

# Bioaccumulation of metals in *Montrichardia linifera*: aquatic macrophyte of Amazon Region

## Bioacumulação de metais em *Montrichardia linifera*: macrófita aquática da Região Amazônica

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### Contents

- [1. Introduction](#)
- [2. Materials and Methods](#)
- [3. Results and discussion](#)
- [4. Concluding Remarks](#)
- [Acknowledgments](#)
- [Bibliographic references](#)

#### ABSTRACT:

Concentrations of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  in sediments, water and different tissues of the *Montrichardia linifera* growing naturally in Guama river (Belém, "Metropolis of the Amazon", Brazil) were investigated. The aim was to define which plant tissues exhibit the greatest accumulation and find possible differences on the minerals composition among the collection site (riverbank and igapo). *M. linifera* accumulated more nutrients on the riverbank than igapo (exception for  $\text{Zn}^{2+}$ ). The plant showed almost two times more  $\text{Mn}^{2+}$  (in the leaves) and four times more  $\text{Fe}^{3+}$  (in the roots) on the riverbank than on the igapo, which in turn accumulates five times more  $\text{Zn}^{2+}$  (roots and leaves) than on the riverbank. So, there is a potential interest for use this specie in phytoremediation studies of polluted waters.

**Keywords:** Amazon, bioaccumulation, *Montrichardia linifera*, nutrients content.

#### RESUMO:

Foram investigadas concentrações de  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  e  $\text{Mn}^{2+}$  em sedimentos, água e diferentes tecidos da *Montrichardia linifera* que crescem naturalmente no rio Guamá (Belém, "Metrópole da Amazônia", Brasil). O objetivo foi definir quais os tecidos das plantas que apresentam a maior acumulação e encontrar possíveis diferenças na composição dos minerais no local de coleta (margem do rio e igapó). A *M. linifera* acumulou mais nutrientes na margem do rio do que no igapó (exceção para  $\text{Zn}^{2+}$ ). A planta mostrou quase duas vezes mais  $\text{Mn}^{2+}$  (nas folhas) e quatro vezes mais  $\text{Fe}^{3+}$  (nas raízes) na margem do rio que no igapó, que por sua vez acumula cinco vezes mais  $\text{Zn}^{2+}$  (raízes e folhas) do que na margem do rio. Portanto, há um interesse potencial para usar essa espécie em estudos de correção de águas poluídas.

**Palavras chave** Amazônia, bioacumulação, *Montrichardia linifera*, conteúdo de nutrientes.

## 1. Introduction

Water pollution is nominally one of the most dangerous hazards on both developing and developed

countries (FAWZY, BADR, EL-KHATIB & ABO-EL-KASSEM, 2012). In a series of studies on the environmental impacts inflicted upon the Amazonian region by anthropogenic activities, environmental contamination by metals is considered one of the worst problems affecting the Amazonian ecosystem (SERUDO, OLIVEIRA, ROCHA, PATERLINI, ROSA, SILVA & BOTERO, 2007).

In the Amazon, Guama River is also an example of environmental problem. This river supplies the city of Belem (capital of Para State, North Region of Brazil) with 1.425.923 inhabitants (RIBEIRO, 2004). The city is the entrance gate to Amazon River and known as the "Metropolis of the Amazon", it is headquarters of the Metropolitan Region of Belem that with a population of 2.437.297 inhabitants (IBGE), is the 2nd most populous of the region, 13th of Brazil and 177th of world, representing the largest urban agglomeration in the region (MERCÊS & BASTOS, 2011). Guama river supplies about 75% of all water consumed in Belem, but 11 of its tributaries are contaminated by irregular disposal of urban waste. In the north region of the Brazil, about 8.8 million people don't have sewer collector network, of which 60% this concentrated in Para State (SANTOS, HOLANDA, PEREIRA, RODRIGUES, PEREIRA & MESQUITA, 2014).

It has been known for long time that aquatic plants, both living and dead, are heavy metal accumulators and, therefore, the use of aquatic plants for the removal of heavy metals from wastewater has gained high interest (FAWZY, BADR, EL-KHATIB & ABO-EL-KASSEM, 2012; KUYUCAK & VOLESKY, 1988). Moreover, treatment systems with aquatic plants are low-cost technologies and can be adopted by developing countries for recycling/treatment of waste water, especially contaminated by heavy/toxic metals (FAWZY, BADR, EL-KHATIB & ABO-EL-KASSEM, 2012; FIGUEIRA & RIBEIRO, 2005). This technology is considered as an alternative solution for conventional methods to clean up heavy metals from contaminated waters (FAWZY, BADR, EL-KHATIB & ABO-EL-KASSEM, 2012; KHAMBHATY, MODY, BASHA & JHA, 2009), applied at various industrial events (VERMA, GUPTA & RAI, 2005). This technology can be used to treat both organic and inorganic pollutants present in soil (solid substrate), water (liquid substrate), or on the air (SALT, SMITH & RASKIN, 1998).

