Universal Journal of Environmental Research and Technology
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Available Online at: www.environmentaljournal.org
Volume 1, Issue 2: 160-168

Open Access **Research Article**

Potential of *Cyperus Papyrus* in Yard-Scale Horizontal Flow Constructed Wetlands for Wastewater Treatment in Cameroon

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Abstract:

The objective of this study was to evaluate the performances of *Cyperus papyrus* in horizontal flow constructed wetlands used for domestic wastewater treatment. Two system configurations were used: the horizontal surface flow (HSF) and the horizontal subsurface flow (HSSF). Each wetland was continuously fed by primarily treated wastewater, at an average organic loading rate of 106 kg BOD/ha-d. Growth and productivity of the plant were assessed alongside the reduction of physicochemical and microbiological characteristics of water in both wetland configurations. Progressive increase in the plant density, shoot length and stem diameter were observed. Above-ground and underground biomasses of 41 and 90 tonnes of dry weight/ha/year respectively were estimated. The reduction of several physicochemical parameters and that of faecal coliforms and faecal streptococci were not significantly different in the vegetated as compare to the non vegetated control wetlands in both HSSF and HSF configurations. The HSF was nevertheless more efficient in the removal of faecal coliforms and faecal streptococci as compared to the HSSF. The rate of absorption of ammonia nitrogen by *C. papyrus* was estimated to about 1.11 g/m^2/d in the HSSF and 2.0 g/m^2/d in the HSF wetlands, while that of nitrate nitrogen was estimated to about 0.35 g/m^2/d and 0.57 g/m^2/d respectively.

Keywords: constructed wetlands, *Cyperus papyrus*, plant performance, treatment efficiency.

1.0 Introduction:

Constructed wetlands are nowadays considered as low-cost alternative for effective wastewater treatment especially where suitable land can be available (Tang, 1993; Agendia, 1995; Kadlec, 1995; Ayaz and Sagin, 1996; Crites *et al*, 1997; Ji *et al*, 2002; Vymazal, 2002). Even though wastewater treatment is accomplished through the integrated combination of physical, biological and chemical interactions amongst biotic and abiotic components of the ecosystem, macrophytes cultivated in constructed wetlands make one of the essential components in the treatment process. Plants are known to provide surface area for microbial growth, to uptake pollutants and nutrients, and also to transport oxygen from the atmosphere to the rhizosphere (Gersberg *et al*, 1986; Armstrong *et al*, 1990). Oxygen enhances the microbial biodegradation process in the root zone and alleviates the stress associated with the anoxic conditions (Fitter and Hay, 1995; Brix, 1996; Li *et al.*, 2008). Plant biomass produced in the wastewater treatment process is an added value of the constructed wetland since it can be exploited as food, medicine, paper and biofuel (Polprassert, 2007). Wetlands systems have been proven suitable for treating wastewater from agricultural industry and produce clean water which then can still be used for other purposes such as irrigation water, fisheries and other necessities (Kurniadie, 2011).Constructed wetlands are known to be site-specific, and because year-round flow is necessary to sustain the plants, they are not appropriate for seasonal residences (Hoffmann *et al.*, 2011). Land requirement has also been raised as a concern, especially in urban areas (Agendia, 1995). Also, macrophytes exploited in constructed wetlands are not ubiquitous so as to be used worldwide (Fonkou *et al.*, 2010).

Cyperus papyrus is a perennial aquatic macrophyte inhabiting subtropical and tropical wetlands. High quality papers have been produced from this plant. In South Africa the starchy rhizomes and culms are eaten raw or cooked by the population while young shoots are frequently grazed by livestock and culms are used as building material (Archer, 2004). This plant has a relatively high potential of producing biomass from solar energy, which is one of the criteria for the selection of macrophytes to be used in constructed wetlands (Perbangkhem and Polprassert, 2010). Some macrophytes including *Phragmites* sp. and *Typha* sp. are well known for their potentials in constructed wetlands for wastewater and fecal sludge treatment and literature on their performances is well documented (Kadlec, 1995). These well-known macrophytes are however not found in all regions of the world and effort is being made worldwide to select potential candidates to be exploited locally in wetland technology. In Cameroon, some indigenous macrophytes have been found growing luxuriously in polluted wetlands, and were proven to concentrate high amount of heavy metals in their tissues (Fonkou *et al.*, 2005). In-depth investigations have therefore been carried out on the behavior of some of these indigenous macrophytes including *Echinochloa pyramidalis* and *C. papyrus* in stressful environments created by wastewater from distillery or fecal sludge applications (Kengne et al., 2009; Fonkou et al., 2010). The present study aimed at assessing the potentials of *C. papyrus* in domestic wastewater treatment using a laboratory scale horizontal flow constructed wetlands. Morphological parameters, as well as productivity of the plant and the treatment efficiency of the vegetated wetlands are investigated with respect to nutrient load and wetland's configurations.

