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Phytoremediation: Synergistic Effect of Thalia *geniculata* and *Crassipes Eichhornia* (Water Hyacinth) During Domestic Wastewater Treatment

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Abstract: The treatment of wastewater and removal of pollutants before discharge into natural water reserves, remain a major concern of the 21th century. Many of treatment techniques based on phytoremediation present limits regarding the treatment efficiency. In order to improve the efficiency of nutrients abatement in gray water, the synergy between *Thalia geniculata* and *Crassipes Eichhornia* (water hyacinth) was studied. Three treatments: *Thalia geniculata* (TG), water hyacinth (JE) and the combination of the two [*Thalia geniculata* and water hyacinth, (TJ)] in three different basins have been setup for the treatment of domestic wastewater. The water physicochemical parameters and nutrients concentrations were determined during the treatment process. After twelve days of treatment, results revealed a remarkable reduction of pollutants (NO_3^-, NTK and PO_4^{3-}) in the basins TG and JE, with removal efficiencies of (68.62%, 55.71%, 23.55%) and (53.98%; 39.52%; 89.27%), respectively. As for the treatment combining the two species (TJ), the yield of pollutants abatement was 97.75% for NO_3^-, 82.83% for NTK and 24.84% for PO_4^{3-}. An excellent treatment performance of the basin TJ was noticed regarding nitrogen removal against phosphate (PO_4^{3-}) which was poorly removed. Accordingly, the results indicated an interesting synergistic effect between TG and JE; with the dominance of the TG tendency to remove nutrient (NO_3^-) from wastewater. The observed synergistic effect of *Thalia geniculata* and water hyacinth could be effective and promising for the sequestration of nitrogen in domestic wastewater within a couple of days. However, further studies are still needed to better understand the mechanism governing the removal of nitrogen to the detriment of phosphate when combining the two species.

Keywords: Phytoremediation, Domestic Wastewater, Synergy Effect, Pollutants, *Thalia geniculata*, *Eichhornia Crassipes*

1. Introduction

Phytoremediation is a technique of rehabilitation, remediation, decontamination and restoration of environment (soil, air and waste water) [1]. The increase of produced wastewater due to urbanization poses environmental pollution, groundwater contamination and health problems [2-5]. Groundwater is an important source of water supply in Africa and particularly in Cotonou town (Republic of Benin). The latter is polluted due to poor maintenance and weak drainage of wastewater [6-8]. To remediate this major challenge, number of techniques including: filtering, application, flotation, flocculation, coagulation, electrocautery, trickling, bios filters, constructed wetlands, lagoons, phytoremediation etc. for wastewater treatment have been developed [9, 10]. For better treatment efficiency, the authors explored several macrophytes (reeds, popular hybrid, iris, reeds, marshes, water hyacinth, duckweed, water lettuce etc.) with various purification yields [11-15]. Clogging related deficiencies of the system and phosphorus release were reported [16]. To remedy this issue, filters planted on gravel and sand beds have been associated with bacterial beds and physicochemical treatments [10, 17, 18]. Despite the variation of residence time (3-12 days) depending on the authors [19, 20], the removal of pollutants is not satisfactory. The efficiency of *Eichhornia Crassipes* and *Thalia geniculata* in the reduction of pollutants has been proven by several authors [21-25]. Both macrophytes are effective in reducing one of orthophosphate ions and the other in nitrate reduction, both ions are a great responsibility in the phenomenon of eutrophication of water reserves and surfaces water [26]. This study aims to investigate the possible combination of the macrophytes to improve nutrients removal efficiency from domestic wastewater and study their synergetic effect.

2. Materials and Methods

2.1. Materials

Two species of plants: *Thalia geniculata* and *Eichhornia Crassipes* were used in this study. The plants were collected in a water body located in Fifadji and Hêvié (South Benin). The wastewater was collected from a wastewater collector in Agla area located in the 13th district of Cotonou town (Department of Littoral) (Fig. 1). The water collector, during the dry season particularly receives gray water (washing, laundry, shower, and water valves etc. The basins used for the experiments are of a planting density equal to 50 plants/m². To achieve our goal four basins including one control and three equipped with a macrophytes have been designed as shown in figures below (Fig. 2).

