

Influence of light intensity on growth and flowering ornamental plants in constructed wetlands

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Abstract: Light is an indispensable source for the photosynthesis of plants, but also for their growth and development. On the other hand, the production of ornamental plants requires multiple nutrients for their proper development, a source available in high concentrations in wastewater. Recent research on constructed wetlands (CWs) that use ornamental plants to treat wastewater and at the same time are used as a means of growth, is considered a sustainable alternative. This study evaluated the influence of light intensity on the growth and flowering of ornamental plants (*Lavandula* sp., *Anthurium* sp., *Zantedeschia aethiopica* and *Spathiphyllum wallisii*) in constructed wetlands, fed with domestic wastewater. 30 mesocosms of constructed wetlands were used as a culture medium for ornamental plants, the effect of light intensity on the development of the plants was measured, as well as the removal of Nitrogen (N-NO₃), phosphate (P-PO₄) and biochemical demand of oxygen (DBO₅). The plants were able to adapt and grew healthy in the three-support media with the exception of *Lavandula* sp., which did not survive in any of the systems, showing that in the months when the light intensity was higher, a higher growth rate was reached to 9.5 % on average. In terms of the removal of N-NO₃ (45- 60%), P-PO₄ (20-23%) and COD₅ (60-85%), no significant differences were found between any of the substrates. The above allows us to affirm that CWs, are suitable means for cultivation of ornamental plants and the development of them is favored with intensities of light in ranges from 720 to 856 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$. On the other hand, the substrates used proved to be efficient to remove contaminants, but at the same time to facilitate the healthy development of the used ornamental vegetation, with the exception of the lavender sp. Research is required to evaluate the effects of light intensity on the production of ornamental plants in controlled environments.

Keywords: Intensity of light, ornamental plants, constructed wetlands, residual waters.

Introduction

The light is fundamental for the photosynthesis of the plants, but it also favors its growth and development (Paniagua et al., 2015). Plants in tropical areas manage to grow mostly on foot, due to the ambient conditions and greater intensity of light to which they are exposed (Rodríguez y Lazo, 2012), but in turn need nutrients that facilitate their rapid and adequate growth (Castro y Cristina, 2019); however, the cultivation of many ornamental plants is limited by the lack of economic resources for their production, this by the purchase of fertilizers and nutritional inputs required by the vegetations to achieve an adequate development (Alvarado et al., 2018). In this sense, taking advantage of wastewater treatment systems as an organic plant crop is an adequate and little researched alternative, due to the high presence of nutrients that these contain (Sandoval et al., 2019). One of these systems can be the constructed wetlands (CWs), these engineering systems of domestic and industrial wastewater treatment have been widely evaluated in countries of temperate climates, these systems consist of cells with substrate that are usually tezontle and sand. These plants are usually macrophytes, typical of natural wetlands, such as *Cyperus papyrus* and *Typha* spp., (Wu et al., 2015 y Vymazal, 2011), where water flows, and through biochemical processes remove pollutants from water (Wu et al., 2015). These systems, besides being low cost of implementation, operation and highly efficient in the removal of contaminants, have been little used in tropical developing countries. (Vymazal, 2011). Most of the research on the use of plants in CWs has been about macrophytes typical of wetlands and has been carried out in temperate climates, and reported in the literature there is little research on ornamental plants that produce flowers adapted to constructed wetland conditions to treat contaminated water, both in regions of temperate climates and in regions of tropical climates such as Mexico, where the environmental conditions of higher light intensities, warmer temperatures can provide adequate conditions for rapid development and that can contribute to a significant absorption of contaminants (Li et al., 2017 y Casierra et al., 2017). The production of ornamental plants that produce flowers is an economic activity that takes place in multiple communities in the world (Sánchez y Díaz, 2019), generating economic income of more than 5 million dollars a year, and represents an important economic activity in developing countries such as, Mexico,

