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Performance Comparison of Vertical Flow Treatment Wetlands Planted with the Ornamental Plant *Zantedeschia aethiopica* Operated under Arid and Mediterranean Climate Conditions

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Abstract: This work compares the performance of vertical subsurface flow treatment wetlands (VSSF TWs) for wastewater treatment, planted with *Zantedeschia aethiopica* (Za), here operated simultaneously under two different climate conditions, arid and Mediterranean. The experimental setup was divided into two treatment lines for each climate condition: three VSSF TWs planted with *Schoenplectus californicus* (Sc) (VSSF-S), as the control, and three VSSF TWs planted with *Zantedeschia aethiopica* (Za) (VSSF-Z), as the experimental unit. The four treatment systems were operated at a hydraulic loading rate of 120 mm/d during spring and summer seasons, in two locations, Iquique (Atacama Desert, Chile) and Talca (Central Valley, Chile). The water quality in effluents, plant development, and water balance were used as performance measures. In terms of the water quality, the influents' characteristics were similar in both climates and classified as "diluted". For the effluents, in both climate conditions, average COD and TSS effluent concentrations were below 50 mg/L and 15 mg/L, respectively. In both climate conditions, average TN and TP effluent concentrations were below 40 mg/L and 2 mg/L, respectively. Furthermore, only total nitrogen (TN) and total phosphorus (TP) in effluents to VSSF-Z had a significant effect ($p < 0.05$) in relation to the climate condition. Regarding plant development, *Za* showed a lower height growth in both climate conditions, with arid consistently 0.3 m and Mediterranean decreasing from 0.6 m to 0.2 m. However, the physiological conditions of the leaves (measured by chlorophyll content) were not affected during operation time in both climates. Water balance showed that it was not influenced by the climate conditions or plant, with water loss differences below 5%. Therefore, taking into account the water quality and water balance results, *Zantedeschia aethiopica* can be used in VSSF TWs in a way similar to traditional plants under arid and Mediterranean climates. However, its use has to be carefully considered because lower height could affect the esthetics for its implementation in the VSSF TWs.

Keywords: arid; Chile; Mediterranean; ornamental plants; vertical treatment wetlands; *Zantedeschia aethiopica*

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1. Introduction

Treatment wetlands (TWs) are considered reliable wastewater treatment technology [1,2]. Among the different types of TWs, vertical subsurface flow (VSSF) is an alternative to traditional horizontal subsurface flow (HSSF), which is the most commonly used TW worldwide [3,4]. VSSF are becoming more common than HSSF because of their potential to cope with higher organic loadings (>6 g BOD_5/(m^2-d) [5]), capacity to nitrify (ammonium removal above 80% [6,7]), and smaller footprint demand (VSSF TWs, 2–4 m^2/Inhab [5,8]; HSSF TWs, 5 m^2/Inhab [9]). Additionally, VSSF TWs have more design and operational options (surface area, bed depth, filter medium, feeding mode, plant species [10]) compared with HSSF; therefore, its adaptability to operational conditions makes VSSF more suitable as a sustainable sanitation system.

VSSF TWs with sequential loading patterns are the most commonly employed and recommended by the few existing design guidelines, which come mostly from developed countries with typical temperate climate conditions [8,11–13]. However, the design parameters and operation schemes of VSSF TWs must be selected based on the environmental conditions of the site (including climate), the discharge quality, and the characteristics of the influent water [10,14]. Therefore, the implementation of VSSF TWs and their adaptation to new climate conditions (arid, tropical, Mediterranean, boreal) must be assessed, and efforts are underway to better understand the pollutant removal performance, plant selection, and innovative operational schemes [1,15–17]. However, up to now, no performance comparative studies between VSSF TWs of systems operating in two very different climates, such as arid and Mediterranean, or reporting on the use of ornamental flowers have been published.

Plants grown or maintained for their aesthetic features, such as color, fragrance, flower production, attractive patterns, or design, are called ornamental plants [18]; these plants are a promising alternative for use in TWs because of their aesthetic and commercial value, possibility for site integration, and other added value related to biodiversity and ecosystem services [19]. Ornamental plant species such as *Agapantus* spp., *Canna* spp., *Iris* spp., *Heliconia* spp., *Tulbaghia* spp., *Cyperus* spp., *Strelitzia* spp., and *Zantedeschia* spp. have been used in TWs [20–22]. Among the species used in TWs, *Zantedeschia aethiopica* has been reported as having different development patterns in tropical, subtropical, and Mediterranean climate conditions, similar to the way that *Phragmites australis* (a more common plant used in TWs) has been used [19,23,24], but information about its use in TWs under arid conditions has not been reported.

Based on this information, the present paper compares the performance of VSSF TWs planted with *Zantedeschia aethiopica* that are operated simultaneously to treat wastewater under two different climate conditions, arid and Mediterranean.

2. Materials and Methods

2.1. Influent Water

Wastewater was used as the influent for feeding the experimental systems. In the case of the arid climate, wastewater was obtained after passing through a 20 mm screen from a full-scale wastewater treatment plant (WWTP), which serves approximately one-third of the Iquique city. Subsequently, the water was stored in 20 L plastic cans in a dark place at 4 °C for a maximum storage time of 3 weeks [25–27]. For feeding the experimental setup, wastewater was diluted by 30%, simulating an effluent from the primary treatment (treatment stage recommended previous to TWs in different guidelines [8,13]), here considering the average BOD_5 removal capacity of this treatment stage [5,28]. For the system installed in the Mediterranean climate, wastewater was obtained from effluents from a septic tank (primary treatment), serving a single household of six inhabitants. For both climates, the influent was transported to a pumping well and subsequently pumped into the experimental system. Table 1 shows the physical and chemical influent characteristics in both climate conditions.

Table 1. Physical and chemical characterization of the wastewater.

