

Effectiveness of Floating Treatment Wetlands with *Cyperus papyrus* Used in Sub-Humid Climate to Treat Urban Wastewater: A Case Study

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ABSTRACT

The wastewater from small communities and rural areas, usually discharged in an unsuitable manner, requires an appropriate treatment. The floating treatment wetland has revealed a great potential due to good performance, low cost and low maintenance means of improving water quality over a broad range of applications. The aim of this article was to present the results of the adaptation period (57 days) of a macrophyte plant "*Cyperus papyrus*" and its potential for treating wastewater generated by the campus of the National Office of Electricity and Drinking Water (ONEE) of Rabat. Two hydraulic retention times were applied: 2 and 4 days. Pilot experimental setups (two tanks) were installed: one tank where the macrophyte, being the subject of the study, was installed and the other served as a control. The macrophyte plants were suspended in floating mat, keeping the plant roots permanently in contact with the water and removing pollutants via several processes. During the adaptation of the plant which concerned four parameters: the evolution of the density, the height of the stems, the number of shoots as well as the state of health of the plants, a period of adaptation to the medium of implantation of fifty-seven days was observed. Along this adaptation phase, the results showed that: plant density increased from 9 to 29 units; the heights of the four identified stems of *Cyperus papyrus* increased from 15, 6, 11 and 8 cm to 73, 43, 30 and 24 cm, respectively; the appearance of 72 shoots and the plant has completed the adaptation phase in good health (absence of disease Symptoms). The treated water obtained from outlet and wastewaters were analyzed for various water quality parameters, such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Suspended Solids (SS). The floating treatment wetlands system is able to remove 37.8% of COD; 47.6% of BOD₅ and 74.4% of SS for HRT of 2 days and 63.7% of COD; 78.4% of BOD₅ and 89.1% of SS for HRT of 4 days. Moreover, it was found that the purification efficiency in terms of these three pollution parameters is all the more important as the hydraulic retention time is high.

Keywords: phytoremediation, wastewater, floating treatment wetlands, *Cyperus Papyrus*, removal efficiency.

INTRODUCTION

In order to implement the solutions that take into account the diversity of different wastewater treatment technologies, researchers have turned to the treatment solutions that are simple and cheaper. Phytoremediation is one of these solutions used for the treatment of small communities that has shown a good efficiency in the

abatement of biodegradable organic pollution. Indeed, a purification efficiency of 80% in terms of BOD₅ has been reached in the case of a vertical filter planted with *Cyperus papyrus* with a low instantaneous hydraulic load [El Hafidi, 2021], which is easy to maintain and less expensive than a conventional septic tank. A recent variant of phytoremediation is floating treatment wetlands (FTWs). These are purification systems

that consist of emergent plants implanted in a floating mat, in which the aerial part (stems and leaves) is above the water as well as the root part sinks into the water column to absorb dissolved pollutants [Headley and Tanner, 2012]. FTWs, as a new type of constructed wetlands (CWs), are popular, innovative, and profitable because they are inexpensive and relatively easy to implement, due to the relatively low need for post-implementation management, with minimal operation and maintenance costs, tolerance of flooding surface water, and improvement of the aesthetic value of urban rivers [Headley and Tanner, 2012; Pavlineri et al., 2017; Wang et al., 2020a, 2020b; Afzal et al., 2019].

These systems present some advantages over subsurface CW, such as the absence of requirements for substrate materials (such as sand and gravel), which considerably reduces the construction costs and removes clogging risks because no substrate pores are present, also in addition to the larger and permanent contact area between roots and the water [Colares et al., 2020]. Besides urban wastewater, floating treatment wetlands systems can be used for several applications, such as treating industrial wastewaters [Tara et al., 2019]. This technology is considered a sustainable and environment-friendly alternative, as it can provide long-term remediation and pollutant degradation with minimal environmental intervention [Ijaz et al., 2015].

This paper presents the results of the adaptation phase of the *Cyperus papyrus* plant and its purification performance, in the context of the search for alternative solutions adapted to the Moroccan rural context and small communities.

MATERIALS AND METHODS

Site of the study

The experimentation took place in the training platform of the International Institute of Water and Sanitation of the National Office of Electricity and Drinking Water (ONEE)-Water Branch at the Bouregreg Complex in Rabat, which is located in the upstream of the Bouregreg valley and downstream of part the Sidi Mohamed Ben Abdallah, Northwest of Morocco (Figure 1).

Experimental setup

The plant subject of the study "*Cyperus papyrus*" was recovered from a vertical filter already installed at the same site in a previous study [El Hafidi, 2021]. *Cyperus papyrus* (CP), commonly known as papyrus or paper plant, is a plant in the Cyperaceae family. It has been harvested for a long time and has been used for millennia to make paper for the ancient Egyptians [Terer et al., 2012].

