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Effect of Ornamental Plants, Seasonality, and Filter Media Material in Fill-and-Drain Constructed Wetlands Treating Rural Community Wastewater

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Abstract: The effects of *Canna indica* (P1), *Pontederia sagittata* (P2), and *Spathiphyllum wallisii* (P3) growing in different filter media materials (12 using porous river rock and 12 using tepezyl) on the seasonal removal of pollutants of wastewater using fill-and-drain constructed wetlands (FD-CWs) were investigated during 12 months. Three units of every media were planted with one plant of P1, P2, and P3, and three were kept unplanted. *C. indica* was the plant with higher growth than the other species, in both filter media. The species with more flower production were: *C. indica* > *P. sagittate* > *S. wallisii*. Reflecting similarly in the biomass of the plants, *C. indica* and *P. sagittata* showed more quantity of aerial and below ground biomass productivity than *S. wallisii.* With respect to the removal efficiency, both porous media were efficient in terms of pollutant removal performance ($p > 0.05$). However, removal efficiency showed a dependence on ornamental plants. The higher removal of chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total kjeldahl nitrogen (TKN), nitrates (NO_3^--N), ammonium (NH_4^+-N), and phosphates (PO_4^{-3}-P) oscillated between 81% to 83%, 80% to 84%, 61% to 69%, 61% to 68%, 65% to 71%, 62% to 68%, and 66% to 69%, respectively, in P1 and P2, removals 15% to 30% higher than P3. The removal in planted microcosms was significantly higher than the unplanted control units ($p = 0.023$). Nitrogen and phosphorous compounds were highly removed (60%–80%) because in typical CWs, such pollutant removals are usually smaller, indicating the importance of FD-CWs on wastewater treatments using porous river rock and tepezyl as porous filter media. (BOD_5), chemical oxygen demand (COD), (NO_3^--N), (NH_4^+-N), (TKN), and (PO_4^{-3}-P).

Keywords: removal pollutants; fill-and-drain constructed wetlands; tepezyl porous media; porous river rocks; ornamental plants

1. Introduction

Constructed wetlands (CWs) are environmentally friendly technologies that have demonstrated high efficiency in removing pollutants from wastewater [1–3]. This sustainable ecotechnology is based on natural wetland processes for the removal of contaminants, including physical, chemical, and biological routes, but in a more controlled environment compared with natural ecosystems [1,4].

The success of these systems depends on various factors, such as the hydraulic retention time, tolerance of the selected plants to the wastewater, and the optimum porous media for microorganism growth [1,2,5]. The water pollution problems and the growing potential of this sustainable technology demands the need for the optimization of CW designs. Various types of CWs can be used for the exclusion of toxic compounds (superficial or subsuperficial flow) [1,5,6]. In particular, the systems with saturated bed (subsuperficial flow) are suitable for this purpose. However, the water presence favors anaerobic conditions, which inhibit biological processes, such as nitrification, that require mainly aerobic conditions. Improved nitrogen compound removal involves both nitrification (in aerobic conditions) and denitrification (anaerobic conditions) processes. In the fill-and-drain (FD)-CWs (also commonly known as tidal flow CWs), the bed is intermittently saturated, which is related to the fill and drain phases. Such systems are mostly applied when increased oxygen transfer is needed [6], but may also be used to promote anaerobic processes when the holding phase is extended. The shortcomings of the FD-CWs are that the conditions in the system are not constantly anaerobic as compared to, for example, upflow CWs. It is thus necessary to evaluate the viability of FD-CWs using ornamental plants for the treatment of wastewater. The vegetation in CWs is one of the most important features; the vegetation can improve the water quality mainly by absorbing pollutants from the water, and have rich belowground organs (i.e., roots and rhizomes) in order to provide substrate for attached bacteria and the oxygenation of areas adjacent to roots and rhizomes [7,8]. In tropical and subtropical regions, the most popular vegetation used in constructed wetlands are *Phragmites australis* (Common reed), species of the genera, *Typha* (*latifolia*, *angustifolia*, *domingensis*, *orientalis*, and *glauca*), and *Scirpus* (e.g., *lacustris*, *validus*, *californicus*, and *acutus*) spp. [8]. However, there are local ornamental plants (plants grown or maintained for its aesthetic features, like its color, fragrance, flower production, attractive pattern, or design, are called ornamental plants) that have not been tested for their ability to remove pollutants, even though ornamental plants represent an economic alternative for developing countries, where wastewater treatment represents a large expenditure of the municipal budget [9–11]. Another important feature in treatment wetlands' design is the filter media. Some constructed wetlands are filled with expensive or uncommon materials as the substrate, such as zeolite [12,13], maerl (calcified seaweed) [14], wollastonite [15], shale [16], or cobbles [17]. However, in rural communities, where the economic conditions are deficient, it is worth taking into consideration the use of local materials and plants that have rarely been evaluated. Consequently, the main goals of this study were: (a) To examine the seasonal effect on growth and pollutant removal of different ornamental plants (*Pontederia sagittata*, *Canna indica*, and *Spathiphyllum wallisii*) with economical vision in the removal of pollutants using FD-CWs., and (b) to evaluate the use of different filter media (porous river rock and tepezyl) in the growth of plants and removal of pollutants in order to find the optimal design characteristics of constructed wetlands.