Parameter	Units	Arid		Mediterranean	
		Average ± Standard Deviation	Range (Min–Max)	Average ± Standard Deviation	Range (Min–Max)
pH	Uni.	7.6 ± 0,4	7.2–8.2	7.2 ± 0.5	6.7–7.9
T	°C	23.7 ± 1.5	20.8–25.4	20.2 ± 2.3	15.5–22.1
EC	µS/cm	3045 ± 386	2250–3439	1037 ± 420	440–1550
COD	mg O_2/L	143 ± 50	100–223	116 ± 53	60–206
TSS	mg TSS/L	238.9 ± 196.2	67–516	29.1 ± 9.5	17.7–47.0
NH_4^+-N	mg NH_4^+-N/L	49.9 ± 15.2	30.9–73.8	23.2 ± 8.5	10.0–40.8
NO_3^--N	mg NO_3^-N/L	0.5 ± 0.4	0–6	0.0 ± 0.0	0–0
TN	mg TN/L	56.3 ± 14.5	41.1–78.0	23.3 ± 8.7	11.2–41.6
PO_4^{-3}-P	mg PO_4^{-3}-P/L	3.5 ± 1.2	1.6–5.3	3.4 ± 1.7	0.4–5.5
TP	mg TP/L	5.9 ± 2.9	3.0–10.2	3.6 ± 1.7	0.4–5.5
Coliforms	Log_{10} (MPN/100 mL)	5.8 ± 2.4 [a]	2.8–7.7	6.2 ± 0.9 [b]	5.0–7.5

n = 6 for all water quality parameters in each location. [a] in the arid conditions is fecal coliforms. [b] in the Mediterranean conditions is total coliforms.

The concentrations in Table 1 show similarities between the two wastewater influents for the arid and Mediterranean climate conditions. Furthermore, the values in Table 1 are in agreement with wastewater characteristics reported in several studies for arid and Mediterranean climate conditions [1,23,25,27]. According to Henze et al. [29], the wastewater can be considered "diluted" or "very diluted", which is expected for primary treated wastewater. Three of the parameters show important differences: electrical conductivity (EC), total suspended solids (TSS), and total nitrogen (TN). For the arid conditions, EC values were above 1500 µs/cm, which are typically found in wastewater under this climate condition [1,27]. EC values below 5000 µs/cm have not shown significant influence on organic matter, nitrogen, and phosphorus removal in TWs [30]. TSS differences are related with the primary treatment employed at each climate condition before the TWs: for Mediterranean conditions a septic tank, and for arid conditions only a 20 mm screen. Despite this difference in influent solids concentrations, an effect on the effluents is not expected since TWs are very effective in removing solids (removals above 90%) [8]. TN for the influent under arid conditions was taken from a full-scale WWTP, receiving water from different sources, and therefore not only domestic wastewater is discharged, which is different from the influent of the Mediterranean condition. This TN increase for arid conditions will increase TN loadings on TWs, and thus, an effect on the N species in the effluents could be associated to it [20].

2.2. Experimental Setup

Six experimental unit mesocosm VSSF TWs were constructed and operated in each one of the evaluated two climate conditions. VSSF TWs were designed and built following the Danish guidelines [8]. Under arid conditions, the experimental units were installed at the CIDERH Experimental Laboratory at Arturo Prat University (Huayquique Campus) in the city of Iquique (Coast of the Atacama Desert, Tarapacá Region, Chile, 20°16′14″ S, 70°07′45″ W; average annual temperature, 19.2 °C; average annual precipitation, 1.3 mm; Köppen–Geiger climate classification, BWn, coastal desert with abundant cloudiness [31–34]). These experimental units were isolated only from the exterior environment by anti-aphid mesh for protecting plants. Meanwhile, the systems under Mediterranean conditions were installed in a room covered by a translucent roof to allow natural light and without temperature control to guarantee environmental temperatures. The lab was located close to the city of Talca (Maule Region, Central Valley, Chile, 35°27′50″ S, 71°37′15″ W; average annual temperature, 14.2 °C; average annual precipitation, 643 mm; Köppen–Geiger climate classification, CSa, hot summer Temperate Mediterranean [31–33]). The experimental setup was divided into two treatment lines in each climate condition; three of the VSSF TWs were planted with *Schoenplectus californicus* (Sc) as a blank or control

(VSSF-S), and three of the VSSF TWs were planted with *Zantedeschia aethiopica* (Za), which served as the experimental unit (VSSF-Z). The VSSF TWs were built using 0.2 m diameter PVC pipes and a total bed depth of 1.10 m. A 0.1 m freeboard was used at the top for all the VSSF TWs. The VSSF TWs were filled with a 0.1 m gravel layer (Ø, 19 mm) at both the top and bottom layers. Sand (Ø, 0.06–4.75 mm) was used as the main support media with an effective depth of 0.8 m. Sand was used as a support medium (in both experimental sites) in agreement with the proposed values for the sand percolation rate (SRP) between 45 s and 75 s [12]. Figure 1 summarizes the characteristics of the construction of mesocosm VSSF TWs. One individual of *Schoenoplectus californicus* (Sc) and *Zantedeschia aethiopica* (Za) were planted in each experimental unit.