A recent study at Nile River showed that the aquatic macrophytes *Ceratophyllum demersum*, *Eichhornia crassipes*, *Myriophyllum spicatum*, *Echinochloa pyramidalis*, *Typha domingensis* and *Phragmites australis* can survive in extreme conditions and tolerate very high heavy metals concentrations, making them an excellent choice for phytoremediation and biomonitoring programs (FAWZY, BADR, EL-KHATIB & ABO-EL-KASSEM, 2012).

In Guama River, previous studies reported high levels of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Mn}^{2+}$  on the leaves and fruits of *Montrichardia linifera*, an aquatic macrophyte popularly known as aninga (AMARANTE, SILVA, MÜLLER & MÜLLER, 2011; AMARANTE, MÜLLER, DANTAS, ALVES, MÜLLER & PALHETA, 2010; AMARANTE, SILVA, SOLANO, NASCIMENTO, MORAES, SILVA & UNO, 2009), indicating that perhaps this plant has the ability to bioaccumulate metals in their biomass and thus, promote phytoremediation. *M. linifera* belongs to the family Araceae and occurs significantly along the rivers and streams of the Amazon, including River Guama (Figure 1), and serve as food for fishes, turtles, manatees and buffaloes (AMARANTE, MÜLLER, DANTAS, ALVES, MÜLLER & PALHETA, 2010; AMARANTE, SILVA, SOLANO, NASCIMENTO, MORAES, SILVA & UNO, 2009).

The aim of this study was to investigate the levels  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  in different tissues of *M. linifera* (root, stem, leaf) as well as sediment and surface water, collected in two different areas (at riverbank, with periodic flooding according to the movement of the tides, and at "igapó", permanently flooded area) in order to ascertain whether there are differences in the composition of these minerals in relation to the collection site, to know which part of the plant these elements are concentrated and calculate the Bioaccumulation Factor (BAF) and Bioconcentration Factor (BCF) as phytoremediation parameters.

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## 2. Materials and Methods

### 2.1. Study area, sampling and preparation samples

Surface water, sediments and aquatic plant *Montrichardia linifera* were sampled from two sites located in right bank of the River Guama (Figure 2), on the campus of the Federal Rural University of Amazonia, Belem, Para, Brazil. Site I (01°27'53.10" S, 048°26'02.90" W and average altitude of 4 m) is at riverbank and affected by irregular disposal of urban waste effluents, with periodic flooding according to the movement of the tides; site II (01°27'42.90" S, 048°26'10.70" W and average altitude of 10 m) is

located 500 m far from site I, toward the mainland, at igapo. All samples (water, sediments, and plants) were collected in triplicates, in three equidistant points on each site, in march/2012, between 8:00 and 10:00 a.m., at low tide time at both sites. In the Amazon, as a rainforest, there is no defined seasons as dry and rain and since these areas are always covered by the tides, regardless of the time of year.

**Figure 1**

Population of *M. linifera* in the River Guama. Significant occurrence in the Amazon.



Author Photo: Cristine Bastos do Amarante

Local: Mangal das Garças, Belem-PA, Brazil

1. Surface sediment (0 – 20 cm) was collected with auger and the samples were packed in sterile plastic bags. The sediments samples were air dried, disaggregated, homogenized and passed through a sieve coarse mesh (2 mm). For determination the metals  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  were determined using 5 g of homogenized sample and the extraction was performed with 25 mL of solution Mehlich 1 ( $\text{HCl}$  0.05 mol  $\text{L}^{-1}$  +  $\text{H}_2\text{SO}_4$  0.0125 mol  $\text{L}^{-1}$ ), followed by stirring for 5 min to 120 rpm. After stirring, the suspension was filtered through Whatman filter paper No. 42 (BOTERO, SOUZA, SANTOS, OLIVEIRA & AMARANTE, 2014).

