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# Influence of pH on Water Hyacinth Ponds Treating and Recycling Wastewater

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## Abstract

This work has examined the effects of pH on the treatment efficiency and biomass production rate of water hyacinth ponds (WHP) treating domestic wastewater. Experiments were carried out outdoor in WHP, working under batch and subtropical environmental conditions, using pre-treated sewage with pH varying from 5 to 9. It was observed that the plants regulated the pH of the medium to within 6.4 to 7.1 during the treatment processes independently of influent wastewater pH ranges. This adjustment reduced the treatment performances and the biomass production in ponds, the alkaline conditions in ponds being less favorable to the activities of the plants. The optimal removal and biomass production was achieved with influent pH of 7 lying in the above interval. So the optimum influent pH for the growth of plants and the removal of nutrients and organic matters in WHP is within pH 6.4 to pH 7.1.

## Keywords

Sewage, Treatment, Biomass Production, Water Hyacinth, pH

## 1. Introduction

Water hyacinth (WH), *Eichhornia crassipes* (*Martius*) *Solms-Laubach*, is an erect, stoloniferous, free-floating, perennial and vascular aquatic weed with elongated petioles (5 cm of diameter; 30 to 50 cm of length, but can reach up to 1.5 m) [1] [2]. In the absence of its original suite of natural, enemies, and usually in nutrient-enriched waters, *E. crassipes* populations increase rapidly, doubling under suitable conditions every 6 to 18 days [3]. Due to their vigorous productivity and their ability to reproduce successfully in new nutrient-enriched habitats make

WH a good candidate for wastewater purification and nutrient recycling [4] [5] [6] [7]. Water hyacinth ponds (WHP) have been proved to be efficient in improving effluent quality from oxidation ponds and as a main component of an integrated advanced system for treatment of municipal, agricultural and industrial wastewaters [5] [6] [8] [9]. However, as for all biochemical processes, the potential of hydrogen (pH) could be a limiting factor to this ability of WH to treat wastewater and produce biomass [10].

pH is an important environmental parameter in wastewater treatment. Water pH affects many biochemical processes involved in macrophyte growth and metabolism, including the bioavailability of carbon dioxide for photosynthesis and the availability and absorption of nutrient ions. The pH can affect the availability of essential minerals (phosphate, iron, molybdenum, zinc, manganese) or the solubility of toxic substances [10]. Low pH increases the risk of the presence of metals (copper, for example) in a more toxic ion form. High pH increases the concentrations of toxic ammonia [11] [12].

WH is reported to tolerate pH ranging between 4 and 10. However, several studies have shown that pH can significantly inhibit WH growth, as for several aquatic plants [1] [2] [13] [14]. Similarly, Azov and Goldman [15] have reported that high pH level is detrimental to WH growth due to deficiencies in nitrogen stripping [15].

However, the direct influence of pH on the wastewater purification performance of WH has not been investigated. Most research works on the effect of pH on WH have focused mainly on the determination of the limit pH after which plants cannot growth.

The present research focused on determining the relationship between pH and the performance of WHP for domestic wastewater treatment and nutrient recycling. The objectives of present research are to study the effects of acidic, neutral and basic ranges of pH on WH biomass production and performance in WHP for wastewater treatment in a batch flow condition in order to determine the optimum range of pH for efficient treatment and biomass production.

## 2. Materials and Methods

The study is conducted on the University Campus of Abomey-Calavi, located in Abomey-Calavi, a city of southern Benin. Benin is a tropical country of West Africa, located near the equator and between the parallels 6˚30' and 12˚30' of latitude and 1˚ and 3˚40' of longitude. The average temperature varied between 23˚C and 32˚C with an annual average sunshine period of 2290 hours, an average annual rainfall recorded of 1308 mm and an average evaporation of 7200 mm/day for the southern part [16] [17].