The experimental setup consists of two test tanks with a volume of one cubic meter (1m^3) each: One tank where the macrophytes, being the subject of the study, were planted (tank 1) and the other served as a control (tank 2). The two test tanks were covered by black plastic to avoid the phenomenon of photosynthesis (Figures 2 and 3). Macrophytic plants are suspended in a floating mat composed of a mesh (Figure 4) with plastic supports (Figure 5) allowing their buoyancy. Planting was done in mid-July with a density of 9 plants/ m^2 . The choice of *Cyperus papyrus* was based on its classification among the most



Figure 1. Installation site of the experimental device



Figure 2. *Cyperus papyrus* tank (tank 1)



Figure 3. Control tank (tank 2)



Figure 4. Floating carpet for hanging plants



Figure 5. Plant buoyancy support

common emergent macrophytes applied in FTWs [Colares et al., 2020].

Monitoring protocol for the adaptation period

Before the purification monitoring of the different plants in normal regime, these plants were monitored for a period of about two months. The objective was to test the adaptation of these plants to the new environment (Tank 1). To do this, observations and measurements were carried out regularly once a week in the tank (Tank 1). During each measurement campaign, a set of parameters were recorded (Table 1). Hereafter the table illustrating the various parameters of

follow-up. During the whole adaptation period, the *Cyperus papyrus* plant was watered to meet its requirements. The watering was done daily with a mixture of drinking water and wastewater during the 1st week and thereafter with wastewater only.

Weather data

The meteorological data recorded over the city of Rabat [www.Accuweather.com, 2021] during the adaptation period are presented as follows:

- A daily temperature that varies between 17.5 °C and 27 °C ;
- No rainfall was observed during the adaptation period.

Table 1. Monitoring parameters by organ during the adaptation period

Organ	Parameters
Stem	Density: number of stems Height: four plants of <i>Cyperus papyrus</i> were followed (plant n°1, n°2, n°3 and n°4) State of health: observation of symptoms (chlorosis, lodging, death, etc.)
Leaf	State of health: observation of symptoms (wilting, mottling, etc.).
Shoot	Appearance and growth. A shoot is considered as a plant when its stem exceeds 20 cm [R.Lombard et al., 2015].

Sampling and analysis

To control the efficiency of the phytoremediation of wastewater by the *Cyperus papyrus* plant, the FTW was subject to two measurement campaigns at a rate of 6 tests per campaign involving the measurement of 3 physicochemical parameters at the inlet and outlet of the system. The adapted operating mode is illustrated below:

- The hydraulic retention time (HRT) applied for the first campaign was 4 days and 2 days for the second campaign,
- After each test period, either 2 days or 4 days, samples were taken at the half-empty level, then the 2 tanks were completely emptied and filled to level with wastewater,
- The time needed to add water to the two installations was ± 40 min,
- The water level was measured at each sampling.

The measurement campaign of 4 days was conducted from 09/12/2021 to 28/01/2022 and the 2nd of 2 days from 02/02/2022 to 28/02/2022. The physicochemical parameters monitored are chemical oxygen demand (COD), biological oxygen demand for 5 days (BOD_5) and suspended solids (SS).



Figure 6. Density at the beginning of the experiment

RESULTS AND DISCUSSION

Plant density

When monitoring the development of the plant, no new plants of *Cyperus papyrus* were noticed during the first three weeks. Thereafter, the density increased very slowly over the next 15 days to reach 16 plants and 29 plants at the end of the adaptation period (Figures 6 and 7). The same result was observed at the level of the *Cyperus papyrus* plant planted in the natural soil used as a control during a study conducted under the same climatic conditions and the same site with a departure of 3 plants per m^2 over 45 days [El Hafidi et al., 2020]. Figure 8 illustrates the evolution of the density of the *Cyperus papyrus* plant.

Stem height

The heights of the identified stems followed a regular rhythm of development from the first week until the 5th week. Thereafter, these heights remained almost stable until the end of the adaptation period. Throughout the adaptation period, the heights of the identified stems of *Cyperus papyrus* increased from 15, 6, 11,



