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Full Length Research Paper

Domestic wastewater treatment with a vertical completely drained pilot scale constructed wetland planted with *Corchorus oliterius*

Lacina Coulibaly[1*], Issiaka Savané[2] and Germain Gourène[1]

[1]Laboratoire d'Environnement et de Biologie Aquatique, Unité de Formation et de Recherche en Sciences et Gestion de l'Environnement (UFR-SGE), 02 BP 801 Abidjan 02, Côte d'Ivoire.
[2]Laboratoire de Géosciences et Environnement, Unité de Formation et de Recherche en Sciences et Gestion de l'Environnement (UFR-SGE), 02 BP 801 Abidjan 02, Côte d'Ivoire.

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A pilot scale constructed wetland planted with *Corchorus oliterius* was developed for domestic wastewater treatment. The reactor system was composed of rectangular beds realized in cement. Each bed was filled from the bottom to the top with 0.1 m of gravel (15/25 mm) and 0.30 m of a uniformly distributed medium grain (mean sand diameter = 426,66; uniformity coefficient = 0,37) white sand from the Ebrié lagoon. Two beds planted with yang *C. oliterius* plants (high density: 40 plants/m²; low density: 10 plants/m²) and one control (unplanted bed) were used to perform the experiment. The beds filtrates pH was neutralized to 7. The planted beds removed the COD (low density = 61%, high density = 65%) more than the control (54%). Nutrients were also best removed in the planted beds (NH_4^+: 67%, PO_4^{3-}: 52%) than in the control (NH_4^+: 11%; PO_4^{3-}: 56%). The increase of the plant density did not influence significantly ($p < 0.05$) pollutants removal. However, this augmentation increased the bed performance. The plants leaves were less contaminated at 0.9 m above the bed surface, suggesting this height for their harvesting for sale.

Key words: Domestic wastewater, constructed wetland, treatment, *Corchorus oliterius*.

INTRODUCTION

Developing countries are faced with the problem of degradation by release of urban wastewater into the water bodies. Eutrophication of these waters in densely populated areas, causes loss of biodiversity and formation of toxic algae blooms which endangers drinking water supply and limits recreational activities (Carpenter et al., 1998; Smith et al., 1999; WHO, 2003). This is essentially due to the anthropogenic nutrients containing in these wastewaters. This situation may continue in the future because water pollution continues to increase in developing countries due to population increase in their megalopolis and also due to lack of budget to provide metropolises with conventional wastewater treatment processes (WHO, 2000). Consequently, there is a need to develop a sustainable wastewater treatment system adapted to these countries realities. Constructed wetland (CW) seems to be an alternative technology to treat such wastewater. The CW can easily be integrated in the urban environment to treat wastewaters (Billore et al., 1998; Cooper et al., 1996). Moreover CW is an economical wastewater treatment system compared to conventional biological sewage treatment (Kadlec and Knight, 1996). In developing countries, land price is not so high and the weather is generally favorable to plants, algae and bacteria growths, thus making CW a practical option.

Previous CW developed (subsurface and surface free wetland) presented risks of odors, nitrous oxide, nitrogen and methane gas emission to the atmosphere (Mander et al., 2005; Mitsch et al., 2005). There were also some risks of water pollution by the hydrolysis products of the debris of wetland litter, mosquitoes breeding in the water and biomass management problems (Knight et al., 2003; Russell, 1999; Thullen et al., 2002).

The utilization of a vertical completely drained constructed wetland could reduce the above health and

*Corresponding author. E-mail: coulacina2003@yahoo.fr.

Figure 1. A view of the vertical completely drained constructed wetland planted with *Corchorus oliterius*. 1: the bed structure in cement brick; 2: irrigation device in PVC; 3: wastewater stocking tank, 4: filtrate drain in PVC; 5: *C. oliterius* after three months on the bed. A: A view f a bed just after planting the yang *C. oliterius*. B. A view of the planting bed with *C. oliterius* after three months.

environmental problems. The sustainability of the system would be attained if it produced funds for financing itself. This could be achieved by the sale of vegetables with economic value such as edible vegetables (Amaranth, Corchorus, etc.), fodder or jute (Corchorus) which could be grown in the wetland. *Corchorus oliterius* is one of the vegetable growing in most natural wetland in developing countries and could be the best choice for planting in a constructed wetland plants. It is also used worldwide because of its nutrition value, pharmaceutical properties and fibers utilization (Balemie and Kebebew, 2006; Francisca and Pablo, 2007; Mwaikambo, 2006; Akoroda, 1988).

The aims of this research were (i) to develop a constructed wetland planted with *C. oliterius* for domestic wastewater treatment; (ii) to evaluate the performance of the system, (iii) to investigate the impact of plants densities upon the pollutants transformation kinetics, and (iv) to apprehend the biological contamination of the edible vegetable.

MATERIAL AND METHODS

Reactor system: The pilot constructed wetland was composed of 3 rectangular beds (Length x wide x depth = 1.75 x 0.75 x 0.45 m^3) made of cement (Figure 1), giving a bed surface of 1.3 m^2. It was filled from the bottom to the surface by respectively 0.1 m of granitic gravel (15/25 mm), textile and 0.3 m of a uniformly distributed medium grain (mean sand diameter = 426,66; uniformity coefficient = 0,37) white sand from the Ebrié lagoon. The sand and gravel were washed with a potable water to remove clay, loam and organic materials before using them to fill the bed. Two beds were planted with yang *C. oliterius* plants (1 bed at 40 plant/m^2, 1 bed at 10 plants/m^2), and one was preserved unplanted and used as control. The bed bottom slope was oriented 1% towards a PVC pipe (diameter: 0.032 m) for draining the filtrates out of the bed. Each bed was equipped with irrigation devices composed of 8 PVC pipe (length: 1.70 m; diameter: 0.08 m) perforated with 60 lateral holes of 0.02 diameter each.

Plant cultivation. The yang *C. oliterius* plants (3 weeks aged) were obtained from a previously cultivated *C. oliterius* seedbed. *C. oliterius* seeds used were obtained with the local market gardener from an endemic plant. *C. oliterius* yang plants were cultivated on the bed in small holes previously filled with approximately 30 g of local topsoil. The distance between two plants was maintained at 37.5 or 26 cm to obtain the high and low density beds respectively.

