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Aromatic Compounds and Organic Matter Behavior in Pilot Constructed Wetlands Treating *Pinus Radiata* and *Eucalyptus Globulus* Sawmill Industry Leachate

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Abstract: The objective of this research was to evaluate the fate of aromatic compounds and organic matter in pilot constructed wetlands (CW) treating *Pinus radiata* and *Eucalyptus globulus* sawmill industry leachate. Six lab-scale surface flow CW were built and fed in batches. Three CW were fed with *P. radiata* leachate, while the other three CW were fed with *E. globulus* leachate. Each group of three CW included two CW planted with *Phragmites australis* and one unplanted CW as control unit. A stable hydraulic retention time of seven days was maintained in each CW. The organic loading rate was gradually increased in three phases in the CW fed with *P. radiata* leachate (i.e., from 12 to 19 g COD/m^2/day) and with *E. globulus* leachate (i.e., from 14 to 40 g COD/m^2/day). The operation of the six CWs lasted 98 days. The CW treating *P. radiata* and *E. globulus* leachate had a similar performance. The highest performance was obtained by the unplanted CW (approximately 10–20% higher than the planted CW), without significant differences observed between the *P. radiata* and *E. globulus* leachate treatment, regarding the removal efficiencies of organic matter and total phenolic compounds. The planted systems were probably affected by the high concentrations of these compounds applied, which probably created a toxic environment hindering the microbial community growth.

Keywords: woodwaste leachate; *Eucalyptus globulus*; *Pinus radiata*; constructed wetlands; sawmill industry; agro-industrial wastewater; aromatic compounds; phenolic compounds

1. Introduction

Effluents from the sawmill industry are generated by the sprinkling of logs and percolation through the piles of logs, bark, and wood stored [1,2]. This leachate is then drained into surface water or groundwater. The main specific compounds in the leachate from *Pinus radiata* and *Eucalyptus globulus* are resin acids (up to 512 mg/L), terpenes, fatty acids (up to 90 mg/L), phenols (1–30 mg/L), tannins, and lignins (900–3000 mg/L), among other compounds commonly found in wood processing wastewater [3–5]. Endocrine disruption effect can be produced by some of these specific compounds in sawmill industry leachate [4,6]. Moreover, organic matter measured as biological oxygen demand (BOD_5; 500 to 5000 mg/L) could be infiltrated to the groundwater [7]. Such leachates have been treated in aerobic trickling filters reaching high removal rates of BOD_5, chemical oxygen demand (COD), tannins, and lignins [8]. The combination of biological treatment with ozonation has also shown good results for BOD_5, COD, tannins and lignins with 99%, 80%, and 90% removals, respectively [2,9]. However, these technologies are not easily applicable in small-scale industries, with production of 2000 to 20,000 m^3 sawn per year, given the high costs for both investment and maintenance-operation and their technical complexity. Thus, it is necessary to study alternative technologies with less operational costs and maintenance requirements [3,4].

Constructed wetlands (CW) are an established nature-based solution for wastewater treatment [2,8,10–15], providing multiple economic and environmental benefits coupled with high treatment performance for various wastewater sources [5,14–17]. Moreover, CW have mechanisms to eliminate aromatic compounds via bacteria [13]. High removal rates have been reported for pollutants such as COD, BOD_5, long-chain fatty acids, tannins, and lignins in wood leachate treated in CW [7,10,11]. Removal rates up to 91% are reported for various phenolic compounds such as gallic, syringic, and ellagic acids from corkwood processing wastewater [5]. A complete removal of phenols is also reported in pilot CW treating groundwater contaminated with fuel hydrocarbons and petroleum derivatives [16]. In general, international experiences dictate the strong potential of CW system to remediate contaminated effluents from various agro-industries [15,18,19].

Due to the different feedstock, leachates from *P. radiata* and *E. globulus* sawmill have different concentrations of aromatic compounds (i.e., resin acids, terpenes, fatty acids, phenols, and tannins and lignins). At the same time, there is limited information in the published literature on the behavior of aromatic compounds in constructed wetland systems. In order to examine the behavior of these specific pollutant groups during aerobic treatment, the relation with UV-vis measurements was previously evaluated [12]. It has also been indicated that a kraft mill wastewater treatment plant can be monitored using UV/VIS spectroscopy [20]. Considering the above, the goal of this study was to investigate the behavior of aromatic compounds and organic matter contained in *Pinus radiata* and *Eucaliptus globulus* sawmill industry leachate treated in pilot constructed wetlands and evaluate their efficiency.

2. Materials and Methods

2.1. Influent Generation

The leachate was obtained from sawdust of the *P. radiata* and *E. globulus*. About 500 g of *P. radiata* sawdust and 500 g of *E. globulus* sawdust were extracted each into 10 L of water. Samples were stirrer for 24 h, settled for 1 h and, finally, stored in dark at a temperature of 4 ± 1°C [21].