Colombia, Bolivia and others (Ramos et al., 2019). However, this activity is limited by the need for water for production. The means in which they are grown in some geographical areas are scarce, which indicates the need to propose alternative growing media, with alternative substrates that can reduce environmental impacts such as polymeric materials that are easy to obtain in the study areas that do not generate investment costs at the same time (Hernández et al., 2018 y Avellán y Gremillion), and that additionally allow their development in a healthy way. In this sense, the main objective of this study was to evaluate the influence of light intensity on the growth and flowering of ornamental plants (*Lavandula* sp., *Anthurium* sp., *Zantedeschia aethiopica* and *Spathiphyllum wallisii*) in constructed wetlands, planted on porous river rock substrates, red volcanic gravel and PET, this way to take advantage of wastewater in the production of ornamental plants and improve their production with the nutrients present in them, as well as to establish if their development is dependent on the luminosity and environmental conditions present in tropical zones.

Materials and Methods

The study took place in Misantla city, located in the northern center in the state of Veracruz, Mexico. The weather is classified as damp-rainy during the year (45%), damp warm with rains all year (38%) and damp warm with abundant rains during the summer (17%); increasing the temperatures during summer and decreasing during winter, from June 2016 to March 2017 (Figure 1) (CONAGUA, 2017). Location with characteristics of a tropical climate.

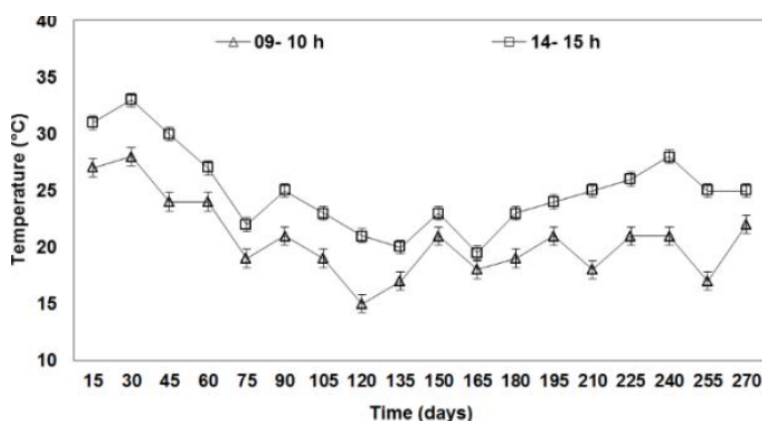


Figure 1. Ambient temperature of 09-10 and 14-15 h.

The 30 mesocosms to scale (Figure 2) consisted of plastic cylindrical units of 29 cm in diameter and 36 cm in height, simulating fully saturated CWs systems. Ten experimental units were filled with polyethylene terephthalate (PET) as substrate, using rough sections with folds taken from recycled bottles, which had a diameter between 3 to 5 cm and with an available space of water flow 0.50, with the purpose of favoring the development of bacterial communities. The units were filled to a height of 26 cm, adding a layer of VGR (10cm).

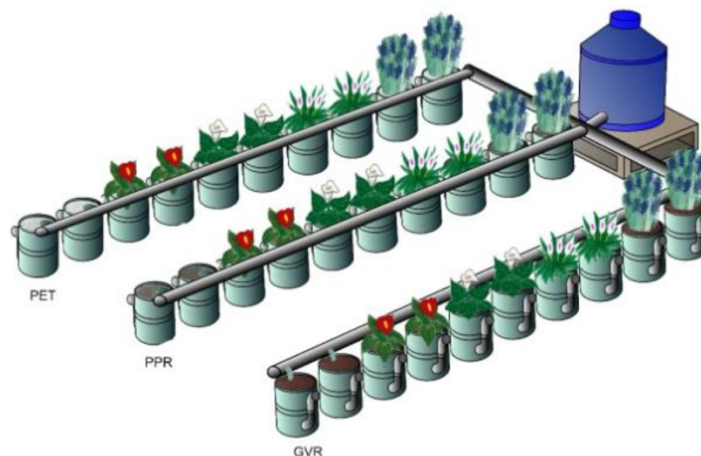


Figure 2. Microcosm of Wetlands Built on porous river rock substrates (PPR), red volcanic gravel (RVG) and polyethylene terephthalate (PET).