Figure 7. Density after 57 days

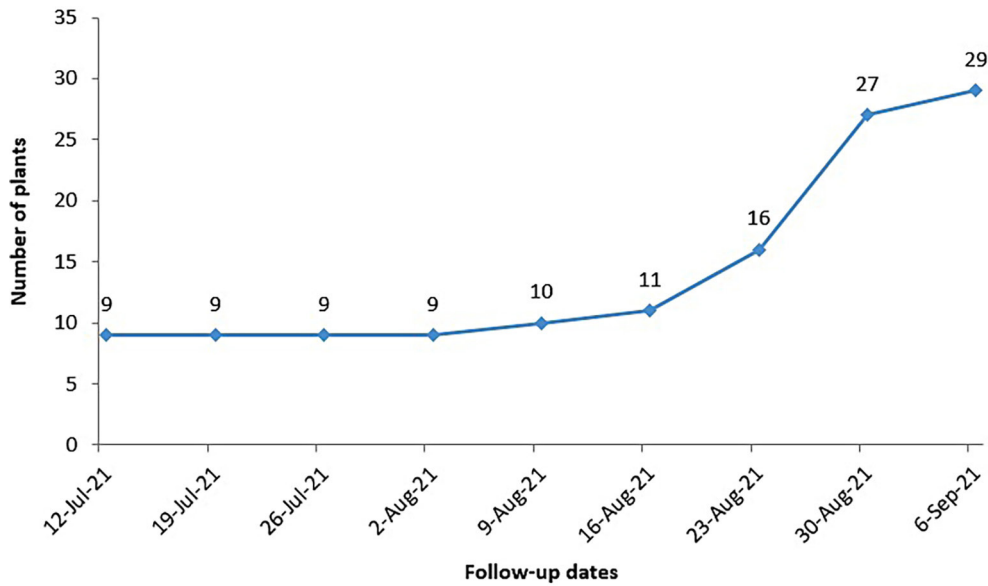


Figure 8. Plant density in number of plants

and 8 cm to 73, 43, 30, 24 cm at plant No. 1, plant No. 2, plant No. 3, and plant No. 4, respectively (Figure 9).

Shoots

After the first week of adaptation, the shoots appeared in a progressive way to reach 72 at the end of the adaptation period, which is 57 days (Figure 10). A release number of about 20 were found by [El Hafidi et al., 2020] over 45 days in a study of *Cyperus papyrus* in a vertical filter. Figure 11 shows the evolution of *Cyperus papyrus* releases as a function of adaptation time:

State of health

The different symptoms that appeared on the different organs of the plants during the monitoring of their health status in adaptation period are presented in Figure 12:

- A plant is considered vigorous when its tissues are bright green, it does not show wilting, lodging or any other symptom of suffering and new leaves or shoots appear [Lombard et al., 2015],
- A lightly affected plant is a plant with weak symptoms of photosynthetic apparatus damage: weak mottling, chlorosis and necrosis,
- A severely damaged plant is a plant with severe symptoms of damage to the photosynthetic

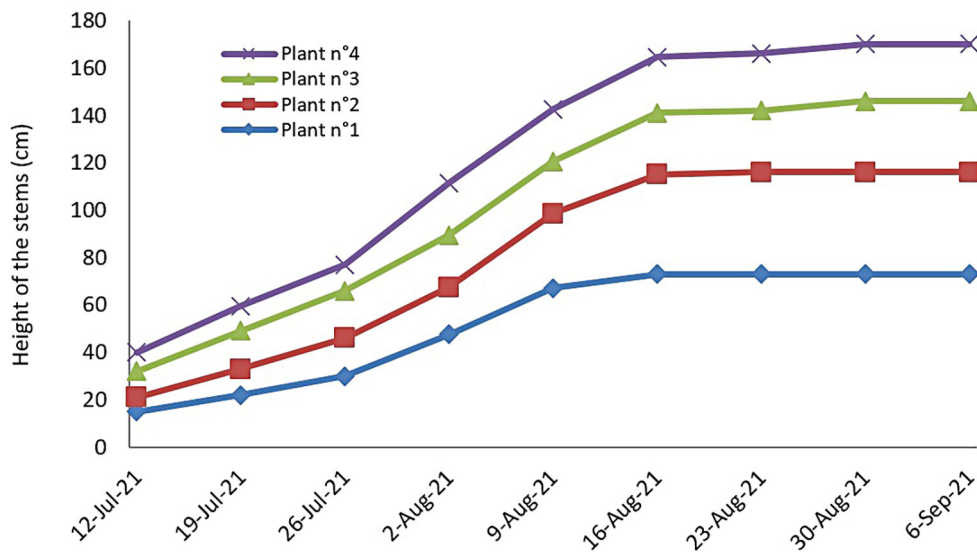


Figure 9. Stems height evolution of *Cyperus papyrus* plants (Tank 1)