Water: Two types of water were used in this study; domestic wastewater and potable water. Potable water was used to perform hydraulic essay. Domestic wastewaters obtained from two sewers at Koumassi-Sicogi 1 and Abobo-Sogephia, were stocked in five (1 m^3) tanks (0.7 x 0.7 x 1.10 m) of the pilot system at the University of Abobo-Adjamé, and used to perform the treatment essays. One wastewater tank was used to irrigate only the control bed and the others were applied to the two planted beds. The reactor system was irrigated with 0.05 m^3 twice a week on Mondays and Thursdays, giving an average flow rate of 14.3 x $10^{-3}m^3$/d (hydraulic loading = 11 x 10^{-3}m/d). Before wastewater application, the feeding tanks were mixed to obtain homogeneous liquor. The water infiltration period was noted and used to calculate the infiltration flow rate into the beds. Wastewater samples were taken into the influent and the filtrate (outlet) of each cell in an ethylene bottle placed below

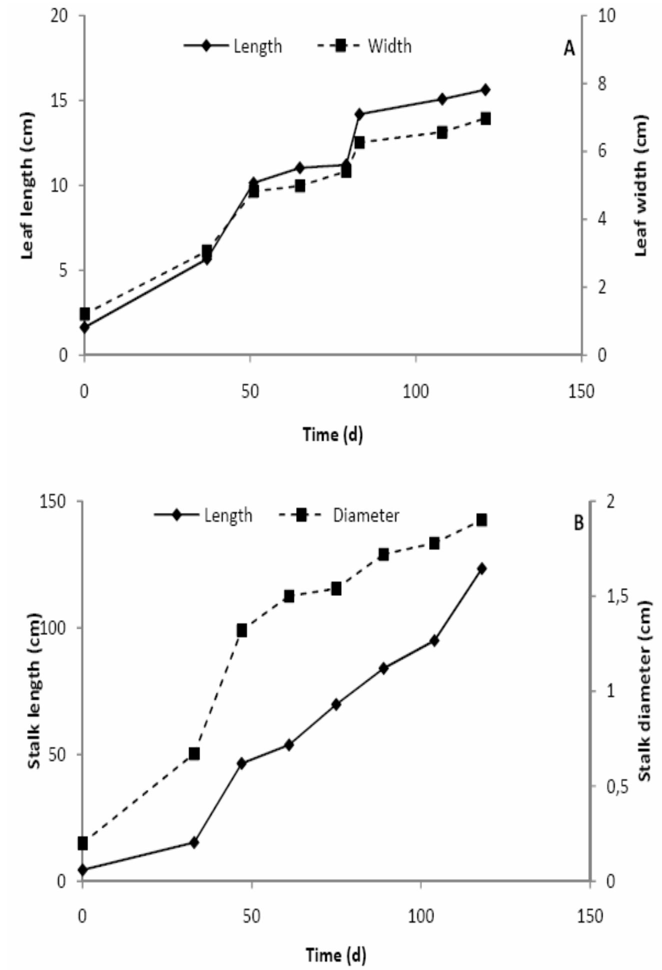

Figure 2. Kinetics of *C. oliterius* leaf and stalk growth on the constructed vertical completely drained beds. **A**: leaf growth; **B**: stalk growth.

the outlet pipe. They were preserved at 0°C until analysis in the laboratory to determine their qualities. Water outlet flow rate mean value was determined by dividing the total volume of the filtrate collected in the outlet pipe of the reactor cell by the time period of collection.

Plant growth and quality: Plant growth was evaluated by measuring its leaf and stalk characteristics. For each planted bed, five plants (one at each corner (4) and one at the center of the bed) were chosen for the measurement of the leave and the stalk growth. The mean of these measures constituted the parameter of the plant growth. Leaves growth was evaluated by measuring with a graduated ruler, the length and the maximum width of selected leaves. Stalk growth was evaluated by measurement of its maximum diameter and length with a flexible graduated rubber.

Leaf bacteriological quality: *C. oliterius* leaves were harvested from the bottom (0.1 m) up to the extremity of its buds (0.5 m) to apprehend their bacterial contamination (Thermotolerant coliform and *Clostridium perfringens*). For the characterization of the bacteria, 25 g of leaves were weighed and crushed in a crusher (Edmon Buhler) to obtain a solution. Thermotolerant coliform and *C. perfringens* were determined following standard methods for these bacteria (AFNOR, 2001a).

Physical and chemical parameters: Chemical oxygen demand (COD) and Nitrite (NO_2^-) were determined respectively according to USEPA 410.4 and 8 153 methods. Ammonium (NH_4^+), Nitrate (NO_3^-), Orthophosphate (PO_4^{3-}), Total hardness, Ca^{2+} and Mg^{2+} were determined following standard methods for these parameters (AFNOR, 2001b). Water electrical conductivity (EC) and salinity were measured with a conductivity meter.

Statistical analysis. The variance analysis was performed using 'Stastica' software for comparison of treatment differences (StatSoft, 1997). A significance level of $p< 0.05$ was used throughout the analysis.

RESULTS AND DISCUSSION

Figure 2 shows the growth profiles of *C. oliterius* leaf and stalk. The leaf grew rapidly than the stalk until day 65. During this period, the length and the width of the leaf reach respectively 11 and 5 cm. The maximum diameter (2 cm) of the plant was obtained on day 100 and at this period, the length of the stalk reached 1.23 cm. This mode of the plant growth seems normal, since *C. oliterius* growth has two phases; the exponential phase (characterized by fast growth) and the stationary one (characterized by the end of plant growth). Figure 3 shows the profiles of the water infiltration rates into the planted beds and the control. Water infiltration rates in the planted beds (7525 and 6817 ml s^{-1}) were superior to the control one (4402 ml s^{-1}), but decreased in the overall beds with time. The reduction of the water infiltration rates could be explained by the solids settlement and biofilm development in the beds (Wu and Huang, 2000). The superiority of the water infiltration into the planted beds to the control could be explained by the channels developed by the plants roots in the bed. These channels improve planted beds permeabilities, contributing in this way to water infiltration into them than in the control. Despite the positive impacts of the plants upon the hydraulic conductivity of the beds, those were clogged. This result could be explained by the saturation of the channels developed by plants roots and the pores of the beds by the solids containing in the wastewater (Sanford et al., 1995). The increase of the water infiltration observed beyond the day 46, could be explained by the removal of the solids accumulated onto the beds surface and their plugging on the first 10 cm. The statistical analysis had given a significant difference ($p < 0.05$) between the water infiltration rates on the planted beds and the control. This result could be explained by the amelioration of the beds permeabilities by plant roots. The comparison between the water infiltration rates of the planted beds with *C. oliterius* at different densities, had given no significant difference ($p > 0.05$). This result could be explained by the two densities used. May be these densities do not allow obtaining significant difference between the plant roots densities that impact significantly the beds permeability's. Figure 4 shows the pH profiles of the raw wastewater and the beds filtrates. The sequence of the pH mean values other the experi-