2. Water samples (500 mL) was collected and stored in sterile bottle, filtered by 1 h of collection using Millipore filter paper type HA 0.45  $\mu\text{m}$  pore size. All samples were kept in amber flasks at 4 °C. Then, aliquots of 25 mL were digested with a mixture of nitric acid (14 mol  $\text{L}^{-1}$ ) and hydrogen peroxide (30% v/v) at a ratio of 3:1 in a digestion block at 150°C for 2 h. After digestion, the samples were filtered and transferred to 50 mL volumetric flasks, measured up to the mark with deionized water.

3. Adult plants were selected for plant material collect. *M. linifera* was identified by Dr<sup>a</sup> Alba Lins

(Coordination of Botany of the Emilio Goeldi Museum) and an exemplar was deposited in the Herbarium João Murça Pires (MG 204905). Plant material was separated in leaves, stem and roots. The leaves were separated in two parts, "petiole+sheath" and lamina. After separation, each part was washed with water, then with deionized water to remove all the debris and other foreign particles and oven-dried (105°C) to constant weight. The dried material was triturated in a knife mill. Approximately 0.3 g of homogeneous samples of leaves (petiole and lamina), stem and roots powder were weighed and digested with a mixture of nitric acid (14 mol L<sup>-1</sup>) and hydrogen peroxide (30% v/v) at a ratio of 3:1 in a digestion block at 150°C for 2 h. After digestion, the samples were filtered, transferred to 50 mL volumetric flasks and measured up to the mark with deionized water (AMARANTE, SILVA, MÜLLER & MÜLLER, 2011; AMARANTE, MÜLLER, DANTAS, ALVES, MÜLLER & PALHETA, 2010).

## 2.2. Analysis samples

For pH measurements in sediment samples were used 10 cm<sup>3</sup> of homogenized samples and adding 25 mL of deionized water, followed by stirring. After 1 hour, the system was again stirred and pH was measured (SILVA, 2009). Water samples pH was measured immediately after collection with pH meter.

Metals concentrations in water, sediment and plant samples were determined by a flame atomic absorption spectrophotometer (FAAS AA 904 (Instrumentos Científicos C.G. Ltda.)). All the analyses were carried out on three subsamples.

The analytical procedure was checked with tests of addition and recovery of the analytes in samples randomly chosen. The samples were fortified by additions of known concentrations of the analytes and the percent recovery (Rec %) was determined according to the formula I:

$$\text{Rec}(\%) = \frac{C_F V_F - C_A V_A}{C_S V_S} \times 100 \quad (\text{formula I})$$

wherein: CF concentration of the analyte in the sample fortified; VF volume of sample of the recovery test (VA + VS); CA concentration of the analyte in the sample not-fortified; VA volume of sample used in the recovery test; CS concentration of standard of the analyte used to fortify the sample; VS volume of standard of the analyte used in the recovery test.

Further, to verify the accuracy of the method, the same digestion method of plant dry matter was applied to Ca<sup>2+</sup>, Mg<sup>2+</sup>, Fe<sup>3+</sup>, Cu<sup>2+</sup>, Zn<sup>2+</sup> and Mn<sup>2+</sup> determination in certified reference material, Poplar leaves powder GBW 07604 of National Research Center for Certified Reference Materials (CRMs, Beijing, China).

## 2.3. Bioaccumulation and bioconcentration analysis

In the present investigation, the bioaccumulation factor (BAF) was calculated using the formula II outlined by SADIQ (1992) and the bioconcentration factor (BCF) was calculated using the formula III according to ESRINGÜ & TURAN (2012):

$$\text{BAF} = \frac{\text{element concentration in plant}}{\text{element concentration in water}} \quad (\text{formula II})$$

$$\text{BFC} = \frac{\text{element concentration in plant}}{\text{element concentration in soil}} \quad (\text{formula III})$$

Results of analytes concentrations in water and sediment samples, in relation to the collection site, were subjected to analysis of variance (F test).

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## 3. Results and discussion

To further verify the accuracy of the method, the developed method was applied to the determination of Ca<sup>2+</sup>, Mg<sup>2+</sup>, Fe<sup>3+</sup>, Cu<sup>2+</sup>, Zn<sup>2+</sup> and Mn<sup>2+</sup> in certified reference materials of poplar leaves GBW 07604, and the analytical results are given in Table 1 with the limit of detection (LOD) and limit of quantification (LOQ). The obtained values by the proposed method fitted very well with certified values.