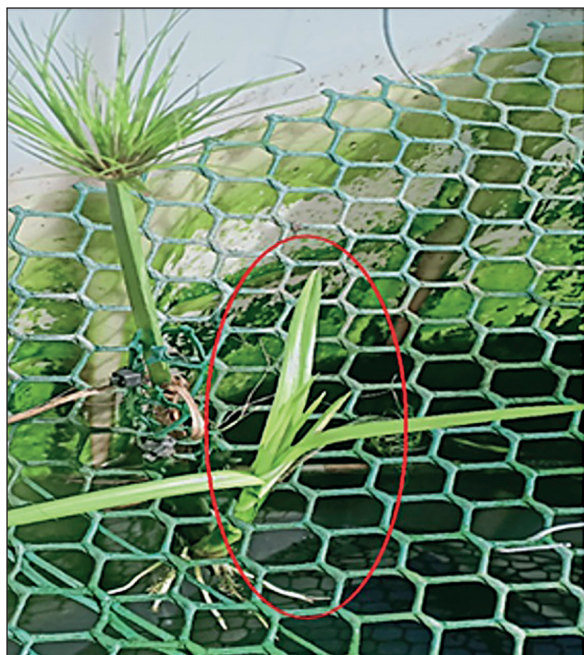


Figure 10. *Cyperus papyrus* shoot example in tank 1

apparatus: accentuated mottling, chlorosis, necrosis and even deaths.

Observations on organ color (stem and leaf) reflect the photosynthetic activity of the plant [Lombard et al., 2015]. From the beginning of

the 2nd week, the *Cyperus papyrus* plants were lightly affected by diseases such as mottling and chlorosis. They resumed their normal life by the end of the 2nd week of the 2nd month. Note that some plants were affected by severe chlorosis and necrosis and some even died during the 5th week of the adaptation period. The following figures illustrate an example of the health status of *Cyperus papyrus* (Figures 13 and 14).

Analysis of raw and treated wastewater

The wastewater feeding the test tanks came from the frame city located within the ONEE in Rabat (Morocco). The samples were taken at the inlet and outlet of each tank. The following table 2 and figures illustrate the results of the physic chemical parameters measured for different hydraulic retention times (HRT). The analysis of the raw wastewater shows that:

- The average COD varies from 234 to 319 mg of O₂/l,
- The average BOD₅ varies from 112 to 117 mg of O₂/l,
- The average SS varies between 67 and 101 mg/l.

These values are slightly lower than the usual range of Moroccan wastewater [ONEP-GTZ,

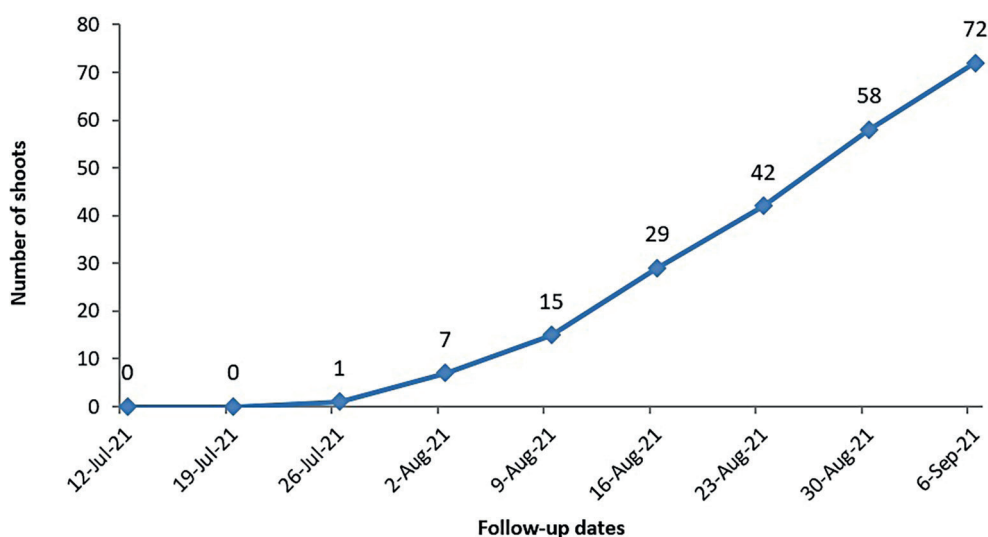


Figure 11. Evolution of the number of shoots

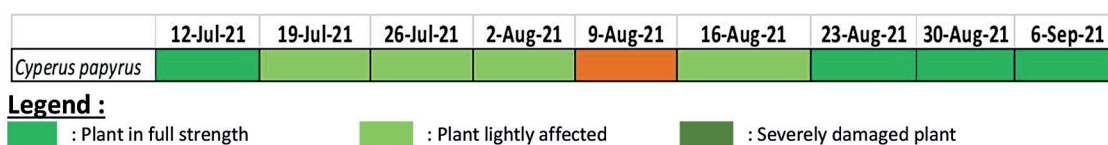


Figure 12. Observations synthesis of the plants health state



Figure 13. Plant with chlorosis (2 August 2021)



Figure 14. Dead plant (9 August 2021)

1998], due to the fact that they are diluted because of a pre-decantation before feeding the two tanks.

Phytoremediation of wastewater by *Cyperus papyrus*

The plant is studied for two different hydraulic retention times: 2 days and 4 days. The following figures show the results of the evolution of the concentrations of the different physicochemical parameters monitored.