The experiment was carried out with mini-ponds consisting of plastic containers of 52.0 cm of length, 42.5 cm of width and 35.5 cm depth, filled with 50 l of anaerobically treated wastewater from university halls. The characteristics of the raw wastewater and anaerobic pond effluent are shown in **Table 1**.

**Table 1.** Raw wastewater and anaerobic pond effluent.

| *Parameters* | *Unit* | *Raw sewage* | *Anaerobic pond Effluent* | *Removal rate %* |
|---|---|---|---|---|
| Temperature | ˚C | 26.8 ± 0.1 | 28.3 ± 0.1 | |
| pH | | 6.47 ± 0.01 | 6.773 ± 0.001 | |
| $e_H$ | | 24.1 ± 0.8 | 6.5 ± 0.1 | |
| $r_H$ | | 13.75 ± 0.05 | 13.16 ± 0.03 | |
| $\chi$ | µS/cm | 745 ± 5 | 108 ± 2 | |
| Turbidity | NTU | 150.7 ± 1.5 | 72.5 ± 1.3 | 52% |
| COD | mg/l | 516.9 ± 25 | 175.4 ± 7.0 | 66% |
| $BOD_5$ | mg/l | 218 ± 35 | 101 ± 2 | 54% |
| MES | mg/l | 160 ± 2 | 75 ± 0.5 | 53% |
| NTK | mg/l | 20.86 ± 0.50 | 15.7 ± 0.3 | 25% |
| $N\text{-}NO_3^-$ | mg/l | 1.56 ± 0.01 | 1.1 ± 0.0 | 29% |
| $N\text{-}NO_2^-$ | mg/l | 0.00 ± 0.00 | 0.22 ± 0.00 | |
| $P\text{-}PO_4^{3-}$ | mg/l | 26.6 ± 0.5 | 5.55 ± 0.10 | 79% |
| Faecal Coliforms | /100ml | 1.05E+05 ± 465 | 1.57E+04 ± 165 | 85% |

Five (05) mini ponds MP (with 2 duplicate for each which made in total 15) containing anaerobically treated wastewater at different pH varying from 5 to 9 were used. These pH were chosen to comply with the pH range for the survival of WH [1]. The ponds occupied a total surface area of about 4 $m^2$; the small surface covered reduced the environmental heterogeneities in the ponds. The cultures were started with six (06) WH healthy plants.

In previous studies on the effect of the pH on other plants species, researchers used strong acid such as $HNO_3$, $H_2SO_4$ or HCl and strong acid such as KOH or NaOH to adjust the initial pH of the culture medium [10] [18] [19] [20]. The initial pH of the effluent from the anaerobic pond used in this study was 6.8.

To obtain the desired pH, the effluent from the anaerobic pond was spiked with sulphuric acid ($H_2SO_4$) or sodium hydroxide (NaOH) depending on the pH level to be achieved.

The WH clones used were collected on Lake Nokoue located in southern Benin. They were then grown for several months in a pond on the University Campus of Abomey-Calavi. Healthy plants of similar size, shape and height were washed several times using tap water. Six of these plants were chosen and were introduced directly into the experimental pond without further acclimatisation. The behaviour of the plants depends on their immediate previous history [21]. To avoid systematic errors related to the use of populations of different histories, the experiments for each study were carried out simultaneously in parallel in different mini-ponds under the same conditions with plants from the same source.

The total experimental period was twenty-one (21) days. The MP were operated under batch flow and natural tropical environmental conditions. The influent medium used was not replaced during the whole experimental period. The plants were left to grow in the ponds for the retention time or until complete wilting, if it occurred before the end of this experimental period.