Therefore, it did not have any role in the treatment, it just prevents the polyethylene terephthalate (PET) from floating and the development of vectors. 10 units were filled with river porous stone (PPR), with a diameter of 2.5 cm, the non-homogeneous surface with porosity of 0.5, collected in the Misantla river and the remaining 10 with red volcanic gravel (RVG), porous surface material (0.79), of low hardness and low density with a diameter of 1.5 cm.

They were fed with Hydraulic Retention Time (TRH) for 3 days. Four ornamental plant species were used: *Anthurium* sp., *Lavandula* sp., *Zantedeschia aethiopica* and *Spathiphyllum wallisii*, and according to (Figure 2) 24 individuals were planted in duplicate. To select the vegetation, it was needed for the plants to be of easy adaption, and mostly to be resistant to agents of weathering. Duplicated units filled with each substrate, but without vegetation, were used as control. The study was taken at room temperature under shade using a polyethylene shadow mesh.

Sampling and analysis

a) Vegetation development

Plant development was measured every 30 days with a tape measure from 5 cm of the lower part of the stem, in the period June 30, 2016, to March 12, 2017, in order to determine if its development is adequate in CWs, fed with wastewater and seeded on different substrates. Flower production was also measured during the same period.

b) Light intensity

The luminous intensity was measured every fifteen days with a luxmeter (HYELEC MS8233E 2000) in the morning and in the afternoon (from 9:00 to 10:00 and from 14:00 to 15:00), during the period of study in different climatic seasons to establish if the incidence of this favored the development of vegetation in CWs and could be used as a culture medium for ornamental plants that produce flowers.

c) Measurement of contaminants

During the study period, every 15 days, samples of effluent and influent of CWs were taken. It was determined in duplicates the BOD₅, N-NO₃ and P-PO₄ (APHA, AWWA, WEF, 2005) and pH, STD, EC and water temperature with a waterproof meter, pH (Combo pH and EC - Waterproof).

Treatments and experimental design

A two factor design with blocks was used, the block being the number of days, the factor 1 was defined as the type of substrate: PPR, RVG and PET and factor 2 as a species of ornamental plant: *Lavandula* sp., *Anthurium* sp., *Zantedeschia* a and *Spathiphyllum* wall in their respective controls, the response variables being the intensity of light and the pollutants measured. For the height of the plant and number of flowers, a completely randomized design with a 5% significance was used.

Statistic analysis

For the statistical analysis of the results of plant and contaminant development, between the different treatments, an analysis of variance (ANOVA) of fixed effects was used at a confidence level of 95%, as well as ANOVA of two factors. In addition, the comparison of means with the test of the Minimum Significant Difference (LSD) at a level of significance of 5% was made, using the statistical package Minitab ver. 16-1.0.

Results and Discussion

Light intensity effect on plant development

The plant growth was favored by the light intensity conditions during the study (Figure 3), with values between 720 and 856 $\mu\text{mol m}^{-2} \cdot \text{s}^{-1}$. The values agree with the ones Olguín reported, (Olguín et al., 2008), who found similar ranges for the growth of plants in tropical climates. On the other hand, the ranges of light intensity suitable for the

development of ornamental plants in tropical climates are between 400 to 1,000 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ (Sandoval et al., 2018). Between these ranges the values reported in this study were found, which indicates that the luminosity conditions could favor the adequate development of the vegetation.

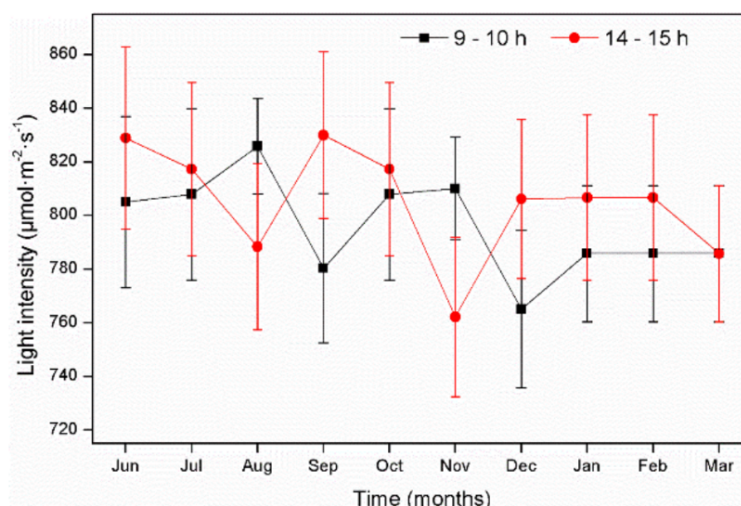


Figure 3. Intensity of light recorded between 9-10 and 14-15 h during the study period, with its mean standard error.