2. Materials and Methods

2.1. Study Area

The experimental FD-CWs were conducted in the rural locality of Pastorías (municipality of Actopan), Veracruz, Mexico (−96° 57′ 08″ N and 19°55′ 83″ S). The microcosms were established in a backyard with a transparent roof. Weather in the region is tropical with an annual precipitation of 947.1 mm and annual average temperature of 24.5 °C (26.1, 26.6, 25.2, and 20.3 °C in spring, summer, autumn, and winter, respectively, during the study from March 2015 to February 2016). The wastewater used was directly pumped from a community sewer (620 people). Three different ornamental plants were used in the FD-CWs: *Canna indica*; *Pontederia sagittata*, and *Spathiphyllum wallisii.* The plants with an individual height between 0.25 and 0.32 m were collected in riparian and creek zones near the study area. The porous river rocks (PR) and tepezyl (TS; sandy-like inert mineral of a fine grain that is lightweight and low cost, and is used in blocks for construction) were the only two different types of filter media employed. PR was collected from the riparian zone of the local river (Topiltepec) and was washed prior to its use in CWs. TS porous media was collected from the residues of building material supplied by some members of the community. The porosity of PR and TS was 50% and 40%, respectively. Both filter media had an average diameter of 1.2 cm.

2.2. Design FD-CWs Microcosm

The wastewater was filtered of big solids by a mash (pretreatment 1) and subsequently stored in a 1.1 m^3 plastic tank where the water was sedimented during three days (pretreatment 2). After such processes, the water was used in the experimental units (constructed wetlands treatment). Twenty-four microcosms were constructed in cylindrical plastic containers (0.36 m height and a 0.30 m diameter) (Figure 1). Twelve microcosms contained PR and the remaining 12 were filled with TS as a porous media. The microcosms in every porous filter media were labeled as *Pontederia sagittata* (A, B, and C), *Canna indica* (A, B, and C), *Spathiphyllum wallisii* (A, B, and C), and control (unplanted) (A, B, and C). Two vegetation species were planted in each microcosm with flora. The species selected were plants that were easy to adapt and resistant to agents of weathering, considering its acclimatization in the zone, were collected in riparian and creek zones near the study area. The first 30 days after planting the vegetation, the experimental units were fed with tap drinking water. Starting from day 31 of the study, and for 30 days thereafter, the wastewater was added in proportions of 20% every 3 days in order to adapt the vegetation to the new water quality conditions. CWs were 100% fed with wastewater that was stored in the tank. In such an adaptation of the plants, it was not necessary to use any kind of fertilizer for the survival of the ornamental plants; the elements (nitrogen, phosphorous, etc.) present in the wastewater were the base of the natural nutrients for the plants. All microcosms' flow rates were adjusted for three days of the hydraulic retention time and 4 cm d^{-1} of the hydraulic loading retention rate, both during the filling phase in the subsurface down-flow wetland conditions. The fill-and-drain mode in CWs consisted of two phases: Filling phase and draining phase. Two hours every 3 days the experimental units were fed in the draining phase. For each microcosm experiment, the treated volume of wastewater was ~3 L/day^{-1}.

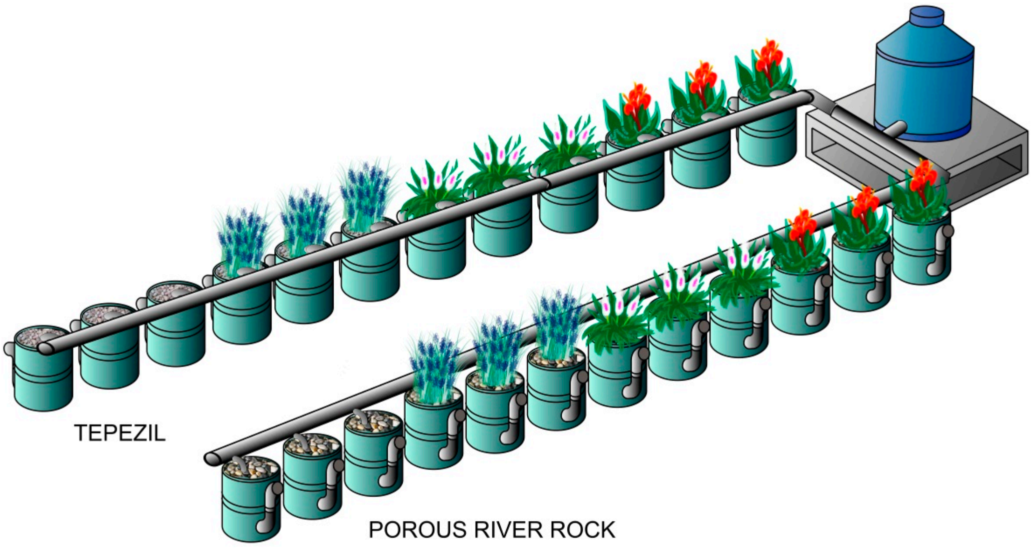

Figure 1. Scheme of constructed wetlands (CWs) used in this study.