2.2. Laboratory-Scale Constructed Wetlands Description and Operation

For this study, six surface flow CW (SFCW) units were built in the laboratory. Each CW unit was a rectangular tank with internal dimensions of 0.29 m length, 0.21 m width, and 0.20 m depth (Figure 1). A 0.10 m layer of gravel (mean diameter 0.22 mm) was placed at the bottom of each unit, where *Phragmites australis* was planted. Four CW units were planted and two remained unplanted as control units. Two seedlings of *Phragmites australis* were planted in each planted CW.

All SFCW units were fed in daily batches. Three CW units were operated with *P. radiata* leachate (two planted and one unplanted), while the other three CW units were fed with *E. globulus* leachate (two planted and one unplanted). The operation strategy was to gradually increase the organic loading rate (OLR) from 12 to 13 and then 19 g COD/m^2/day (phases I, II, and III, respectively) for the CW units fed with *P. radiata* leachate. The OLR was also gradually increased from 14 to 26 and then 40 g COD/m^2/day (phases I, II, and III, respectively) for the CW units fed with *E. globulus* leachate. The hydraulic retention time (HRT) was set at 7 days in each CW and the operation period of the six SFCW was 98 days.

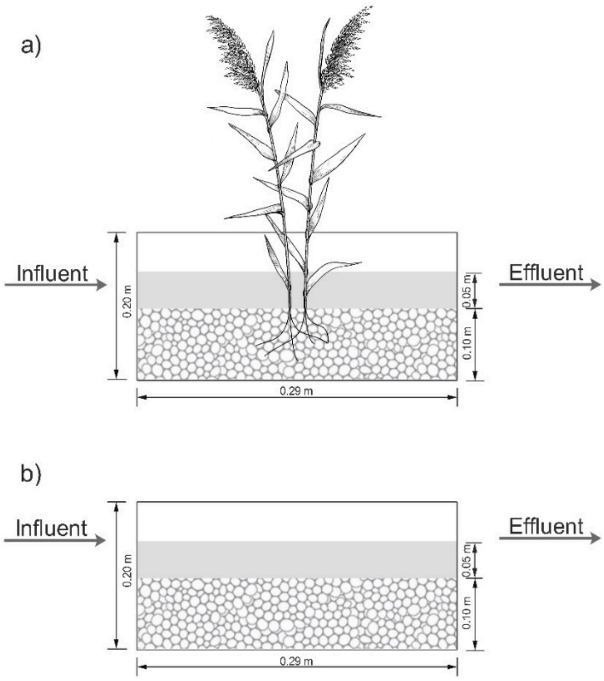

Figure 1. Experimental setup of the lab-scale constructed wetland (CW) units: (**a**) Planted and (**b**) unplanted.

The CW performance was monitored for the following parameters: COD, BOD_5, total phenolic compounds, color, lignin and derivates at 272 nm and 280 nm absorbance, and lignosulphonic acid, according to the following equation:

$$R(\%) = \frac{Q_i \times C_i - Q_o \times C_o}{Q_i \times C_i} \times 100 \quad (1)$$

where R (%) is the removal percentage; Q is the flow rate (L/d); C is the concentration (mg/L); and the subindex "*i*" and "*o*" correspond to the inflow and outflow, respectively.

2.3. Analytical Methods

Chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), phenols, lignin, and tannins were measured following APHA Standard Methods [22]. The total phenolic compounds (UV phenols) concentration was measured by UV absorbance in a 1 cm quartz cell at 215 nm, at pH 8.0 (0.2 M KH_2PO_4 buffer) and transformed to concentration using a calibration curve with phenol as standard solution. Spectrophotometric measurements of filtered samples were mainly performed at wavelengths of 436 (color), 346 (lignosulphonic acids), 254 (aromatic compounds), and 272 and 280 nm (lignin-derived compounds) in a 1 × 1 cm quartz cell using a Genesys UV-VIS spectrophotometer, and were determined according to the Chamorro et al. [12] procedure. All samples were membrane-filtered (0.45 µm).

3. Results

3.1. Physico-Chemical Characterization of the P. Radiata and E. Globulus Leachate

Table 1 shows the physico-chemical characteristics of the *P. radiata* and *E. globulus* leachate. The pH range of the *P. radiata* leachate was between 5.21–6.58 and 5.85–6.69 for the *E. globulus* leachate. COD values for the *P. radiata* and *E. globulus* leachate ranged between 236–341 mg/L and 271–832 mg/L, respectively, where BOD_5 was 2.0–3.8 times lower than COD for both leachates. Additionally, total phenolic compounds show values range of 1,909–13,077 mg/L while lignin derived compounds presented an absorbance range of 0.8–10.44. As Table 1 shows, *E. globulus* leachate compared to *P. radiata* leachate showed higher values for all measured compounds and pollutants.

Table 1. Physico-chemical characteristics of the *P. radiata* and *E. globulus* leachates.