The Figure 4 shows the development percentage of the plants in the experiment time in RVG (figure 5), PPR (figure 6) and PET (figure 6) in order to evaluate the sustained growth in the height of the plants during the period tested, with the exception of the *Lavandula* sp. which did not survive on any of the substrates. Although this species is resistant to different weather conditions, it failed to adapt to any of the tested substrates. The pH of the water was found between the permissible limits of development, ranging from 7.0 to 8.5 (Ríos y Peñuela, 2015). In RVG, PPR and PET the pH values were between 7 - 7.4 (table 2), which indicates that the conditions had nothing to do with their death; even though having an aerenchymous tissue with similar characteristics to the ones from wetland plants, it was enough to adapt to the CWs. In all the substrates, the ZA plant had better growth, being in RVG where it had the highest rate with 20.36%, in PPR it had 19.09% while in PET it obtained growths of 16.67%. The substrates did not show significant differences between them ($P > 0.05$) but between plants ($P < 0.05$).

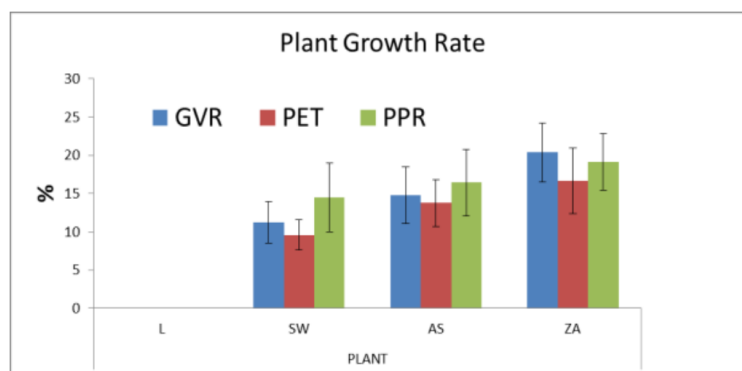


Figure 4. Growth rate of different plants in different substrates: *Lavandula*, (L), *Spathiphyllum wal* (SW), *Anthurium* sp., (AS) and *Zantedeschia aethiopica* (ZA), on different substrates red volcanic gravel (GVR), polyethylene terephthalate (PET) and porous river stone (PPR), during the study period.

In relation to the growth of the four plants (cm) in the three substrates, the ANOVA showed that the growth is affected by the type of substrate and plant species over time ($P < 0.05$), ZA had the highest growth as length of the experimental period in the three substrates, with averages of 50.7, 36.5, and 45.4 cm respectively RVG (figure 5), PPR (figure 6) and PET (figure 7). The above could be due to high light intensities present in this study (figure 3), which could favor the development of these in CWs, fed with domestic wastewater. The results are consistent to the ones found by Kang et al. (Kang et al., 2019), under controlled conditions of light intensities 10 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ o 20 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, the

plants are affected in their spill in low light conditions. Greater luminosity conditions favor the development of tropical plants.