Fig. 1. *(a) Gray wastewater collector in Agla (South Benin) (b) Samples of gray wastewater.*

Fig. 2. *(a) Basin control EB (b) Basin with Thalia geniculata TG (c) Basin Water Hyacinth JE (d) Basin with both Thalia geniculata and Water Hyacinth (TJ).*

2.2. Analytical Methods

2.2.1. Physicochemical Parameters

The physicochemical parameters of wastewater including temperature (T), electrical conductivity (χ), total dissolved solids (TDS) were measured using a multi parameter of type Combo Hanna waterproof according to NF EN 27888 (January 1994). The pH was measured with a pH meter type Mettler Toledo with a probe LE 409 (NFT 90-008) and color (col) by APHA Platinum-Cobalt method. Turbidity (Turb) and redox potential (EH) were respectively determined with a colorimeter DR/890 and the meter type WTW pH/EH 340i following the mitigation of radiation and potentiometric method (NF EN 27888). The dissolved oxygen (O_2 Dissolved) is measured with a WTW type pH / O_2 Innolab 740i according to French standard (NF EN 25814).

2.2.2. Pollution Parameters

Suspended solids (SS) were determined by the colorimetric method as recommended by the French standard (NF EN 872, January 1997). The readings were made with a colorimeter of type HACH DR/ 890. Orthophosphate (PO_4^{3-}) are determined by a colorimetric measurement of phosphomolybdic complex formed; using a spectrophotometer molecular absorption type DR/2800 according to the AFNOR standard (AFNOR T90-023). Total Kjeldahl Nitrogen (TKN) is dosed by AFNOR method NFT90-110. This method consists into the mineralization of organic nitrogen into ammonia nitrogen by sulfuric acid followed by the dosage of the obtained ammonium by acidimetric; after distillation with a (Buchi kjeldahl Auto K370). Nitrate (NO_3^-) was determined by colorimetric method via diazotization according to French standard NF EN ISO 13395 (1994) using a spectrophotometer HACH DR / 800 after reduction by passing through a cadmium column.

3. Results and Discussion

3.1. Suspended Solids (SS)

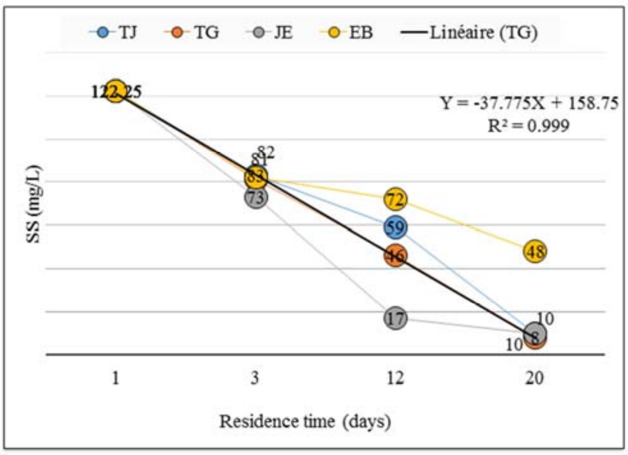


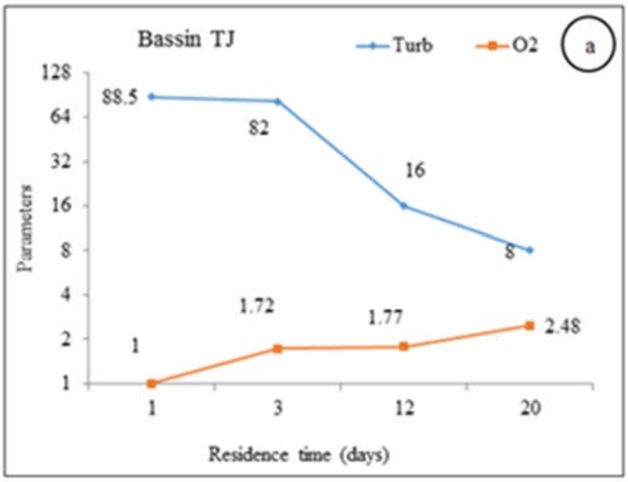
Fig. 3. *Profile of suspended solids over time in the basins.*