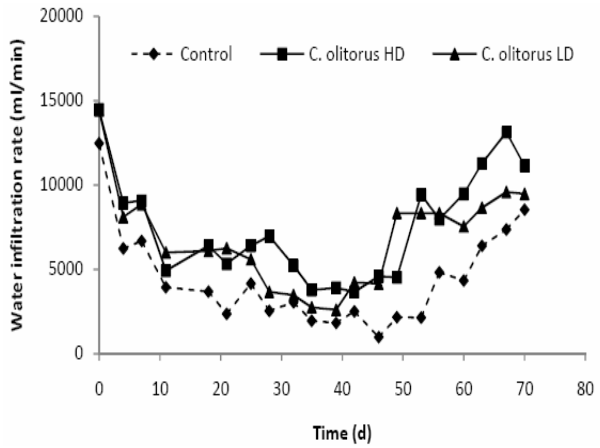

Figure 3. Water infiltration rates profiles in the control and planted beds with *C. oliterius* at low (LD) and high (HD) densities. The arrows indicate the period of solids removal on the bed surface.

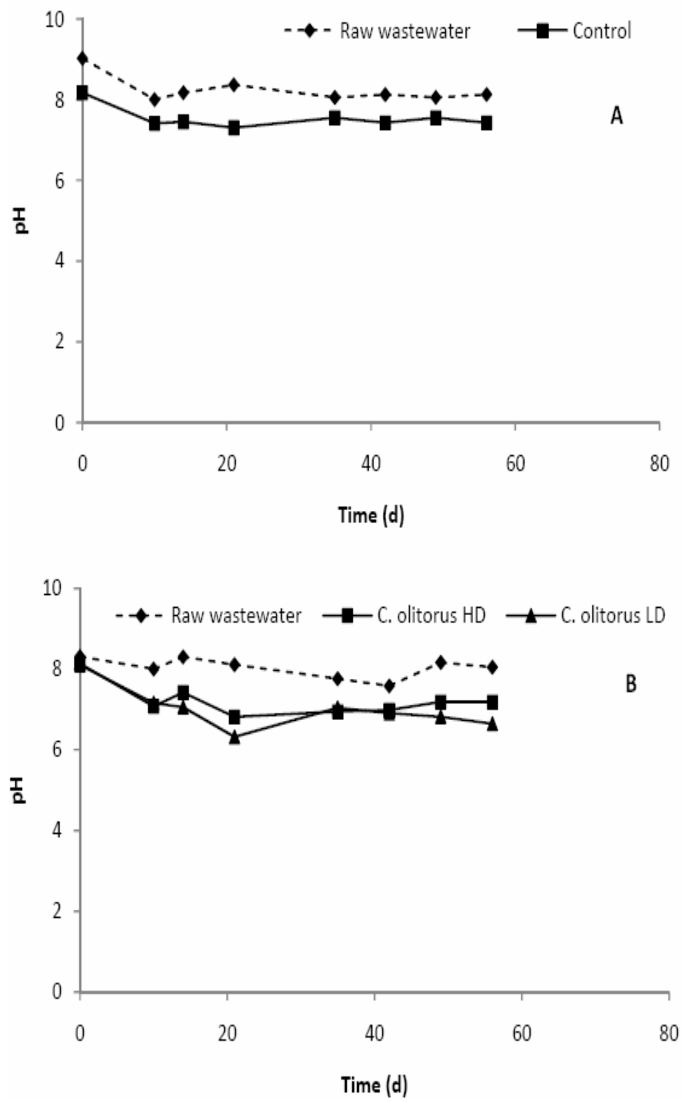

Figure 4. pH profiles of the raw wastewater and the filtrates of the control (**A**) and the planted beds (**B**) with *C. oliterius* at low (LD) and high (HD) densities.

mental period was: raw wastewater (8) > filtrate of control (7.5) > filtrate of planted bed with *C. oliterius* at low density (7) > filtrate of planted bed with *C. oliterius* at high density (7.2). This result is different from that of Finlayson and Chick (1983). These authors had obtained an increase of the pH into the filtrates of their planted beds with *Typha latifolia*. The difference between these two researches could be explained by the soil type used and the impact of nitrification on the planted bed filtrate acidity. It is well known that nitrification of 1 g of NH_4^+ requires about 7.07 g of alkalinity as $CaCO_3$ (Metcalf and Eddy, 2003). Nitrification is influenced in a planted wetland by the oxygen concentration of the media, which is bringing in subsurface flow wetland by the plant roots and by its transfer at the interface atmosphere-bed surface. Indirectly, the plant types used could influence oxygen transfer in the sand media, which can more or less impact nitrification. So, nitrification will be induced by a plant transferring high concentration of oxygen in its roots zones, with regard to plant transferring low oxygen in the same media. As a consequence, more alkalinity will be consumed (pH decrease) in the media with high oxygen than a media with low oxygen. Figure 5 shows the NH_4^+ profiles in the raw wastewater, the filtrates of the planted beds and the control. The mean value of the NH_4^+ removal by the control, planted bed with *C. oliterius* at low and high densities were respectively 11, 66 and 67.5%. The results of this study are similar to those of Abissy and Mandi (1999). These authors had observed a better reduction of NH_4^+ in their planted bed than in the control. The statistical comparison of the two planted beds did not show a significant difference ($p > 0.05$) between the concentrations of NH_4^+ in their filtrates. But there was an interest to augment the plant density, since this increased NH_4^+ removal. Figure 6 shows the profiles of NO_2^- in the filtrates of the control, the planted beds with *C. oliterius* and in the raw wastewater. NO_2^- concentration increased in all of the beds filtrates than in the raw wastewater. The sequence of NO_2^- mean concentration over the experimental period was: planted bed with *C. oliterius* high density (16 mg l^{-1}) > planted beds with *C. oliterius* at low density (6.3 mg l^{-1}) > control (5 mg l^{-1}) > raw wastewater (2 mg l^{-1}). The increase of NO_2^- concentration in the filtrates of the beds suggests a nitrification process taking place in these matrices. NO_2^- accumulation in the filtrates could result from a combining action of an important nitritation and low nitratation, because of the short hydraulic retention time prevailing in the beds (Sirianuntapiboon et al., 2006). Figure 7 shows NO_3^- profiles in the beds filtrates and in the raw wastewater. Comparing the concentration of NO_3^- in the beds filtrates allows distinguishing the following order:

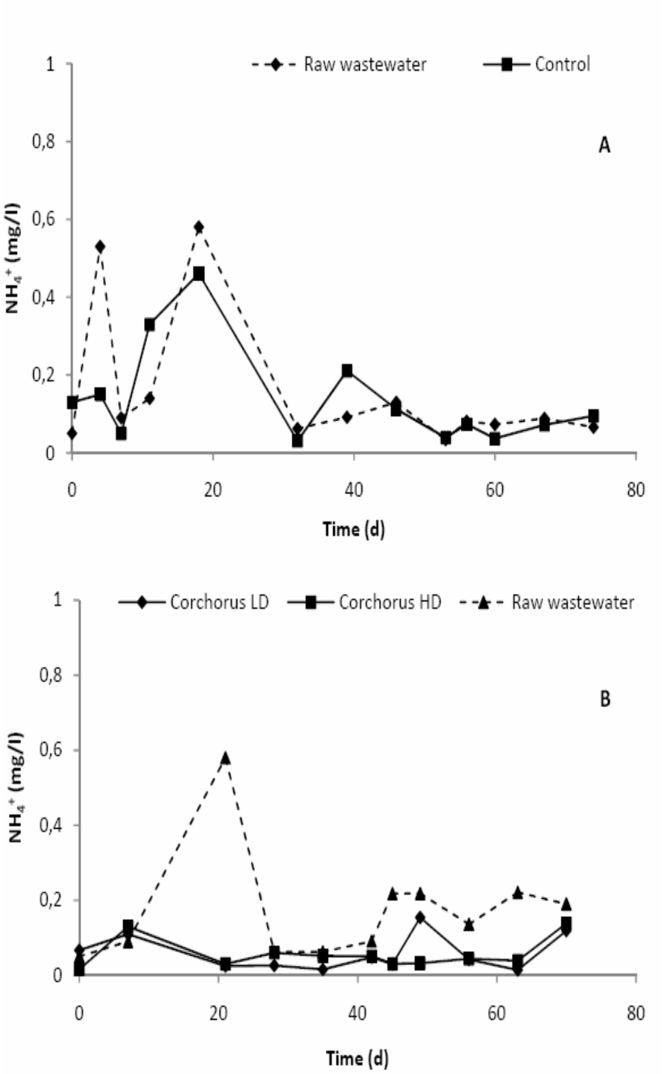

Figure 5. Kinetics of NH_4^+ removal in the control (**A**) and the planted beds (**B**) with *C. oliterius* at low (LD) and high (HD) densities.

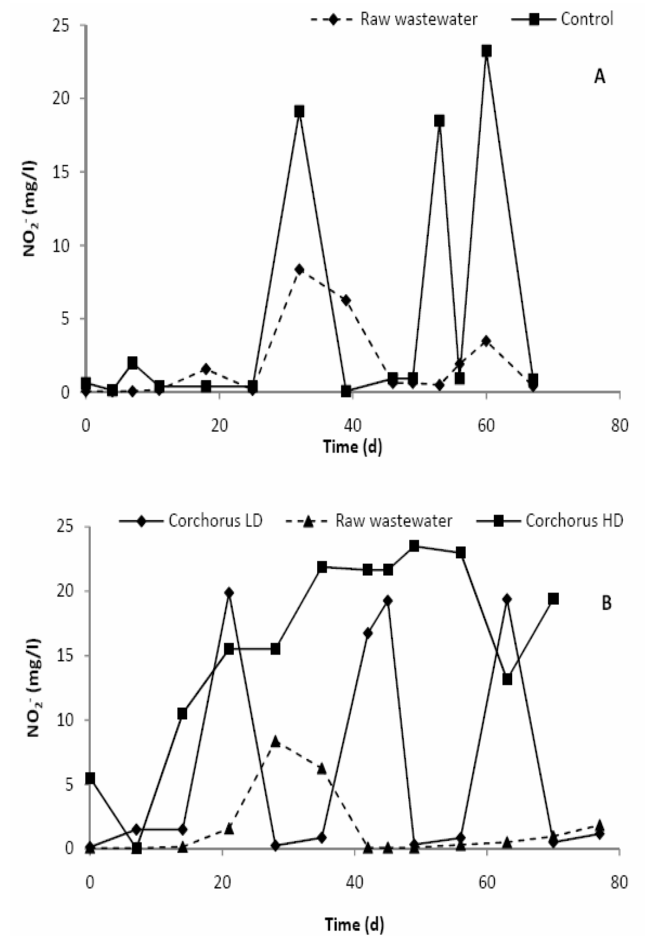

Figure 6. NO_2^- profiles in raw wastewater, filtrates of control (**A**) and the planted beds (**B**) with *C. oliterius* at low (LD) and high (HD) densities.