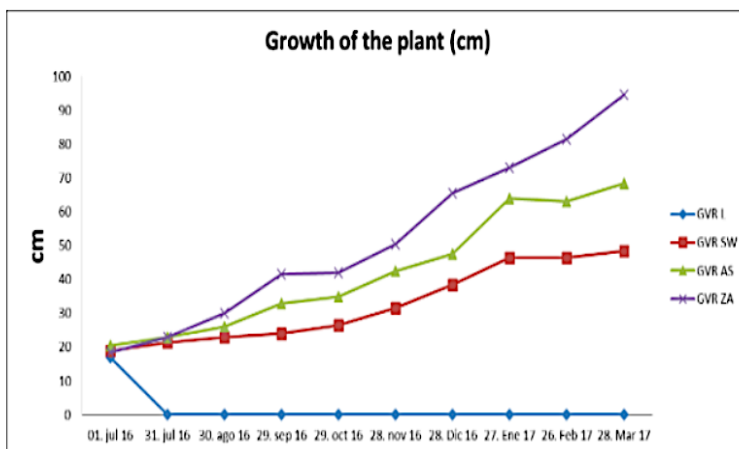


Figure 5. Development of ornamental plants in red volcanic gravel substrate (RVG): *Lavandula* sp., (L), *Spathiphyllum wallisii* (SW), *Anthurium* sp., (AS) y *Zantedeschia aethiopica* (ZA).

The growth behavior of the plant in the RVG substrate is shown. The plant *Zantedeschia aethiopica* (ZA) developed better, having an average growth rate of 20.36%, followed by AS with 14.1% and SW with 11.22%.

During the 9 months of study, the *Zantedeschia aethiopica* recorded a height of 84.5 cm in CW with RVG substrate (Figure 5); with PET it recorded a height of 63 cm. The data was consistent with the results of normal growth over a 12-month period of 1.5 m published by Zurita et al. (Li et al., 2019). The growth of *Spathiphyllum wallisii* was slower compared to that of the *Zantedeschia aethiopica* (from 15-38.5 cm in RVG to 15.5-34 cm in PET) (Figure 4 and 5). The environmental conditions were ideal for the development of the plants and the environmental temperature 20-26 °C (Figure 3) and are consistent with those reported by Tresserras (Maine et al., 2019), where the optimum temperature ranges from 12 to 25 °C.

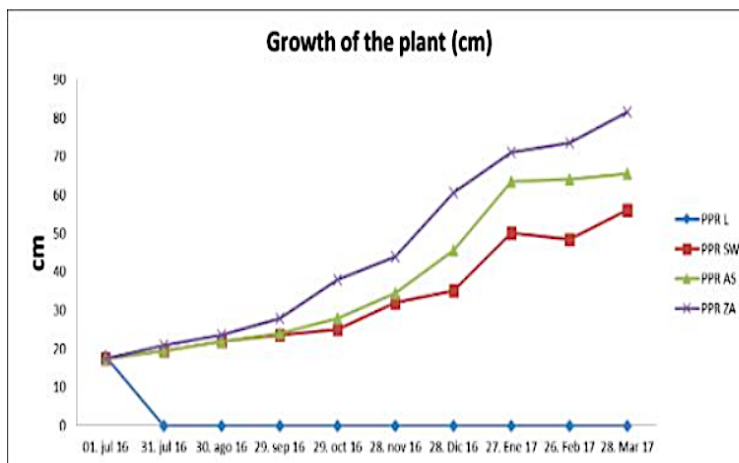


Figure 6. Development of ornamental plants in Porous Rock substrate of Rever (PPR): *Lavandula* sp., (L), *Spathiphyllum wallisii* (SW), *Anthurium* sp., (AS) and *Zantedeschia aethiopica* (ZA).

In Figure 6, the growth behavior of the plant in the PPR substrate is shown. The plant ZA developed better, having an average growth rate of 19.09%, followed by AS with 16.42% and SW with 14.46%. The information on the development of ornamental plants in wastewater treatment systems (in CWs), is scarce and little known in relation to this type of plants. This study is one of the first precedents that report the development of this type of species in CWs, which treat wastewater, with the purpose of using it as a culture medium.