COD removal

For the hydraulic retention time of 2 days, the COD content at the inlet varied from 226 to 444 mg O₂/L. This concentration was reduced after treatment by phytoremediation to a value that varied from 157 to 291 mg O₂/L with an average of 192

mg O₂/L. However, the COD content at the outlet of the control varied from 215 to 401 mg O₂/L with an average of 263 mg O₂/L (Figure 15). On the other hand, and for a hydraulic retention time of 4 days, the COD content at the inlet varied from 160 to 306 mg O₂/L. This concentration was reduced after the treatment with phytoremediation to a value that varied from 41 to 122 mg O₂/L with an average of 83 mg O₂/L, while the COD content at the outlet of the control varied from 93 to 220 mg O₂/L with an average of 158 mg O₂/L (Figure 16).

BOD₅ removal

For the hydraulic retention time of 2 days, the BOD₅ content at the inlet varied from 74 to 140 mg O₂/L with an average of 112 mg O₂/L. This concentration was reduced after the treatment with *Cyperus papyrus* to a value that varied from 42 to 97 mg

Table 2. Raw wastewater quality parameters

Tests	COD (mg O ₂ /l)		BOD ₅ (mg O ₂ /l)		SS (mg /l)	
	HRT=2 d	HRT=4 d	HRT=2 d	HRT=2 d	HRT=4 d	HRT=2 d
Test 1	335	203	105	126	114	135
Test 2	226	240	109	140	67	97
Test 3	276	160	113	71	70	36
Test 4	228	290	74	127	54	130
Test 5	444	207	131	130	60	106
Test 6	405	306	140	108	36	100
Average value	319	234	112	117	67	101