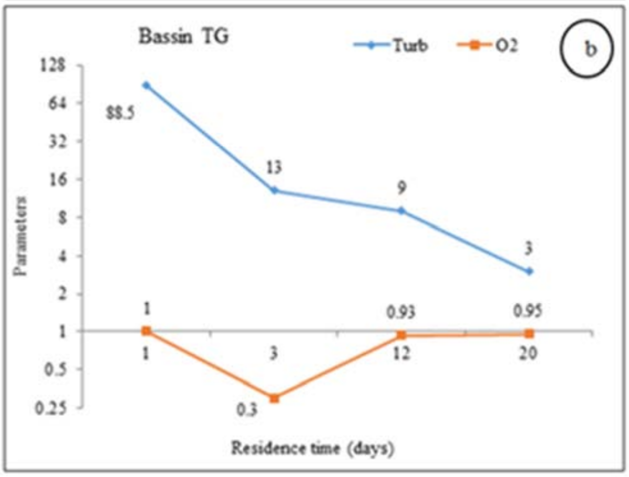
Suspended solids content in each basin during the treatment was helpful for the appreciation of the quality of greywater and the systems efficiency over time. Fig. 4 shows the SS profile in each basin over time.

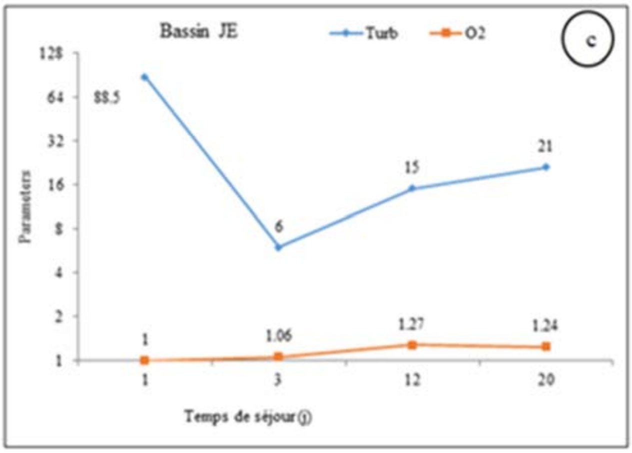
Suspended solids in the wastewater was evaluated at 122.25 mg/L at the beginning. This value dropped continuously to around 8-10 mg/L the 20th day in all basins. The maximum abatement yields were: TG (93.45%), TJ (91.82%) and JE (91.82%). It is important to note that already after 3 days of treatment, SS diminished to around 70 and 80 mg/L. This corresponds to the time of adaptation of gray water microorganisms to treatment medium [12, 22]. On the 12th day, the basin (JE) containing water hyacinth macrophytes, abate two time fold SS that the basin (TG) containing macrophyte *Thalia geniculata* and three times fold the basin (TJ) containing both species (water hyacinth and *Thalia geniculata*). In addition, the basin (JE) reduced SS in short time; TJ and TG basins reduced SS following almost the same trend. As for the basin TG, SS abatement over the residence time followed a linear function according to the equation $Y = -37.77X + 158.7$. It is remarkable that after 12 days of treatment the rate of reduction of SS is estimated at 51.73% in the basin TJ compared to 86.09% and 62.37% in the JE and TG, respectively. After 20 days residence time, TSS were highly eliminated in all basins. It shows that the synergistic effect regarding the elimination of SS is negative for a shorter residence time (12 days) and positive for a relatively long residence time (20 days) [16]. A comparison between the profile of SS abatement curves shows that the settling of the raw wastewater doesn't eliminate properly SS.

