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REVIEW OF RESEARCH

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PERFORMANCE OF CONSTRUCTED WETLAND IN THE DECONTAMINATION OF WATER CONTAMINATED WITHPOTENTIALLY TOXIC METALS: EFFICIENCY OF THE CONSORTIUM PISTIA STRATIOTES AND ALOCASIAMACHORRIZA

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ABSTRACT:

Vertical subsurface-flowwetland (SSFW)in filteringpotential toxic metal (PTM)of contaminated water.SSFWconsisted of a tank with Pistia stratiotes coupled to a planted filter with Alocasiamachorrizacultivatedinchemically modified clayey soil. For assessing the SSFWwater filtering capacity,we carried out three batches of metal-contaminated water collectedfrom a stream called "Igarapé do Quarenta" (IG40). To validate the filtering capacity, the pH, conductivity and PTM concentration in five water samples collected in intervals of 24 hours, were analyzed. Our findings showed a reduction in PTMconcentrations mainly Co and Pb. In addition, Pistia stratiotesproved to be betterremoving PTM than planted filter, absorbing high concentrations of Pb and Fe in their roots and leaves. However, Alocasiamachorrizaabsorbs Ni and Pb in their leaves, Co, Ni in their stems and Pb, Ni and Co in their roots.

KEYWORDS: *Amazonia, Algae, water filtration.*

INTRODUCTION

Planted filters are biofiltration systems that use plants to improve the efficiency of filteringin removing wastewater of different sources, such as a household, roads, mining, and industrial(Zhi andJi, 2012).Vegetation is the principal component of a constructed wetland, reed, (*Phragmites* spp.), cattail (*Typha*spp.), rush (*Juncus* spp.), and bulrush (*Scirpus*spp.) being commonly recommend(*Scholz andLee*, 2005). However, the most common plant species worldwide is *Phagmitesaustralis*(Cav.) Trin. ex Steud(Lee et al., 2006). Particularly, in biofiltration systems found in Europe and Northern America the vegetation reportedly used, were macrophytes (Cooper et al., 1996).

Used alone or combined withplanted filters, water lettucehas shownto be a feasible alternative to filter several contaminants, especially PTM(Favas et al., 2012). For having very high growth rates andquick adaptation(Mishra andTripathi, 2008), duckweeds *Eichhorniacrassipes*float on water,Lemna sp. andwater lettuce *Pistiastratiots* are widely used in the treatment of metal-contaminated water(Pio et al., 2013).However, planted filters use fillers, such as soil, forfiltering contaminated aquatic ecosystem while plants absorb PTMin roots, soil substrates adsorb metal ions during the percolation of contaminated water (Lizama et al., 2011).

Accordingto the literature,picking out new plants, mainly native speciesare essential for filtering water contaminated byPTM(Prasad et al., 2001). For example, *AlocasiamachorrizaandPistia* stratiotes occur naturally inthe IG40 region, whichis highly contaminated byPTM. Industrial activities and municipal wastewater commonly dischargedCu, Pb,Ni, Cr, Co andZndirectly into the IG40. These metals are likely to accumulate within the sediment, plants and waters ofthe IG40 region(Santana, 2015;Pio et al., 2014; Souza and Santana, 2014). As a rule, native species are preferredto exotic plants, which can be invasive and endanger the harmony of the ecosystem. Therefore Alocasiamachorriza and Pistia stratiotes are two potentially phytoremeding plants.

The performance of the consortium *Pistiastratiotes* and *Alocasiamachorriza* in a planted filter (SSFW)was evaluatedin order to assess the efficiency in the decontamination of water with high concentration of PTM.

MATERIALS AND METHODS

Planted Filter designand water treatment

Figure 1 shows the design of SSFWused to develop this work. SSFW consisted of i) two coupled tanks; ii) two plants *Pistiastratiotes* and *Alocasiamachrorriza*; and iii) synthesized pebble material and white sand. For the construction of the coupled tanks twopolyvinyl chloride (PVC) tanks with a capacity of 150 L each were used. In the first tank,*Pistia stratiotes* (collected in a small community located in the West, in Manaus - Amazonas) and in the second,*Alocasiamachorriza*(collected in a preserved area of the campus of the Universidade Federal do Amazonas), were cultivated. The clay material usedin the *Alocasiamachorriza* tank was Oxisol (8.00 kg) with size $\leq 0,042$ mm deposited in layers of 3.00 cm of pebbles and 2.00 cm of sand. *Alocasiamachorriza* seedlings were planted at intervals of 10.00. and were 30 cm long by 15.00 cm wide with an individual weight of about 0,100 g. In the Pistia stratiotestank, 70 L of metal-contaminated water from IG40 was added.