2.3. Physical-Chemical Parameters and Plant Growth Measurement

The microcosms were studied from March 2015 to February 2016 for their efficiency on pollutants' removal. Surveyed water quality parameters were biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrates (NO_3^--N), ammonium (NH_4^+-N), total kjeldahl nitrogen (TKN), and phosphates (PO_4^{-3}-P). Water samples (250 mL) were taken from the influent and effluent of each microcosm every 15 days (600 samples during one year) and analyzed in the laboratory according to standard methods [18]. The removal efficiency (%) of the FD-CWs was calculated using the average of the inflow and outflow concentrations [4,9,19]. Other parameters measured were the redox potential (Eh) at a 15 cm depth in all the microcosms (near the rhizosphere zone in the planted units) with platinum electrodes according to Hernández et al. [20]. Total solids (TS), electrical conductivity (EC), pH, and water temperature were measured with a YSI 550 multiparameter at each microcosm.

The individual plant height of each unit was measured every 15 days by tape, and then an average of the measurements was calculated. Four random plants of each species were harvested and their heights were recorded every month for biomass measurement. The plants were harvested and separated individually into root and aerial biomass (steam and leaves), after they were washed and dried at 40 °C to obtain constant weight [20].

2.4. Statistical Analysis

All statistical analyses were performed using SPSS software for Windows (SPSS Inc., Chicago, IL, USA, version 20). The significant differences between plants and porous media in pollutant removal were analyzed using two-way ANOVA followed by LSD (Least Significant Difference) tests (at $\alpha = 0.05$ level). Values are presented as the mean ± standard error.

3. Results and Discussion

The features of the wastewater under study are present in Table 1. The pH during the experimental period was between 7.4 and 7.6 in the influent and controls, while in the microcosms with plants, the pH values decreased to nearly neutral values (6.9–7.2). This decrease is consistent with Romero [21], who observed that bacteria receive sustenance from nitrification–denitrification reactions causing alkalinity reduction and such reactions can be intensive in the plants' presence. Dissolved oxygen (DO) showed a range between 1 and 4.8 mg L^{-1}. The water temperature in the microcosms was between 18 and 19.7 °C. Many wetland processes, such as microbial mediated reactions, are affected by temperature, and some authors [17,22] reported that the optimum temperature for the survival of microorganisms responsible for pollutant removal is within 15 and 30 °C, a range that involves our own observed values. The electrical conductivity (EC) of soil affects the ability of plants and microbes to process the waste material flowing into a constructed wetland. In this study, EC varied between 1013 and 1245 μS/cm (Table 1), the optimum range as a growth medium that favors the removal of pollutant processes [17]. The redox potential changed in microcosm FD-CWs according to planted and unplanted systems, obtaining values of up to 300 mV in the most superficial areas and near the roots of the plants, which was related to the oxygen supply of the rhizosphere zone. Among the unplanted systems, the values of Eh were slightly less oxidized (222 and 257 mV) than in the experimental units with vegetation (308–376 mV). The average measured value of the total suspended solids (TSS) in the influent was 211 ± 16 mg L^{-1}, a value higher than the control units (144 to 153 mg L^{-1}; indicating the role of substrates as a filter of TSS), but values lesser of TSS were observed in the planted units (112 and 122 mg L^{-1}), indicating the importance of the substrates together with the root of the plants as a retention of TSS.

Table 1. Parameter concentrations at the inputs and outputs of the microcosm wetlands.

Parameter	Wetland Plants in Different Substrates								
	Influent	***Canna indica***		***Pontederia sagittata***		***Spathiphyllum wallisii***		***Control***	
		PR	**TS**	**PR**	**TS**	**PR**	**TS**	**PR**	**TS**
pH (pH units)	7.6 ± 0.2	7.2 ± 0.4	7.1 ± 0.9	7.2 ± 0.1	7.2 ± 0.8	7.1 ± 0.9	6.9 ± 0.6	7.5 ± 0.1	7.4 ± 0.1
DO (mg L^{-1})	1.0 ± 0.2	4.2 ± 0.8	3.9 ± 0.7	4.2 ± 0.6	4.7 ± 0.8	4.8 ± 1.2	3.4 ± 0.9	1.5 ± 0.2	1.3 ± 0.2
Temperature (°C)	18.5 ± 0.7	19.1 ± 0.9	19.2 ± 1.8	19.4 ± 0.9	19.3 ± 0.7	18.2 ± 1.4	18.6 ± 0.8	19.7 ± 0.6	19.7 ± 0.4
EC (µS/cm)	1151 ± 143	1155 ± 101	1212 ± 139	1124 ± 161	1245 ± 67	1124.2 ± 98	1130.8 ± 110	1126 ± 130	1013.8 ± 77
Eh to 0.10 m depth	ND	318.6 ± 34	317.5 ± 43	356.6 ± 33	371.8 ± 24	309.6 ± 58	308.1 ± 26	222.5 ± 20	257.84 ± 18
TSS (mg/L^{-1})	211 ± 16	112 ± 19	117 ± 41	114 ± 36	118 ± 52	122 ± 38	112 ± 35	144 ± 42	153 ± 44