Parameter	Unit	Phase	*E. Globulus* Leachate	*P. Radiata* Leachate
pH	-	I	6.58 ± 0.48	6.69 ± 0.63
	-	II	6.32 ± 0.71	6.45 ± 0.55
	-	III	5.21 ± 0.48	5.85 ± 0.29
BOD_5	mg/L	I	n.d.	n.d.
		II	144.00 ± 0.00	78.50 ± 0.00
		III	216.00 ± 0.00	104.00 ± 0.00
COD	mg/L	I	271.70 ± 24.79	236.80 ± 18.52
		II	500.05 ± 93.25	253.80 ± 39.04
		III	832.80 ± 88.38	341.40±67.44
Aromatic compounds (UV_{254nm})	Absorbance	I	3.35 ± 0.40	0.92 ± 0.16
		II	7.74 ± 1.77	0.97 ± 0.17
		III	12.26 ± 0.17	1.41 ± 0.71
Lignin derived compounds (UV_{280nm})	Absorbance	I	2.81 ± 0.21	0.80 ± 0.14
		II	6.51 ± 1.42	0.86 ± 0.11
		III	10.44 ± 0.37	1.29 ± 0.69
Lignosulphonic acids (UV_{346nm})	Absorbance	I	1.02 ± 0.17	0.28 ± 0.06
		II	2.07 ± 0.29	0.35 ± 0.04
		III	4.08 ± 0.65	0.56 ± 0.43

n.d. no data.

3.2. Performance of CW Treating P. Radiata Leachate

Table 2 shows the overall results of the CW unit operation with OLR ranging from 12 to 19 g COD/m^2/day. A BOD_5 removal rate of 90 and 85% was found in the planted and unplanted CW units, respectively. The pH of the effluent reached maximum values between 7.3–7.4.

Figure 2 shows the removal efficiency of the aromatic compounds at the different OLRs tested. The maximum removal efficiency of aromatic compounds (UV_{254nm}) was approximately 70% and was detected at the OLR of 13 g COD/m^2/day. At the highest OLR of 19 g COD/m^2/day, the efficiency was decreased 50–60% and the absorbance value was 0.67 ± 0.26 and 0.57 ± 0.27 for the planted and unplanted CW, respectively (Table 2). Similar behavior was observed for lignin-derived compounds measured at wavelengths of 280 and 272 nm with respective maximum removals of 60% and 70% for an OLR of 13 g COD/m^2/day. At the OLR of 19 g COD/m^2/day, the removal efficiency dropped to 50% and 60%, respectively. Similar behavior was also found for the lignosulphonic acids (Figure 2).

Table 2. Physico-chemical characteristics of the Constructed Wetlands (CW) effluents treating *P. radiata* and *E. globulus* leachates.

Parameter	Unit	Phase	*E. Globulus* Leachate		*P. Radiata* Leachate	
			Planted CW	Unplanted CW	Planted CW	Unplanted CW
pH	-	I	7.34 ± 0.06	7.52 ± 0.12	7.40 ± 0.05	7.40 ± 0.06
	-	II	7.43 ± 0.19	7.30 ± 0.36	7.43 ± 0.14	7.36 ± 0.25
	-	III	7.05 ± 0.51	7.04 ± 0.54	7.32 ± 0.34	7.37 ± 0.46
BOD_5	mg/L	II	78.00 ± 0.00	60.00 ± 0.00	16.10 ± 0.00	22.50 ± 0.00
		III	15.50 ± 0.00	40.00 ± 0.00	8.25 ± 0.00	15.60 ± 0.00
COD	mg/L	I	79.28 ± 22.97	118.38 ± 23.98	49.41 ±24.10	74.97 ± 15.49
		II	137.55 ± 61.55	209.20 ± 62.08	52.39 ± 13.04	78.36 ± 30.06
		III	417.73 ± 77.44	330.50 ± 63.25	121.64 ±46.68	91.98 ± 28.68
Aromatic compounds (UV_{254nm})	Abs	I	1.49 ± 0.14	1.66 ± 0.19	0.26 ± 0.05	0.31 ± 0.06
		II	2.74 ± 0.82	3.67 ± 1.47	0.32 ± 0.14	0.43 ± 0.15
		III	7.80 ± 0.37	5.74 ± 0.67	0.67 ± 0.26	0.57 ± 0.27
Lignin derived compounds (UV_{280nm})	Abs	I	1.19 ± 0.11	1.38 ± 0.18	0.24 ± 0.04	0.27 ± 0.04
		II	2.26 ± 0.69	2.94 ± 1.10	0.25 ± 0.12	0.37 ± 0.12
		III	6.27 ± 0.39	4.76 ± 0.50	0.57 ± 0.28	0.49 ± 0.29
Lignosulphonic acids (UV_{346nm})	Abs	I	0.55 ± 0.04	0.71 ± 0.14	0.06 ± 0.02	0.08 ± 0.03
		II	1.13 ± 0.37	1.46 ± 0.57	0.09 ± 0.05	0.11 ± 0.06
		III	3.04 ± 0.26	2.33 ± 0.24	0.22 ± 0.16	0.21 ± 0.15