2.0 Material and Methods:

2.1 Site of Study:

This study was conducted in a laboratory scale constructed wetlands system in the University of Dschang campus. Dschang is located between 5°25' and 5°30' latitude North and between 10°00' and 10°5' longitude East in the Western Highlands region of Cameroon. The climate in this region is of equatorial type with two seasons, a 4 months dry season from mid-November to mid-March, and an 8 months rainy season from mid-March to mid-November. Annual precipitations ranged between 1433 mm and 2137 mm, while annual mean temperature is estimated at 20.8°C with thermal amplitude of 2°C (Anonymous data from the local meteorological station, 1978-2008). Wastewater used in the study was collected from a small primary treatment plant receiving domestic liquid wastes from the students' residence at an inflow rate of 3 m^3 per day. Part of the primary treated effluent was channeled into a 1.3 m^3 gutter from where it was distributed to the experimental wetlands using PVC pipes (figure a).

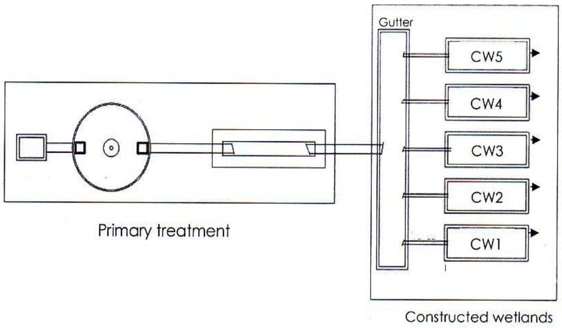

Figure a: Laboratory Scale Setup of the Experiment

2.2 Design of the Experimental Wetlands:

Five wetlands CW1, CW2, CW3, CW4 and CW5 of 3 × 1 × 0.6 m^3 each were constructed using cement blocks. In order to ensure water proofing, an admix called Sikalite^{TM} was mixed with cement and used to cover the inners parts of the structures. A slope of 1 % was respected on the bottom of each bed to ease the circulation of water from the inlet to the outlet. Gabions of 30 cm made up of stones of 5-8 cm diameter were arranged at the inlet and the outlet zones of the beds, while a drainage layer of about 10 cm was arrange at the bottom. The outlet structures were adjustable to enable the regulation of the water level on the substrate (figure b). The main filter substrate was a 45 cm column of sand having particles size < 2 mm. CW3 was used as the non vegetated control bed, while the other beds were vegetated. The present paper presents the results from CW5 vegetated with *C. papyrus* and CW3.

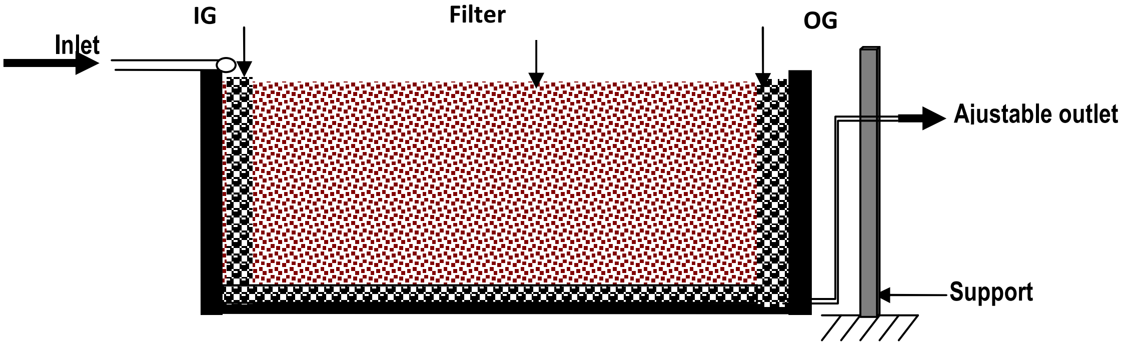

Figure b: Design of an Experimental Treatment Bed (IG: inlet gabion, OG: outlet gabion)