control (55 mg l^{-1}) > planted beds with *C. oliterius* at low density (43 mg l^{-1}) > planted bed with *C. oliterius* high density (40 mg l^{-1}) > raw wastewater (36 mg l^{-1}). NH_4^+ removal mechanisms in wetlands are usually of physical, chemical or biological orders (Nurk et al., 2005; Tanner, 1996; Toet et al., 2005; Vymazal, 2002; Xue et al., 1999). The biological nitrification activity is induced in the planted beds by the oxygen transferred via photosynthesis, in the plant roots zones (Armstrong and Armstrong, 1988; 1990; Gesberg et al., 1986). As a consequence, NO_3^- is more accumulated in the filtrates of the planted bed than the control. However, the important accumulation of NO_3^- in the control than in the planted beds filtrates combined with the its accumulation in the planted beds filtrates than in the control gives evidence that this element was removed by the plants in the planted beds parallel to its production. Figure 8 shows the PO_4^{3-} profiles in the beds filtrates and in the raw wastewater. The PO_4^{3-} concentrations in the beds filtrates were lower than in the raw wastewater; traducing its removal in the beds. The PO_4^{3-} removal mean values in the control, the planted bed with *C. oliterius* at low and high densities were respectively 56, 53 and 50%. These results suggest that the mechanisms of PO_4^{3-} removal in the reactor system are the combining actions of physical or chemical reactions reactions and biological uptake as proposed by Kadlec and Knight (1996). But the superiority of the PO_4^{3-} removal in the control than in the planted beds highlight that the dominant process in PO_4^{3-} removal in this study could be of chemical or physical orders (precipitation of PO_4^{3-} by Ca^{2+}, adsorption) in the sand media. The experimental condition (pH ≥ 7, high concentration of PO_4^{3-} and Ca^{2+}) is favorable to such reaction (Nichols, 1983; Howard-Williams, 1985). Also, plants roots galleries in the sand media reduce the planted beds performance. Through these galleries, the water applied on the beds is drained out with important PO_4^{3-}, increasing in this way this nutrient concentration in the planted bed filtrate than the control. The increase of the plants density had no

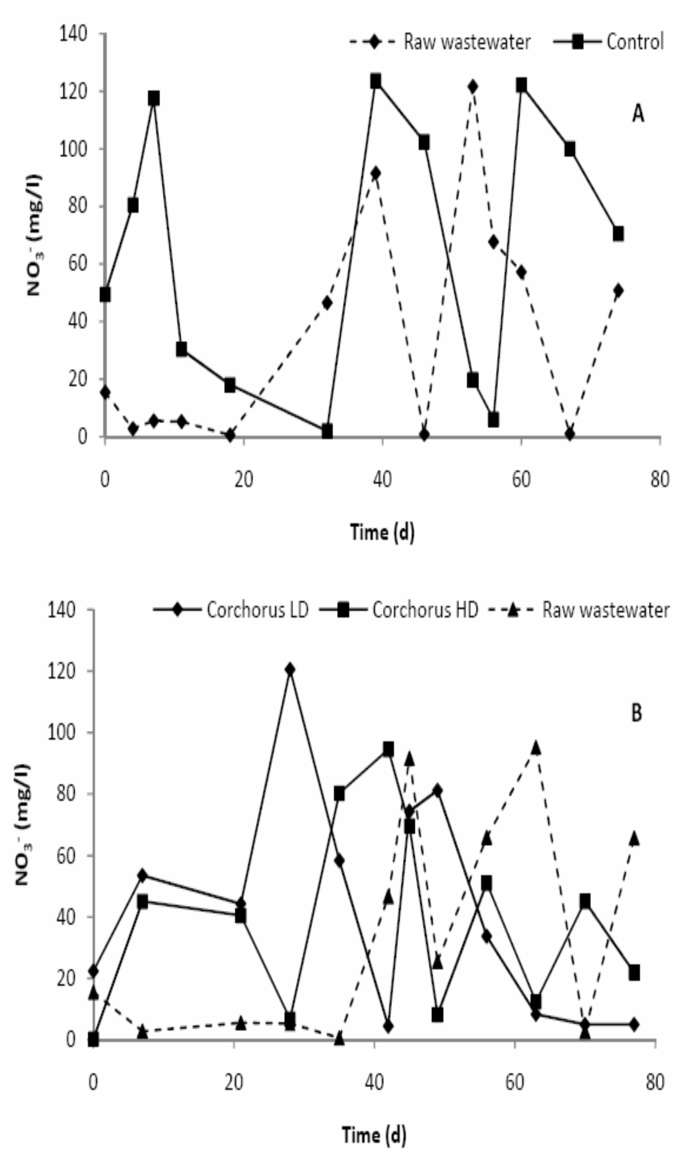

Figure 7. Profiles of NO_3^- in raw wastewater, filtrates of control (**A**) and the planted beds (**B**) with *C. oliterius* at low and high densities.

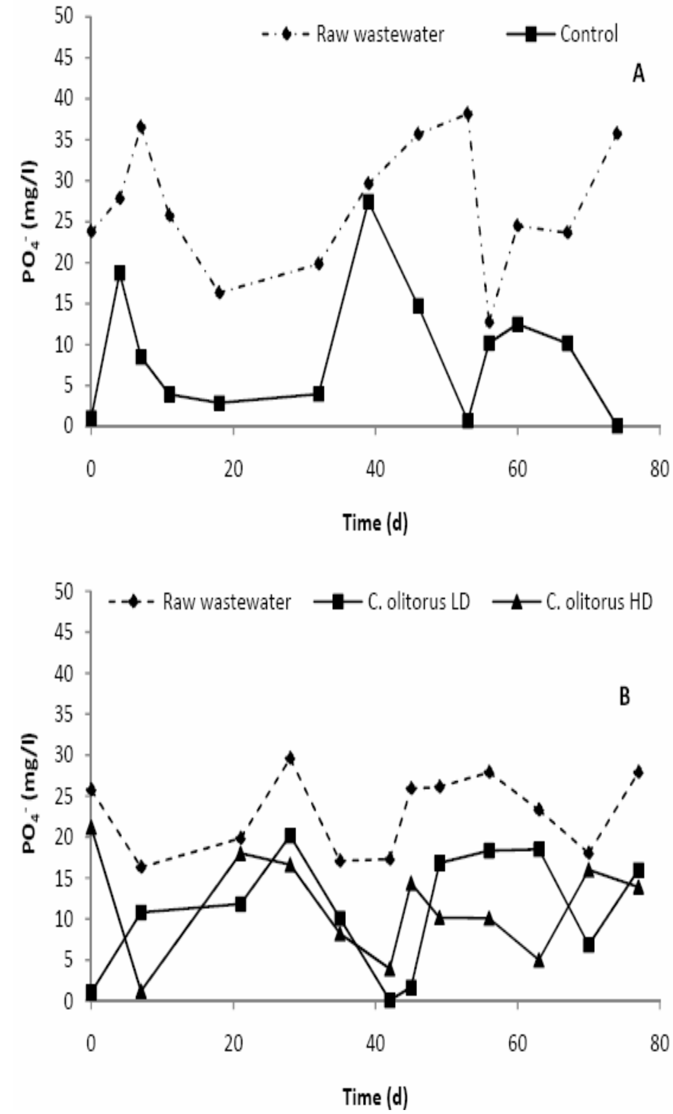

Figure 8. PO_4^{3-} removal profiles in raw wastewater and the filtrates of the control (**A**) and the planted beds (**B**) with *A. hybridus* at low (LD) and high (HD) densities.