**Table 1**

Analytical results for  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  in certified reference material GBW07604 (poplar leaves) and limit of quantification (LOQ) and limit of detection (LOD).

Sample	Element	Measured value * ( $\mu\text{g g}^{-1}$ )	Certified value ( $\mu\text{g g}^{-1}$ )
GBW07604	$\text{Ca}^{2+}$	18093.00 $\pm$ 69.87	18100
	$\text{Mg}^{2+}$	6498.00 $\pm$ 29.86	6500
	$\text{Fe}^{3+}$	270.97 $\pm$ 1.15	274
	$\text{Cu}^{2+}$	9.37 $\pm$ 0.12	9,30
	$\text{Zn}^{2+}$	36.94 $\pm$ 0.27	37
	$\text{Mn}^{2+}$	45.04 $\pm$ 0.21	45

\*Values expressed as mean $\pm$ s ( $n = 3$ ). LOD:  $\text{Ca}^{2+}$  - 23.17  $\mu\text{g L}^{-1}$ ;  $\text{Mg}^{2+}$  - 20.11  $\mu\text{g L}^{-1}$ ;  $\text{Fe}^{3+}$  - 2.13  $\mu\text{g L}^{-1}$ ;  $\text{Cu}^{2+}$  - 5.21  $\mu\text{g L}^{-1}$ ;  $\text{Zn}^{2+}$  - 2.04  $\mu\text{g L}^{-1}$ ;  $\text{Mn}^{2+}$  - 3.77  $\mu\text{g L}^{-1}$ . LOQ:  $\text{Ca}^{2+}$  - 69.88  $\mu\text{g L}^{-1}$ ;  $\text{Mg}^{2+}$  - 99.16  $\mu\text{g L}^{-1}$ ;  $\text{Fe}^{3+}$  - 11.05  $\mu\text{g L}^{-1}$ ;  $\text{Cu}^{2+}$  - 30.08  $\mu\text{g L}^{-1}$ ;  $\text{Zn}^{2+}$  - 11.12  $\mu\text{g L}^{-1}$ ;  $\text{Mn}^{2+}$  - 27.87  $\mu\text{g L}^{-1}$ .

The water and sediment pH in two sites were similar, water pH were 6.41 and 6.17, and sediment pH were 5.04 and 5.02 at river bank and igapo respectively, indicating that both systems are acids.

The results for concentrations of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  in sediment samples, water and different tissues of *Montrichardia linifera* collected in two different sites, riverbank and igapo, are presented in Table 2.

**Table 2**

Concentrations of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  in water, sediment and *Montrichardia linifera* organs collected in different sites (riverbank and igapo).

Metals	RIVERBANK					
	Water ( $\text{mg L}^{-1}$ )	Sediment ( $\text{mg kg}^{-1}$ )	Leaf			
			Root ( $\text{mg kg}^{-1}$ )	Stem ( $\text{mg kg}^{-1}$ )	Petiole+Sheath ( $\text{mg kg}^{-1}$ )	Lamina ( $\text{mg kg}^{-1}$ )
$\text{Ca}^{2+}$	1322.12 $\pm$ 110.00	2013.45 $\pm$ 18.03	6063.33 $\pm$ 198.70	3725.13 $\pm$ 324.49	26791.13 $\pm$ 805.59	12165.70 $\pm$ 402.11
$\text{Mg}^{2+}$	778.33 $\pm$ 111.55	747.08 $\pm$ 93.55	1415.17 $\pm$ 329.99	131.04 $\pm$ 2.21	3185.27 $\pm$ 194.81	2523.12 $\pm$ 81.89
$\text{Fe}^{3+}$	4.33 $\pm$ 0.04	797.87 $\pm$ 42.41	17369.57 $\pm$ 1764.61	152.79 $\pm$ 17.69	521.72 $\pm$ 56.30	164.05 $\pm$ 9.66
$\text{Cu}^{2+}$	< LD	3.63 $\pm$ 0.10	< LD	< LD	< LD	< LD