2.3 Wetland Configurations and Operational Procedures:

Horizontal surface flow (HSF) and horizontal subsurface flow (HSSF) are the two wetland configurations that were used in this study. In the HSF, water level was adjusted to 5 cm above the substrate while in the HSSF, it was kept below the surface. The system was primarily used in the HSF configuration for 6 months after which, and was transformed to the HSSF configuration by lowering the adjustable outlets of the beds. In both configurations, wastewater from the primary treatment plant of the University of Dschang campus was continuously fed into each bed at an average organic loading rate of 106 kg BOD/ha/d.

2.4 Assessment of the Growth Parameters of the Plant:

Fragments of rhizomes carrying young shoots of *C. papyrus* were collected from a natural wetland and transplanted in CW5 at a density of 6 rhizomes /m^2 (figure c). A 6 weeks acclimation period was observed during which many young shoots appeared from these initial rhizomes. Growth parameters of the young plants were measured at two weeks intervals alongside the physicochemical characteristics of water at the inlet and the outlets of the wetlands, for 2x6 months periods in the HSF and HSSF configurations respectively. The plant was tested in the HSF system configuration from January to June, and in the HSSF system configuration from August to January.

Figure c: Aspect of *C. papyrus* in the Wetland 6 Weeks after Planting

The following plant parameters were considered: density in the bed, plant height, stem diameter and biomass. Plant density, shoot length and stem diameter were measured at two weeks intervals, while dry biomasses were estimated after each of the two harvests by weighing the fresh biomass of all aboveground stands and estimating the water content of 4 randomly selected plants after drying them in an oven at 105 °C for 24 hours. Plant density in the bed was obtained by counting all the plants, while shoot length and basal diameter were measured on 30 randomly selected plants in the bed using a graduated rope. The biomasses of the aboveground stands were measured after harvest at the end of the survey in each of the configurations, and the below ground biomass was estimated at the second harvest.

2.5 Assessment of Water Quality Improvement:

Water quality improvement in the wetlands was assessed by monitoring some physicochemical and microbiological characteristics of wastewater at the inlets and the outlets. Physicochemical parameters considered in water samples included conductivity, pH, colour, 5 days Biochemical Oxygen demand (BOD$_5$), Chemical Oxygen Demand (COD), Nitrate nitrogen (NO_3^--N) and orthophosphate (PO_4^{3-} -P). Water conductivity and pH were tested with the Hach TDS/Conductivity meter and the Consort530™ multimeter respectively. BOD$_5$ was measured using the Hach BOD Track™ system. COD was read using the DR2500 spectrophotometer after the dichromate digestion of the samples on the Hach DRB200™ reactor. The other parameters were measured on the DR2500 spectrophotometer following standards methods described by Hach (1997) in the handbook of water analysis. Microbiological parameters considered were faecal coliforms and faecal streptococci counts with the membrane filtration technique. These parameters were also measured at two weeks intervals throughout the study period, following standard procedures (Hach, 1997). The percentage improvement (PI) of the water quality was calculated for each parameter using the formula

$$\mathrm{PI} = \frac{Inlet - Outlet}{Inlet} x100$$

PI: Percentage improvement; Inlet: value of the parameter at the inlet; Outlet: value of the parameter at the outlet.

These percentages were calculated each day after the analysis and the averages estimated at the end of the study period as the overall efficiency of the system in the reduction of each parameter. These means were then separated using the Student T test.

3.0 Results and Discussion:

3.1 Growth Characteristics of the Plant in the System:

From a density of 6 rhizome fragments per m^2, 33 plants per m^2 were obtained after 6 weeks acclimation in the filter bed during which the system was continuously fed with primary treated wastewater. At the end of the 25 weeks experiment in the HSF, a density of 70 plants per m^2 was recorded, while from the density of 27 plants per m^2 after the first harvest, a density of 72 plants per m^2 was obtained at the end of the experiment in the HSSF (figure d). Relative changes in the plant height and the stem width were estimated at $6.8x10^{-3}$ cm.cm^{-1}.day^{-1} and $3.9x10^{-3}$ cm.cm^{-1}.day^{-1} respectively in during the HSF experiment, while in the HSSF, the estimates were $8.5x10^{-3}$ cm.cm^{-1}.day^{-1} and 4.2 cm.cm^{-1}.day^{-1}.