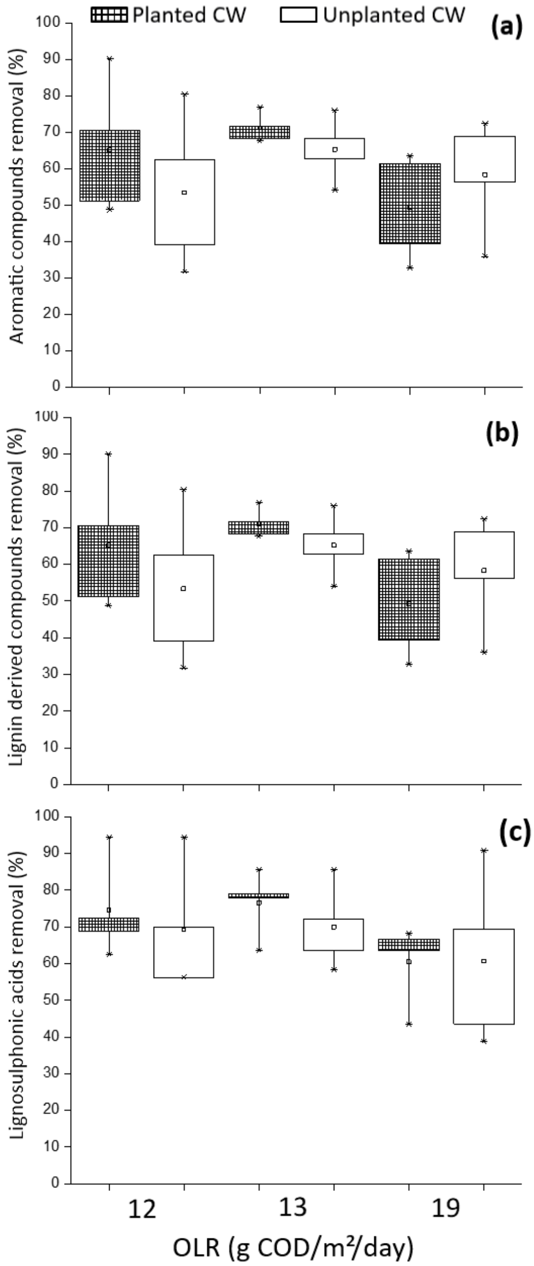

Figure 2. Removal efficiency of (**a**) aromatic compounds; (**b**) lignin-derived compounds; and (**c**) lignosulphonic acids contained in *P. radiata* leachate treated in the planted and unplanted CW.

Figure 3a shows the COD variations during the CW operation under OLR from 10 to 20 g COD/m^2/day. In the planted CW, COD removal was 70% at the OLR of 13 g COD/m^2/day and 65–70% at the OLR of 19 g COD/m^2/day. Effluent concentrations were 100 and 120 mg/L in the planted and the unplanted CW, respectively. On the other hand, COD removal in the unplanted CW was 80% at the OLR of 13 g COD/m^2/day and 70% at the OLR of 19 g COD/m^2/day, with effluent COD concentration of 120 mg/L.

Figure 3b shows the total phenolic compounds variations. The planted CW at the OLR of 13 g COD/m^2/day showed 60% removal and an effluent concentration of 200 mg/L, while at the OLR of 19 g COD/m^2/day, the removal dropped to 50% with effluent concentration of 1000 mg/L. Moreover, the performance of the unplanted CW at the OLR of 13 g COD/m^2/day was 70% with effluent concentration up to 550 mg/L and at the OLR of 19 g COD/m^2/day the removal efficiency was 60% with effluent total phenolic compounds concentration up to 700 mg/L.