Values are given as the average ± standard error (n = 72). PR: microcosms with porous river rock, TS: microcosms with tepezyl. ND = Not determined.

3.1. Plant Height and Biomass Changes

The individual plant height change is shown in Figure 2. *C. indica* was the plant with higher growth than the other species, in both filter media. The maximum heights were 1.25 and 1.18 m in PR and TS filters, increasing almost 1 m of height during the study. *Pontederia sagittata*s howed lower increments in the height than *C. indica*. In both filters, the maximum height was 0.8 m, increasing almost 0.6 m from March 2015 to February 2016. *S. wallisii* plants grew up to just 0.22 m during the study in both filter media. In general, the adaptation of plants was good; the wetland conditions did not affect their survival, becoming an important feature for the use of plants in constructed wetlands.

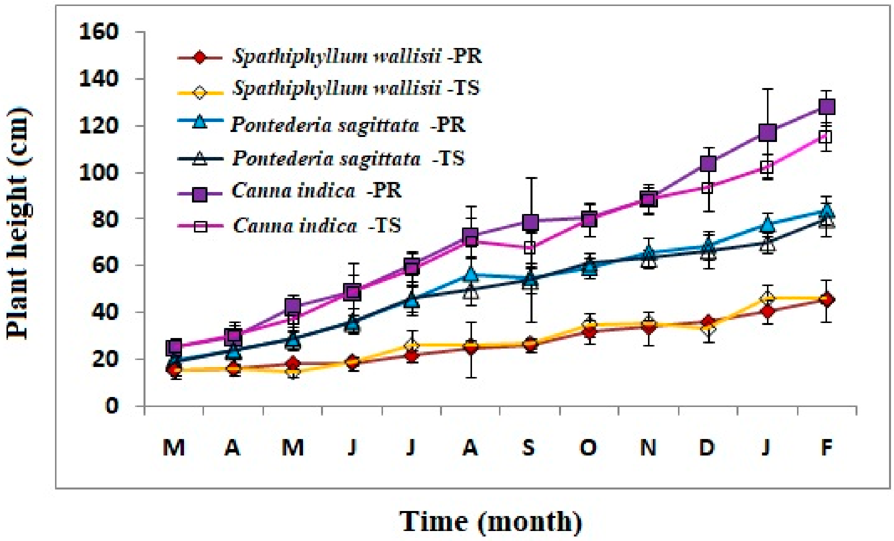

Figure 2. Individual plant height curve change with time.

Physical observations on the vegetation were evaluated during the study according to the wilting degree, growth situation of stems and leaves, diseases and pests, and flower production (Table 2). *C. indica* and *S. wallisii* were the plants without symptoms and considered the best, while *P. sagittata* showed some yellow leaves, pests, and diseases during the adaptation period (three weeks), but such conditions did not affect the flower production. The species with greater flower production were: *C. indica* > *P. sagittate* > *S. wallisii*. The last species, the one with less flower production, was related to the direct exposure to the sun (failed to adapt easily to CWs). Given that *S. wallisii* species are more likely to adapt in shadowed areas [23], the data observed in this study because of their use in CWs is not widely documented. However, it is important to mention that the adaptation of *S. wallisii* in CW conditions is an opportunity to stimulate the use of eco technologies; for example, removing pollutants and creating an esthetic landscape of the system with species flowers in CWs in backyards or in big areas for the production of plants and the potential of selling these plants as living specimens for interior design. In tropical regions, where temperatures range between 20 to 32 °C, Conover [24] recommended the use of shadow mesh over the CW for better *Spathiphyllum* production. Studies with *S. wallisii* in CWs without direct exposure to the sun are necessary in future experiments. In the case of *C. indica* and *P. sagittata*, these are species more typical of wet soils and both are likely to adapt to direct exposure to the sun.

Table 2. Growth characteristics of plants.

Plant	Filter Media	Wilting Degree (Number of Plants)	Growth Characteristics Stems-Leaves-Flowers [a]	Diseases and Pests [b]	Number of Flowers during the Study
Canna indica	PR	0	-	-	42
	TS	0	-	-	39
Pontederia sagittata	PR	0	XX	X	29
	TS	0	X	X	31
Spathiphyllum wallisii	PR	1	-	-	11
	TS	2	-	-	9

[a] Growth characteristics of stems and leaves: -, plant grew normally; X, upper leaves withered; XX, the leaves of the whole individual plant turned yellow. [b] Diseases and pests: -, no diseases and pests; X, slightly diseases and pests; XX, serious diseases and pests.