3.2 Biomass Production:

Table 1 presents the dry biomass estimates during the 6 months consecutive experiments in the HSF and the HSSF wetlands configurations. Although there was no meaningful difference between the aboveground biomasses in the two wetland types, the underground biomass estimate after the study was almost similar to the sum of these aboveground estimates.

3.3 Water Quality Improvement:

Table 2 presents the physicochemical characteristics of the effluent monitored at the inlet and the outlets of the wetlands in the HSSF configuration. The monitoring of water quality in the systems revealed that globally, the physicochemical characteristics of the effluent were progressively improved upon since a dramatic decline was recorded from the inlet to the outlets of the experimental beds. Although the role of the plant in the wastewater treatment process has been questioned.

Table 1: Dry Biomass Production of *C. Papyrus* in the HSF and the Following HSSF wetlands

Biomass tons.ha^{-1}	HSF	HSSF
Above ground	16.9	16.5
Underground	*	33.4
Total	16.9	49.9

*The underground biomass was not measured in the HSF wetland

With the exception of the conductivity and total dissolved solids in the non vegetated wetland, the treatment efficiencies of the wetlands in both configurations were above 50 %. Meanwhile, percentages reduction of all the parameters monitored were higher in the vegetated wetland. Similar results have been obtained by Zhang *et al.* (2010) with *Phragmites australis* in HSSF used for saline wastewater treatment. The rate removal of conductivity, total dissolved solids, suspended solids, turbidity, colour, and biochemical oxygen demand between the non vegetated and vegetated wetlands likewise between the different vegetated wetlands were not significantly different. However, the rate removal of ammonia, nitrate, phosphate and COD were proved to be significantly high in the vegetated when compared with the non vegetated wetlands.

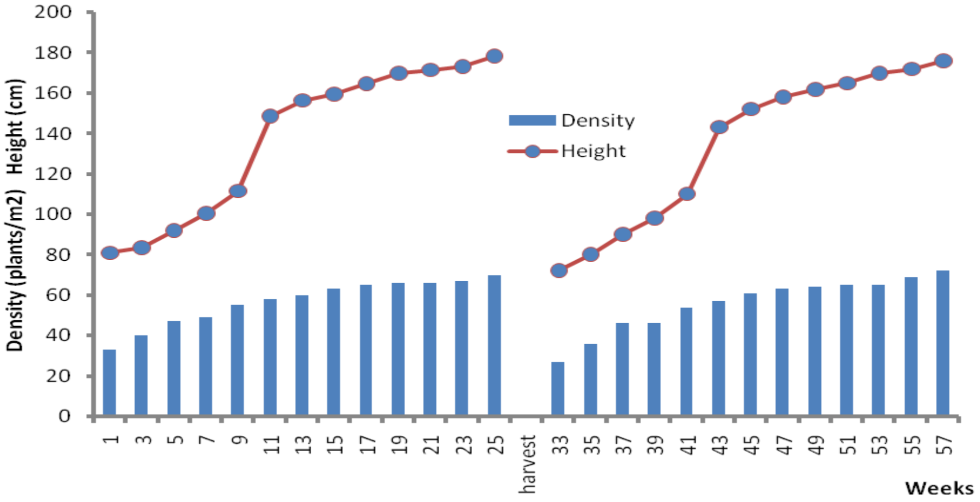

Figure d: Changes in Plant Density and Height of *C. papyrus* in the Horizontal Surface Flow after Planting (1st -25th weeks) and the Horizontal Subsurface Flow wetland after the above ground harvest (33rd-57th weeks).