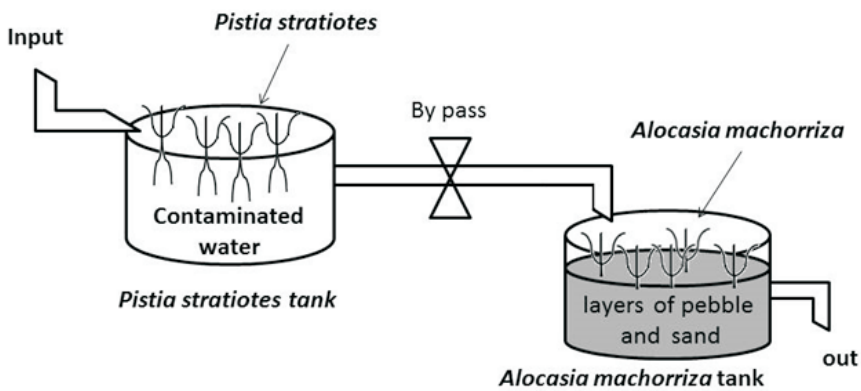

Figure 1. Constructed wetland design.

Batch experiments

To evaluate the SSFWperformance three sequential batch experiments were carried out.Each experiment started after 48 hours, the time needed for the adaptation of the *Pistia stratiotes* and *Alocasiamachorriza* .First, 70 L of IG40 contaminated water was put into the tank area and covered with 40% (approximately 0.500 g humid mass) of Pistia stratiotesThen, all water volumeswere transferred to the*Alocasiamachorriza tank*covered with 40% of *Alocasiamachorriza*. 1.00 L of water was collected every 24 hours along a period of 240 hours of the batch experiment.Two otherwater-contaminated chargeswere carried out in SSFW(two batch experiments)as described previously.

Efficiency of the contaminated water treatment

Measurements of pH values, electrical conductivity and dissolved PTM concentrations were variables used for evaluatingthe quality of the water. To measure the pH values and the electrical conductivity a digital pH meter WTW 330i and Lutron CD-4303, were usedrespectively.In water aliquotsat 100 ml previously filtered througha 0.45-mm pore diameter membrane using a frontal filtration unit, the dissolved PTM concentrationswere analyzed.Each aliquot received concentrated nitric acid at 10 ml and the volume reducedto 10 mlin the digester block through 100 °C.For analyzingthe Cd, Co, Cu, Fe, Mn, Ni and Pbconcentrations by flame absorption atomic spectrometry (air/acetylene), the digested solutionwas quantitatively transferred to a volumetric flask and the volume completed to 25.00 mlwith deionized water (Santana andBarroncas, 2007).

Determination of PTMin the plant

For analyzing the PTM concentration, dried leaves, stems and roots of the two plant species and 0.500 g of each plant part were digested with 15 ml of HNO_3 at 200 °C for two hours or until clearance of the extract was completed. According to the following procedure described above the concentrations of Cd, Co, Cu, Fe, Mn, Ni and Pbwere analyzedby atomic absorption flame (air/acetylene).

RESULTS AND DISCUSSION

Electrical Conductivity and pH values

The metal-contaminated IG40 water usedin the three batch experiments presented pH values between 7.43 and 6.67, and electrical conductivity from 0.290 and 0.440 mS cm^{-1}. These values were different from those found inthe Central Amazonia natural environmentswith pH values ranging from 4.3 to 5.5 and electrical conductivity ranging from 0.070 to 0.280 mS cm^{-1}(Sioli, 1984).After the three batch experimentsthe final values showed that pH reduced to 0.72 and electrical conductivity to S 0.15 mS cm^{-1}(Figure 2). These reductions weregreater thanof the control tanks, indicating that the proposed SSFWalters the quality of contaminatedwater. Commonly, the reductions in pH values promote theincrease of the metal bioavailability(Pilon-Smits, 2005).A reduction of the metal bioavailability was observed in two plants in SSFWbecause of thelower pH obtained in the final batch experiment.