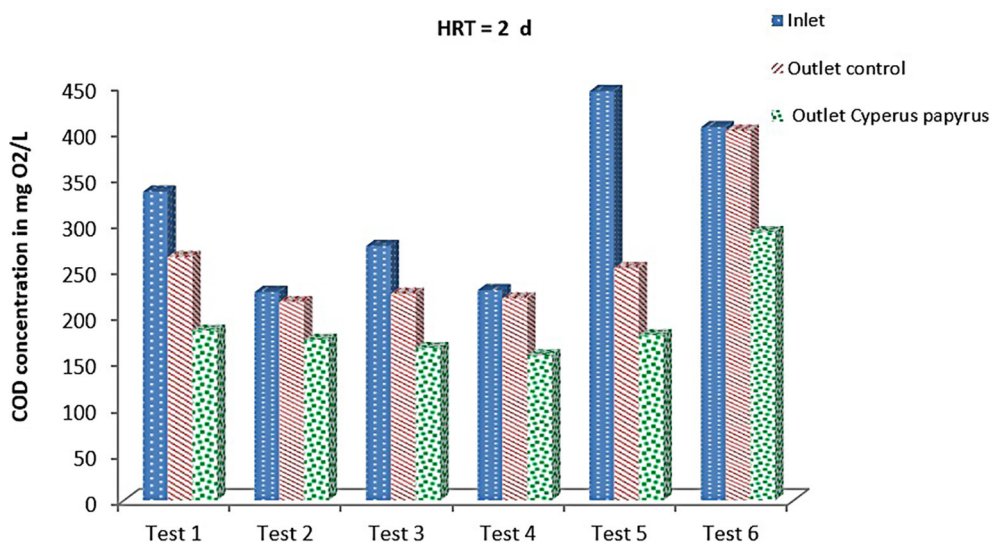


Figure 15. COD variation before and after treatment for HRT = 2 days

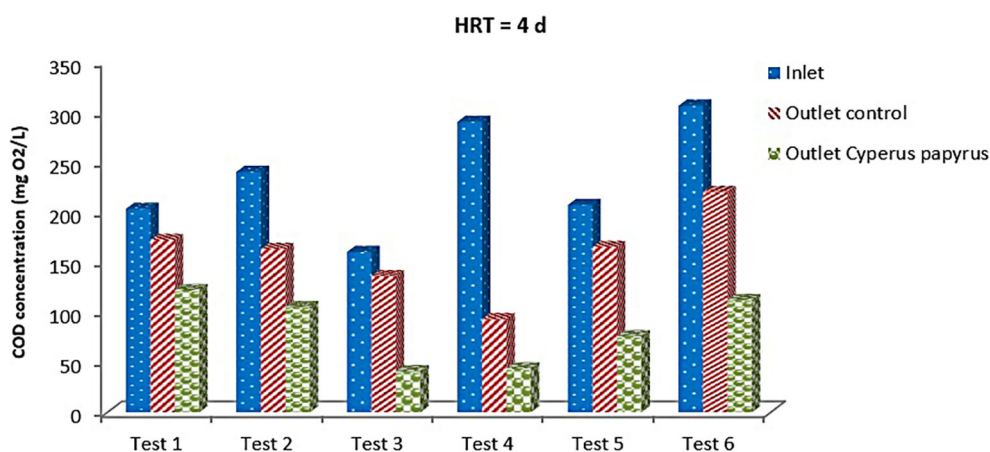


Figure 16. COD variation before and after treatment for HRT = 4 days

O₂/L with an average of 59 mg O₂/L; on the other hand, the BOD₅ at the outlet of the unplanted control varied from 59 to 134 mg O₂/L with an average of 94 mg O₂/L (Figure 17). In turn, for a retention time of 4 days, the BOD₅ content at the inlet varied from 71 to 140 mg O₂/L with an average of 117 mg O₂/L. This concentration was reduced after the treatment with *Cyperus papyrus* to a value that varied from 9 to 53 mg O₂/L with an average of 26 mg O₂/L; on the other hand, the BOD₅ at the outlet of the unplanted control varied from 33 to 85 mg O₂/L with an average of 61 mg O₂/L (Figure 18).

SS removal

In turn, suspended solids are mostly inorganic particles that are larger than 2 μm, but can also be of organic nature (i.e. algae, bacteria). As inorganic particles have no nutritional value for organisms,

they are not directly taken up by plants or biofilm. However, suspended solids can be effectively removed from the water column by sedimentation.

The results in Figure 19 show that for a HRT of 2 days: the SS concentration at the inlet varied from 36 to 114 mg/L with an average of 67 mg/L. After the treatment with *Cyperus papyrus*, this concentration decreased to a value between 5.5 and 26 mg/L with an average of 20 mg/L. For the unplanted control, this concentration ranged from 29 to 62 mg/L with an average of 43 mg/L (Figure 20). Suspended solids are effectively removed by sedimentation and filtering within the rhizosphere [Ran Bi et al., 2019]. Moreover, for a retention time of 4 days: the SS content at the inlet varied from 36 to 135 mg/L with an average of 101 mg/L. This concentration was reduced after the treatment by the studied plant to a value