With regard to the biomass of plants, the porous media material did not have a significant effect on the above or below ground biomass production (p = 0.084, 0.076; Figure 3). However, there was a significant effect between different plants on biomass (p = 0.012), i.e., *C. indica* and *P. sagittata* showed a greater quantity of aerial and below ground biomass productivity than *S. wallisii*, similar to the height of plants observed in Figure 2, which could be reflected in the findings about the removal of pollutants of this study. Both characteristics are important for the selection of constructed wetland plants [25]. By having different ornamental plants in the CWs, the treatment system will be more attractive aesthetically and the function of the removal of pollutants is active. In another study with ornamental plants (*Zantedeschia aethiopica* and *Alpinia purpurata*) growing in CWs, the biomass production was similar to the findings in this study [26,27]. However, using plants of natural wetlands (*Typha* spp., *Juncus* sp.), biomass production has been reported to be higher in short time periods [28,29]. Such differences are common because ornamental plants are not typical of wetlands, and the production of biomass require adaptation (longer periods that natural plants) of the plants in the constructed wetland conditions (wastewater, material filter, and environmental conditions).

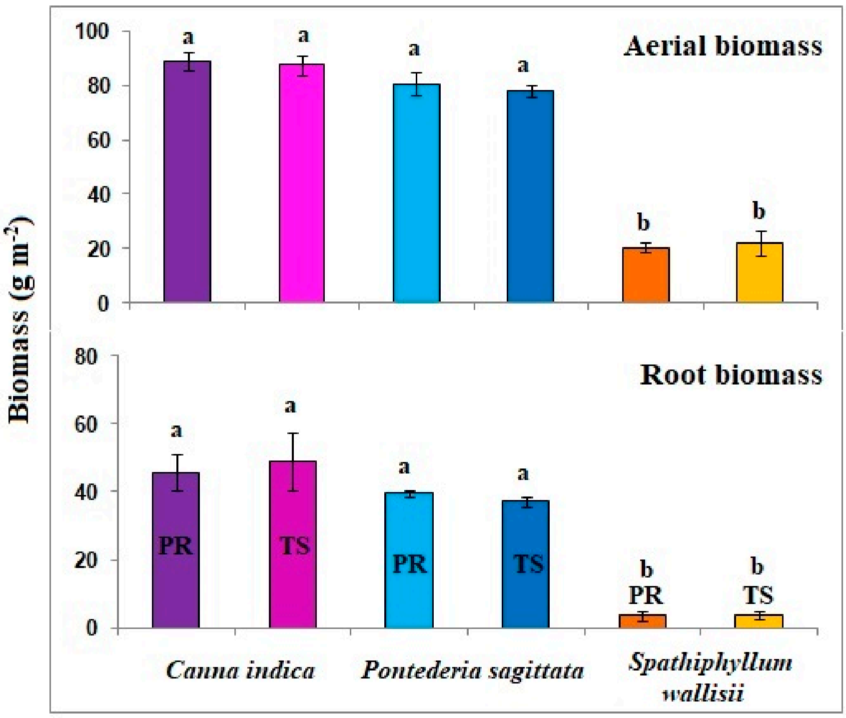

Figure 3. Effect of substrate media and plants on biomass production of different ornamental vegetation. PR = Porous river rock substrate, TS = Tepezyl substrate. Values are average ± standard error. Different letters indicate significant differences ($p < 0.05$).

3.2. Nutrient Removal

Influent and effluent concentrations and percent removal for COD, BOD_5, TKN, NO_3^--N, NH_4^+-N, and PO_4^{-3}-P are summarized in Table 3. The respective mean influent water concentrations for the physic-chemical parameters were 375, 298.3, 60.2, 8.88, 30.06, and 9.51 mg L^{-1}. The corresponding removal oscillated within 28% to 73%, 44% to 83%, 19% to 69%, 18% to 7%, 31% to 68%, and 18% to 69%, respectively. The porous media did show any differences in the removal ($p \geq 0.05$); both filter materials were excellent at removing pollutants of the wastewater. In the presence of vegetation in the experimental units, for all parameters measured as pollutants, the removals were between 15% and 50% higher than CWs without plants, indicating the phytoremediation influence.

The CWs with *P. sagittata* and *C. indica* were the microcosms where the removal efficiency was higher compared with units containing *S. wallisii* and units without vegetation for all parameters measured. The differences within plants are related to the lesser growth of *S. wallisii* and the slow adaptation of such species affected by the exposure to the sunlight. The positive effect on the removal of pollutants by the plants is related to what some authors have stated [6,30], with it being found that planted wetlands out-perform un-planted controls mainly because in the presence of plants, the rhizosphere area functions as a zone for the attachment of microorganism communities that remove pollutants, release gas, and exudate carbon, thus creating aerobic niches, avoiding re-suspension of nutrients and sludge, and increasing aerobic degradation. This activity was confirmed with the Eh values (Table 1), where more aerobic conditions in planted microcosms were observed (308–357 mV) compared with unplanted microcosms (222–258 mV), such redox conditions in microcosms with plants can favor the removal of nitrogen by nitrification.