The number of plants was counted in each MP at the beginning, the seventh, the fourteenth and the twenty-first day. Samples were taken on the same days for the measurement of total suspended solids (TSS), the chemical oxygen demand (COD), the biochemical oxygen demand measured after five-day at 20˚C ($BOD_5$), the total nitrogen (TN), orthophosphates and Total Nitrogen Kjeldahl (TNK). The environmental parameters such as temperature, turbidity and pH were measured on daily basis. The plant fresh weight (FW) and the faecal coliforms content of the medium were measured at the beginning and the end of the experiment. The fresh weight was measured by removing the excess water by placing and rolling the plants cautiously between absorbent paper tissues and by weighing the biomass immediately after that. Knowing the biomass weight, the plant relative growth rate (RGR) was calculated by equations below [10] [22] [23]:

$$\text{RGR} = \left[\ln\left(m_f / m_i\right)\right] / t \tag{1}$$

where $m_i$ and $m_f$ are respectively the initial and the final wet weight of plants at the start and the end of the experimental period and t is the number of days between two weighings.

The significance of the relation between the pH, growth rate and removal performances of the WH was studied by means of statistical analysis using p-values by correlation matrix.

## 3. Results and Discussions

### 3.1. Evolution of the Environment Parameters

The temperature conditions in the different WHP are presented in **Figure 1**. The water temperature varied between 24.9˚C and 27.3˚C in all the ponds with an average temperature of 25.9 ± 0.6 throughout the experimental period.

The water temperature showed reasonably low variation and stayed within the optimum temperature range (22˚C to 30˚C) for WH growth [14]. The pattern of temperature changes was almost the same in all ponds. The changes in temperature did not depend on the initial pH of the pond but were related to the weather conditions.

The initial turbidity of 72.5 ± 1.3 NTU dropped progressively from the first day to the eighth day where it reached average values of 2.5 ± 1.3 NTU (**Figure 2**). This was due to the rapid settling of suspended solids. From the eighth day, the turbidity value passed from an average of 3.81 NTU to 23.36 NTU in the ponds with pH 9, and remained around this value till the end of the experiment. This increase in turbidity can mainly be explained by the growth of algae

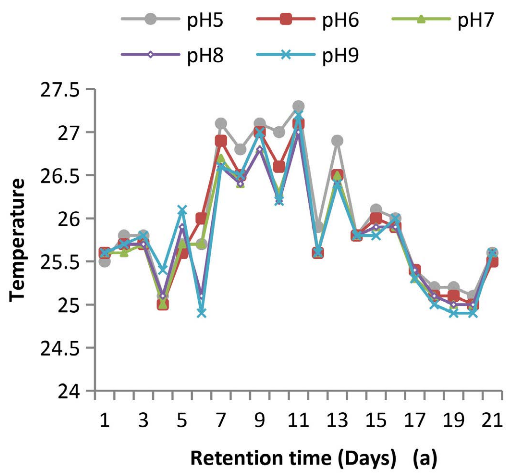


**Figure 1.** Evolution of temperature in ponds.

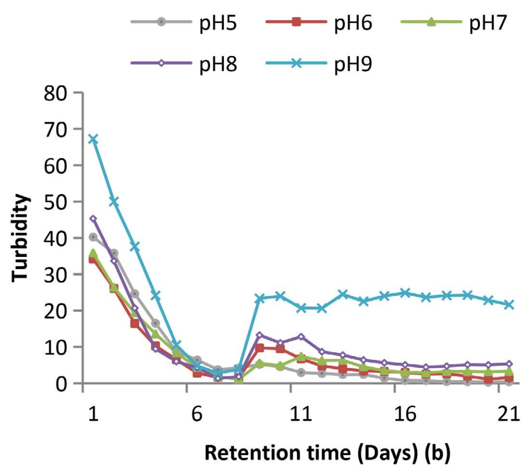


**Figure 2.** Evolution of the turbidity in ponds.

biomass in ponds with pH 9, which remained in ponds till the end of experiment due to the low growth rate of WH observed.

## 3.2. Evolution of the Potential of Hydrogen (pH)

The evolution of pH in ponds was highly related to the influent pH (**Figure 3**).

In ponds with acidic initial pH, the daily recorded pH values increased rapidly the first days of the experiment. From the fifth day, the values continued increasing, but slowly, to reach an average pH of 6.44 in both ponds with initial pH of 5 and 6.