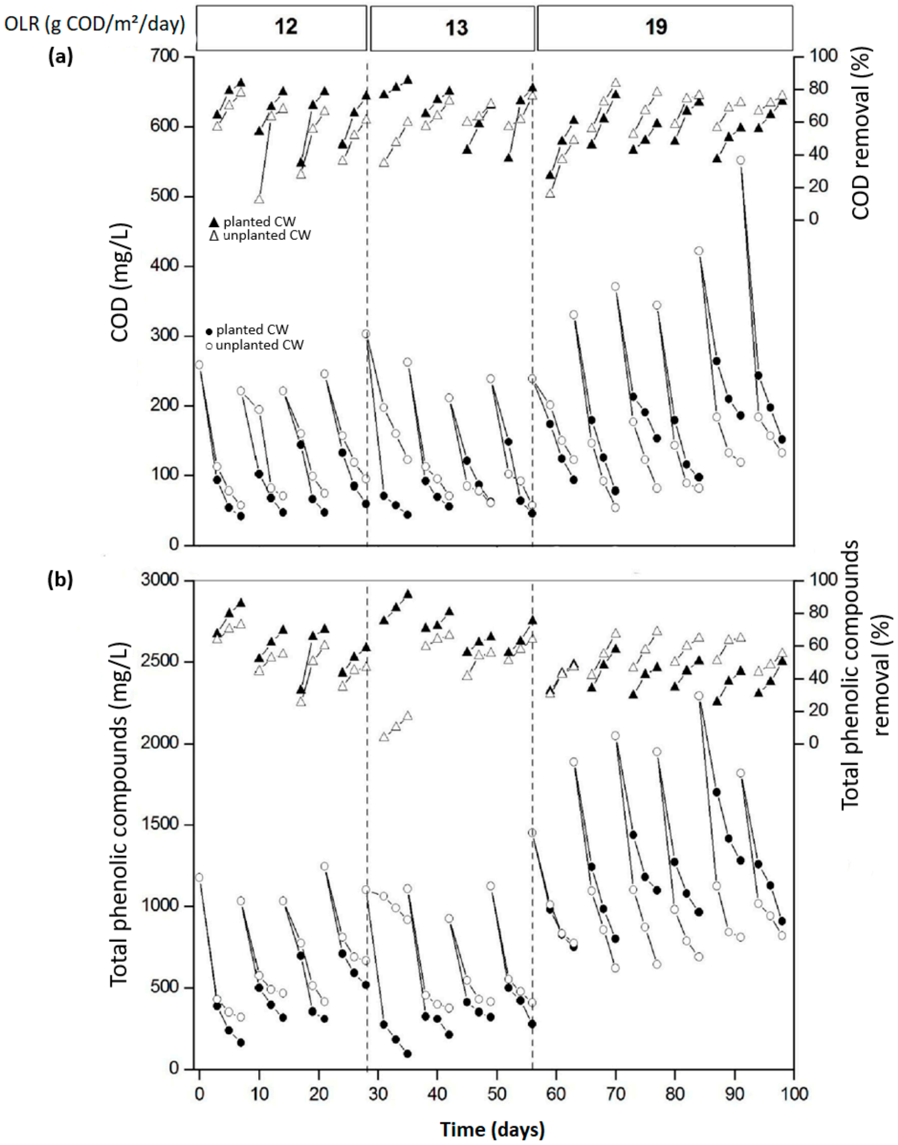

Figure 3. Variations of (**a**) effluent chemical oxygen demand (COD) and (**b**) effluent total phenolic compounds concentration and respective removal rates in the planted and unplanted CW treating *P. radiata* leachate.

3.3. Performance of CW Treating E. Globulus Leachate

Table 2 shows the effluent quality of the CW treating *E. globulus* leachate. BOD_5 removal was 93% and 82% in the planted and unplanted CW, respectively, at an OLR of 19.5 g COD/m^2/day. The effluent pH during the operation was increased from 6.8 to 7.3.

Figure 4 presents the behavior of the measured specific compounds. Aromatic compounds had a different behavior depending on the applied OLR. The removal efficiency of aromatic compounds (measured as UV_{254nm}) at the low OLR (14.1 g COD/m^2/day) was 50% and 75% in the planted and unplanted CW, respectively, whereas at the OLR of 40 g COD/m^2/day, the respective average reductions were 49% and 60%. The same behavior was found for lignin (measured as UV_{272nm} and UV_{280nm}). The efficiency at 14.1 g COD/m^2/day ranged 50–70%, while at 40 g COD/m^2/day it was 47% and 55% for the planted and unplanted CW, respectively. On the other hand, the efficiency of lignosulfonic acids (measured as UV_{346nm}) removal was 30–46% for the OLR of 14.1 g COD/m^2/day and 30–42% for the higher ORL of 40 g COD/m^2/day.

Figure 5a shows the COD removal from the *E. globulus* leachate in the CW units at OLR ranging from 10 to 40 g COD/m^2/day. Different removal rates were found for the planted and unplanted CW. The planted CW showed 60% BOD_5 removal with an average effluent concentration of 80 mg/L. On the other hand, at the higher OLR of 40 g COD/m^2/day the BOD_5 removal efficiency was 55% and the effluent concentration was 420 mg/L. However, the unplanted CW showed 70% BOD_5 removal at an OLR of 14 g COD/m^2/day (with an effluent BOD_5 concentration of 200 mg/L), and at the higher 40 g COD/m^2/day, the BOD_5 removal was 65% (with effluent BOD_5 concentration of 330 mg/L).