Zn <sup>2+</sup>	< LQ	8.7 ± 0.53	76.05 ± 2.98	22.19 ± 3.39	41.88 ± 1.82	36.29 ± 1.61
Mn <sup>2+</sup>	0.54 ± 0.03	206.89 ± 7.93	1443.77 ± 24.75	221.60 ± 3.48	1445.71 ± 54.20	1871.89 ± 21.86
<b>IGAPÓ</b>						
Ca	2081.66 ± 320.00	1793.65 ± 43.28	10010.98 ± 310.14	5725.48 ± 716.57	14674.60 ± 504.34	8622.30 ± 700.04
Mg	710.00 ± 60.00	708.65 ± 38.62	1670.73 ± 47.56	77.87 ± 4.23	2021.13 ± 70.48	1988.27 ± 102.54
Fe	9.09 ± 0.27	735.87 ± 35.90	8161.68 ± 163.84	364.47 ± 75.19	82.41 ± 7.31	83.77 ± 16.05
Cu	< LOD	2.80 ± 0.25	< LOD	< LOD	< LOD	< LOD
Zn	< LOQ	12.35 ± 0.53	250.75 ± 13.51	192.00 ± 17.27	378.75 ± 39.03	525.75 ± 44.42
Mn	0.78 ± 0.01	431.93 ± 1.35	365.02 ± 0.23	515.95 ± 20.13	1509.69 ± 117.46	1914.18 ± 42.67

LOD = Limit of detection; LOQ = Limit of quantitation. Values expressed as mean±standard deviation (n = 3)

The concentrations of the studied metals in the sediment and water have the same trend in the two sites, in sediment samples Ca<sup>2+</sup> > Fe<sup>3+</sup> > Mg<sup>2+</sup> > Mn<sup>2+</sup> > Zn<sup>2+</sup> > Cu<sup>2+</sup> and in water samples Ca<sup>2+</sup> > Mg<sup>2+</sup> > Fe<sup>3+</sup> > Mn<sup>2+</sup>. In the water samples, the elements Cu<sup>2+</sup> and Zn<sup>2+</sup> showed to be below the limits of detection (LODCu<sup>2+</sup> = 67.19 µg L<sup>-1</sup>) and quantitation (LOQZn<sup>2+</sup> = 106.01 µg L<sup>-1</sup>), respectively, in both sites.

The results expressed by analysis of variance (ANOVA) showed that there are differences between the sampling sites in the concentration of Ca<sup>2+</sup>, Mg<sup>2+</sup>, Fe<sup>3+</sup> and Mn<sup>2+</sup> in the water (p < 0.05) and Ca<sup>2+</sup>, Cu<sup>2+</sup>, Zn<sup>2+</sup> and Mn<sup>2+</sup> in the sediment (p < 0.01) (Table 3). However, for concentrations of Fe<sup>3+</sup> and Mg<sup>2+</sup> in the sediment, and Zn<sup>2+</sup> in the water there was no significant variation in relation to the collection sites.

**Table 3.**  
F values (ANOVA) of the nutrients concentration in the water and in the sediment in relation to the collection sites.

Variable		Ca	Mg	Fe	Cu	Zn	Mn
Site	Water	14.8*	13500.6*	885.2*	-	0.12ns	5769.8*
	Sediment	65.95**	0.43 ns	3.73 ns	27.94**	70.24**	2349.76**

\*p < 0.05; \*\* p < 0.01; ns not significant

In the plant, the elements Ca<sup>2+</sup>, Mg<sup>2+</sup> and Mn<sup>2+</sup> were concentrated in the leaves. Practically twice of Ca<sup>2+</sup> is deposited on the region "petiole + sheath" (riverbank = 26791.13 ± 805.59 mg kg<sup>-1</sup>; igapo =

14674.60 ± 504.34 mg kg<sup>-1</sup>) compared to the leaf lamina (riverbank = 12165.70 ± 402.11 mg kg<sup>-1</sup>; igapo = 8622.30 ± 700.04 mg kg<sup>-1</sup>) (Table 2). High Ca<sup>2+</sup> and Mg<sup>2+</sup> concentrations were expected, compared to the other elements analyzed, since they are macronutrients. However, for Mn<sup>2+</sup> (a trace element) the high levels found in the plant can be justified by the fact that the soil remains at long time flooded, and as the concentration of manganese in the soil solution increases after the submersion of the soil (MATTAR, VIEIRA & SILVA, 2002), due to the reduction process occurs greater availability of manganese in the soil and increased plant uptake (IWATA, 1975; ABREU, FERNANDES, MARTINS & RODRIGUES, 2006).