Table 2: Physicochemical Characteristics of the Effluent Monitored for A 6 Months Study Period at the Inlet and the Outlet of the HSSF Wetland (mean ± SEM, n=26)

Parameter	Inlet	Outlets	
		Unplanted Bed	Planted Bed
TDS (mg/L)	865.43 ±146.96	778.14 ±155.83	499.71 ± 52.15
CND (µS/cm)	1751.93 ±291.1	1463.86 ±257.23	1007.14 ± 107.00
SS (mg/L)	475.71 ±48.64	94.14 ±16.90	166.07 ± 44.33
Colour (PtCo)	1673.29 ±406.2	940.29 ±295.46	562.64 ± 111.49
Turbidity (FTU)	477.14 ±49.67	150.43 ±22.17	221.57 ±48.23
NH_3-N (mg/L)	108.57 ±22.18	14.60 ±3.90	32.41 ± 7.50
NO_3^--N (mg/L)	40.57 ± 12.03	2.92 ±1.05	7.78 ±3.46
PO_4^{3-} (mg/L)	14.36 ± 7.86	1.23 ±0.44	4.56 ±1.59
COD (mg/L)	1142.00 ± 334.30	775.14 ±360.29	324.00 ±7.40
BOD_5 (mg/L)	455.43 ± 32.51	133.83 ±16.08	99.14 ±7.40

Table3 showed the physicochemical characteristics of the effluent monitored at the inlet and the outlets of the wetlands in the HSF configuration. Although the reduction percentages of conductivity, total dissolved solids, colour and turbidity were not significantly different between the planted and the unplanted bed, the reduction ammonia nitrogen, nitrate nitrogen, orthophosphates as well as suspended solids contents, BOD_5 and COD were significantly higher in the planted bed (table 4).

Table 4 shows the averages of the percentage reduction of several physicochemical parameters of the effluent in the wetlands. Except the TDS and the conductivity in all the wetlands, colour and COD in the non vegetated HSSF wetland, all the parameters were reduced by more than 50% irrespective of the configuration considered. The configuration of the system was important in the reduction of several parameters, since the reduction percentages of nitrate, ammonia and orthophosphates were significantly higher in the HSSF wetland and that of COD higher in the HSF. With the vegetation in the wetlands, the system showed better performances, except for the reduction of nitrates, orthophosphates and ammonia in the HSSF wetland. Some wetland plants including *C. papyrus* and *Carex pendula* have proven to accumulate large amounts of nutrients and heavy metals in their tissues especially in the roots (Fonkou *et al.,* 2005; Yadav *et al.*, 2011). In general, the vegetated HSF wetland was more efficient in the reduction of the physicochemical parameters monitored, even though the reduction of colour in this configuration was not significantly different from that recorded in the vegetated HSSF wetland.

Table 3: Physicochemical Characteristics of the Effluent Monitored for A 6 Months Study Period at the Inlet and the Outlet of the HSF Wetland (mean ± SEM, n=26)

Parameter	Inlet	Outlet	
		Unplanted bed	Planted bed
TDS (mg/L)	1095.07 ±206.31	1016.79 ±232.25	778.14 ±155.83
CND (µS/cm)	2205.79 ±411.79	2017.21 ±465.06	1463.86 ±257.23
SS (mg/L)	1290.71 ±379.88	211.79 ±48.86	94.14 ±16.90
Colour (Pt Co)	3135.36 ±606.22	1566.36 ±574.17	940.29 ±295.46
Turbidity (FTU)	1462.84 ± 470.73	416.93 ±128.49	150.43 ±22.17
NH_3- N (mg/L)	123.97 ±25.97	49.28 ±13.67	14.60 ±3.90
NO_3^- (mg/L)	59.95 ±18.78	22.15 ±3.81	2.92 ±1.05
PO_4^{3-} P (mg/L)	34.36 ±10.34	10.26 ±3.85	1.23 ±0.44
COD (mg/L)	7236.00 ±2836.61	1619.30 ±773.19	775.14 ±360.29
BOD_5 (mg/L)	467.67 ±29.16	146.33 ±8.34	133.83 ±16.08

3.4 Nutrient Absorption Rates by C. papyrus in the Vegetated Wetlands:

The rate of removal of nitrogen and phosphorus resulting from the presence of *C. papyrus* in the wetland was estimated from of the concentrations of ammonia, nitrate and orthophosphate in the effluent at the exit of the vegetated and the control wetlands.

