Chapter

Perspective Chapter: Uptake Capacity of Metals (Al, Cu, Pb, Sn, Zn) in Contaminated Water Metal Production Trade Village Dong Xam, Thai Binh, Vietnam by *Vetiveria zizanioides*

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Abstract

This chapter describes experiments, carried out under controlled environment conditions to investigate the uptake capacity of metals (Al, Cu, Pb, Sn, and Zn) by *Vetiveria zizanioides* to treat contaminated water from "metal production trade village Dong Xam, Thai Binh, Vietnam." The roots have a high hyperaccumulation capacity of Al, and it is much more than "reference plant" about 17- up to 30-folds, and the upper parts of shoots S2, and S3 are higher 1.2-fold. In vetiver plant the Cu concentration can be obtained up to 660 mg/kg in root, and 46.2 mg/kg in shoot, and it can withstand and be alive at 46 mg/L of contaminated solution. The lead translocation from root to shoot reached to about 41%. The tin is absorbed in the leaf chop with ratio: Root varied from 82% up to ~277% in the leaf chop. The zinc may be moved from roots and accumulated by the shoots of vetiver. The ratio shoot: root gets up to 46%. The study shows that vetiver had the high tolerance to trace metals Al, Cu, Pb, Sn, and Zn than other species plants. This plant has potential for usage in the phytoremediation of metals contaminated soil and wastewater from trade villages of Vietnam and other countries.

Keywords: uptake, metals Al, Cu, Pb, Sn, Zn, *Vetiveria zizanioides*, metal production trade village Dong Xam, Thai Binh, Vietnam

1. Introduction

There are heavy metal contaminations in the soil erosion from agricultural lands, urban wastes, and the products from rural, industrial, and mining industries that attracts worldwide concern, especially in developing countries [1, 2].

Nowadays, in Vietnam, lots of trade villages (about thousand villages) are developing by many kinds of professions, and they have problems with wastewater and solid waste. Among waste matter, there are many types of metal contaminations.

The vetiver grass was first developed for soil and water conservation in farmlands. Morphological, physiological, and ecological characteristics of vetiver have a key role in the environmental protection. The vetiver root system can be reached up to 3–4 m in the first year. Vetiver can be tolerant to extreme climatic variation flood, prolonged drought, submergence, and extreme temperature. Vetiver can live in very harsh environments where surface temperature from −13°C exceeds 55°C, soil pH, from 3.0 to 10.5, high soil salinity, sodicity, acidity [2–4].

It seems that vetiver as other Panicoideae plant subfamily follows the same conjugation detoxification pathway, and vetiver is close to sorghum [5]. The transformation known to be positive for the environment, due to major metabolism of atrazine in vetiver grown in hydroponics was conjugation, mainly in leaves [6].

The vetiver grass was selected for wastewater treatment purpose from metal production trade village Dong Xam, Thai Binh, because of many reasons as at firstly, it can tolerate in wide range of pollution conditions [7–9], second, low-cost alternative mean to vegetate the heavy metal-contaminated area [3]. Vetiver is fast growth, and has strong root system and a long-lived perennial and can survive up to 50 years or more [10]; and vetiver can be produced 99 tons/ha/year (average dry matter yield) [11].

Many previous studies [2, 3, 6, 12–18] had reported the uptake capacity of some heavy metals by vetiver, but metals such as Al, Cu, and Sn have not been investigated completely, especially the pollution likes in "metal production trade village Dong Xam, Thai Binh" with numberless of heavy metal contaminations.

2. Materials and methods

2.1 Vetiver growth conditions

The soil materials were collected from five points in the study area, then sieved through a 2-mm mesh, and well mixed to obtain composite homogeneous samples. Seedling of vetiver was wrapped with the composite soils and irrigated with different chemical pollution regimes (**Figure 1a**).

The contents of Al, Cu, Pb, Sn, and Zn elements at soil in two pots (TB10 and TB6) are the same for vetiver cultivation, respectively, at 2.5, 55.6, 0.15, 7.7, and 24.4 mg (take out from wastewater of metal production trade village Dong Xam (**Table 1**)) and one pot (control) in the clean tap water. No fertilizer was applied during the entire growing period. Temperature in the laboratory growth chamber was 25 ± 2°C.