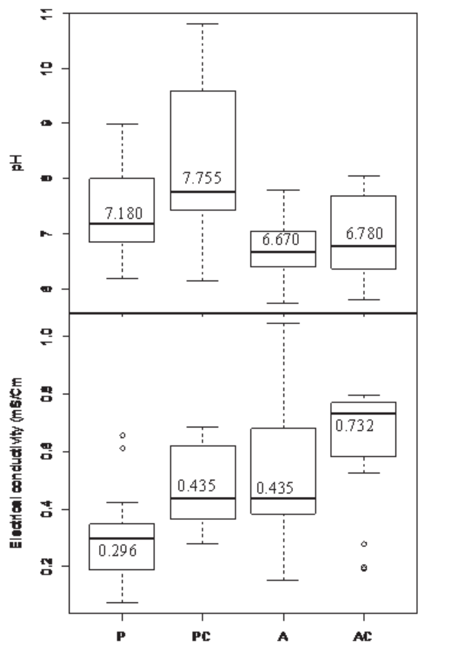

Figure 2: Electrical conductivity and pH box plot of the contaminated water. P = *Pistia stratiotes tank*, PC = *Pistia stratiotes* control tank, A = *Alocasiamacrorrhiza*tank, AC = *Alocasiamacrorrhiza*control tank.

Boxplot graphs (p 95%) were usedto evaluate the normal distribution and its symmetry; recognize outliers and compare median data. Thegraphs shows that the medians for both the *PistiaStratiotes* and the

AlocasiaMachorriza tanks varied slightly throughout all experiments (Figure 2). The third quartile of the control tank presented the highest pH values (~ 9.5) throughout allthe experiments. Thegraphs shows that the medians forthe *PistiaStratiotes*, and the control tanks aregreater than the *AlocasiaMachorriza*,and the control tanks, indicating that thegreatest alteration occurred in the first moment ofcontact with contaminated water. On the other hand, thegraphs of the electrical conductivity medianswere considerably reducedin both tanks. Thesefindingsindicate that the SSFWis able to reduce the ionic chargein IG40 contaminated water.

Water - PTM reducing

Table 1 shows the concentrations of PTM found in IG40 contaminated water. The relationship between the PTMconcentrations present in contaminated water and the control tank (filter efficiency) varied from 33% (Cu) to 67% (Co). However, in the *Pistiastratiotes*tank a remarkable reduction of the PTMconcentrationswas observed. Thesereducing rates obeyed the following order: Co >Pb> Cr >Mn> Ni > Fe > Cu.Besides, a linear trend of PTMconcentration reduction with time (0 to 120 hours) is observedin the cases of Pb ($r^2$0.97), Co ($r^2$0.96), Cu ($r^2$0.90) and Ni ($r^2$0.92).

The linear trend for removing PTM, mainly Cr^{6+}, Cr^{3+} and Pb^{2+}, was reported by Chakraborty et al. (2014) andLima et al. (2013)in sorption study of the *Pistiastratiotes*. However, these authors used different sorption models for explaining the Cr^{6+}, Cr^{3+}, and Pb^{2+} uptake. The first author fitted the isotherms with the model of pseudo second and secondLangmuir and Freundlich.In spite of sorption models, this work showed that the PTM uptake from contaminated water occurs with linear trend. Ourfindings also suggest that the *Pistiastratiotes* has good efficiency in filtering contaminated water. Nonetheless, the good capacityof PTMremoval by the Pistia stratiotesthrough rhizofiltration of a highly contaminated solution is well reported in the literature (e.g.Jadia and Fulekar, 2009;Vesely Et Al., 2011).

Table 1. Efficiency of the *PistiaStratiotes* and *Alocasiamacrorrihza* tanks in heavy metal uptake from contaminated water

Metal	Contaminated water	*Pistiastratiotes tank*		*Alocasiamacrorrhiza tank*		CONAMA
		Mean	efficiency	Mean	efficiency	
Cd	1.052	0.591±0.283	43.83	0.372±0.231	3.12	0.01
Co	7.862	2.593±1.011	67.01	1.007±0.400	40.76	0.2
Fe	7.522	4.640±1.980	38.31	2.983±1.055	8.66	0.3
Ni	4.846	2.906±0.778	40.03	2.282±0.481	5.11	0.025
Pb	7.356	2.755±1.366	62.54	3.002±2.123	20.66	0.01
Mn	2.258	1.315±0.271	41.76	1.353±0.418	9.55	0.5
Cu	1.942	1.298±0.310	33.16	0.887±0.632	5.43	0.009

Ourfindings showed a reductionin the PTM concentrationofmetal-contaminated water. However,filtering efficiency of the *Alocasiamacrorrhiz*a tank is lower than that of the *Pistiastratiotes* tank. The filtering efficiency obeyed the following sequence: Co >Pb>Mn> Fe > Cu > Ni > Cd. The filtering process has a linear trend only for Cu (r20,980). This result suggests that the filtering efficiency in the *Alocasiamacrorrhiza*tank in removingPTM is low, being more efficient only for Cu.These findings highlight the need for further studies because the efficiency of phytoextraction can be determined by calculating the bioconcentration factor and the translocation factor. The wetland constructed with the *Pistiastratiotes* and the *Alocasiamacrorrhiza*tanks needs optimization to improve its performance in reducing the PTM concentration.