Furthermore, studies in soil samples from the right bank of Guama River, on the Universidade Federal Rural da Amazonia (UFRA) next to the study research's area, showed pH values < 5 of acidic soils (LOPES, FERNANDES, GRIMALDI, RUIVO, RODRIGUES & SARRAZIN, 2006). The high acidity was also found in the same study area at different times of the year, regardless of the period that the flood occurs (ABREU, FERNANDES & RUIVO, 2007). In general, acidic pH conditions favor toxic concentrations accumulation of manganese, due to the increased solubility at pH 5.0 (FOY, 1973; VELOSO, MURAOKA, MALAVOLTA & CARVALHO, 1995). The highest Fe<sup>3+</sup> concentrations were found in the roots on both sites, the riverbank (17369.57 ± 1764.61 mg kg<sup>-1</sup>) and igapo (8161.68 ± 163.84 mg kg<sup>-1</sup>) (Table 2). Cu<sup>2+</sup> was not detected in any plant part, as results for this element were all below the detection limit (LOD = 25.91 µg L<sup>-1</sup>).

Zn<sup>2+</sup> was the exception, once presented higher concentrations in the samples from the igapo, ranging from 192.00 to 525.75 mg kg<sup>-1</sup>, compared to the riverbank where the variation was from 22.19 to 76,05 mg kg<sup>-1</sup> (Table 2). In fact, the content of Zn<sup>2+</sup> on igapo sediment (12.35 mg kg<sup>-1</sup>) was higher than on the riverbank sediment (8.7 mg kg<sup>-1</sup>) and this difference may be related to the fact that the soil of igapo is permanently flooded, unlike the soil of the riverbank that is periodically flooded, and influenced by tidal movement. In acid soils of pH < 5.5 and anaerobes, as is the case of the igapo in this study, the nitrification rate is very low, which results in accumulation of ammonia (NH<sub>3</sub>) (ABREU, FERNANDES & RUIVO, 2007; SILVA, VALE, ANDERSON & KOBAL, 1999). Although Zn<sup>2+</sup> is a low mobility cation, strongly adsorbed on metal oxides and clay, also can form insoluble sulfides (GUILHERME, MARQUES, PIERANGELI, ZULIANI, CAMPOS & MARCHI, 2005). Once on the environment can form complexes with ammonia and may be remobilized off the sediment for form these complexes and therefore get available to the plant (FATMA, 1999).

The distribution of this element in the plant was also different. At igapo the highest Zn<sup>2+</sup> content was found in the leaf (525.75 mg kg<sup>-1</sup>) while on the riverbank the highest content was found in the root (76.05 mg kg<sup>-1</sup>) (Table 4). Possibly, the anaerobic conditions of igapo soil (permanently flooded) allow the plant to absorb more Zn<sup>2+</sup> than the plant that inhabits the riverbank and is exposed to tidal movement.

In Table 4 are shown the percentages of each element found in the system (water-sediment-plant), and it's possible to map how *M. linifera* stocks these nutrients in their biomass. Among all the Ca<sup>2+</sup> from riverbank, over 90% was stored in the biomass of *M. linifera* and only 2.54% in the water and 3.87% in the sediment. 74.80% were stored in leaves. Also on igapo 90% of Ca<sup>2+</sup> was in biomass and of this amount, 54.29% was found in the leaves, 4.85% in the water and 4.18% in the sediment. The Mg<sup>2+</sup> behavior was similar in both collection sites, approximately 80% of total was found in the biomass. On average 60% was present in the leaves and just about 9 - 10% in the water and in the sediment, respectively.

Of all the Fe<sup>3+</sup> found in the systems (riverbank and igapo), 95.77% and 92.10% was in the biomass, respectively, where a percentage of 91.37% and 86.48% was stored in the roots and only 0,02 - 0.10% in the water and 4.20 - 7.80% in the sediment, respectively (Table 4).

Mn<sup>2+</sup> also showed the same storage tendency, in both collection sites, i.e., more than 90% were present in the biomass, and only about 0.01 - 0.02% in the water and 4 - 9% in the sediments. In the biomass, about 60 to 70% of Mn<sup>2+</sup> was also found in the leaves (Table 4).

The Mn<sup>2+</sup> concentrations obtained from the leaves of *M. linifera* in this study were similar to those obtained in a previous study (AMARANTE, SILVA, SOLANO, NASCIMENTO, MORAES, SILVA & UNO, 2009), around 3000 mg kg<sup>-1</sup> (Table 5).

In relation to  $\text{Cu}^{2+}$  in the systems, it was found only in sediments from both collection sites. Indeed, in other studies, this element also showed lower concentrations not only in species of *Montrichardia*, but also in other aquatic plants, such as some species of *Eichhornia*, *Pistia* and *Salvinia*, as shown in Table 5.