On the other hand, nitrogen and phosphorous compounds are macronutrients for plants and microorganisms. Thus, a certain amount of N and P could serve for biomass synthesis, and thus, it is expected that there will be a higher removal in microcosms with plants than in unplanted systems. Other routes of nitrogen removal in CWs (partial nitrification-denitrification, anammox, dissimilatory nitrate reduction, and Canon process) need to be evaluated in order to identify the complete panorama on nitrogen removal as described by Saeed and Sun [31] and Mitsch and Gosselink [32]. In the case of COD and BOD_5, a high biodegradability of organic material is expected when the relation BOD_5/COD is close to 1. In this study, the value was 1.25 [33]), with the observed removal values oscillating between 52% and 73% for COD and 67% and 83% for BOD_5 (Table 3). The values obtained revealed that the water was considered as not being heavily contaminated and was almost acceptable in quality, according to the references of the Mexican National Water Commission [34]. This Commission has been monitoring the water quality of surface water since 1974 based on COD, BOD_5, and TSS parameters.

Besides, in studies using gravel with typical plants of wetlands (*Cyperus*, *Phragmites*, and *Typha* spp.), the removal of pollutants was similar to those obtained in this study, mainly using *P. sagittata* and *C. indica* (Table 4).

Table 3. Water quality parameters in the influent and effluent, and mean removal percentages in the microcosms (n = 600).

Parameter	Wetland Plants in Different Substrates							
	Canna indica		*Pontederia sagittata*		*Spathiphyllum wallisii*		Control	
	PR	TS	PR	TS	PR	TS	PR	TS
COD								
IC	375 ± 72.8							
EC	70.7 ± 19.8	67.9 ± 20.2	65.6 ± 16.9	62.7 ± 12.8	124.6 ± 12.8	110.3 ± 13.3	205.6 ± 21.9	209.4 ± 20.5
Removal (%)	81.1 ± 18.4 [a]	81.9 ± 22.6 [a]	82.5 ± 16.5 [a]	83.3 ± 17.9 [a]	66.8 ± 19.3 [b]	70.6 ± 11.3 [b]	45.2 ± 14.1 [c]	44.2 ± 16.9 [c]
BOD_5								
IC	298.3 ± 69.2							
EC	82.2 ± 18.4	80.6 ± 20.1	82.6 ± 22.6	83.9 ± 31.2	104.8 ± 18.8	100.6 ± 21.9	200.6 ± 28.4	212.4 ± 29.6
Removal (%)	72.4 ± 22.6 [a]	73.0 ± 32.2 [a]	72.3 ± 26.3 [a]	71.8 ± 12.9 [a]	54.8 ± 16.6 [b]	52.9 ± 12.5 [b]	32.8 ± 16.4 [c]	28.8 ± 18.1 [c]
TKN								
IC	60.2 ± 09.7							
EC	20.2 ± 06.8	19.5 ± 10.1	18.6 ± 12.3	23.1 ± 11.6	34.5 ± 09.7	32.6 ± 10.9	45.7 ± 08.4	48.7 ± 09.0
Removal (%)	66.4 ± 12.1 [a]	67.6 ± 11.4 [a]	69.1 ± 10.3 [a]	61.6 ± 12.9 [a]	42.7 ± 16.6 [b]	45.8 ± 12.5 [b]	24.1 ± 16.4 [c]	19.1 ± 18.1 [c]
NO_3^--N								
IC	8.88 ± 0.24							
EC	3.06 ± 0.61	2.85 ± 0.16	2.56 ± 0.92	2.82 ± 0.83	2.81 ± 0.64	5.78 ± 0.72	7.13 ± 0.33	7.23 ± 0.24
Removal (%)	65.5 ± 11.8 [a]	67.9 ± 9.6 [a]	71.2 ± 14.8 [a]	68.2 ± 12.0 [a]	34.6 ± 16.3 [b]	34.9 ± 16.2 [b]	19.7 ± 7.6 [c]	18.5 ± 2.3 [c]
NH_4^+-N								
IC	30.06 ± 0.64							
EC	10.08 ± 0.17	10.14 ± 0.22	10.0 ± 0.32	10.06 ± 0.30	10.49 ± 0.29	10.54 ± 0.31	20.11 ± 0.31	20.04 ± 0.32
Removal (%)	64.7 ± 14.1 [a]	62.7 ± 11.3 [a]	67.6 ± 12.2 [a]	65.4 ± 13.6 [a]	51.3 ± 12.1 [b]	49.7 ± 11.2b [b]	31.0 ±04.1 [c]	33.3 ± 03.5 [c]
PO_4^{-3}-P								
IC	9.51 ± 0.97							
EC	3.22 ± 0.19	3.01 ± 0.33	2.92 ± 0.22	3.06 ± 0.41	4.86 ± 0.67	4.26 ± 0.78	7.54 ± 0.48	7.74 ± 0.45
Removal (%)	66.1 ± 4.6 [a]	68.3 ± 5.8 [a]	69.3 ± 6.6 [a]	67.8 ± 6.1 [a]	48.9 ± 9.4 [b]	55.2 ± 8.3 [b]	20.9 ± 2.8 [c]	18.8 ± 1.8 [c]