significant effect upon orthophosphate removal. This result is evidence, because although phosphorus uptakes by plant are dependent on plant type, it is generally small (Ansola et al., 1995; Hocking, 1989; Cooke, 1992). The transparencies of the beds filtrates were highly improved than the raw wastewater (Figure 9). But the quality of the control filtrate was best ameliorated than the planted beds. This result could be explained by the important settlement of solids and colloids in the control bed media. In the planted beds, plant roots create some channels through which solids migrate to the filtrate, degrading its transparency. Figure 10 shows the profiles of the ratio of the electrical conductivity (EC) of the beds filtrates and that of the raw wastewater. The EC of the planted beds filtrates varied randomly but remained superior to that of the control. A similar result was obtained by Abissy and Mandi (1999) in their planted bed filtrate, which was established in uncovered soil. The augmentation of the EC in the planted beds filtrates than in the control and the raw wastewater could be explained by the oxidation of organic matters; which could create acidic condition because of CO_2 release. As a consequence the salts containing in the beds are lixiviated and increase the filtrates EC. The difference between the EC of the planted beds filtrates and the raw wastewater was not statistically significant ($p > 0.05$). There was also any plant density impact upon the EC of the planted beds filtrates. Figure 11 presents the profiles of the total hardness of the planted beds and the control filtrates. The total hardness of the beds filtrates was superior (mean value: 228 - 242 mg/l) than the raw wastewater

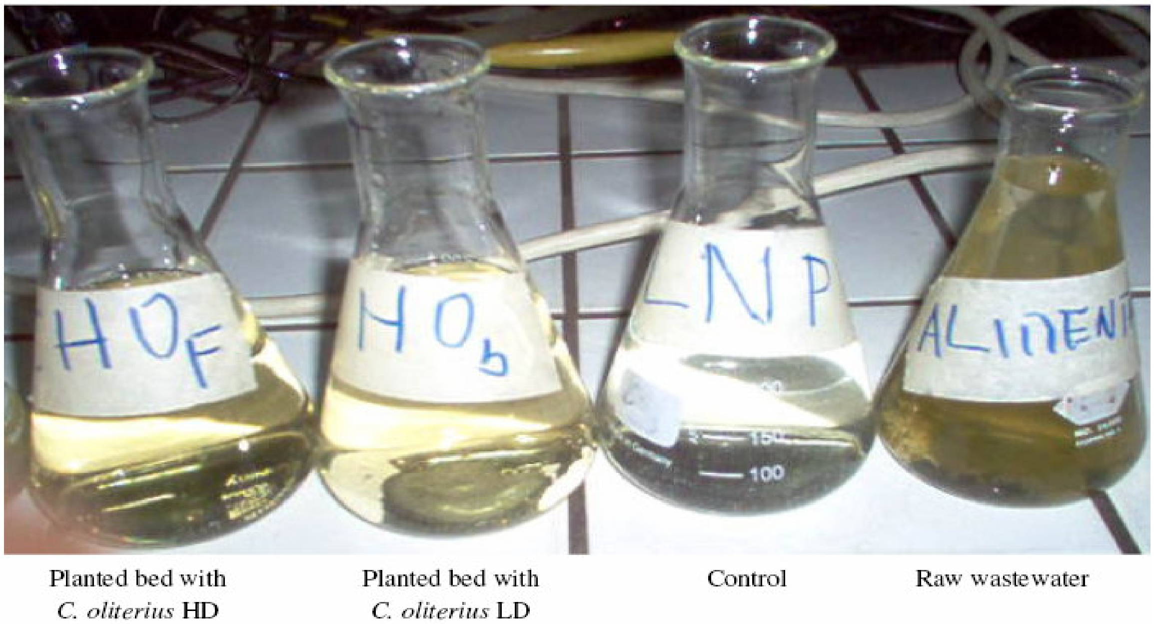

Figure 9. Transparency of the raw wastewater, the filtrates of the planted beds with *C. oliterius* at high (HD) and low densities (LD), and the control.

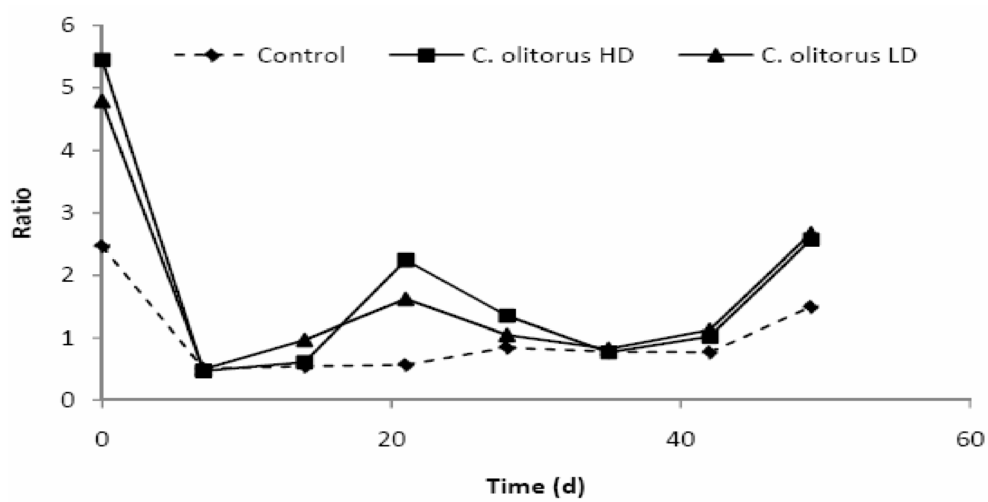

Figure 10. Profiles of electrical conductivity (EC) ratio of the raw wastewater, the control and the filtrates of the planted beds with *C. oliterius* at low (LD) and high (HD) densities.