For all the nutrient parameters considered, the absorption rates in the HSF were higher than those in the HSSF (figure e). In the HSSF as well as in the HSF wetlands, the rate of removal of nutrients (phosphorus, and nitrogen) progressively increased with time. In the HSSF wetland, there were positive correlations between the removal of ammonia and changes in the plant density and height (R = 0.62 and R = 0.57 respectively). The correlation factor between the rate of removal of nitrate and the plant density and height were 0.38 and 0.44 respectively. Phosphorus removal rates were also positively correlated with plant density (R = 0.52) and plant height (P = 0.68). In the HSF wetland, the removal of ammonia, nitrate, phosphorus and the reduction of COD were consistent. The rates of removal of ammonia, nitrate and phosphorus also increased progressively as the plant height and density increased. In the HSF, the rate of removal of ammonia, nitrate and phosphorus were also positively correlated with plant density (R = 0.67, R=0.54 and 0.38 respectively) and plant height (P = 0.46, 0.48 and 0.35 respectively).

Table 4: Percentages Reduction of Several Physicochemical Parameters of the Effluent in the Vegetated and the Non-Vegetated HSSF and the HSF Constructed Wetlands

Parameters	**% Reduction**			
	HSSF		**HSF**	
	Non Vegetated	**Vegetated**	**Non Vegetated**	**Vegetated**
TDS	10.09^a	42.26^b	7.15^a	28.94^c
CND	16.44^a	42.51^b	8.55^a	33.64^c
SS	80.21^a	65.09^b	83.59^a	92.71^d
Colour	43.81^a	66.38^b	50.04^a	70.01^b
Turbidity	68.47^a	53.56^b	71.50^a	89.72^c
NH_3- N	86.55^a	70.15^b	60.25^c	88.22^d
NO_3^-	92.80^a	80.82^b	63.05^c	95.13^a
PO_4^{3-}	91.43^a	68.25^b	70.14^b	96.42^a
COD	32.12^a	71.63^b	77.62^c	89.29^d
BOD_5	70.61^a	78.23^b	68.71^a	71.38^d

Values followed by the same letter on the same row are not significantly different at $p<0.05$.

The reduction of nitrogen content in the wetland could be attributed to absorption by the plants and to microbial activity (Juren, 1999). At pH > 7 as recorded in both wetland configurations, volatilisation of ammonia does not extend 20% of NH_4-N reduction (Mars, 1999), so the significant difference in the removal of ammonia and nitrate recorded in the vegetated wetlands may have resulted from plant uptake. The superiority of the vegetated wetlands in the removal of nitrogen has also been observed by Gerberg *et al.,* (1986), Wathugala *et al.,* (1987), Breen, (1990), Roger *et al., (*1991) and Clarke and Baldwin (2001) in pilot scale investigations with macrophytes including *Scirpus latifolia, S tabernaemontani, Typha latifolia and Junceus effecus*. The rate of absorption of ammonia nitrogen by *C. papyrus* was estimated to about 1.11 $g/m^2/d$ in the HSSF and 2.0 $g/m^2/d$ in the HSF wetlands, while that of nitrate nitrogen was estimated to about 0.35 $g/m^2/d$ and 0.57 $g/m^2/d$ respectively. According to Lin *et al.* (2002), phosphorus removal in a wetland treatment system is solely based on sedimentation and plant uptake. The rate of removal of PO_4^{3-} by *C. papyrus* was estimated to about 0.2 $g/m^2/d$ in the HSSF system and 0.52 $g/m^2/d$ in the HSF system. Reduction of phosphate concentrations in the vegetated wetlands were significantly higher than those recorded in the non vegetated wetlands, and were significantly correlated with the growth and productivity of the plants in the different systems.

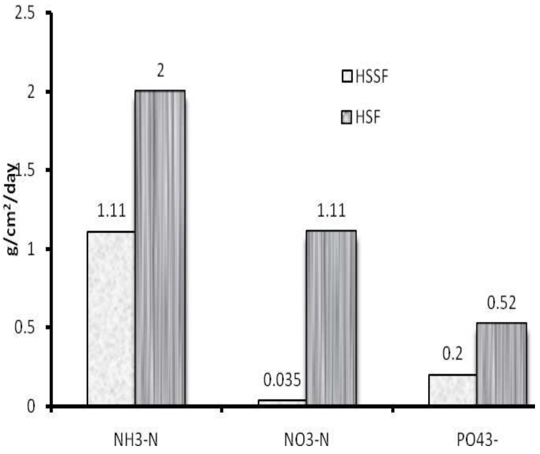

Figure e: Nutrient Absorption Rates ($g.m^{-2}.day^{-1}$) by *C. papyrus* in the Vegetated Beds