3.2. Turbidity (TDS) and Dissolved Oxygen (DO)

Figure 4 shows the profile of turbidity and dissolved oxygen in each treatment. From the Fig. 4a and b, considerable decrease in the turbidity in the basins TG and TJ over time could be noticed; while the dissolved oxygen increased. Compared with basins (TG and JE), the reduction of turbidity remained low during the first 12 days in the basin TJ. This confirms the above statement regarding the abatement of SS. The diminution of turbidity and increase the oxygen content in the control (basin EB) is low compared to other basins (TJ, TG and JE). Fig. 4a, b and c, also shows a significant decrease of turbidity and a remarkable increase of dissolved oxygen content during the treatment. This confirms the hypothesis that macrophytes produce in their rhizomes, dissolved oxygen, which facilitates the degradation of organic materials [27, 28]. Our results are in agreement with those of [22, 29] who found that after treatment, the obtained water was rich in dissolved oxygen. Furthermore, in Figure 4, we can deduce that the treated waste water by macrophyte water hyacinth (JE) is turbid after a long residence time. It is thus important to be kept in mind that water hyacinth will not be effective for long-term treatment. Similarly, the sedimentation of the wastewater (basin EB), is not effective for removing the turbidity of the grey water. As for treatment TJ and TG, they considerably reduced the grey water turbidity, resulting in an increase in dissolved oxygen content. The removal rate of turbidity achieved at the end of treatment was 90.96% in TG and 96.61% in TJ. These yields are better compared to that reported (72%) by [30] and comparable to that obtained (95%) by [31]. The sharp increase in the dissolved oxygen content of treated water in the basin TJ reveals a probable synergistic effect between the two species (water hyacinth and *Thalia geniculata*).







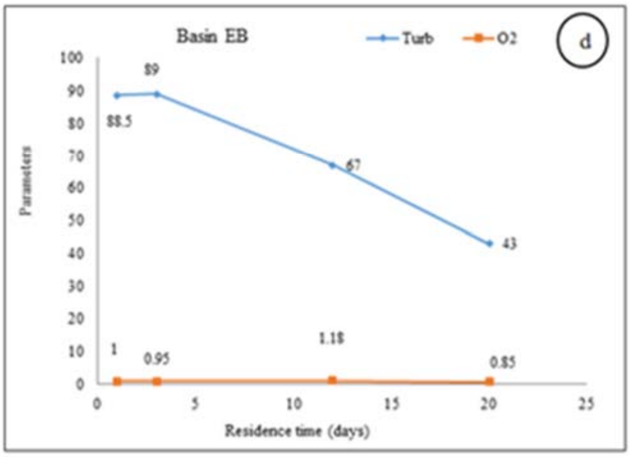


Fig. 4. Profile of the turbidity (NTU) and dissolved O_2 (mg/L) in (a) Basin with both Thalia geniculata and Water Hyacinth (TJ), (b) Basin with Thalia geniculata TG (c) Basin Water Hyacinth JE, (d) Basin control EB.

3.3. Others Physicochemical Parameters

Measurement of total dissolved solids (TDS), color, electrical conductivity, pH and temperature of the wastewater and treated water are shown in Table 1 below. Data show that on the 12th day, the basin TG owns the highest removal of the conductivity (95.54%) followed by the basins TJ (76.6%) and JE (93.76%). The basins TJ and JE successfully reduced color up to 91.75% and 85.5%, respectively compared to 81.96%. Regarding TDS 81% was removed in TJ, 84.31% in TG and 87.59% in JE. The purification yields on the day 12 were higher compared to those obtained on the 20th day in TG (Cond: 8.3%) and in JE (TDS: 55.03%); but relatively lower than those achieved in the basin TJ (Color: 96 94%; Cond: 92.37%; TDS: 93.38%). To be noticed the basins TG and JE effectively abated physicochemical parameters in a short time while their combination reduced it a longer time. This may be justified by the fact that rhizomes of two macrophytes absorb more pollutants from water depending on the residence time [32]. This phenomenon, could be highlighted when compared the yields in TJ with those obtained in the basin control (EB) (Color: 91.75%; Cond: 54.73%; TDS: 67.76%). The reveals good yield achieved by the later. It confirms our observation and proves that the rhizomes are sites for the development of microorganisms responsible for the degradation of organic matter [33]. Macrophytes JE and TG therefore contribute to better mineralization gray water pollutants through rhizomes microorganisms [13, 21, 22]. Their association would be interesting for removing pollutants and charged particles from the wastewater. The basin EB has good yields for color with respect to residence time (20 days). The settling of wastewater in aerated basins is not effective for a short residence time[1]. It can be stated that settling much more efficient in removing color and the achieved yield in our study was beyond that achieved by [31] which is equal to