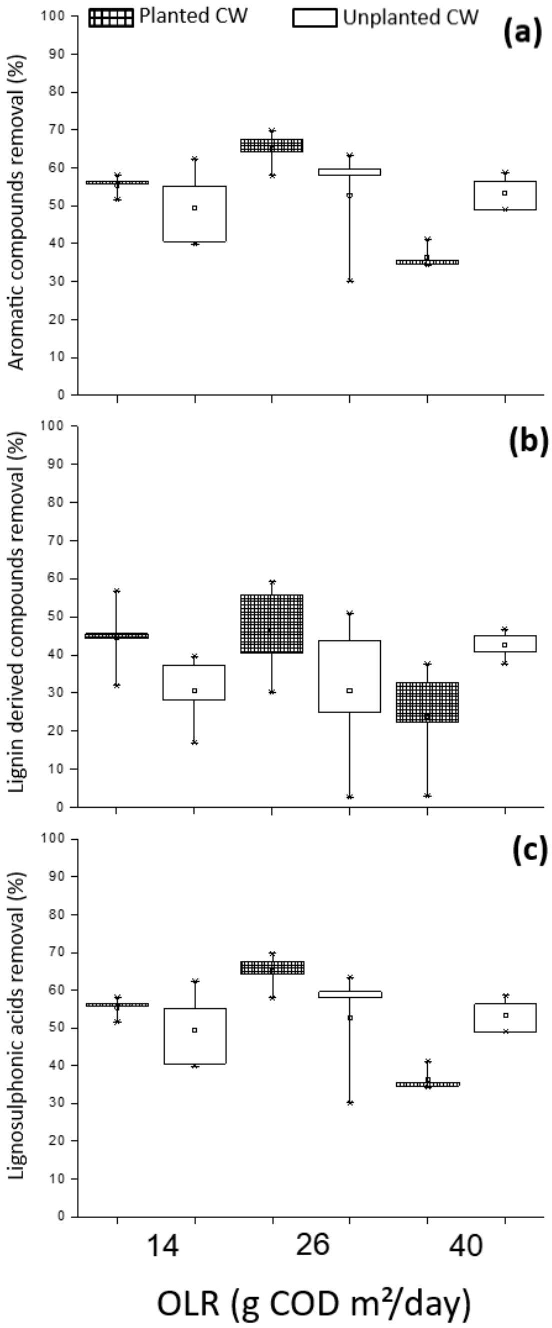

Figure 4. Removal efficiency of (**a**) aromatic compounds; (**b**) lignin-derived compounds; and (**c**) lignosulphonic acids contained in *E. globulus* leachates treated in the planted and unplanted CW.

Figure 5b presents the removal rates of the total phenolics compounds for the different OLR applied to the CW units. The planted CW showed removal efficiencies up to 55% at an OLR of 14 g COD/m^2/day with effluent concentration of 1000 mg/L. At the higher OLR of 40 g COD/m^2/day, the removal efficiency was 55% and the effluent concentration was 5700 mg/L. On the other hand, the removal efficiency in the unplanted CW was 70% at the OLR of 14 g COD/m^2/day (with 2200 mg/L of total phenolic compounds in the effluent) and 65% at the OLR of 40 g COD/m^2/day (with 4500 mg/L of the total phenolic compounds in the effluent).