In contrast, in ponds with pH 8 and pH 9, the pH dropped, following almost the reverse trend compared to that of acidic influent water. At the end of the 21 days retention time, the average pH values recorded were 6.98 and 7.08 respectively in ponds with initial alkaline pH 8 and pH 9.

In ponds with pH 7, a decrease in pH values was observed but it was not pronounced. The pH passed from 7 to an average value of 6.75 at the end of the experiment.

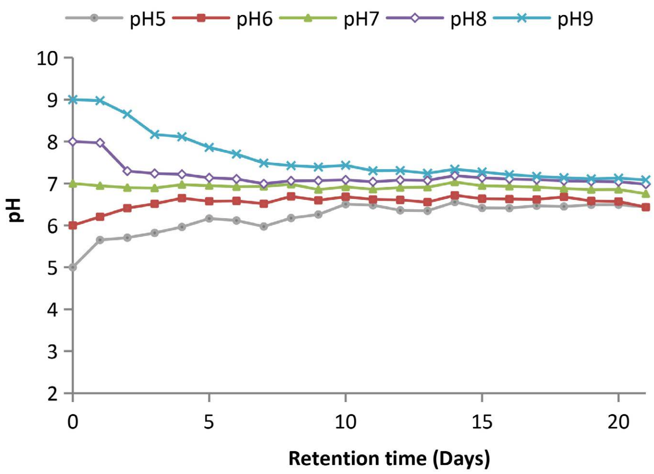


**Figure 3.** Evolution of pH in ponds.

It has been observed that all the pH values converged toward pH values in the range of 6.4 and 7.1. WH seemed to find this range of pH values optimal for their growth. This range is closer to optimum range for WH growth observed in previous studies. In fact, Balasooriya *et al.* [24] has reported, by studying WH growing in different water streams polluted by certain industrial effluents water, that optimum hyacinth growth occurred at pH within 6.0 and 7.0. Delgado *et al.* [25], meanwhile, found this optimum growth occurring between pH ranges of 6.7 to 7.3 with an experiment carried out in a greenhouse at a temperature between 28˚C and 30˚C using slurry containing pig manure as the nutrient source.

It has been observed here that when the influent pH is not within the optimal range for the plants' growth, but within the levels of pH 4 to pH 10 which they can tolerate for their survival as stated by Center *et al.* [1], WH seems to have the ability to adjust the medium pH, whether initially acidic, neutral or alkaline, to their requirement.

This adjustment can be associated with the changes in carbon-equilibrium states [26].

It is known, the carbonate ions ( $CO_3^{2-}$ ) and the bicarbonate ions ( $HCO_3^-$ ) act as the primary buffer for most natural waters. Reactions that produce or consume carbon dioxide ($CO_2$) may alter the pH temporarily until equilibrium with the atmospheric $CO_2$ is re-established (Gilmour, 1992). The drop in pH under alkaline conditions could then be due to the inability of WH to use up all the $CO_2$ produced during respiration. Then, the $CO_2$ passes into the culturing medium through plant roots. On the other hand, under acidic conditions, WH consumed the $CO_2$ at higher rate than it was produced by respiration. This will result in the dissociation of carbonate and bicarbonate ions by the reaction in Equation (2):

$$\begin{aligned} &CO_2 + 2H_2O \leftrightharpoons HCO_3^- + OH^- \\ &2HCO_3^- \leftrightharpoons CO_3^{2-} + H_2O + CO_2 \\ &CO_3^{2-} + H_2O \rightleftharpoons 2OH^- + CO_2 \end{aligned} \quad (2)$$

Water hyacinth will fix the molecules of $CO_2$ formed, whilst the hydroxide ions ($OH^-$) produced are used to increase the pH as alkaline conditions are created in algae ponds [27] [28].