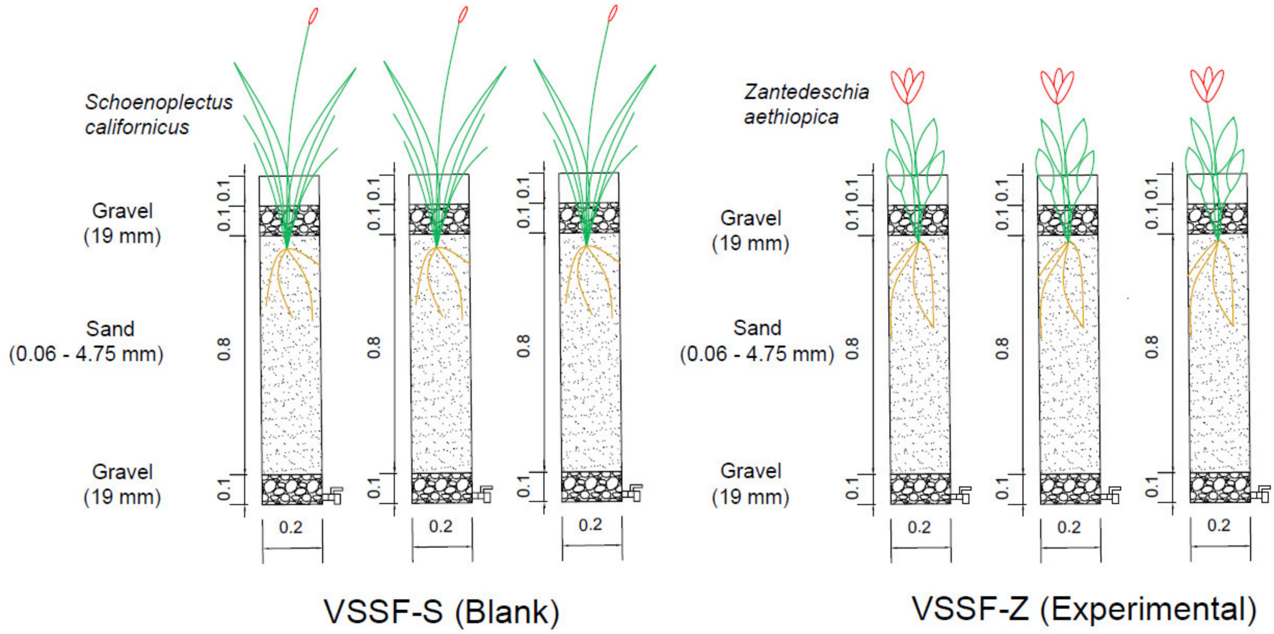

Figure 1. Experimental setup. Dimension in meters if there are no specifications.

2.3. Operation and Monitoring Strategy

A hydraulic loading rate (HLR) of 120 mm/d was applied to feed the VSSF TWs. The HLR was defined after considering a contribution of 100 L/(inhab-d) [35], here applied to an area of approximately 0.85 m^2/inhab for instantaneous HLR (recommended for design, 3.0 m^2/inhab for the total VSSF TWs system). The daily loading was applied in 12 pulses per day according to recommendations by Brix and Arias [8], Olsson [36], and Stefanakis et al. [37]. For each treatment line, a 5-day loading period and a 10-day resting period were employed as an operational strategy according to recommendations by Stefanakis et al. [37]. The VSSF TWs were operated under testing conditions for a period of 1 month as a startup to allow the development of biofilm as a plant establishment, and, after that, for 5 months.

Water grab samples were collected at the influent and effluents that passed through VSSF-S and VSSF-Z. The physical and chemical parameters of pH, temperature (T), oxidation reduction potential (ORP), EC, chemical oxygen demand (COD), total suspended solids (TSS), ammonium (NH_4^+-N), nitrate (NO_3^--N), TN, phosphate (PO_4^{-3}-P), and total phosphorus (TP) were measured every 3 weeks. In the case of pathogens, fecal coliforms (FC) were measured for arid conditions and total coliforms (TC) for Mediterranean condition every 3 weeks. The samples were taken, transported refrigerated, and analyzed upon arrival. The transportation time was less than 30 min. For the systems tested under arid conditions, water samples were analyzed at the Water-Plant-Soil CIDERH Laboratory, except for FC, which was analyzed in the laboratory of the water enterprise, Aguas del

Altiplano, both laboratories located at Iquique city. For the systems run under Mediterranean conditions, samples were analyzed at the Water Quality Laboratory at Universidad Católica del Maule (UCM) in Talca city.

To accurately determine the water balance (water loss by evapotranspiration and evapotranspiration rate (ETP)), influent and effluent water volume was measured for each loading period. Meteorological information (air temperature) was obtained from MeteoChile [33] using meteorological stations, Diego Aracena Airport for arid conditions, and UC-Maule for Mediterranean conditions.

To assess plant development in the VSSF TWs, the physiological characteristics of the plants, such as height and chlorophyll content of the leaves, were measured every week. These measures were taken from the startup period. In the case of chlorophyll, nondestructive methods (optical method) were employed. Because of the leaf thickness of *Schoenoplectus californicus*, chlorophyll content was measured at the top of the leaf according to Vera-Puerto et al. [38], here at a point 10 cm before the leaf ending.

2.4. Analytical Methods

The influent and effluent samples were filtered with a 0.7 µm pore size Whatman membrane. Here pH, T, ORP, and EC were measured with specific electrodes using a multiparameter Portable Hana HI 98194. The physical and chemical parameters COD, NH_4^+-N, NO_3^--N, TN, PO_4^{-3}-P, and TP were measured photometrically using a multiparameter photometer Hanna HI83399. The reagent test kits were as follows: (a) COD, HI-93754B (medium range); (b) NH_4^+-N, HI-93715 (medium range) and HI-93733 (high range); (c) NO_3^--N, HI-93728 (medium range); (d) TN, HI-93767 (low range); (e) PO_4^{-3}-P, HI-93713 (low range) and HI-93717 (high range); (f) TP, HI-93763B (high range). The determinations correspond to modifications of the standard methods from APHA-AWWA-WPCF [39]. TSS were analyzed gravimetrically according to the procedures in APHA-AWWA-WPCF [39]. The FC pathogens were analyzed using multiple tube fermentation according to INN [40], and TC were analyzed using the Colilert simplified method [41].

Plant development was measured by using a tape measure [27,42]. Chlorophyll content was measured using a portable SPAD-502 Plus Konica Minolta [43,44].

Water volume was measured using a graduated cylinder. ETP was calculated as the difference between water volume influent and effluent, as divided by area and number of days for each operative cycle (5 days) [27].

2.5. Statistical Analysis

Statistical analysis was performed using INFOSTAT with a significant level of $\alpha = 0.05$ [45] to determine the significant influence of plant and climate. For a response, the pH, T, EC, ORP, COD, TSS, TN, NH_4^+-N, NO_3^--N PO_4^{-3}-P, and TP concentrations from the VSSF TWs were used. In addition, chlorophyll measured at each plant and data calculated for ETP were also compared. The data were subjected to the Shapiro–Wilk normality test to determine the statistical test for comparison. Then, to determine the effects of plant VSSF-S versus VSSF-Z for each climate condition (arid and Mediterranean), the following were compared: (a) data with normal distribution, *t*-test, and (b) data without a normal distribution, Wilcoxon test. For the effect of the different climate conditions, VSSF-Z (arid) versus VSSF-Z (Mediterranean) and VSSF-S (arid) vs. VSSF-S (Mediterranean) were compared: (a) data with normal distribution, *t*-test, (b) data without normal distribution, Wilcoxon test.