3.5 Removal of Faecal Coliforms and Faecal *Streptococci:*

The bacteriological characteristics of the domestic wastewater recorded in the outlets of the unplanted bed and the planted beds confirmed a dramatic decline of the faecal coliforms and the faecal streptococci colonies counts (Figure d). However, there was no significant difference in the rate of removal of the faecal coliforms and the faecal streptococci between the vegetated and the non vegetated wetlands. Nevertheless, the reduction of these faecal contamination indicators was significantly higher in the HSF than in the HSSF wetlands.

The reduction of bioindicators was attributed to the different physicochemical and biological mechanisms responsible for the elimination of bacteria (Martin and Bonnefont, 1986; Green *et al.,* 1996; Ottova *et al.,* 1996; Vymazal *et al.,* 1996) as well as high HRT and temperature (Reed *et al.*, 1988). These authors described the elimination of bacteria in a natural treatment system based on the reduction of organic charge in the water or through bacteria sedimentation in the case of fixation of bacteria on the substrate particles as well as photolysis and biological mortality (interspecific competition, bacteria lyses, predation and natural death).

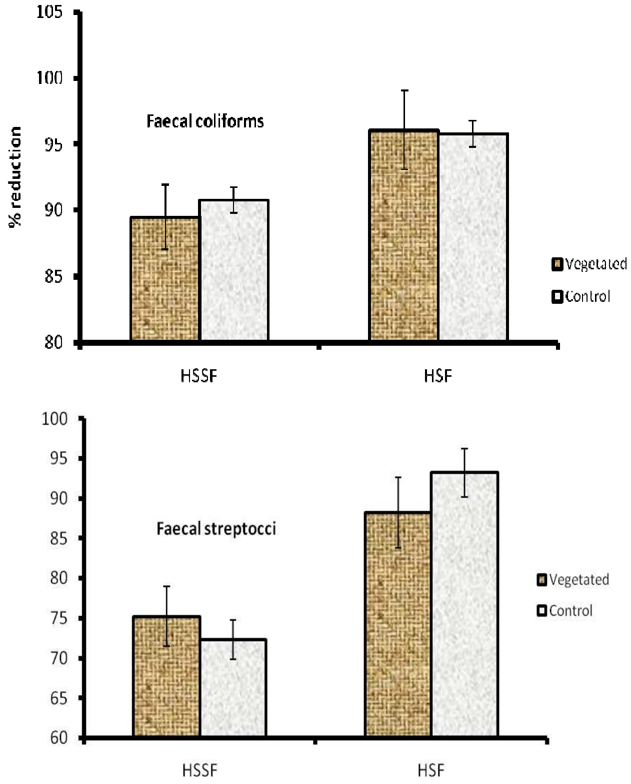

Figure d: Percentages Reduction of Feacal Coliforms and Faecal Streptococci Counts in the HSF and the HSSF Wetlands

4.0 Conclusions:

Vegetation of *Cyperus papyrus* in the wetlands significantly influences the rate of removal of nutrients in wastewater. The efficiency of this plant in the removal of pollutants showed that growth rate and productivity of the plant have little or no influence in the reduction of CND, TDS, Colour, Turbidity, SS, BOD_5, and COD in the HSSF and HSF systems. Progressive increase in the plant density, shoot length and stem diameter were observed. Above-ground and underground biomasses of 41 and 90 tonnes of dry weight/ha/year respectively were estimated. The reduction of several physicochemical parameters and that of faecal coliforms and faecal streptococci were not significantly different in the vegetated as compare to the non vegetated control wetlands in both system configurations studied. Nevertheless, the configuration of the system had a significant influence on the reduction of parameters like NO_3-N, NH_4-N and PO_4^{3-}-P which had higher percentages reduction in the HSSF than in the HSF. The chemical composition (nutrients and fibre contents) of the plant cultivated in the wetland need further investigations in order to assess the possibility of exploiting the biomass produced as fodder or in compost production.

5.0 Acknowledgment:

The authors thank the International Foundation for Science (IFS) for the financial support to the corresponding author through the grants N° W/3782-1 and N° W/3782-2

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