IC = Influent concentration (mg/L^{-1}), EC = Effluent concentration (mg/L^{-1}). Values are average ± Standard error, different letters indicate significant differences between the columns at 5% significance level PR: microcosms with porous river rock, TS: microcosms with tepezyl.

Is important to describe that similar to this study, other works have reported a high removal efficiency of pollutants by growing ornamental plants in CWs (Table 4). For example, Olguín et al. [4] used *Pontederia sagittata* for the removal of diluted sugarcane molasses, using volcanic gravel as substrate, showing removals of organic matter between 80% and 85%. Such results revealed that TS and PR should be used for similar removals, without the necessity of purchasing volcanic gravel, and allowing the reuse of TS of residues in construction. Besides, in this study, the molasses was diluted, a situation that was not necessary in this study. Another case is the study by Calheiros et al. [35], who reported that the use of ornamental flowering plants (*Canna indica*, *Iris pseudacorus*) and typical vegetation of natural wetlands (*Typha latifolia*, *Phrgamites australis*), grown in expanded clay (Filtralite®MR) as the substrate, in treating tannery wastewater showed COD reductions of41% to 73% and BOD_5 reductions of 41% to 58%. Furthermore, the plants from natural wetlands were the only plants that were able to establish successfully. In this study, the ornamental flowering plants revealed a removal efficiency when grown in TS and PR substrates, reinforcing the instructions of using such material as filters in CWs. On the other hand, Cui et al. [36], using coal burn slag, blast furnace slag, and sand slag as filter media and plants of *Canna indica*, reported that in one year of study, 60% of phosphorous and ammonium was removed. In this study, the removals of the same parameters was similar in the presence of *Pontederia s.* and *Canna i.*, with the difference in the substrate of reuse (TS), and PR was easy to obtain in areas with rivers. In an experimental study, Macci et al. [37] reported removals of nitrogen and phosphorous by 63% to 67% using gravel as the substrate and *Canna indica*. Those studies showed the importance of plants and substrates in the removal of pollutants in CWs, and reported removal efficiencies similar to those reported in this study with TS and PR, thus highlighting such substrates should be considered in new CW design.

Another aspect that can be considered for future studies is the use of *S. wallisii* in polyculture CWs, where the position of this species could be close to the effluent. It is important to consider that in the entrance, there are more charges of nutrients and it will be more difficult for this plant to uptake, given the fact that this species was the least adapted to CWs according to the growth measures (Figure 2; Figure 3). While in the final area of a cell of CWs, the charge of nutrients is low, a characteristic that may be feasible for the better growth of ornamental plants, such as *S. wallisii* [38,39].

Table 4. Comparison of removal pollutants within different plants of natural wetlands versus the ornamental plants used in this study.

Plants	Parameters (Removal %)					Filter Media	Source
	BOD_5	COD	NH_4^+-N	NO_3^--N	PO_4^{-3}-P		
Canna indica, *Iris pseudacoru*, *Typha latifolia*, *Phrgamites australis*	41–58	41–73	-	-	70	expanded clay	[35]
Canna indica	-	-	60	-	60	coal burn, blast furnace and sand	[36]
Canna indica	-	-	67.4	-	63.5	Gravel	[37]
Cyperus ligularis	-	69	38	58	26	Gravel	[40]
Cyperus esculentus	-	59	36	50	42		[41]
Typha sp.	82	-	-	60	56	PR	[25]
Phragmites australis	-	75	26	-	17	Gravel	[42]
Phragmites australis	78	73	78	75	64	Gravel	[43]
Typha latifolia	81	84	69	71	71	Gravel	[43]
Pontederia sagittata	84.8	80.4	6.12	57.3	0	Volcanic gravel	[4]
				33–67	54–70	Gravel	
Canna indica	72–73	81–82	62–65	65–68	66–68	PR and TS	This study
Pontederia sagittata	71–72	82–83	65–68	68–71	67–69	PR and TS	This study
Spathiphyllum wallisii	52–55	66–71	49–51	34–35	48–55	PR and TS	This study

3.3. Climatic Conditions Effect

No statistic effect ($p > 0.05$) of the removal of pollutants was observed after comparing within climatic seasons by species (Figure 4). Stein and Hook [44] reported that the net effect of seasonal variation in water treatment in wetlands is greater in winter, because along the season, the plant-mediated oxygen transfer is affected by cold temperatures. This occurs mainly in temperate zones, however, in the tropical areas, such as this study, all the seasons were similar in temperature (26.1, 26.6, 25.2, and 20.3 °C in spring, summer, autumn, and winter, respectively). Also, DO and Eh in the water showed good conditions for the survival of microorganisms, and plant growth. Such conditions are important for the treatment of wastewater (Table 2). Allen et al. [45] only observed differences in the removal of pollutants in wetland microcosms when the temperature changed from 24 °C to 4 °C, changes not observed in this study.