3. Results and Discussion

3.1. Operational Conditions: pH, T, Ec and ORP

Table 2 summarizes the behavior of pH, T, EC, and ORP for effluents to the VSSF TWs operated in arid and Mediterranean climate conditions. The average values of pH between 8.0 and 9.0 are similar between VSSF planted with Sc and Za for both climate conditions. No significant difference ($p > 0.05$) was found based on plant species (in each climate condition), or for the effect of climate condition. Thus, the pH values are not expected to affect the removal process for organic matter (COD), nutrients ($NH_4{}^+$-N and $PO_4{}^{-3}$-P), and plant development [25,26,46]. In the case of temperature, for all VSSF TWs, average values are above 20 °C. However, a significant difference (p < 0.05) was found due to the effect of the climate condition. Despite this, the similarity between the mean values for temperature in arid and Mediterranean climate conditions indicates that temperature should not have an effect on the process removal of organic matter and nutrients, especially nitrogen, because the temperature is above 15 °C, which is an appropriate temperature for nitrification to take place in TWs [25]. These results were expected because the experiment took place during the austral spring and summer seasons; this coincides with previous results reported during this operation time in Mediterranean climate conditions [25,42]. However, it is possible that temperature reductions during the autumn and winter seasons, and especially a focus on nitrogen behavior, have to be followed.

Table 2. pH, temperature (T), electrical conductivity (EC), and oxidation-reduction potential (ORP) for each treatment wetland in both climate conditions.

Parameter	Units	Arid		Mediterranean	
		VSSF-S	VSSF-Z	VSSF-S	VSSF-Z
pH	Uni.	8.4 ± 0.6	8.6 ± 0.8	8.4 ± 0.2	8.3 ± 0.1
T	°C	23.2 ± 1.7	23.0 ± 1.5	20.2 ± 1.5	20.1 ± 1.4
EC	µS/cm	3384 ± 532	3326 ± 594	1274 ± 168	1347 ± 438
ORP	mV	±147 ± 140	±108 ± 100	±168 ± 17	±167 ± 17

n = 6; T, temperature; EC, electrical conductivity; ORP, oxidation-reduction potential.

The average values for EC in Table 2 have similar values for the influent wastewater for each climate condition (Table 1). For both climate conditions, an increase of around 10% for all effluents to VSSF TWs can be found. This increase in EC effluent concentration is explained by evapotranspiration because of plant development in the treatment system [27]. In the case of arid conditions, EC average values for all effluents are above 3.300 µS/cm, while for the systems running under Mediterranean conditions, the average values for all effluents are above 1250 µS/cm. A significant difference (p < 0.05) was found between the two climate conditions and for each one of the plants evaluated, Sc and Za. The EC measured in the effluents can be explained by the EC measured in the wastewater employed for feeding the treatment system. On the other hand, the similar behavior in EC for effluents (p > 0.05) to VSSF TWs planted with Sc and Za in each climate condition shows that the change of a typical plant (Sc) for an ornamental plant (Za) did not show an effect on EC.

The average ORP values for all VSSF TWs in the two climate conditions were similar, with values above +100 mV suggesting aerobic conditions. No significant difference (p > 0.05) was found based on plant species (in each climate condition), or for the effect of climate condition. These ORP values (>+100 mV) are in accordance with the results from other VSSF TWs that are unsaturated and operated with sequential feeding schemes (fed by pulses), indicating that aerobic conditions were present in all TWs [8,47].

3.2. Effluent Concentrations and Removal Efficiency

Table 3 and Figure 2 summarize the effluent concentration and removal efficiencies for all VSSF TWs operated under the two climate conditions. Table 3 and Figure 2 show the average COD effluent concentrations below 45 mg/L, here with the 75th percentile below 60 mg/L. No significant difference (p > 0.05) could be established based on the plant species or climate condition. COD removal efficiencies for arid conditions were always above 65%, with less than a 10% difference in the removal efficiencies achieved in Mediterranean conditions (around 55%, Table 3). This removal capacity can be explained by the oxidizing conditions present in the TWs, which can cope with organic matter in both climate conditions (ORP > +100 mV, Table 2). The average TSS values were always below 15 mg/L, and even the 75th percentile was always below this value. TSS removal efficiencies were always above 85% for both climate conditions and for the two plant species. The TSS removal capacity in both climate conditions can be explained by the physical filtration that was developed in the VSSF TWs [47]. The similarity in removing organic matter and solids shows that Za can be recommended as a plant species for VSSF TWs, even in arid conditions. Furthermore, the results for organic matter and solids removal are in agreement with other VSSF TWs operated under arid conditions [17,48] and Mediterranean conditions [49–51] with ornamental or common plant species.

Regarding NH_4^+-N, there were no significant differences ($p > 0.05$) in terms of effluent concentrations between VSSF TWs planted with Za and Sc for both climates, and when the same plant species were compared between the two climate conditions. The almost complete removal of ammonium (>95%) transformed to nitrate was achieved during the whole experiment time for all treatment systems in both climate conditions. This is, once again, the result of the prevalent aerobic conditions (ORP > +100 mV, Table 2) in all TWs, as expected from VSSF TWs [10,52]. In addition, the average water temperatures between 20 °C and 25 °C, as registered in the effluents of all TWs in the two climate conditions (Table 2), favor the nitrification process because a temperature range between 16 °C and 32 °C is the favorable range for nitrification in TWs [25,53].

The TN effluent concentration showed no significant differences ($p > 0.05$) by plant species in each climate condition, showing a similarity between VSSF TWs planted with common plant species (Sc) and ornamental plant species (Za). On the other hand, there were significant differences ($p < 0.05$), when ornamental plant species were used in different climate conditions. This result can be explained by the effect of influent TN concentrations (Table 1) because the average influent concentrations for the systems in arid conditions are two times higher than those running under Mediterranean conditions [53]. The proportion is maintained for average TN effluent concentrations, and it is reduced to 1.5 times at the 75th percentile (Table 3 and Figure 2). Despite the difference in TN effluent concentrations, Table 3 shows that average removal efficiencies for TN were better in arid conditions—above 30%—while for Mediterranean conditions, the average TN removal was 20%, with a large variability (with a standard deviation higher than mean value). These average removal efficiencies are in accordance with the reported literature for VSSF TWs, which vary between 20% and 80% [54]. Despite this, the results for TN in Table 3 and Figure 2 show that TN processing could be different for each climate condition, but among the different classical pathways for TN removal, such as biological (i.e., ammonification, nitrification, denitrification, plant uptake, biomass assimilation, dissimilatory nitrate reduction) or physical and chemical (i.e., ammonia volatilization, and adsorption) [53], the results of the current study are only conclusive regarding similar behavior for nitrification, hence suggesting the necessity of a specific study of TN processing to understand which one of the pathways has different development as a consequence of VSSF TWs operating under different climate conditions.