Accumulation of PTMin the Plants

The increase of Fe, Pb, and Co concentrations in *Pistiastratiotes* and *Alocasiamacrorrhiza*occurred with the reduction ofPTMconcentrations in contaminated water, indicating that both plants are capable of accumulating PTM (Figure 3). From the phytoremediation perspective, a good metal accumulator should meet the following criteria: (i) it should be able to accumulate a high level of the metal concerned in its harvestable tissues, (ii) it should be a fast growing species, and (iii) it should possess a well-developed root system(Qian et al., 1999). Based on these criteria, we can affirm that the *Pistiastratiote*s and the *Alocasiamacrorrhizaar*e good accumulators of the PTM studied. Since uptake and accumulation of heavy metal directly from contaminated water and assimilation by plants are the greatest benefit of phytoremediation process, our results provide insight into the issue of wetland constructed with *Pistiastratiotes* and *Alocasiamacrorrhiza*. The heavy metal concentrations are higher in the root than in the leaves in two plants. This finding suggests that the metal uptake occurs by rizofiltration.

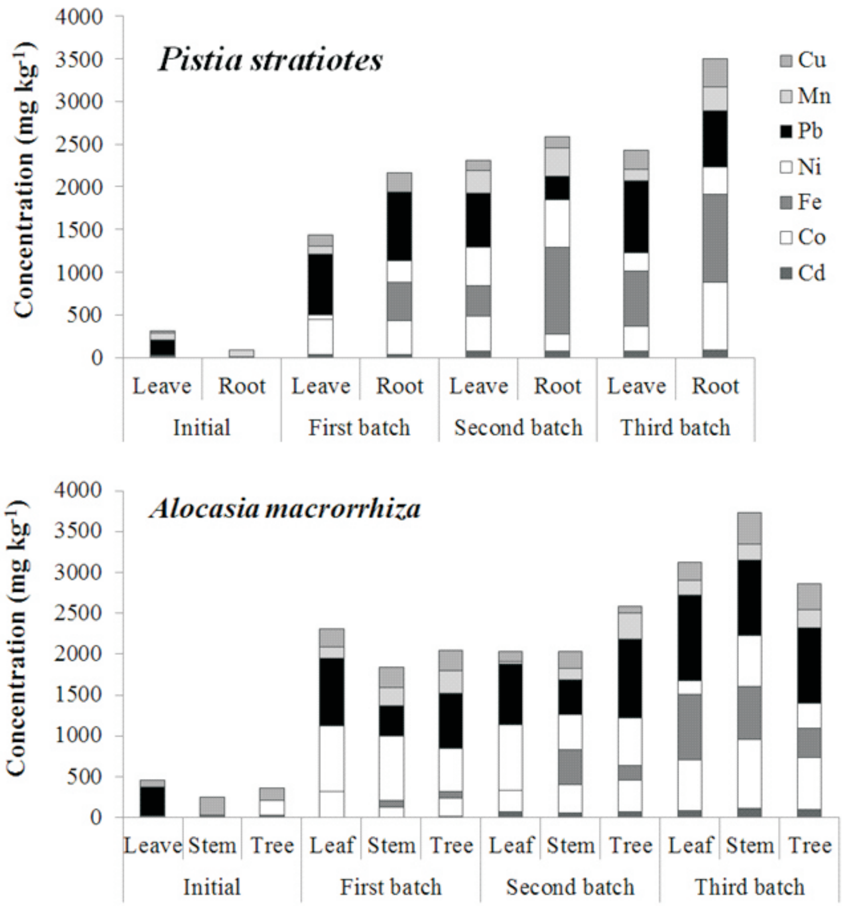

Figure 3. Heavy metal distribution in plants

In general, the *Pistiastratiotes* is tolerant to the high Cd levels. This result matches the study of Das et al. (2014). These authors observed that the *Pistiastratiotes* is able to remove 15 mg $L^{-1}$from contaminated water. Our findings show that *Pistiastratiotes* and *Alocasiamacrorrhiza*are capable of removing Pb from contaminated water. However,*Alocasiamacrorrhiza* is more effective in accumulating a higher Pbconcentration than Pistiastratiotes. This result isaccording to the literature, which attributed to the *Alocasiamacrorrhiza* a rapid growth and propagation with a considerableincrease of biomass in contaminated soil by Pb(Liu et al., 2010).