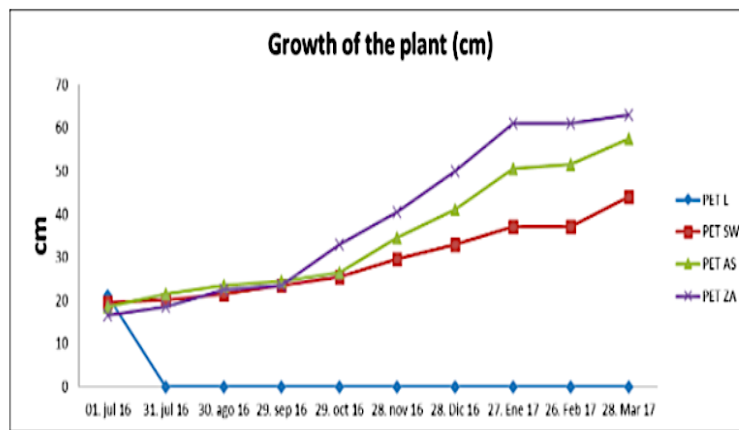


Figure 7. Development of ornamental plants on substrate of polyethylene terephthalate (PET): Lavandula sp., (L), Spathiphyllum wallisii (SW), Anthurium sp., (AS) and Zantedeschia aethiopica (ZA).

The behavior of the growth of the plant in the PET substrate is shown. The plant aethiopica (ZA) developed better, having an average growth rate of 16.67%, followed by AS with 13.75% and SW with 9.60%. The previous results in Figure 4, 5 and 6, showed that there is no difference in height means in Substrate (RVG, PET and PR) $P > 0.05$ but there is a difference in means by type of plant species $P < 0.05$ as it is shown in Figure 7.

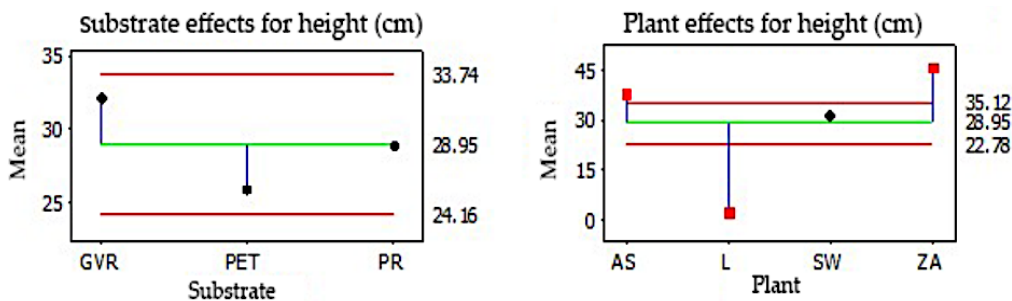


Figure 8. Graph of height measurements of plants: Lavandula sp., (L), Spathiphyllum wallisii (SW), Anthurium sp., (AS) and Zantedeschia aethiopica (ZA), in different substrates red volcanic gravel (GVR), polyethylene terephthalate (PET) and porous river rock (PR) during the study period. (Red dots indicate that the means are outside the calculated limits).

Flower production

Until the month of August, it was observed the flower production in *Spathiphyllum wallisii* in PET substrate, remaining regularly for 6 months, presented on average one flower during the flowering season. It was in RVG where there was a greater production of flowers (on average 2), which remained irregularly for 7 months, maximum 2 flowers during March, September and December. During July, August, September and October, *Zantedeschia aethiopica* had its best production flower until the end of the project. This is due to the fact that this type of plants flowering period can occur during the year, in addition to the light and temperature conditions during the study [6], Table 1, shows the production of flowers and the size of them during the 10 months of study. During the entire study *Spathiphyllum wallisii* showed the highest production with a total of 12 flowers in the RVG substrate. PET substrate only produced 6 flowers less than the RVG. However, *Zantedeschia aethiopica* production was of 7 on Pet substrate and 10 flowers for RVG substrate. data consistent with the production that can be achieved *Zantedeschia aethiopica*, from 2 to 3 flowers per bulb (Zhang et al., 2012).

Using the Tukey comparisons test, flower production by plant type statistically does not present significant differences ($P = 0.0092$), which means that the different sown plants produce on average the same number of flowers (between 2 and 3 flowers *Spathiphyllum wallisii* y *Zantedeschia aethiopica* approximately). In the case of *Anthurium* the production of flowers was very slow in each system there was only one flower per unit plant. There was a significant difference in

the production of flowers by type of substrate ($P < 0.05$), however there was no difference in the number of flowers per plant ($P > 0.05$) during the entire study.