In terms of phosphate, as in TN, no significant differences ($p > 0.05$) by plant species in each climate condition could be established. This shows the similarity in behavior of VSSF TWs planted with common (Sc) and ornamental plants species (Za). However, when both plant species were compared between the two climate conditions, a significant difference ($p > 0.05$) could be established. This result shows that climate conditions could have an influence on VSSF TWs planted with the ornamental plant Za. Despite this, the average effluent concentrations of VSSF TWs planted with Za in arid and Mediterranean climates were always below 0.8 mg/L, with removal efficiencies above 80% (Table 3). This removal capacity is higher compared with the values reported in the literature for VSSF TWs below 60% [8,47,49]. In addition, the same behavior was obtained for TP, with average removal efficiencies above 70% for all VSSF TWs. This high performance can be explained by the high phosphorus removal rates achieved during the early operation periods because the media has all the potential reactive capacity [42]. In TWs, phosphorus is also uptaken by plants or adsorbed onto the substrate and/or precipitated [47,55]. Thus, the adsorption capacity of traditional sand media (<0.05 gP/kg [26]) can explain the removal efficiencies being above 70% in the initial operation period (six months). However, it is expected that this removal will decrease over time.

Pathogens, here measured as coliforms (fecal in arid, and total in Mediterranean), showed similar behavior between the plant species for both climate conditions with removals above 2 Log_{10} MPN/100 mL (Table 3). The average values in all the effluents in the arid climate were below 3 Log_{10} MPN/100 mL of FC, which was considered a standard limit of discharge and/or reuse of effluents included in different guidelines and regulations [56,57]. The works of Otter et al. [51], Zurita et al. [58], and Adrados et al. [59] have reported that VSSF TWs provide removals ranging from one and four log units of pathogens (FC), which is similar to those achieved in the present study. Pathogen removal in VSSF TWs can be explained by removal mechanisms, including natural die-off because of starvation, predation, sedimentation, filtration, entrapment, and adsorption, but filtration would be the main pathway [60]. The similarity in pathogen removal in both climate conditions in the VSSF TWs suggests filtration as the main removal mechanism because all VSSF TWs had the same total bed depth (1.0 m), and no effect of climate condition was found.

Table 3. Final effluent concentrations and removal efficiencies for each treatment wetland in the two climate conditions.

Parameter	Units	Arid		Mediterranean	
		VSSF-S	VSSF-Z	VSSF-S	VSSF-Z
COD	mg O_2/L	31.5 ± 7.0 (77.4 ± 9.6)	45.3 ± 21.0 (68.6 ± 8.0)	41.8 ± 17.8 (56.3 ± 23.4)	42.5 ± 14.2 (56.2 ± 17.3)
TSS	mg TSS/L	8.8 ± 2.2 (94.5 ± 3.1)	12.0 ± 6.0 (92.2 ± 5.5)	1.1 ± 0.7 (96.2 ± 2.8)	2.5 ± 1.3 (88.7 ± 7.8)
NH_4^+-N	mg $NH_4^{\pm}$-N/L	0.4 ± 0.9 (99.4 ± 1.4)	0.3 ± 0.6 (99.9 ± 0.3)	0.2 ± 0.2 (98.9 ± 1.8)	0.3 ± 0.3 (98.4 ± 2.3)
NO_3^--N	mg NO_3-N/L	19.6 ± 6.0 (-)	15.5 ± 2.7 (-)	4.3 ± 2.0 (-)	5.9 ± 3.0 (-)
TN	mg TN/L	31.2 ± 10.6 (49.7 ± 6.6)	31.5 ± 12.2 (40.1 ± 10.6)	21.9 ± 7.5 (−5.2 ± 36.7)	15.8 ± 10.6 (20.7 ± 58.2)
PO_4^{-3}-P	mg PO_4^{-3}-P/L	0.9 ± 0.5 (71.9 ± 11.2)	0.6 ± 0.2 (81.0 ± 15.0)	0.2 ± 0.1 (95.8 ± 1.9)	0.1 ± 0.1 (95.9 ± 3.2)
TP	mg TP/L	1.6 ± 0.9 (71.5 ± 8.6)	1.4 ± 1.2 (80.9 ± 13.5)	0.2 ± 0.1 (95.8 ± 1.9)	0.1 ± 0.1 (96.3 ± 3.1)
Coliforms	Log_{10} (MPN/100 mL)	1.1 ± 1.0 [a] (4.7 ± 2.5)	1.1 ± 0.8 [a] (4.7 ± 2.5)	<3 [b] (>2)	<3 [b] (>2)

n = 6. Number without parenthesis are effluent concentrations. Number in parenthesis reported below concentrations are removal efficiencies (%), with exception in coliforms because removals are reported in log units. In the case of NO_3^--N not removal efficiencies are reported. [a] in the arid conditions is fecal coliforms. [b] in Mediterranean conditions is total coliforms and reported values are below the detection limit.