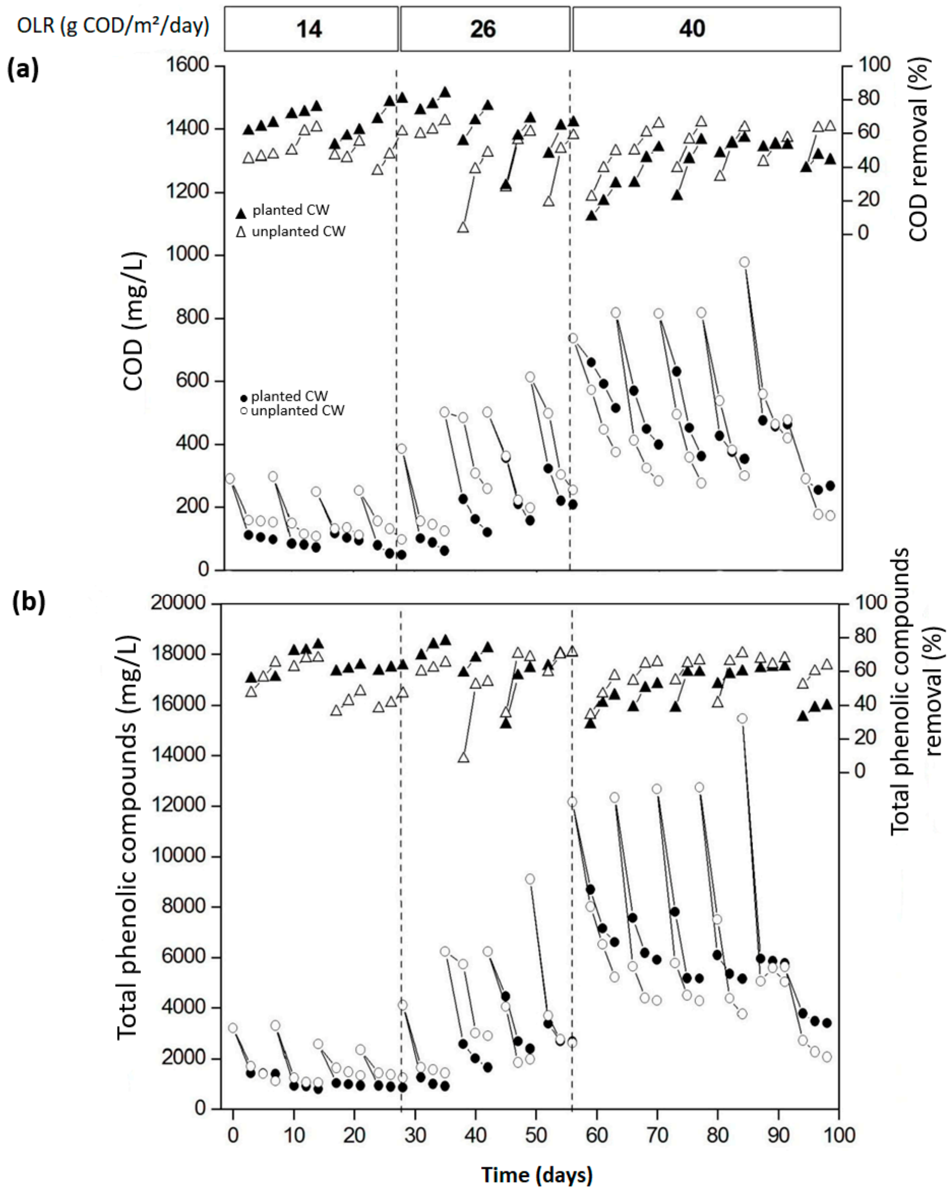

Figure 5. Variations of (**a**) effluent COD and (**b**) effluent total phenolic compounds concentration and respective removal rates in the planted and unplanted CW treating *E. globulus* leachate.

4. Discussion

The physico-chemical characterization of the *P. radiata* and *E. globulus* leachates from the sawmill industry showed BOD_5 concentrations between 100–200 mg/L, COD concentrations between 500–1000 mg/L, and total phenolic compounds between 2000–15,000 mg/L. Moreover, low nutrients concentration was found (1 mg TN /L and 1–4 mg TP/L) and the pH was lower than 5.8 (Table 1). Slightly higher pollutant levels are reported by Hedmark and Scholz [7] for organic matter (i.e., 300–2000 mg BOD_5/L and 1500–10,000 mg COD/L), tanin and lignin (900–3000 mg/L), but lower phenols levels (1–30 mg/L) and pH (3–5). Besides that, low concentration of nutrients (i.e., 1–3 mg/L de TN and 3–4 mg/L de TP) is also reported for similar leachate sources in other studies [1,7,23,24].

Table 2 and Figures 2–5 indicate that the performance of the CW units treating *P. radiata* and *E. globulus* leachates is similar. However, the optimum performance in the planted CW was found at the ORL of 13 g COD/m^2/day for the *P. radiata* leachate and at 25 g COD/m^2/day for the *E. globulus* leachate (Figures 2–5). Moreover, the performance of the planted CW decreased at OLR higher than 19 g COD/m^2/day for the *P. radiata* leachate and 40 g COD/m^2/day for the *E. globulus* leachate. Inhibition of the biological processes and their respective insufficient extent due to the high organic matter and specific compounds contents is one of the possible explanations for these results. Preliminary studies showed that resinic acids contained in *P. radiata* leachate result in bacterial inhibition at 76.7 mg AbA/L for non-acclimated biomass [4,24].

This study revealed higher removal efficiencies by 10–15% in the unplanted than the planted CW for organic matter and specific phenolic compounds. Though the role of plants in CW still remains a topic of discussion, it is generally believed, and several studies have shown, that the presence of plants contributes to the system's efficiency, with regards to organic matter and phenolic compounds [5,14,16,25–27]. It is reported that the rhizosphere of the plants contributes to the creation of an aerobic microenvironment (i.e., *P. australis* transfers 5–12 g O_2/m^2/day through its roots) that stimulates the microorganism growth and, thus, the biodegradation of the organic matter and specific compounds contained in the influents [5,14,28–30]. However, other studies have shown significant differences ($p < 0.05$) for COD and BOD_5 removal between planted and unplanted CW, reporting that organic matter removal can be up to 20% higher in unplanted compared to planted CW [1,2,31]. Another study reports higher COD and BOD_5 removal efficiencies of 50% and 60%, respectively, for an HRT of seven days in an unplanted CW treating wood waste leachate, while for long-chain fatty acids and tannin and lignin, the removal efficiencies were 69% and 42%, respectively [10]. No significant effect of plants is also elsewhere reported for various parameters [31,32]. Most of the organic matter is due to the microbial mechanisms of carbon removal in subsurface flow wetlands [33].

Table 3 shows the aromatic compounds behavior in the effluents of CW units in ratio to effluent COD. This relationship between the aromatic compounds and COD is used as indicator of these recalcitrant compounds removal in comparison to total organic matter removal (COD), as it was proposed by Chamorro et al. [12]. In the case of *P. radiata* leachate, for the total operation period (OLR from 12 to 19 g COD/m^2/day), there was a slight increase in the effluent UV_{346nm}/COD ratio (0.001–0.002), indicating that the lignosulfonic acids contained in the *P. radiata* leachate were removed to a lesser extent than other organic material when COD load was increased. Similarly, the UV_{280nm}/COD ratio shows that the CW units were able to mineralize the lignin compounds as much as organic matter, measured as COD, i.e., the UV_{280nm}/COD ratios for the influent and effluent were 0.003 and 0.005, respectively. Additionally, there was an increase in the UV_{254nm} parameter, which correlates with the aromatic compounds. The UV_{254nm}/COD ratio was increased in the range of 0.130–0.148 during the CW treatment [12].