1http://epnac.irstea.fr/wp-content/uploads/2012/08/exploitation-des-stations-d%C3%A9puration.pdf

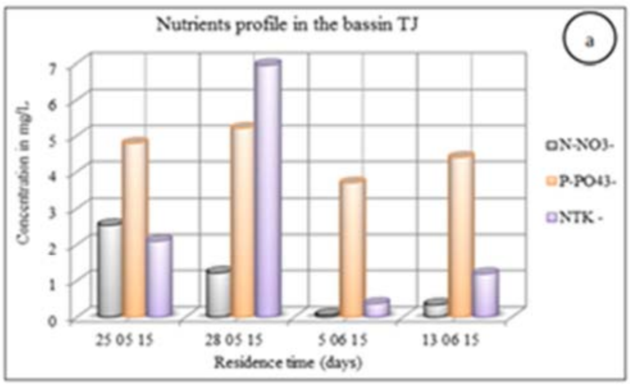
69.74%. The temperature uniformly varied around 28.3°C and 28.7°C in all the basins. This appears to be a good climatic condition for growth of microorganisms responsible of the degradation of pollutants in the wastewater [12]. The water pH varied from the low alkaline pH to the low acidity in the basins TJ and TG, from low alkalinity to a neutral pH in JE. It remained constant around neutrality in the control basin EB. The decrease in pH may be due to the different reactions that transforms organic nitrogen into ammonium environment [28].

Table 1. *Physicochemical parameters of the treated grey water by macrophytes.*

			PARAMETERS			
BASINS	**Residence time (days)**	**T (°C)**	**pH**	**TDS (mg/L)**	**Cond (µS/cm)**	**Color (uca)**
	25/05/2015	28.4	7.72	242	393,25	655.25
	28/05/2015	28.7	8.37	129	481	138
TJ	05/06/2015	28.5	6.43	46	92	54
	13/06/2015	28.4	6.85	16	30	20
Yield (%)	12th day	-0.28	16.70	80.99	76.60	91.75
	20th day	0.07	11.26	93.38	92.37	96.94
	25/05/2015	28.4	8.39	153	539	122
	28/05/2015	28.5	7.52	26	53	71
TG	05/06/2015	28.3	7.06	24	24	22
	13/06/2015	28.5	7.86	192	494	152
Yield (%)	12th day	0.35	15,85	84.31	95.54	81.96
	20th day	-0.35	6.317	-25.49	8.34	-24.59
	25/05/2015	28.7	8.37	129	481	138
JE	28/05/2015	28.5	6.43	46	92	54
	05/06/2015	28.4	6.85	16	30	20
	13/06/2015	28.3	6.91	58	115	28
Yield (%)	12th day	1.04	18.16	87.59	93.76	85.50
	20th day	1.39	17.44	55.03	76.09	79.71
	23/05/2015	28.42	7.72	242	393.25	655.25
EB	28/05/2015	28.4	7.97	163	423	123
	05/06/2015	28.5	7.11	136	272	95
	13/06/2015	28.4	6.89	78	178	54
Yield (%)	12th day	-0.28	7.90	43.80	30.83	85.50
	20th day	0.07	10.75	67.76	54.73	91.75