(mean value: 173 mg/l). There was no significant difference ($p > 0.05$) between the total hardness of the planted beds and the control filtrates, and the raw wastewater. The increase of the total hardness of the beds filtrates than the raw wastewater could be explained by a release of Ca^{2+} and or Mg^{2+} in these filtrates. This lixiviation could result from an ion exchange reaction between the Na^{+} or K^{+} containing in the raw wastewater and the Ca^{2+} or Mg^{2+} washed from some rocks containing these ions in the sand media (Jackson and Myers, 2002). The profiles of Ca^{2+} or Mg^{2+} in the beds filtrates show an increase of their concentrations than in the raw wastewater, confirming their release hypothesis (Figure 12). Figure 13 shows the profiles of COD in the filtrates of the planted beds and the control, and in the raw wastewater. COD removals varied in the filtrates of the planted beds with *C. oliterius* at low and high densities, and the control. But the COD removals mean values overall the experimental period were 54, 61 and 65% respectively for the control, the planted bed with *C. oliterius* at low and high densities. The comparison of the COD concentrations of the beds filtrates with that of the

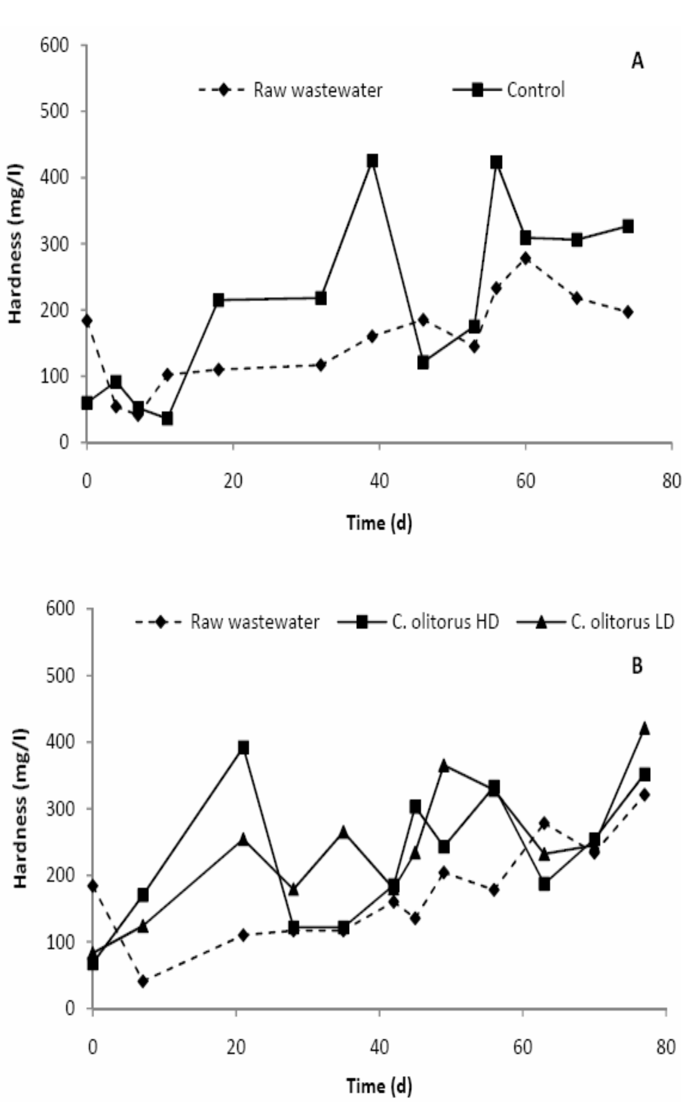

Figure 11. Total hardness profiles in raw wastewater, the filtrates of the control (**A**) and the planted beds (**B**) with *C. oliterius* at low (LD) and high (HD) densities.

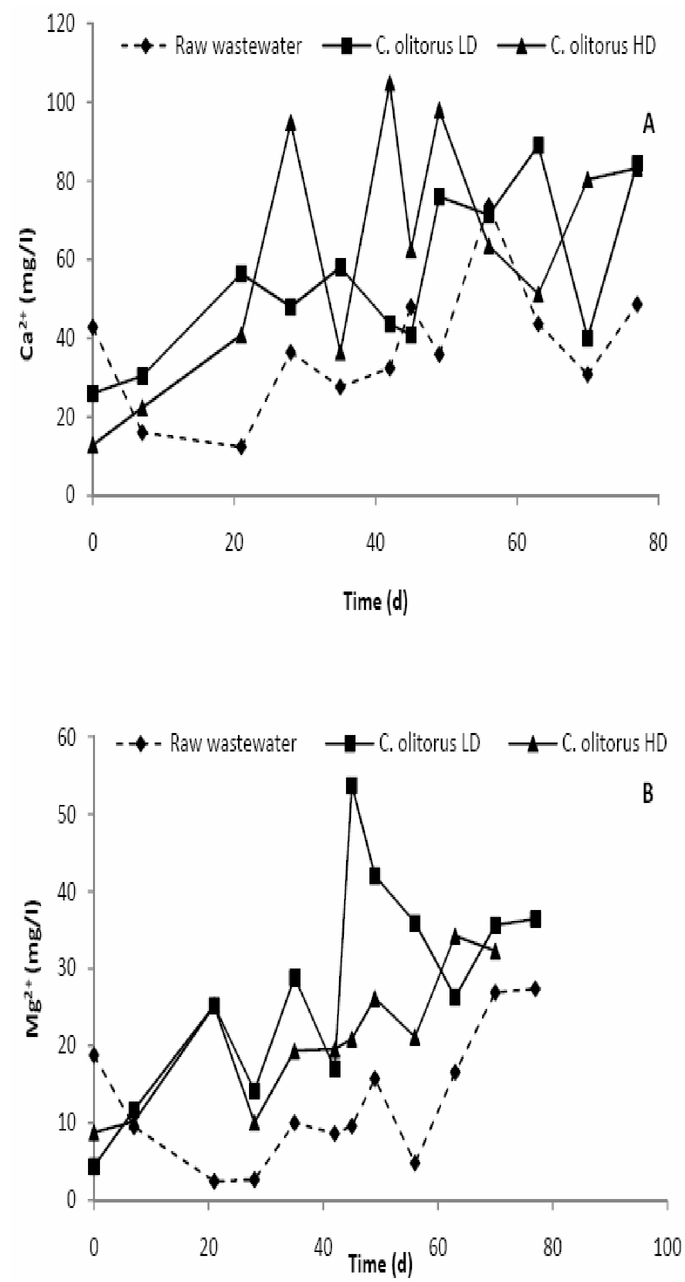

Figure 12. Profiles of Ca^{2+} (**A**) and Mg^{2+} (**B**) in the raw wastewater (feed), the filtrates of the planted beds with *A. hybridus* at low (LD) and high (HD) densities.