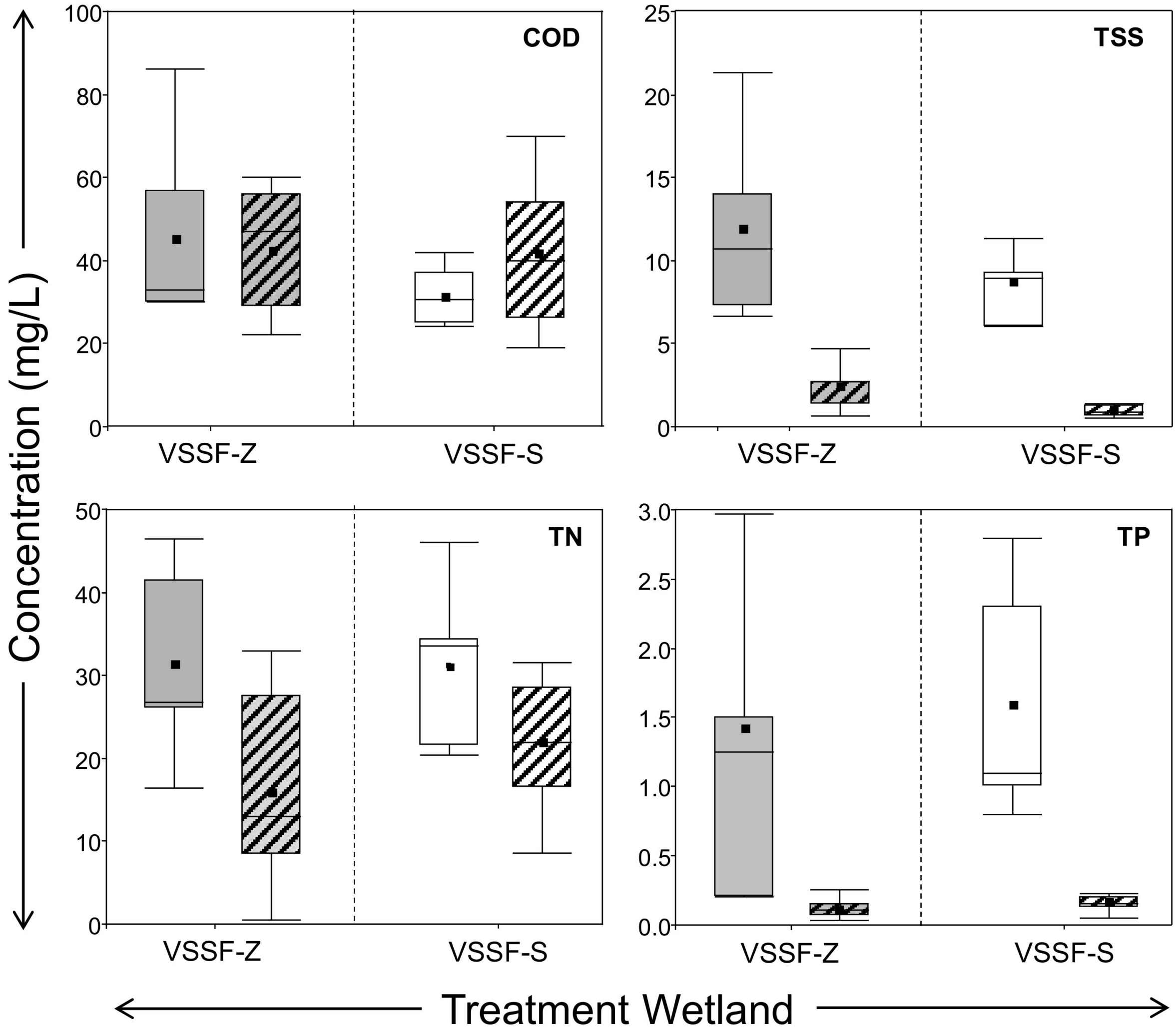

Figure 2. COD, TSS, TN, and TP effluent concentration by treatment wetland in both climate conditions. VSSF-Z (Arid) (■); VSSF-Z (Mediterranean) (▨); VSSF-S (Arid) (□); VSSF-S (Mediterranean) (▨).

3.3. Effect of Climate Variation on Plant Development

Figure 3 shows the heights of Za and Sc in both climate conditions. Table 4 shows the evolution of chlorophyll status for the total experimental time, including for the startup (1 month) and operational period (5 months).

Regarding height, the control plant, Sc, showed similar behavior in the two climate conditions, with mean values around 0.8 m. This result is in accordance with the works of Vera-Puerto et al. [38] (2021) and Vera et al. [27], where TWs operated in Mediterranean and arid conditions, respectively, showed a height of 0.9 m in 6 months of growing for *Schoenoplectus californicus* and 0.70 m for *Schoenoplectus americanus*. In the case of *Zantedeschia aethiopica* (Za) in Mediterranean conditions, the height was affected and decreased from 0.6 m to around 0.20 m at the end of the experimental period. While for Za growing in arid conditions, the height was maintained at around 0.30 m during the entire experimental time. Garner [61] showed that the height of Za varies between 0.45 m and 0.6 m. In TWs, the work of Marín-Muñiz et al. [62] reported a height of up to 0.5 m when Za was planted under tropical conditions and for a period of 6 months. Therefore, the results of the current study show that Za had adaptation problems in both climate conditions in the spring and summer seasons. In the case of a Mediterranean condition, the adaptation problems can be explained by the average air temperature increase because of the warm season. 15.3 °C (month 1) to 21.2 °C (month 6), but especially, its growth was affected by the maximum temperatures in December and January (month 3 and 4), with values above 30 °C [33]. Meanwhile, in arid conditions, the height of Za was affected by luminosity because in the coastal Atacama Desert, values up to 120 Klux have been reported [63]. However, these results should be analyzed carefully because the height of the plants should be followed over longer periods—at least a couple growing seasons, especially during the autumn and winter seasons—to obtain more conclusive results.