The exception was  $\text{Zn}^{2+}$ , although presented a percentage more than 95% of storage in the biomass of both collection sites, it was observed that in the sampling from the riverbank there was a division of this element, where a percentage of 41.08% was stored in the root and almost the same percentage, 42.22%, was stored in the leaf. Different behavior was observed in igapo samples, where only 18.44% was stored in the root while a higher percentage (66.53%) was stored in leaves (Table 4). That in the igapo, the contact of the plant with the soil solution is full time, and so may favor  $\text{Zn}^{2+}$  accumulation in the leaves, contrary to what occurs on the riverbank.

The stem was the tissue of the plant, with the lowest concentrations of all elements, according to the following pattern  $\text{Ca}^{2+} > \text{Mn}^{2+} > \text{Fe}^{3+} > \text{Mg}^{2+} > \text{Zn}^{2+}$  for the plant collected on the riverbank and  $\text{Ca}^{2+} > \text{Mn}^{2+} > \text{Fe}^{3+} > \text{Zn}^{2+} > \text{Mg}^{2+}$  for igapo samples, as shown in Table 2.

Phytoremediation parameters calculated in terms of the Bioaccumulation Factor (BAF) and Bioconcentration Factor (BCF) from the total biomass of *M. linifera* are shown in Table 6 and reveal that this plant has high potential to bioaccumulate  $\text{Mn}^{2+}$  (9227.72  $\text{mg kg}^{-1}$  and 5519.03  $\text{mg kg}^{-1}$ ) and Fe (4205.11  $\text{mg kg}^{-1}$  and 956.25  $\text{mg kg}^{-1}$ ) of both systems, riverbank and igapo respectively, and considerable capacity to bioaccumulate  $\text{Zn}^{2+}$  in igapo system (109.08  $\text{mg kg}^{-1}$ ) compared to the riverbank (20.27  $\text{mg kg}^{-1}$ ).

In general, this plant accumulates more elements at riverbank than igapo (exception for Zn) (Table 4). Thus, the results show that *M. linifera* concentrate almost 1.67 times more  $\text{Mn}^{2+}$  and 4.39 times more  $\text{Fe}^{3+}$  in the riverbank than in the igapo, which in turn accumulates 5.38 times more  $\text{Zn}^{2+}$  than on the riverbank.

**Table 4**  
Percentage (%) of elements  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  in the system water-sediment-*M. linifera*

Elements (%)		$\text{Ca}^{2+}$		$\text{Mg}^{2+}$		$\text{Fe}^{3+}$		$\text{Cu}^{2+}$		$\text{Zn}^{2+}$		$\text{Mn}^{2+}$	
		RB	IG	RB	IG	RB	IG	RB	IG	RB	IG	RB	IG
Water		2.54	4.85	8.86	9.89	0.02	0.10	< LOD	< LOD	< LOD	< LOD	0.01	0.02
Sediment		3.87	4.18	8.51	9.87	4.20	7.80	100	100	4.70	0.91	3.99	9.12
Root		11.64	23.33	16.12	23.28	91.37	86.48	< LOD	< LOD	41.08	18.44	27.82	7.70
Stem		7.15	13.34	1.49	1.09	0.80	3.86	< LOD	< LOD	11.99	14.12	4.27	10.89
Leaf	Petiole+Sheath	51.44	34.20	36.28	28.16	2.74	0.87	< LOD	< LOD	22.62	27.86	27.85	31.87
	Lamina	23.36	20.09	28.74	27.70	0.86	0.89	< LOD	< LOD	19.60	38.67	36.06	40.40
	Total	74.80	54.29	65.02	55.86	3.60	1.76	< LOD	< LOD	42.22	66.53	63.91	72.27



Total in the Biomass	93.59	90.96	82.63	80.23	95.77	92.10	< LOD	< LOD	95.29	99.09	96.00	90.86
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RB = Riverbank. IG = Igapó. Value in bold = the highest percentage found in the plant organ. LOD = Limit of detection

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**Table 5**

Concentration values (mg kg<sup>-1</sup>) of Ca<sup>2+</sup>, Mg<sup>2+</sup>, Fe<sup>3+</sup>, Cu<sup>2+</sup>, Zn<sup>2+</sup> and Mn<sup>2+</sup> in *M. linifera* obtained in this work and compared with other aquatic plants.