raw wastewater gave a significant difference ($p < 0.05$). However, there was not a significant difference ($p > 0.05$) between the COD of the two planted beds filtrates, and with the COD of the filtrate of the control. Despite this statistical result on the effect of the plant density increased from 10 to 40 plants /m^2 on COD removal, there was an interest, because of the enhancement of the COD removal from 61 to 65% parallel to the plant density increase. This result could be explained by the optimization of microbial oxidation of organic pollutants in the planted beds (Brix, 1994). The COD removal capacity of the planted beds developed is superior to that of Urbanc-Beric (1994) (36%). The differences between these two researches, could be explained by the plant type used, the nature of the beds, and the hydraulic retention time of the reactor (Sirianuntapiboon et al., 2006). Bacterial contamination of the vegetable leaves falls parallel to the plant height. Bacterial concentration decrease from 680 to 384 and 64 CFU/g respectively for raw wastewater and plant height at 50 and 90 cm (Figure 14). This result attests that the irrigation devices used do note contaminate the plant leaves and suggests 90 cm to be the height at which those can be harvested with low risk.

Conclusion

The wetland developed has proven goods capacities for

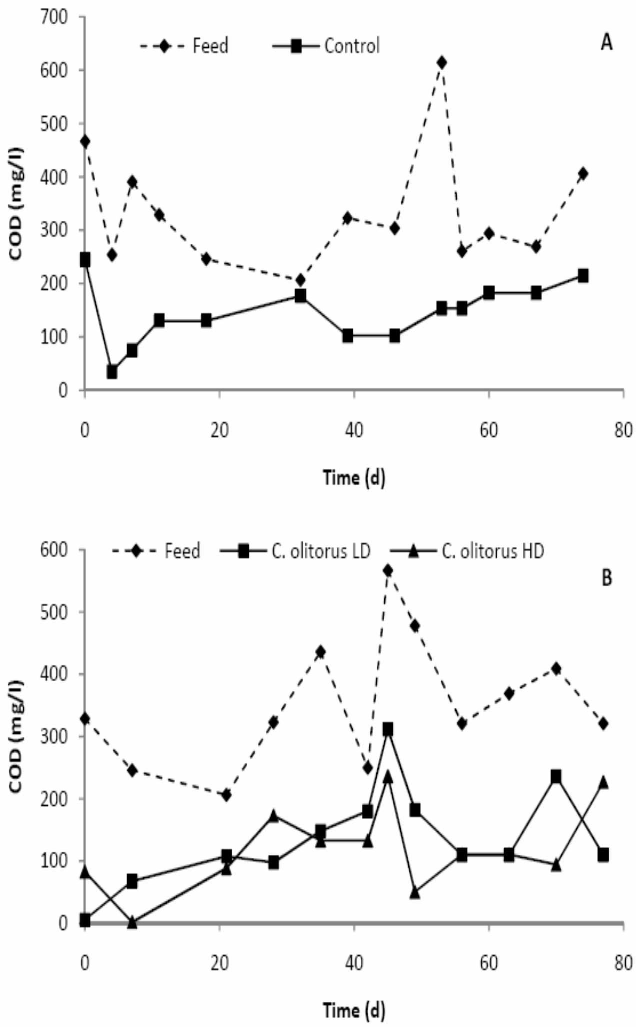

Figure 13. COD removal profiles in raw wastewater (feed), the filtrates of the control (**A**) and the planted beds (**B**) with *C. oliterius* at low (LD) and high (HD) densities.

removing COD, NH_4^+ and PO_4^{3-} from domestic wastewater. COD was best removed in the planted beds than in the control. Ammonium was oxidized to NO_2^- and NO_3^-. PO_4^{3-} removal dominant mechanism seems to be physical or chemical reactions.

The main findings from the study were:

- The presence of plants on the beds increased COD and NH_4^+ removal.
- The pH and the electrical conductivity were reduced.
- The presence of plants on the beds improved water infiltration into the beds alleviating beds clogging scenario.
- The increase of the plants density had no significant effect upon orthophosphate removal.
- The best height to minimize risk of bacterial contamination of plants is 90cm.

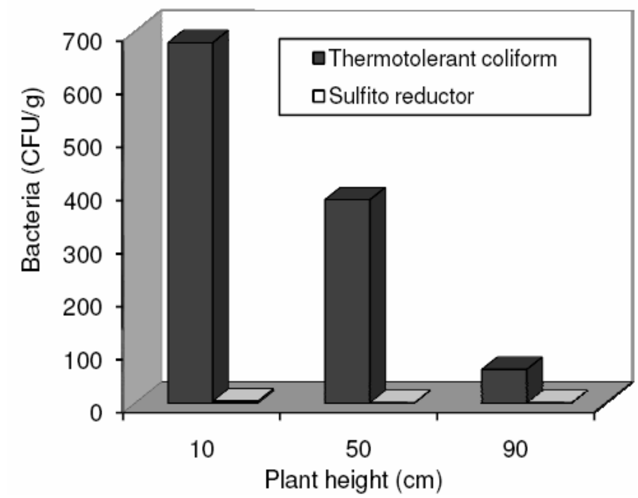

Figure 14. Contamination profiles of the leaf of *C. oliterius* by Thermotolerant coliform and Sulfito reductor bacteria at different height of the plant.

There was globally a relative influence of *C. oliterius* upon pollutants removals and beds permeability. Although, *C. oliterius* density impact was not statistically significant, the system developed could be an alternative for domestic wastewater treatment in developing countries, because of simplicity and hygienic edible vegetables production.

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