Table 1. Flower production

	Total Flowers			
	L	SW	AS	ZA
RVG	0	12	2	10
PET	0	7	2	9
PPR	0	9	2	7

Input and Output pH of the system

The pH values obtained are showed on Table 2, for both influent and effluent. The reduction in alkalinity is caused by the nitrogen removal occurred in the systems, decreasing data in the pH. Higher pH values were found in microcosms planted with *Zantedeschia aethiopica* RVG with 8.1; as well as lower values of 6.3 in PET in microcosm with *Lavandula* sp. In general, during 270 days of study it was found values close to neutral.

Table 2. Chemical Parameters of Entry and Exit of CWs

Substrate	Plant	pH
RVG	Influent	7.08±0.09
	L	7.00±0.05
	SW	7.31±0.06
	ASP	7.33±0.06
	ZA	7.43±0.07
	Control	7.00±0.05
PET	Influent	7.08±0.09
	L	7.21±0.05
	SW	7.70±0.06
	ASP	7.86±0.06
	ZA	7.09±0.05
	Control	7.19±0.06
PPR	Influent	7.08±0.09
	L	7.01±0.05
	SW	7.12±0.06
	ASP	7.40±0.06
	ZA	7.17±0.06
	control	7.04±0.05

Pollutant Removal

a) Chemical demand of Oxygen (BOD_5) at the entrance and exit of the HC

The BOD_5 , is the material susceptible to be oxidized by the biological means that continue a liquid sample, dissolved or in suspension (Vymazal, 2007). Encountered BOD_5 removals (Figure 9) for mesocosms no differences were found ($p > 0.05$) between substrata with vegetation with average removals of 65%, but between systems with and without vegetation ($P < 0.05$), with averages of removal of 53%.

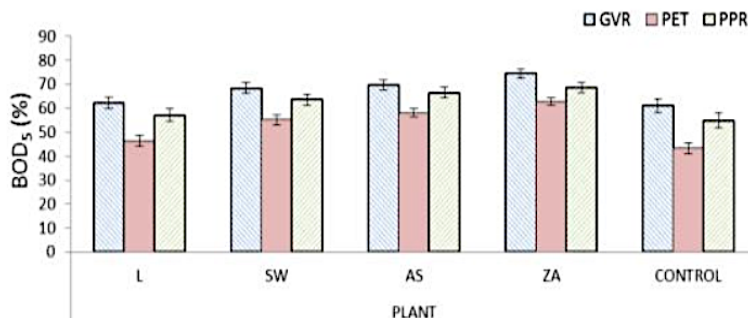


Figure 9. Removal of BOD₅, Anthurium (AS), Lavandula (L), Spathiphyllum wall (SW) and Zantedeschia a (ZA).

The treatment of BOD₅ with RVG had better results, specifically with the ZA and ASP plants, in all the readings were shown atypical data, which is attributed to some external variable that must be analyzed. The percentage of removal of ZA and ASP with RVG was 73.79% and 70.15% removal in relation to the Effluent. The second-best treatment was PPR and finally the PET substrate. The interaction of substrate * plant did not present difference of means ($P > 0.05$). The study results are in ranges of removals reported in the literature using ornamental plants (Zamora et al., 2019).

b) Removal of N-NO₃

In the removal of N-NO₃, the result of the experiment showed that there is a significant difference ($P < 0.05$) between the substrates (RVG, PET and PPR) used, as well as in the plants used (ASP, L, SW and ZA) and days. The best substrate for the removal of N-NO₃ is the Red Volcanic Gravel (RVG), with Zantedeschia aethiopica (ZA) with an average of 5.10 mg / L, removing 58.15% in relation to the control. The second treatment with the best performance was PET substrate with ZA plant with an average of 7.36 mg/L with a 39.6% removal. It is indicated that, in the three substrates, the ZA had better removal of N-NO₃, highlighting a better performance with RVG, on the contrary, L had lower performance in the removal in the three substrates.

