration in the influent ranged between 820 and 1200 mg/l for both cells. The average removal of COD for cell planted with *vetiver* was 46.2%, where as for cell planted with Phragmites the removal was 37.9%.

The influent BOD concentration was between 226mg/l and 282mg/l in both cells. The effluent from the cells, were: 70.6 and 113 mg/l with an average removal efficiency of 61.85% for the *Phragmites mauritianus* and 56.5 and 98.9 mg/l with an average removal efficiency of 67.47% for Vetiver grass.

4.3.2 Heavy metals

Variation of copper (Cu) with time for *vetiver* and *Phragmites mauritianus* is shown in fig.5. The highest removals observed were 73.6% and 64.6% for *vetiver* and *Phragmites* respectively. Removal efficiencies were observed to vary with inlet concentration.

4.3.2 Colour

Variation of colour between inlet and outlet for various days is shown in fig. 6. Higher colour removals of 78.2% and 50.87% were observed for *vetiver* and *Phragmites* respectively. Also removal efficiencies were observed to vary with inlet concentration.

It was also seen that for a period of one-month two out of six *Phragmites mauritianus* plants died, where as no *vetiver* died. Generally it has been concluded that *vetiver* grass performed better than *Phragmites mauritianus* in removing of pollutants.

Fig. 7 Variation of TSS in wetland cells

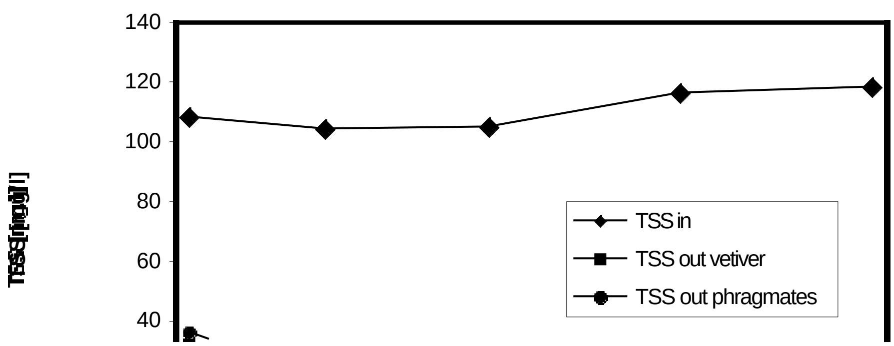


Fig. 8 Variation of copper concentration in the wetland cells

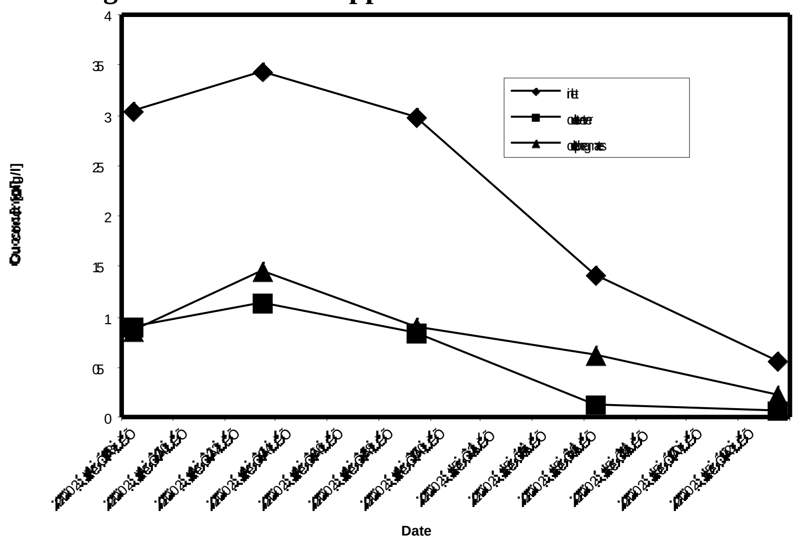
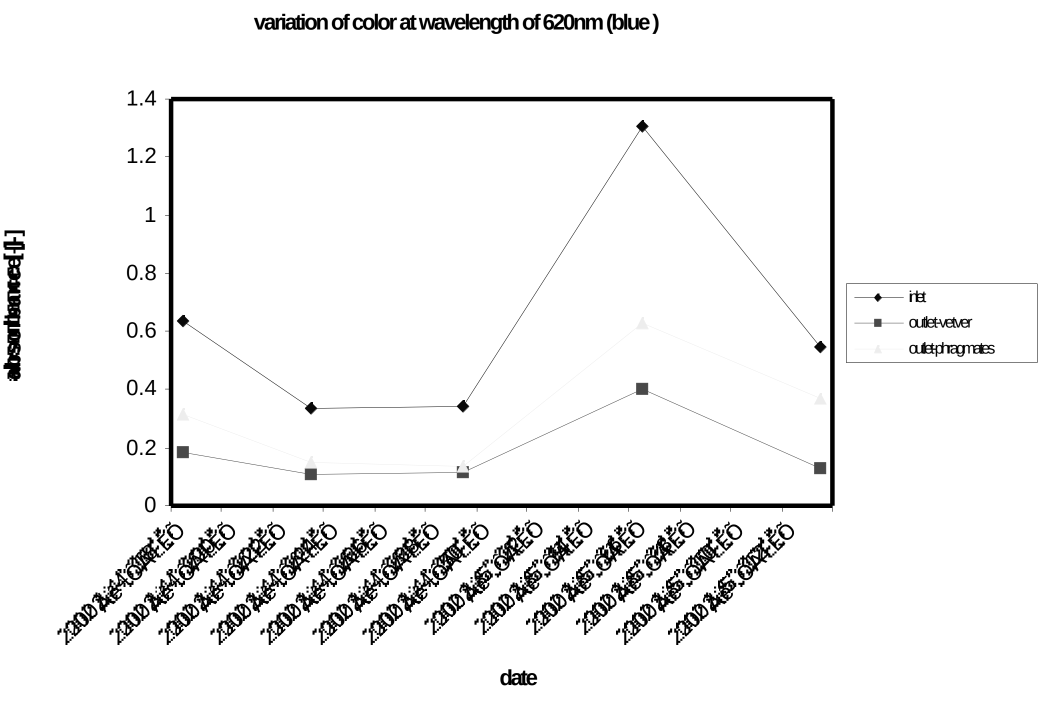


Fig. 9 Variation of color at wavelength of 426 nm (yellow) at inlet and outlet at CW



5 CONCLUSION AND RECOMENDATION

By achieving removals 81.42% TSS, 46.2% COD, 73.6%Cu, and 78.2% color in a cell planted with *vetiver* as compared to 79.3% TSS, 37.9% COD, 64.6% Cu and 50.87% color in cell planted with Phragmites, it can be concluded that vetiver provides much more contribution in treatment of the textile wastewater than Phragmites. It can also be concluded that the COD removal by the wetland is low as compared to literatures.

In almost all experiments, it was concluded that *vetiver* grass performed better than *Phragmites mauritianus* in removing pollutants. For instance the highest removal observed in Org-N removal (Fig. 5).

If vetiver grass is to be incorporated with murram as a substrate, the size distribution of murram should be increased in order to minimize on flooding problems experienced during the sampling period.

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