### 3.3. pH and Treatment Performance

According to **Figure 4(a)** and **Figure 4(b)** and the p-value analysis, COD and $BOD_5$ removal in WHP were highly related to influent pH ($p < 0.02$) even though the cumulative removal rate followed almost the same trend in all ponds. The changes, with regard to initial water pH, showed that the removal of carbon pollution from alkaline water became more and more difficult for WH with an increase in influent water alkalinity. An increase in the influent pH led to a decrease in carbon pollution removal performance. The same trend was observed when influent pH was becoming more acidic. However, WH had better performances in carbon pollution removal in acidic water than alkaline water.

In fact, with an influent pH 5, the overall removal of COD was 30.1 g/m$^2$ while 18.3 g/m$^2$ was registered with a pH 9. The influent water with a neutral pH showed the best removal performance.

From **Figure 4(a)** and **Figure 4(b)**, the carbon pollution removal was not significantly related to the retention time ($p > 0.3$). By looking at **Figure 4(a)** and **Figure 4(b)**, with regard to the retention time, it can be observed that the major part of the organic matter was removed within the first seven days. Indeed, the average influent COD of 175.4 mg/l was reduced after seven days retention, to values ranging from 35 mg/l to 102 mg/l at a removal rates of 17 g/m$^2$ to 32 g/m$^2$.

The highest COD removal within these seven days was achieved in ponds with pH 7 and this reduction represented 96% of the total COD removed during the experimental period. Thus, only an average of 6 mg/l of COD has been removed from the ponds with pH 7 from the seventh to the twenty-first day bringing down the COD to 29 mg/l at the end of the period of experiment. Similarly, the best removal of BOD was achieved with ponds with pH 7 and the major part has been removed within the first seven days. An average BOD of 20.4 g/m$^2$ was removed in these ponds within seven days with a total removal of 21.0 g/m$^2$ at the end of the 21 days of retention. The lower removal of 18.3 g/m$^2$ was observed in ponds with pH 9 at the end of the experimental period.

The high removal observed here within the first seven days is to the fact that the major part of the organic loads are removed in WHP within seven days retention time; therefore there is no need for ponds to have longer retention, the optimal retention time for carbon pollution removal is seven days. Increasing retention time added very little to efficiency with regard to the organic load removal. It may be worthwhile to have two ponds with retention time of about seven days than to have a pond with higher retention time.

The total suspended solids (TSS) removal rate was optimum in ponds with influent pH 7, even though the overall removal of TSS at the end the experimental period was higher in ponds with pH 8 (**Figure 4(c)**). After seven days retention,