Furthermore, the aerial parts (roots and leaves) ofthe *Pistiastratiotes* absorbed high concentration of Pb and Co while,rootsaccumulated high Pb, and Fe concentrations. The total amount of absorbed Fe, Pb and Co concentrationsuggests that the Pistiastratiotes has the capacity of heavy metal uptake(Pilon-Smits, 2005).

Table 2 showsthe PTM found in the three batch experiments as well as in *Pistia stratiotes* and *Alocasiamacrorrhiza*. The PTM order of the three batch experiments suggests that Fe, Pb, and Co concentrations are higher in contaminated water. On the other hand, Cd is the PTM withthe lowest concentration. This PTM order directly influenced the metal uptake by Pistia stratiotes. The high Fe, Pb and Co concentrations in roots and leaves supportthis fact. The minor concentrations in roots and leaves point out the low capacity of the *Pistia* *stratiotes* in the Cd uptake.

For *Alocasiamacrorrhiza*, the PTM order of the three batch experiments suggests i) Fe, Ni, and Fe are higher in contaminated water, ii) Pb, Ni and Co prevail over roots, iii) Ni, Pb and Fe prevail over the stem and Pb, Ni, Fe and Co prevail over the leaves.

Finally, the PTM concentrations indicate both *Pistia stratiotes* and *Alocasiamacrorrhizaas* capable of absorbing high concentrations of heavy metals, for example, Pb, Co and Ni. These findings suggest that the constructed wetland can be designed to maximize the removal of PTM.

Table 2. Heavy metal concentration sequence found in two plants

Samples	Batch experiment	*Pistia stratiotes*	*Alocasiamacrorrhiza*
Contaminated water	1	Co>Fe>Pb>Ni>Cu>Mn>Cd	Fe>Co>Pb>Ni>Mn>Cu>Cd
	2	Pb>Fe>Co>Ni>Mn>Cd>Cu	Ni>Fe>Pb>Mn>Co>Cu>Cd
	3	Co>Fe>Pb>Ni>Mn>Cu>Cd	Fe>Ni>Pb>Co>Cu>Mn>Cd
Root	1	Pb>>Fe>Co>Ni>Cu>Mn>Cd	Pb>Ni>Mn>Cu>Co>Fe>Cd
	2	Fe>>Ni>Mn>Pb>Co>Cu>Cd	Pb> Ni>Co>Mn>Fe>Cu>Cd
	3	Fe>Co>Pb>Cu>Ni>Mn>Cd	Pb>Co>Fe>Cu>Ni>Mn>Cd
Leaves	1	Pb>>Co>Cu>Mn>Ni>Cd>Fe	Pb>Ni>Co>Cu>Mn>Cd>Fe
	2	Pb>Ni>Co>Fe>Mn>Cu>Cd	Ni>Pb>Co>Cu>Cd>Mn>Fe
	3	Pb>Fe>Co>Cu>Ni>Mn>Cd	Pb>Fe>Co>Cu>Mn>Ni>Cd
Stem	1	-	Ni>Pb>Cu>Mn>Co>Fe>Cd
	2	-	Ni>Fe>Pb>Co>Cu>Mn>Cd
	3	-	Pb>Co>Fe>Ni>Cu>Mn>Cd

CONCLUSION

The SSFWhas good performance in reducing all PTManalyzed, however the tank with *Pistia stratiotes* showed a better reduction when compared to the planted filter. Specifically, both the tank and the filter planted were more efficient for Pb and Co. Our finding show that the use of vegetation improved the efficiency of PTM removal from metal-contaminated water. Effectivelyour findings showed that *Pistia stratiotes* absorbsPb and Fethrough its roots and Pbthrough its leaves while *macrorrhizaAlocasia* absorbs Pb and Ni bythe roots, Ni and Fe by stems and Pb and Ni through the leaves. The worst performance in the PTM reduction in both tanks as well as the lowest metal concentration in the plant tissues is the Cd.Finally, the choice of *Pistia stratiotes* in consortium with *macrorrhizaAlocasia* may have marked effects on biofilter effectiveness.

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