The UV_{254nm}/UV_{280nm} ratio is used as an indicator of lignin-derived compounds presence in wastewaters, whereas low values indicate a stronger presence of these compounds. During the treatment process, the UV_{254nm}/UV_{280nm} ratio at the OLR of 1.10 g COD_s/m^2/day was 1.13 and 1.12 for the influent and effluent, respectively. Similarly, Çeçen [34] showed that the UV_{254nm}/UV_{272nm} ratio did not undergo a significant change (ranging between 1.10–1.13). These results led to the conclusion that the residual COD consisted of lignin compounds, which were also the major aromatic species in these leachates [12].

Table 3. Variations of the ratio of aromatic compounds to COD for the effluents of planted and unplanted CW units treating *P. radiata* and *E. globulus* leachates (average values are shown).

OLR	Lignosulfonic Acid	Aromatic Compounds	Lignin	Lignin-Derived Compounds
(g COD/m^2/day)	UV_{346}/COD	UV_{254}/COD	UV_{280}/COD	UV_{254}/UV_{280}
		P. radiata leachate		
Planted CW	-	-	-	-
12	0.001	0.005	0.005	1.083
13	0.002	0.006	0.005	1.280
19	0.002	0.006	0.005	1.175
Unplanted CW	-	-	-	-
12	0.001	0.004	0.004	1.148
13	0.001	0.005	0.005	1.162
19	0.002	0.006	0.005	1.163
		E. globulus leachate		
Planted CW	-	-	-	-
14	0.007	0.019	0.015	1.252
26	0.008	0.020	0.016	1.212
40	0.007	0.019	0.015	1.258
Unplanted CW	-	-	-	-
14	0.006	0.010	0.012	1.203
26	0.007	0.018	0,014	1.248
40	0.014	0.017	0,017	1.206

The partial organic matter removal could be attributed to the *P. radiata* and *E. globulus* leachates composition. Lignin and total phenolic compounds have been indicated as recalcitrant substrates in biological treatment systems (aerobic and anoxic), due to their molecular weight being higher than 10,000 Da [12,21,35]. Also, lignin is responsible for the brown color of these leachates. Approximately 10% of the residual COD consisted of microbially altered organics, while the rest were organics initially present in the wastewater. Similarly, Vidal et al. [35] and Milestone et al. [36] suggested that anoxic environments enhance the phenolic groups in wastewaters with high phenolic compounds concentrations as a result of biological removal of methoxy groups from the aromatic ring structure. Moreover, it has been indicated that color formation is correlated to the anoxic conditions and the availability of readily biodegradable organic constituents during the wastewater treatment process [24]. The high levels of these compounds applied in the CW probably created a toxic environment that affected the development of the microbial community, especially in the planted systems where an enhanced aerobic environment is usually established. High toxicity can be caused not only by increased phenols concentration, but also due to increased generation of intermediates during phenols transformation, as elsewhere reported [25].

In this way, other studies suggest a tertiary treatment stage after the biological treatment stage for specific compounds and recalcitrant organic matter [5,37–39]. Therefore, according to Belmont and Metcalfe [37], using ornamental plants like *Zantedeschia aethiopica* in subsurface flow constructed wetlands remove nitrogen, chemical oxygen demand, and nonylphenol ethoxylate surfactants. On the other hand, *Eichhornia crassipes* has been studied as tertiary treatment stage [39]. Results showed that organic matter and color were removed at a maximum rate of 75% and 25%, respectively, by *Eichhornia crassipes*. On the other hand, tertiary treatment via physical processes [35,40] or advanced oxidation processes [9,41,42] can reduce the recalcitrant compounds by adsorption and destruction, respectively [43].

5. Conclusions

Lab-scale planted and unplanted Constructed Wetland units were tested for the treatment of *P. radiata* and *E. globulus* leachates. In general, similar performances were found for both leachates. However, the unplanted CW units were more efficient in the removal for COD, BOD_5, and total phenolic compounds by approximately 10–20%, possibly due to the recalcitrant nature of the organic matter composition in the influent leachate and their inhibition activity to the microbial growth within the planted units. The highest CW performance was found at an OLR of 13 g COD/m^2/day for the *P. radiata* leachate and at 25 g COD/m^2/day for the *E. globulus* leachate. The CW performance in terms of organic matter and specific compound removal was decreased at higher OLR. Aromatic compounds contained in *P. radiata* and *E. globulus* leachates were removed by almost 95% *w*/*w* of BOD_5, while COD removal ranged between 40–60% *w*/*w*. Furthermore, the low values of the UV_{254}/UV_{280} ratio between the influent (1.13) and the effluent (1.12) at an OLR of 13 g COD/m^2/day for *P. radiata* leachate or 25 g COD/m^2/day for *E. globulus* leachate indicated the recalcitrant behavior of lignin-derived compounds in the influent leachate.

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