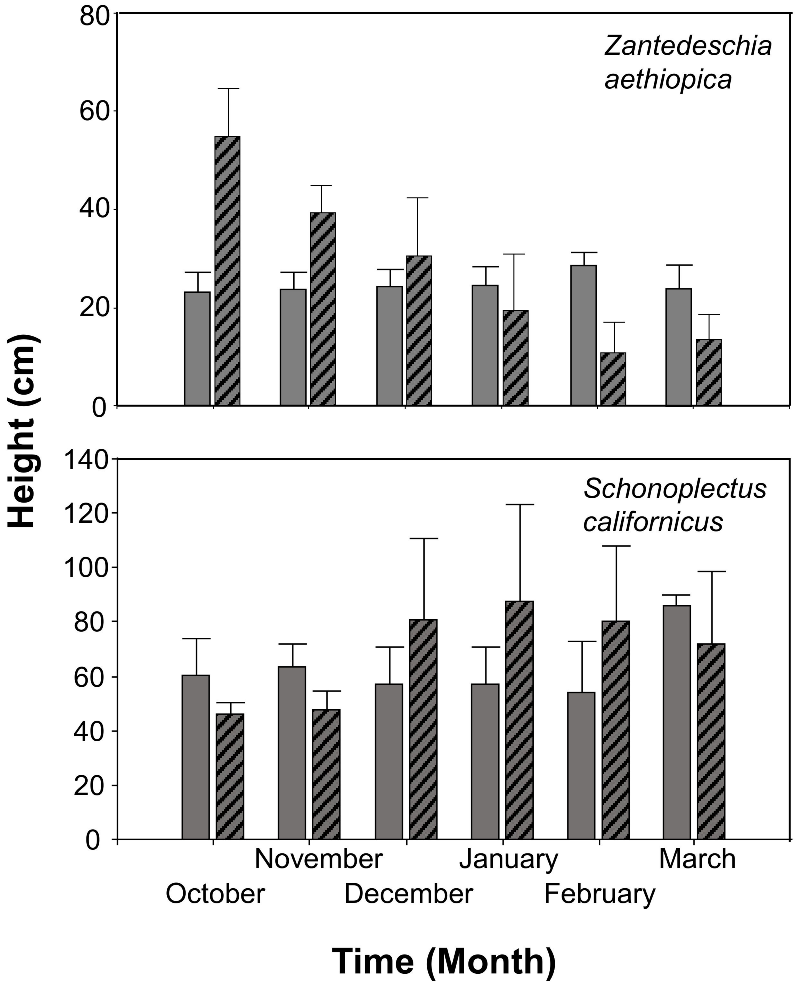

Figure 3. Evolution of plant height for *Zantedeschia aethiopica* and *Schoenoplectus californicus* during experimental time by each treatment wetland in both climate conditions. (Arid) (▭); Mediterranean (▨).

Table 4. Evolution of chlorophyll status (SPAD units) for each treatment wetland system in both climate conditions.

Month	Arid		Mediterranean	
	VSSF-S	**VSSF-Z**	**VSSF-S**	**VSSF-Z**
October (0)	- [a]	-	41.2 ± 30.5	57.4 ± 9.4
November (1)	5.3 ± 1.3	66.7 ± 12.8	48.8 ± 37.8	41.1 ± 16.5
December (2)	27.7 ± 19.1	72.4 ± 16.6	45.2 ± 29.4	41.6 ± 16.0
January (3)	26.6 ± 23.9	66.3 ± 18.1	63.9 ± 26.0	23.2 ± 22.9
February (4)	30.8 ± 13.5	56.1 ± 14.1	47.7 ± 35.3	45.6 ± 19.1
March (5)	-	-	44.9 ± 23.8	58.3 ± 19.1

n = 4 for each month. [a] Data were not taken. Number in parenthesis is the operation month. Month (0) is the startup period.

Table 4 shows the evolution of the chlorophyll content measured in the leaves of the plants. In the case of an arid condition, similar average monthly values above 50 SPAD (nonsignificant difference, $p > 0.05$) were recorded for Za. In the case of Mediterranean conditions, similar average monthly values above 40 SPAD (nonsignificant difference, $p > 0.05$) were recorded for Za (with the exception of the measurements in January). This result indicates regular activity in the plants despite VSSF TWs being operated in different climates. The chlorophyll content of leaves is often used to predict its physiological condition, which is influenced by various natural and anthropogenic factors; this content indicates the plant stress and plant nitrogen status [43]. Therefore, the results in Table 4 show that despite the fact that the Za plants were developed in different climate conditions, the physiological condition was not affected during the spring and summer seasons, regardless of the difference in height explained previously. In the case of Sc, the results in Table 4 show the same trend—similarity (nonsignificant difference, $p > 0.05$) between different average monthly values for both climate conditions tested (exception, arid climate: November). In addition, much like with Za, Sc showed similar chlorophyll content for both climate conditions despite Sc showing more dispersion (standard deviation above 50% of average) in Mediterranean conditions. This dispersion could be associated with the triangle form of the leaf, which could cause problems in the data because the chlorophyll was measured by using an optical method.

3.4. Behavior of Water Loss and Evapotranspiration

Figure 4 shows the probability of water loss for VSSF TWs for both climate conditions. In Figure 4, when the probability is 75%, water loss was below 15% in the two climate conditions for the two plant species, and 5% more was recorded in both plants for arid conditions. This result shows that Za has the same impact regarding water loss than common plants used in TWs, such as *Schopenplectus*, in Mediterranean and arid conditions. In addition, when the probability is 25%, the water loss varied between 18% and 23%, regardless of the plant species and climate condition. Therefore, Figure 4 shows that during the growing season (spring and summer), the water loss was similar, with differences below 5% among the two plant species in each climate condition. This is important in arid environments for two reasons. First, the reuse and reclamation of properly treated effluents is a relevant topic in water management [63]. Second, other plant species, such as *Cyperus papyrus*, have shown water loss differences up to 50% when they are compared with traditional plants used in TWs under this environment [27]. In this way, when water loss increases, the potential volume of water reuse is reduced, and even the pollutant concentrations of the water being treated are affected.

Figure 5 shows the monthly average values of ETP and the relationship between ETP and the average air temperature. The average ETP by month was very similar between the two plant species, here with nonsignificant differences ($p > 0.05$). This result was the same for the two climate conditions and similar to the water loss results. This was expected because ETP is the main process responsible for water loss in TWs [64]. ETP is a process that depends on the climate conditions and the plant growth stage [64,65]. Because the plant growth stage was the same in both climates, the similarity in the results for ETP suggests that the meteorological conditions for each climate condition during the spring and summer seasons would not be related to water loss in the two plant species. This is shown in Figure 5, which displays the similarity in the average air temperatures between the two climate conditions. Despite this, an exponential relationship between ETP and average temperature can be established for the two climate conditions, with an important increase above 17 mm/d for ETP when the average temperature increases above 20 °C (Figure 5). However, these results should be analyzed further because water behavior and ETP should be tracked over longer periods—especially during the autumn and winter seasons—to obtain more conclusive results.