3.4. Nutrient Removal (PO_4^{3-}, NO_3^- and NTK)

The concentrations PO_4^{3-}, NO_3^- and NTK were monitored during the treatment and the results are reported in the histogram of Fig. 5. From the histograms it sorts out that nutrients were reduced from 2.54 to 0.06 mg/L for nitrate and from 2.1 to 0.31 mg/L for NTK when combine *Thalia geniculata* and water hyacinth (Fig. 5a). When using *Thalia geniculata* separately, the concentration dropped from 2.54 to 0.8 mg/L for nitrate (NO_3^-) and 2.1 to 0.93 mg/L for NTK (Fig. 5b); while the concentration decreased from 2.54 to 1.17 mg/L for nitrates and then 2.1 to 1.27 mg/L for NTK when water hyacinth is used (Fig. 5c). These yields correspond to the purifying efficiencies of 97.64% (NO_3^-) and 82.38% (NTK) in the basin TJ; 68.53% (NO_3^-) and 55.71% (NTK) in the basin TG. In the basin JE, the corresponding yields were evaluated at 53.98% (NO_3^-) and 39.52% (NTK). An effective removal of nutrient could be noted with the combination of both *Thalia geniculata* and water hyacinth. A synergistic effect of the two species regarding nitrate removal (basin TJ) could also be noticed. These treatment yields were in agreement with those obtained by [34] (93% NO_3^-) in Britain; and higher than that reported by [19] (46% for NTK). The performance was comparable to that observed by Gourdon [10] (97.2% NTK). In general, orthophosphates were weakly reduced in the basin TJ (22.92%) and TG (23.95%) but were highly eliminated by the water hyacinth (basin JE). This highlighted the significant synergistic effects above-mentioned with respect to the removal of nitrate ions. Furthermore, it was found that the water hyacinth better removed orthophosphates compared to *Thalia geniculata* which better remove nitrate ions [22]. Otherwise, results suggest when combined *Thalia geniculata* and water hyacinth, there is selection of pollutant to remove; with the predominance of the tendency of *Thalia geniculate* to remove NO_3^-.



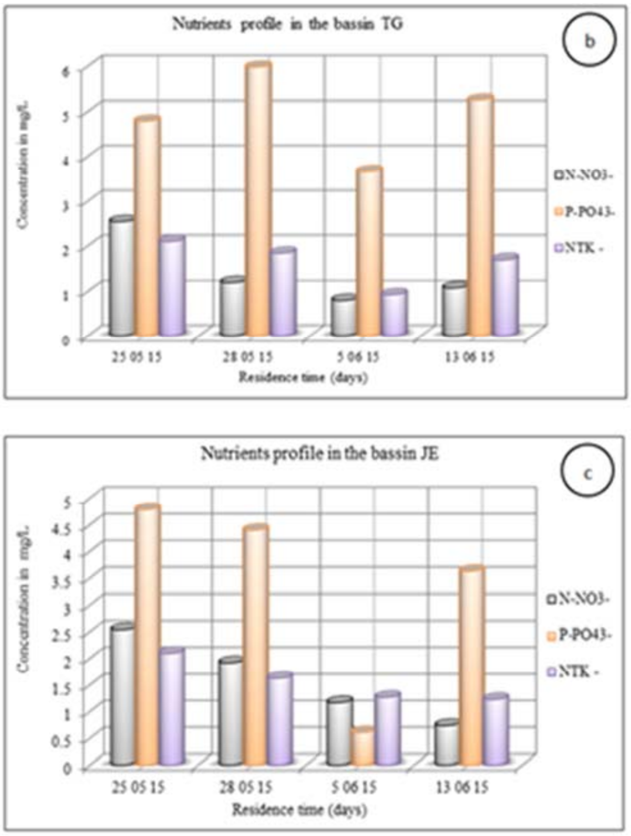


Fig. 5. *Change in nitrate, orthophosphate and in Kjeldahl nitrogen (mg/L) in the (a) Basin with both Thalia geniculata and Water Hyacinth (TJ), (b) Basin with Thalia geniculata TG (c) Basin Water Hyacinth JE.*