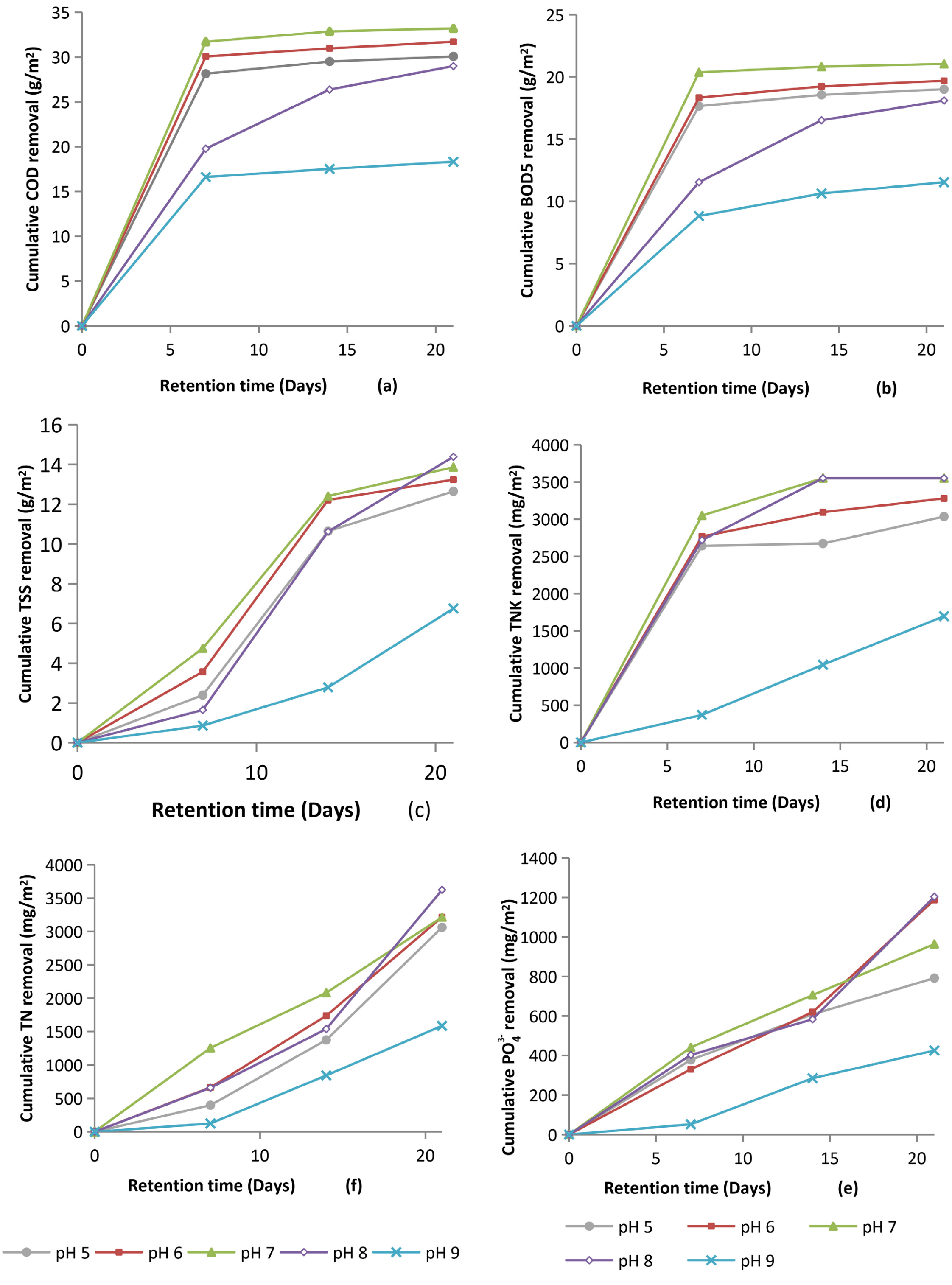


**Figure 4.** Performance changes of water hyacinth with influent at different pH.

the highest reduction in TSS of 4.8 $g/m^2$ was observed in ponds with pH 7. This rate changed to 12.4 $g/m^2$ on the fourteenth day and then 13.9 $g/m^2$ at the end of the experiment. The highest reduction in TSS in ponds with pH 8 was observed between the fourteenth and the twenty-first day for those ponds.

Figure 4(d) and Figure 4(e) show the TNK and TN cumulative removal in ponds at different pH as function of retention time. Apart from the ponds with influent pH 9, the major part of TNK was removed within seven days retention time.

The maximum removal of 3050 mg/m$^2$ achieved within this period was at pH 7, which also had the highest overall removal of 3552 mg/m$^2$ at the end of the experiment. The lowest removal rate of 1697 mg/m$^2$ at the end of the experimental period was observed in ponds with influent pH 9. The removal of TNK seemed to not be significantly ($p > 0.25$) related to the retention time (Table 2), even though the trend of the cumulative removal in ponds with pH 9 seems to be time dependent (Figure 4(d)). TNK cumulative removal rate was used to measure the nitrification rate. The nitrification rate correlated with the carbon pollutant removal rate ($p < 0.0001$) but the correlation with the influent pH seemed not very significant ($p > 0.058$). The low effect of pH on nitrification rate may be due to the rapid adjustment of the medium pH by water hyacinth to values close to optimum pH range for nitrification, 7 to 8 [29].