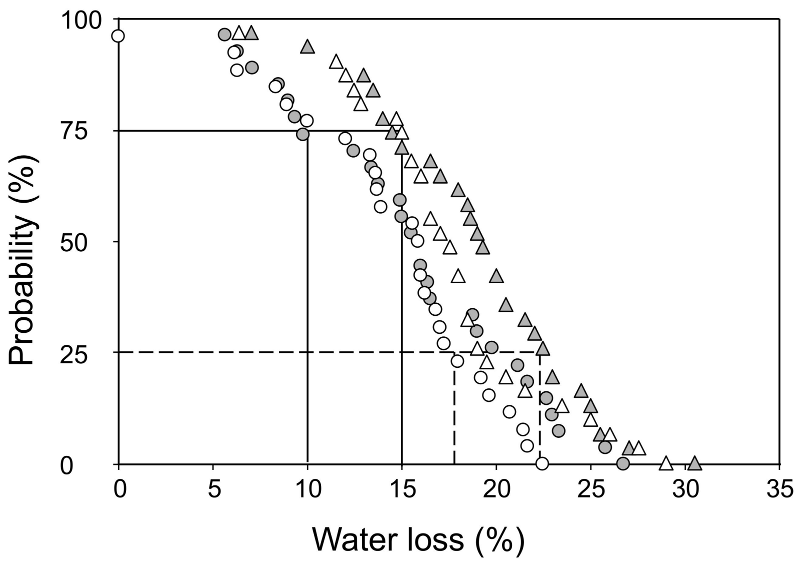

Figure 4. Probability of water loss by treatment wetland in both climate conditions. VSSF-Z (Arid) (▲); VSSF-S (Arid) (△); VSSF-Z (Mediterranean) (●); VSSF-S (Mediterranean) (○).

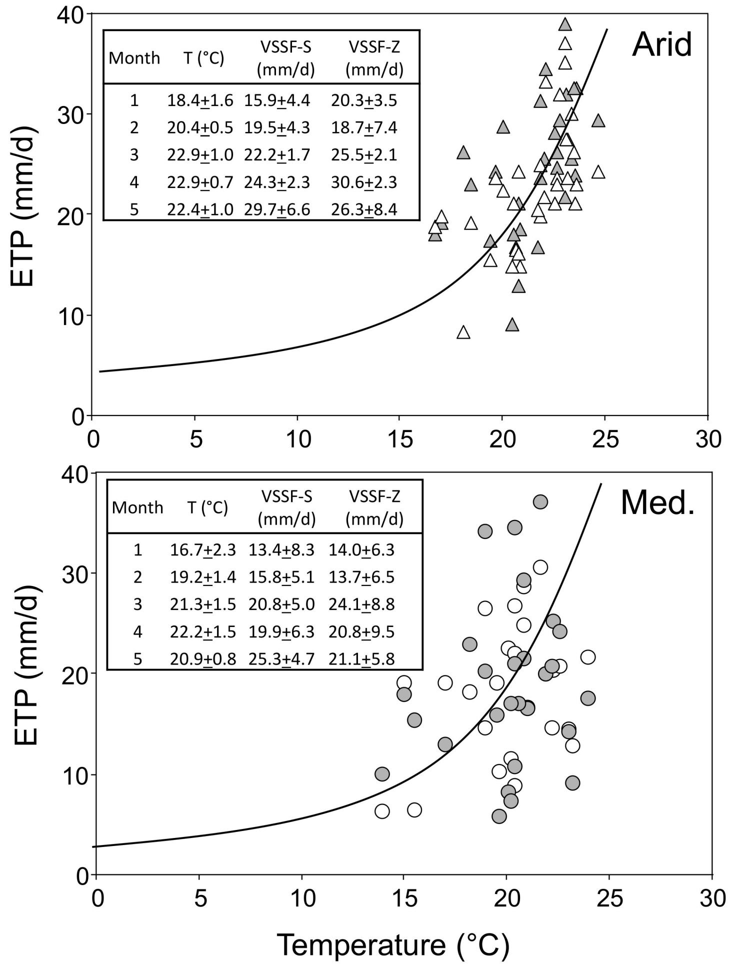

Figure 5. Behavior of evapotranspiration (ETP) in relationship with average air temperature by treatment wetland in both climate conditions. VSSF-Z (Arid) (▲); VSSF-S (Arid) (△); VSSF-Z (Mediterranean) (●); VSSF-S (Mediterranean) (○).

Figure 5 also shows that the average ETP was always below 30 mm/d, and especially, that the average values for the Mediterranean conditions were always below 25 mm/d. The peak values of ETP were near 40 mm/d and correlated with average temperatures 20–25 °C. These values for the spring and summer seasons fit with the findings of Pedescoll et al. [64], who reported similar results for different plant species used in TWs in a Mediterranean climate similar to the one in the current study. Other authors, such as Headley et al. [65] and Filho et al. [66], reported ETP below 20 mm/d for horizontal subsurface flow TWs, which is similar to the values achieved in the present study. Thus, the results of water loss and ETP show that Za is a plant species with similar behavior compared with traditional plant species such as *Schoenoplectus* for use in vertical TWs for arid and Mediterranean climate conditions.

Finally, the use of TWs to treat wastewater have several advantages in comparison to traditional technologies such as activated sludge, namely comparatively low cost, easy operation and maintenance, and green areas that can contribute to biodiversity and ecosystem services and be easily integrated to the landscape, causing less of a visual impact. In addition, the ornamental plants such as *Zantedeshia aethiopica*, can enhance even more the aesthetics of the systems, especially considering their use in arid environments and the results of this work [2–4,19,47].

4. Conclusions

Effluent water quality—especially regarding pH, organic matter, solids, ammonium, and pathogens—suggests similarities between VSSF TWs planted with Za and Sc for each climate condition. In addition, this similarity was maintained between VSSF TWs planted with Za operated in arid and Mediterranean climates. However, in terms of TN and TP, differences in effluent concentrations were found between the two climates evaluated, but these differences were related to differences in the influent concentrations.

Za showed lower height growth in both climate conditions. Despite this, the physiological condition of the leaves of Za as measured by chlorophyll content was not affected. Therefore, during the operation period of the austral spring and summer seasons, environmental factors such as temperature and luminosity can affect only the height of Za in arid and Mediterranean climates. For Sc plants, there were no height differences between the two climate conditions, suggesting good adaptation. However, the height of the plants needs to be tracked over longer periods—especially during the autumn and winter seasons—to obtain more conclusive results.

Za had the same impact in terms of water loss and ETP than common plants used in TWs such as Sc in Mediterranean and arid climate conditions. In addition, an important increase in ETP has to be expected for these two plant species when the average air temperature is above 20 °C for the two climate conditions. Clearly, this temperature condition is to be expected during the warm seasons, spring and summer.

Finally, the performance of the water quality and water balance suggests that *Zantedeschia aethiopica* can be used and that it performs as well as traditional plants used in VSSF TWs in arid and Mediterranean climates. However, if it is used under these climates, one should be aware of the lower height growth that could affect the esthetics of VSSF TWs.

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