Figure 6 shows the removal efficiency of nutrients in the control basin EB. From the histograms, it can clearly bee seen that was negative or poor nutrients removal. Indeed, NTK was removed all through the process; in fact it concentration increased in the medium as the yield achieved were -25%, -5% and -25% respectively on the 3rd, 12th and 20th. Regarding orthophosphates, -5%, 23% and 2% were achieved on the 3rd, 12th and 20th, respectively. This variation of orthophosphate and total Kjeldahl concentration during the treatment is linked to the microbial activities; the increase of orthophosphate and total Kjeldahl nitrogen concentration in the medium on the 3rd day; would be the consequence of the mineralization of nitrogen and phosphorus compounds [35]. The diminution of phosphorus concentration and positive removal yield on the 12th day, is due to the strict aerobic bacteria that absorb P liquid form due to the aerobic aspect of the environment. At the end of the experiment, strict aerobic bacteria reject phosphorus in solid form, due to the decrease in dissolved oxygen content and the anaerobic environment. Similar remark has been previously made during a study carried in Grenoble in 2006[2]. This would justify the low phosphorus removal in the 20th day. Similarly, the improvement of NTK removal on the day 12 compared to day 3, might be the consequence of the denitrification reactions that reduced nitrate content. The contact of sludge with the water in the basin EB at the end of the experiment, would be responsible for the increase of ammoniacal nitrogen, hence that of the total Kjeldahl nitrogen into the basin. This finding was confirmed that of Deronzier [28]. A comparison of results in Fig. 5a, 5b, 5c with those in the Fig. 6 revealed that decantation/settling hardly acts on nutrients. We deduce that aquatic plants play an important role in reducing nutrients from gray water.

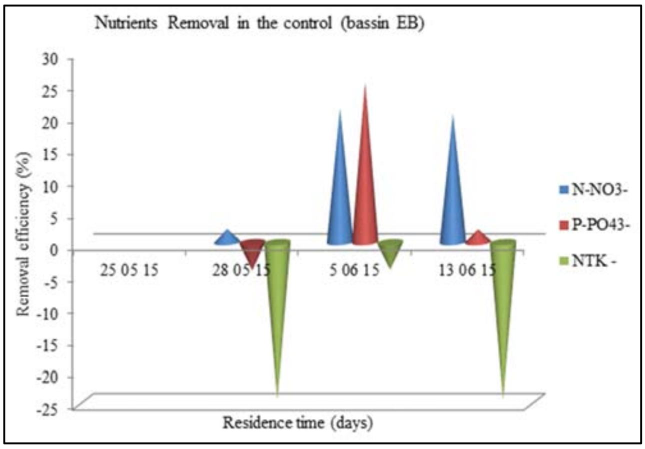


Fig. 6. *Treatment yields of nitrate, orthophosphate and Kjeldahl nitrogen (mg/L) of EB basin.*

4. Conclusion

Synergistic effect of *Thalia geniculate* and water hyacinth during phyto-treatment of domestic wastewater was investigated. Results showed that the basin (TJ) containing the combination of *Thalia geniculata* and water hyacinth provides a better clarification of gray water. This basin had achieved between 12th and 20th day, the yields up to SS (91.82%), turbidity (90.96%), color (96.94%), conductivity (92.37%), TDS (93.38%), nitrates (97.64%), total nitrogen kjeldahl (82.38%) and ortho phosphate (22.92%). The basin TG containing *Thalia geniculata* achievement regarding PO_4^{3-} and SS yields [PO_4^{3-} (23.55%) and SS (93.45%)] were close to those of the basin TJ. Otherwise, results an improvement of nitrate removal when the two species were combined from the treatment of wastewater. This clearly shown the synergistic effect of *Thalia geniculate* and water hyacinth tin he basin TJ. The combination of two macrophytes also facilitated physicochemical parameters of domestic wastewater.

Acknowledgments

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2https://.www.ac-grenoble.fr/disciplines/sti-biotechnologies/articles.php?lng=fr&pg=107

Conflict of Interest

Authors declare no conflict of interest.

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