Analysis of the trends of the curves of Figure 4(e) showed that the optimum TN cumulative removal was achieved in ponds with pH 7, even though the ponds with pH 8 showed the highest overall removal of 3623 mg/m$^2$ at the end of the period of the experiment. In fact, in pH 7 the removal rate was progressive with average values of 1256 mg/m$^2$, 2083 mg/m$^2$ and 3214 mg/m$^2$, the 7$^{th}$, 14$^{th}$, and 21$^{st}$ day, respectively. In pH 8, a sudden increase of the TN removal rate from 1539 mg/m$^2$, the 14$^{th}$ day to 3623 mg/m$^2$ at the end of the experiment was observed. This change may be explained by the high plant growth observed in these ponds those last days after the adjustment of the pH in ponds. The TN removal rate was not correlated to the pH ($p = 0.287$) but it was significantly correlated to the retention time, the organic loads and the phosphate removal rates ($p = 0.001$). The maximum TN removed represented 94.1%, which was higher than 83.26% removal reported by [30] after 4 weeks retention time of water hyacinth ponds receiving fresh wastewater in Nepal. This difference may be due to the high initial TN concentration (192.9 mg/l) of the raw wastewater used by these researchers.

Figure 4(f) shows the orthophosphate removal rate in the different ponds as function of time. The orthophosphate showed almost the same trend with time as the TN removal for the different influent pH values. The optimum removal trend was observed at influent pH 7, while the highest overall cumulative orthophosphate of 1204 mg/m$^2$ was achieved with influent pH 8. The orthophosphate removal rate seemed not related to pH ($p = 0.5$) but to the retention time ($p = 0.001$), the TN removal ($p < 0.0001$) rate and the organic load removal rate ($p < 0.03$).

**Table 2.** Coliform count in influent and effluent of ponds.

| *Pond* | *Effluent from anaerobic pond* | *Ponds pH 5* | *Ponds pH 6* | *Ponds pH 7* | *Ponds pH 8* | *Ponds pH 9* |
|---|---|---|---|---|---|---|
| *Coliforms Number* | 15,700 | 46,000 | 19,600 | 1800 | 20,000 | 2500 |

In general it was observed that organic and nutrients loads removal rates decreased when influent pH increased from pH 7 to alkaline pH or decreased from pH 7 to acidic pH.

From the analysis of **Table 2**, it appears from the coliform count of the effluents of the ponds pH 5, pH 6 and pH 8 that there was an increase in coliform number in the ponds, despite the long retention time and the presence of WH. In ponds with initial pH 7 and pH 9, 89% and 84% coliform removal was achieved.

It has been reported that coliforms can multiply in treatment facilities or watercourses [31] depending on the environmental conditions. The increase of the coliform number observed can be associated with their multiplication in ponds, which is related to the conditions in the WHP. In fact, after day 3, the observed pH in ponds fell within the range of the optimum pH for faecal bacterial growth which is from 6.5 to 7.5 [20]. Also, the effects of high pH and sunlight which have been stated to be one of the most beneficial for disinfection in ponds [32] [33] cannot be expected from WHP, as in these ponds acidic conditions prevailed. Furthermore, some works suggest that the addition of nutrients like glucose and saline increase the survival chances of bacteria under both light and dark conditions [34] [35]. This may explain the survival of coliforms and their multiplication in this experiment. The removal observed in ponds with initial pH 7 is due to the very low quantity of solute added to the influent wastewater for pH spiking. As for the ponds with initial pH 9, the high algae growth and the low WH growth in the ponds may have improved the DO content and the sunlight effect on ponds leading to coliform removal. It would then be wise to provide for a tertiary treatment, in particular the disinfection, after water hyacinth ponds treatment.