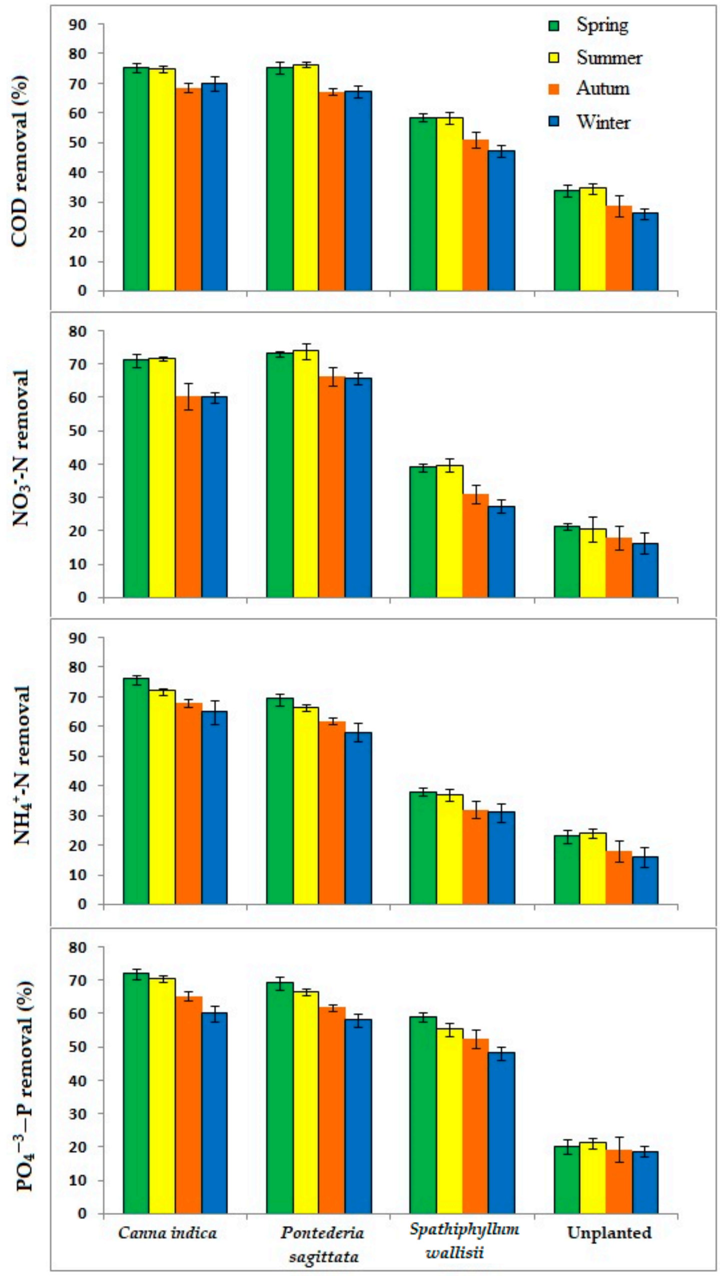

Figure 4. Seasonal pollutant removal in the CWs in the study using different plants.

4. Conclusions

This study highlighted that FD-CWs using ornamental plants (*Canna indica*, *Pontederia sagittata*, *Spatyphilum walisii*) and PR or TS as a filter media, components rarely evaluated in CWs, such CWs design was ffective technologies for the removal of pollutants. In particular, using *Canna indica* and *Pontederia sagittata* with removal efficiencies of COD, BOD_5, TKN, NO_3^--N, NH_4^+-N, and PO_4^{-3}-P around 70% to 85%, showing the importance of fill and drainage design in CWs. The removal of phosphates in this study was similar to removals using typical substrates, indicating the importance of PR and TS as filter media. No statistic effect of the removal of pollutants was observed after comparing within climatic seasons by species related to the similar climatic conditions observed in tropical regions in all the study period. Consequently, this study suggests that *Canna indica* and *Pontederia sagittata* grown in tepezyl and porous rock of river in FD-CWs conditions are a good option for the removal of pollutants. Thus, its use is convenient in future construction of wetland design. This also suggests that additional studies should be carried out in tropical regions with ornamental plants to validate its commercial use as described in this paper. Also, new studies conducting a comparison of tepezyl and porous river rock with other commonly used filling materials on the pollutant removal and suitability for plant growth should be realized.

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