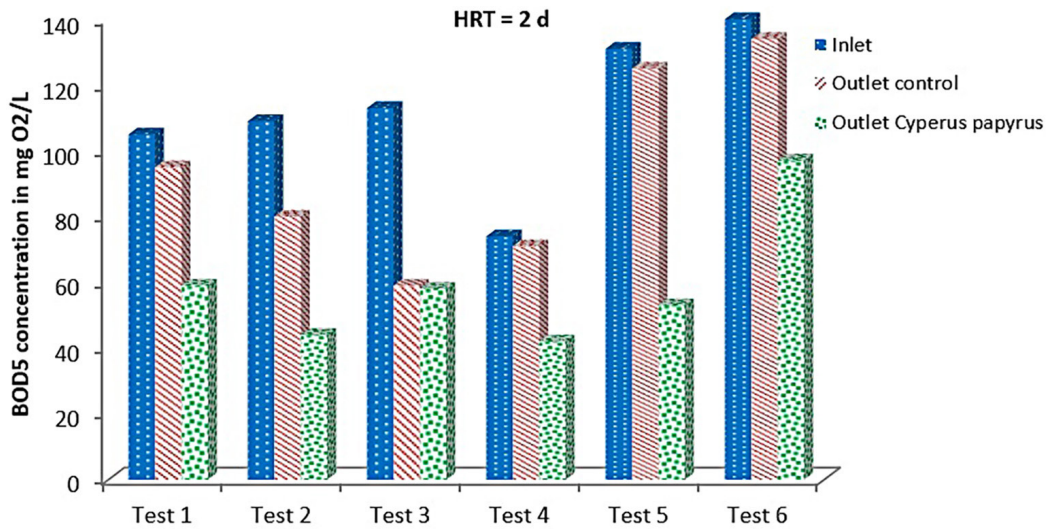


Figure 17. BOD₅ variation before and after treatment for HRT = 2 days

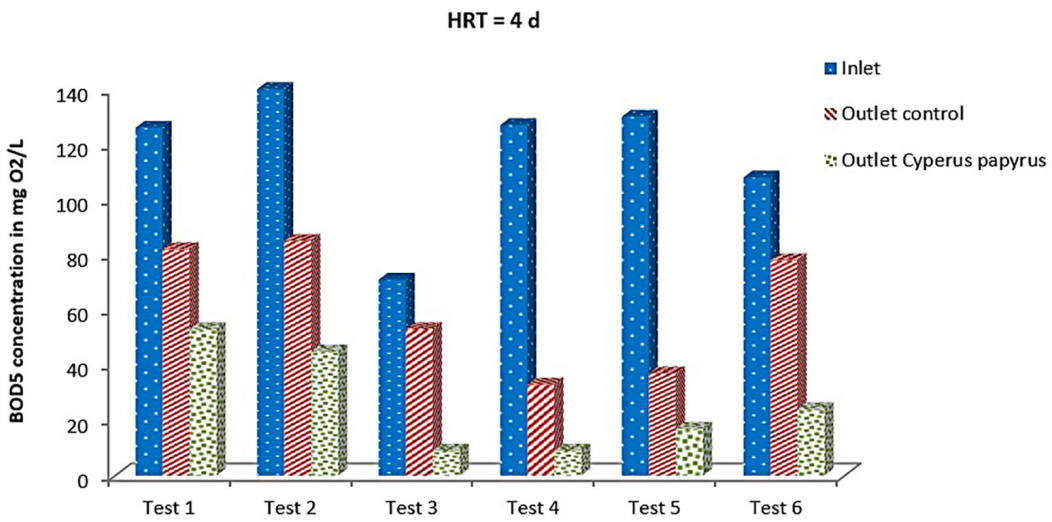


Figure 18. BOD₅ variation before and after treatment for HRT = 4 days

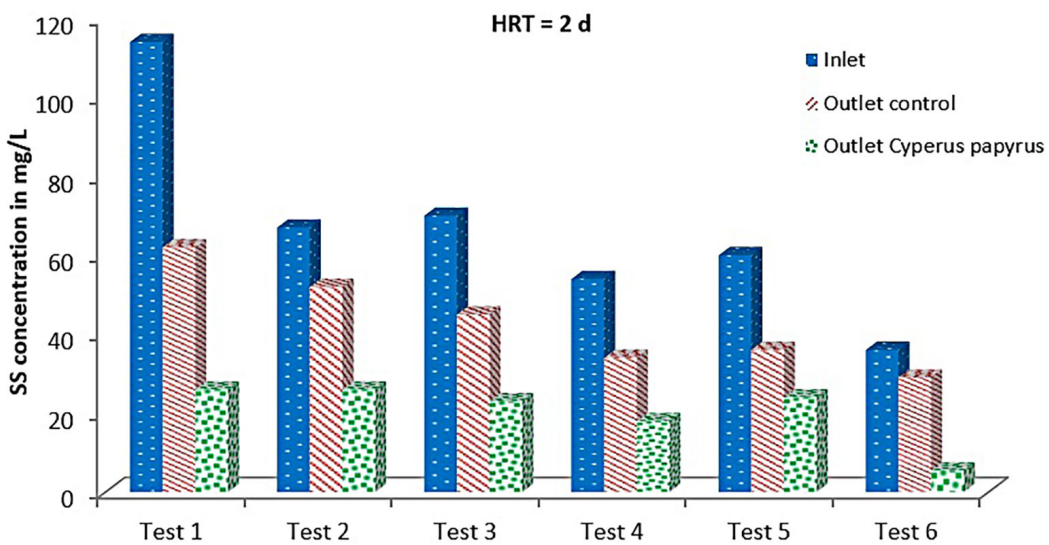


Figure 19. SS variation before and after treatment for HRT = 2 days

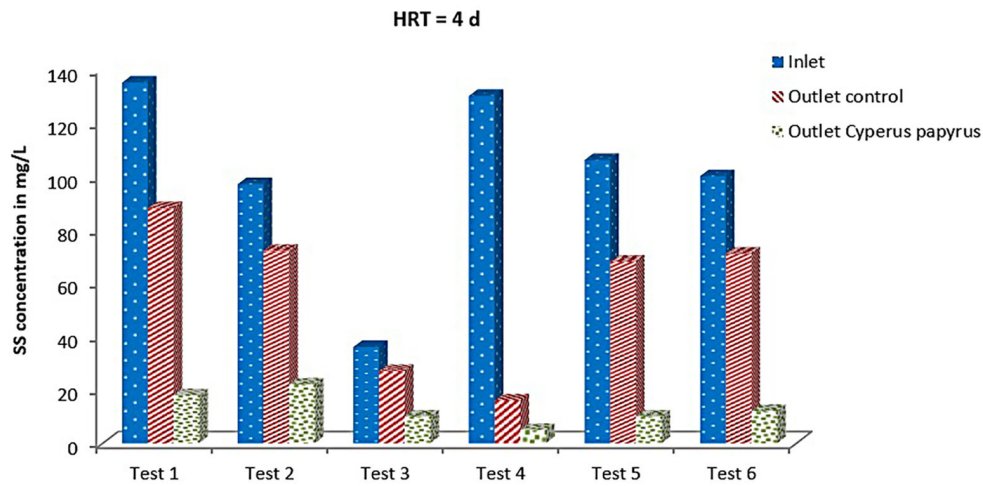


Figure 20. SS variation before and after treatment for HRT = 4 days

of 5 to 22 mg/L with an average of 13 mg/L; on the other hand, the SS value at the outlet of the unplanted control varied from 16 to 88 mg/L with an average of 57 mg/L (Figure 20).