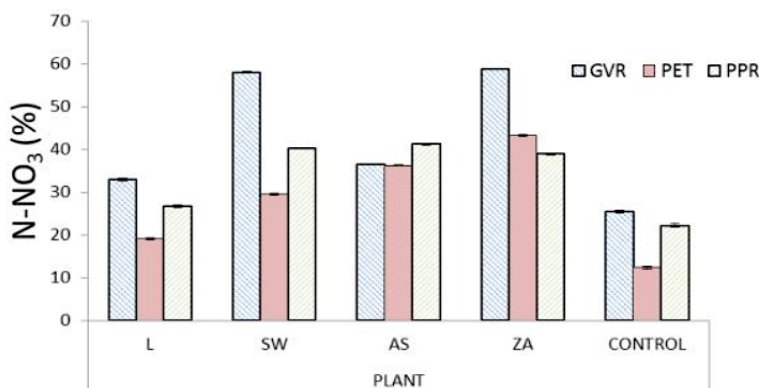


Figure 10. Removal of -NO₃ Anthurium (AS), Lavandula (L), Spathiphyllum wall (SW) and Zantedeschia a (ZA).

To be able to achieve an adequate nitrate removal, aerobic conditions are required, which can be present mainly in mesocosms with presecia vegetation, by the release of this in the radical zones (5). On the other hand, the removal of this compound was greater in systems with vegetation, which could indicate that it was used for the development of vegetation as shown in figures 5, 6 and 7.

c) Removal of phosphates (P-PO₄)

P-PO₄ was removed with substrate of RVG, ZA presented an average of 6.74 mg / L, followed by ASP with 6.96 mg / L, which represents 45.35% and 43.40% removal. Statistically there is no significant difference ($p > 0.05$) in the means of the amount removed from P-PO₄ among the plant species using RVG. The treatment with PPR was the second best obtaining for ASP and ZA 23.09% and 21.42% removal respectively (Figure 11).

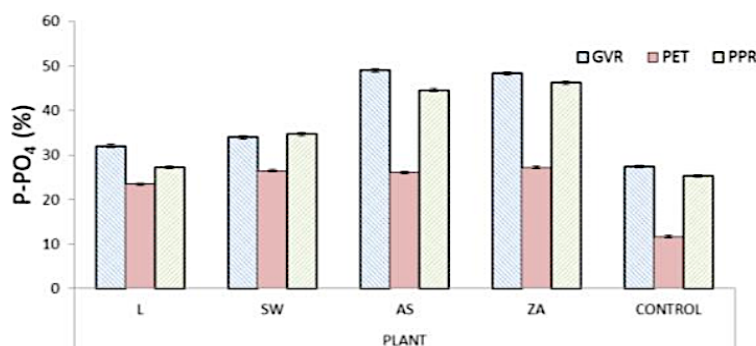


Figure 11. Removals of P-PO₄, Anthurium sp (AS), Lavandula sp (L), Spathiphyllum wallisii (SW) and Zantedeschia aethiopica (ZA).

The box plots indicate that RVG and PPR have a similar behavior among the plants used in terms of trend. With better results in RVG the 4 species of plant using a PET substrate were not shown higher readings in the removal. The obtained results consistent with different studies, indicate that plants favor the removal of phosphates, and it is used to induce flowering (Zamora et al., 2019), as shown in the table (table 1).

Conclusions

The intensity of light is important for the development of ornamental plants. In tropical conditions the greater intensities of light favor the development of plants in CWs, as well as increase the efficiencies of removal of the systems in comparison with areas with lower light conditions. The wetlands built with ornamental plants are an optimal alternative for the treatment and cleansing of domestic wastewater. In the reduction of different pollutants favor the development of vegetation as was the case of *Anthurium* sp, *Spathiphyllum wallisii* and *Zantedeschia aethiopica*, adapted to CWs conditions. On the other hand, these plants showed that they can be cultivated in CWs and take advantage of the nutrients present in the wastewater to reduce the use of fertilizers. It is not recommended to use *Lavandula* sp., for future designs as vegetation in this type of system, since it is not available to adapt to wetland systems. Research aimed at the development of ornamental plants of commercial interest, cultivated in CWs, will be taught, as well as studies at different intensities of light that will allow establishing the optimum ranges in which these can be developed in CWs, with mostly controlled conditions.

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