Species	Part of plant	Concentrations (mg kg <sup>-1</sup> )						References
		Ca <sup>2+</sup>	Mg <sup>2+</sup>	Fe <sup>3+</sup>	Cu <sup>2+</sup>	Zn <sup>2+</sup>	Mn <sup>2+</sup>	
<i>Montrichardia linifera</i> *	Total biomass RB	48745.29	7254.60	18208.13	<LOD	176.41	4982.97	This work
	Total biomass IG	39033.36	5758.00	8692.33	<LOD	1347.25	4304.84	
	Leaf RB	38956.83	5708.39	685.77	<LOD	78.17	3317.60	
	Leaf IG	23296.90	4009.40	166.18	<LOD	904.50	3423.87	
<i>Montrichardia linifera</i> *	Leaf RS	19150.00	5730.00	70.79	7.08	272.02	3279.46	[1]
	Leaf LRS	31530.00	9750.00	58.82	6.81	255.90	3612.23	
<i>Montrichardia arborescens</i> *	Leaf	18500.00	4620.00	1150.00	<LOD	259.00	<LOD	[2]
<i>Eichhornia crassipes</i> <i>Pistia stratiotes</i> *	Total biomass	15100.00	3920.00	5425.00	25.83	81.83	1233.33	[3]
		10900.00	2150.00	1391.67	9.17	29.83	2145.83	
<i>Eichhornia crassipes</i>	Leaf	30200.00	<LOD	<LOD	<LOD	<LOD	<LOD	[4]
<i>Anona sp.</i>	Leaf	14400.00	3200.00	<LOD	<LOD	<LOD	<LOD	
<i>Eichhornia crassipes</i> <i>Pistia stratiotes</i> * <i>Salvinia auriculata</i>	Total biomass	11550.00	2930.00	4671.33	9.75	187.00	1254.00	[5]
		22350.00	4500.00	4050.00	8.58	233.27	1319.00	
		9180.00	2480.00	3206.00	11.14	250.33	1491.00	
<i>Egeria densa</i> <i>Egeria najas</i> <i>Ceratophyllum demersum</i>	Total biomass	17300.00	3600.00	2154.90	5.90	102.90	<LOD	[6]
		16500.00	7600.00	2958.50	5.70	130.50	<LOD	
		11800.00	9800.00	3526.20	4.60	149.00	<LOD	

- [1] , [5] AMARANTE, SILVA, MÜLLER & MÜLLER, 2011;  
 [2] BUSETTI, RUIVO, SALES & BERRÊDO, 2009;  
 [3] HENRY-SILVA & CAMARGO, 2006;  
 [4] PORTAL, LIMA, LUZ & BATAUS, 2002;  
 [6] CORRÊA, VELINI & ARRUDA, 2003.

**Table 6**

Bioaccumulation Factor (BAF) and Bioconcentration Factor (BCF) of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$  in the total biomass of *M. linifera* to the riverbank (RB) and igapó (IG)

Site	Elements											
	$\text{Cu}^{2+}$		$\text{Zn}^{2+}$		$\text{Mn}^{2+}$		$\text{Fe}^{3+}$		$\text{Ca}^{2+}$		$\text{Mg}^{2+}$	
	BAF	BCF	BAF	BCF	BAF	BCF	BAF	BCF	BAF	BCF	BAF	BCF
RB	nd	nd	nd	20.27	9227.72	24.09	4205.11	22.82	36.87	24.21	9.32	9.71
IG	nd	nd	nd	109.08	5519.03	9.97	956.25	11.81	18.75	21.76	8.11	8.13

nd = not determined. Value in bold = the highest value in the site

## 4. Concluding Remarks

The bioaccumulation factor of *M. linifera* for  $\text{Mn}^{2+}$  is 1.67 times greater in the riverbank than in the igapó and this element is concentrated on the leaves, more precisely in the region of "petiole + sheath". The  $\text{Fe}^{3+}$  is deposited in the roots and is bioaccumulated 4.4 times more in the riverbank than in the igapó. Moreover, this plant can concentrate more  $\text{Zn}^{2+}$  in the environment of igapó, around 5.38 times more than in the riverbank. In igapó,  $\text{Zn}^{2+}$  is equally stored in the roots and leaves, while on the riverbank the highest concentration was found on the leaves. *M. linifera* can tolerate very high concentrations of metals which make them an excellent choice for phytoremediation and biomonitoring studies.

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[Índice]

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