Removal efficiency

The removal efficiency is determined as follows:

$$\text{Removal efficiency (\%)} = \frac{(C_{\text{Inlet}} - C_{\text{Outlet}})}{C_{\text{Inlet}}} \times 100 \quad (1)$$

where: C Inlet = Concentration of the parameter considered for raw wastewater; C Outlet = Concentration of the parameter considered after purification.

The following figure (Figure 21) shows the removal efficiency for each parameter measured as a function of hydraulic retention time.

According to the Figure 21, the removal efficiency of the two tanks: *Cyperus papyrus* tank

and control tank in terms of COD, BOD₅ and SS are, respectively:

For HRT = 2 days:

- *Cyperus papyrus*: 37.8%, 47.6% and 74.4%;
- Control: 15.4%, 16.1% and 40.8%.

For HRT = 4 days:

- *Cyperus papyrus*: 63.7, 78.4% and 89.1%;
- Control: 29.8%, 45.4% and 40.4%.

According to the global analysis of the results obtained after purification by the *Cyperus papyrus* plant, it was found that almost all the concentrations of the three monitored parameters (COD, BOD₅ and SS) for the different retention times are strictly lower than the specific limit values of domestic discharge required by the Moroccan legislation (COD = 250 mg of O₂/L; BOD₅ = 120 mg of O₂/L, and SS = 150 mg/L) [Bulletin officiel des rejets domestiques Marocain, 2006].

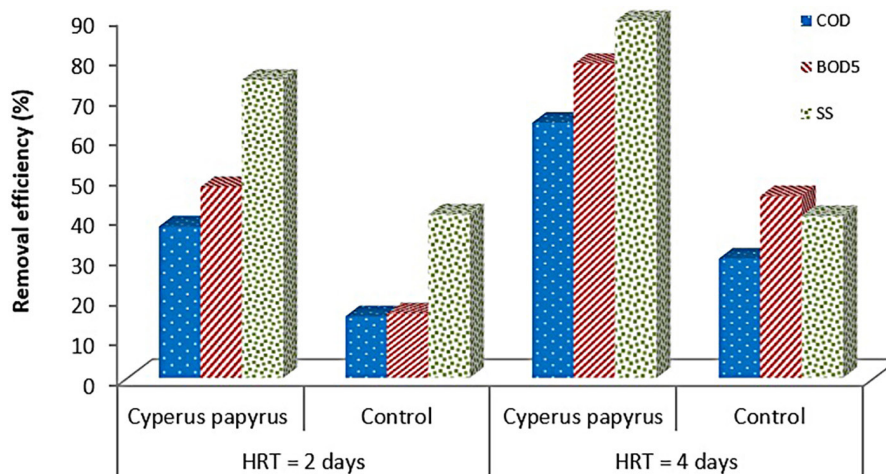


Figure 21. Percent removal of each parameter as a function of hydraulic retention time

The results obtained, compared with the unplanted control, show that *Cyperus papyrus* used as an emergent macrophyte plays an important role in the treatment of domestic wastewater. Indeed, its presence promotes the removal of organic matter COD and BOD₅ [Njenga et al., 2015].

It was also concluded that the hydraulic retention time promotes the increase in the purification efficiency of wastewater. The higher this time is, the more efficient the yield is. In general, COD and BOD removal has a positive correlation with hydraulic retention time [Chen et al., 2016].

CONCLUSIONS

The present study on the purification of domestic wastewater by the emerging macrophyte “*Cyperus papyrus*” is part of the search for rustic and less expensive solutions for the purification of domestic wastewater in small communities and in rural areas. The experimental follow-up of the adaptation period of the aforementioned plant excluding the problems encountered during the first weeks shows that the density of the plants increased from 9 to 29 units. The heights of the four identified stems of *Cyperus papyrus* increased from 15, 6, 11 and 8 cm to 73, 43, 30 and 24 cm, respectively. The appearance of 72 shoots was observed. The plant finished the adaptation phase in good health, despite the appearance of some symptoms of damage such as chlorosis, mottling, and necrosis.

During the last week of adaptation, it was noted that all the *Cyperus papyrus* plants flowered. The monitoring of the purification performances of the phytoremediation by the emergent plant “*Cyperus papyrus*” proves to be important in domestic wastewater treatment. Indeed, the removal efficiency in terms of COD, BOD₅ and SS are respectively: for the hydraulic retention time of 2 days: 37.8%; 47.6% and 74.4%; for the hydraulic retention time of 4 days: 63.7%; 78.4% and 89.1%. Moreover, it was found that the purification efficiency in terms of these three pollution parameters is more important, as the hydraulic retention time is high.

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