### 3.4. pH and Plant Biomass Production

The water hyacinth relative growth, as measured by biomass fresh weight (FW),

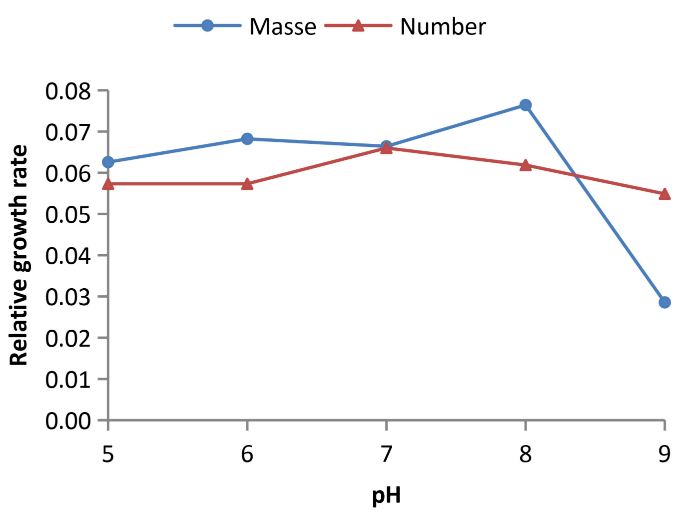


**Figure 5.** Plant relative growth related to the masse and number of plants as function of influent pH.

varied between 0.029 and 0.076 with the highest value observed in ponds with pH 8; but the biggest number of plants was observed in ponds with initial pH 7 (**Figure 5**). In fact the relative growth rate, as measured by the number of plants, varied between 0.055 and 0.066 with the optimum value observed in ponds with pH 7. The lowest growth rate was observed in ponds with pH 9.

The mean initial plant unit wet weight was 42.5 g ± 2.6 g. The final unit plant mass varied between 25.6 g and 56.2 g. The peak values of unit fresh weight were observed in ponds with initial pH 6 and 8. This can be seen by the higher values of relative growth, as measured by fresh biomass weight and the size of the observed plants in ponds.

## 4. Conclusions

The effect of pH on the efficiency of water hyacinth ponds (WHP) in treating domestic wastewater and production of plant biomass was carried out in pilot scale ponds under batch flow conditions. The influent domestic wastewater, pretreated anaerobically, was spiked with $H_2SO_4$ or NaOH to get the desired initial pH for WHP. Five different influent pH (pH 5, pH 6, pH 7, pH 8 and pH 9) were tested. The anaerobic treatment was able to remove 66% of COD, 56% of $BOD_5$ and 53% of TSS after five days retention time.

The observed pH in WHP for wastewater treatment ranged between 6.4 and 7.1. When the initial pH values move outside this interval; the plants regulated the pH of the medium to within this range of 6.4 to 7.1 during the treatment processes. This adjustment affected the performance and the biomass production in the ponds. The alkaline conditions in ponds were less favorable to the activities of the plants.

In fact, removals of COD, $BOD_5$, TNK and growth rates varying respectively, from 18.3 g/m$^2$ to 33.2 g/m$^2$, 11.5 g/m$^2$ to 21.0 g/m$^2$, 1.7 g/m$^2$ to 3.6 g/m$^2$ and from 0.03/day to 0.07/day were observed after 21 days of treatment, the minimal values being observed in ponds with pH 9 and the maxima corresponding to ponds with initial pH 7.

An influent pH value around neutral value was then optimum for treatment processes in WHP, meanwhile, the ponds with influent pH 6 and pH 8 showed higher overall total nitrogen and phosphate removal at the end of the experimental period, when the retention time was over fourteen days.

An increase in the faecal coliforms content was observed in the ponds with influent pH 5, pH 6 and pH 8; a removal is achieved in ponds with initial pH 7 and pH 9. These results showed that it is necessary after WHP to provide for effluent disinfection.

Water hyacinth seemed to find its optimum pH for domestic wastewater treatment and biomass production ranging between 6.4 and 7.1.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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