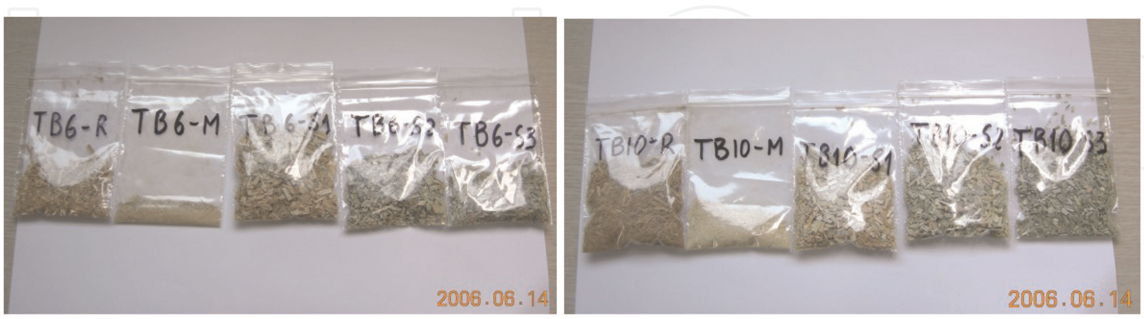
Vetiver plants were harvested after 36 days of growth in laboratory chamber by contaminated water TB10, TB6, and control water. The plant's height was 0.7 m (**Figure 1b**). First, the plants were rinsed three times with tap water and then two times with deionized water to remove all soil and other materials; afterward, it was dried in shade at room temperature for 5 days, and then at 80°C for 2 days in oven to constant weight. The plants were partitioned into five parts: three parts of shoots (S1—10 cm of shoot is from the meristematic region, S2—next 10 cm of shoot, S3—remaining part (about 20–40 cm) in the chop of shoot, meristematic region (M), and root (R)). The samples were sieved through a 2-mm mesh and well mixed (**Figure 2**).

a b

Figure 1.
(a) Vetiver land, and (b) it was grown in laboratory chamber by contaminated water for 36 days.

Elements	TB10		TB6	
	Mean, mg/L	SD	Mean, mg/L	SD
Al	1.242	0.002	2.070	0.003
Cu	27.821	0.0009	46.369	0.0015
Pb	0.075	0.0005	0.125	0.0008
Sn	3.861	0.001	6.435	0.001
Zn	12.225	0.0003	20.375	0.0005

Table 1.
Analytical results of contaminated solutions from two wastewaters (metal production trade village Dong Xam) before treatment by vetiver (mean ± SD).



a b

Figure 2.
(a) Vetiver samples TB6 and (b) TB10 were sieved through a 2-mm mesh and mixed well.

2.2 Chemical analysis

Standard NIST 1568a (Rice Flour) and about 500 mg material from each part of vetiver were placed into 100-ml digesting Teflon bottles. The materials were digested at 5 ml 16 M HNO_3 and 1 ml 12 M $HClO_4$ (5:1, v/v) during 1 day in hotplate 180°C.

Element	Certificate, mg/kg		Found, mg/kg		Recovery (%)	
	Mean	SD	Mean	SD	Mean	SD
Cd	0.022	0.002	0.023	0.0006	104.8	2.6
Cu	2.400	0.3	2.176	0.087	90.7	3.6
Pb	<0.010		0.009	0.0005	91.5	5.0
Zn	19.400	0.5	20.301	0.819	104.6	4.2

Table 2.
Comparison of analytical results (mg/kg) for NIST 1568a (Rice flour).

After evaporation, the solutions were added 0.03 ml 18 M H_2SO_4 and kept at 180°C during 24 hours. The digested samples were brought to a volume 30 ml 2% HNO_3.

Table 1 shows the results of concentrations of Al, Cu, Pb, Sn, and Zn in the digesting solutions, and the standard deviation (SD) is calculated from three times analysis (n = 3). It was determined by ICP MS in Korea Basic Science Institute (KBSI).

A standard reference material NIST 1568a (Rice Flour) was used to verify the accuracy of metal determination by ICP-MS, and the recovery rates of Cu, Zn, Cd, and Pb elements were very high within 90.7 ÷ 104.8% ± 5.0% (**Table 2**). The analytical results are acceptable.

Chemical fingerprint: By the author [19], to overcome the problems of variety of data over scale, we use the type of data interpretation in the form of chemical fingerprints with normalization to "reference plant" for discussion of heavy metals Al, Cu, Pb, Sn, and Zn (**Figure 3**). The "reference plant" was set to zero (normalization), and the data of trace metals Al, Cu, Pb, Sn, and Zn concentrations of parts of vetiver will be given as deviations from the value of "reference plant."

3. Results and discussion

3.1 Aluminum (Al)

Follow [20]: The Al in the plants is controlling colloidal properties in the cell, possible activation of some dehydrogenases and oxydases. But the high availability of Al in nutrient soil is one of the limiting factors in the production of most field crops [21–23]. The physiological mechanisms of Al toxicity are still debate, but Al excess in plants is likely to interfere with cell division and with properties of protoplasm and cell walls [22]. The content of Al in plants varies greatly, depending on soil and plant factors.

Chemical fingerprint: In **Figure 4** is shown the relative deviation of Al from "reference plant." The concentration of Al in root materials is very high and much more than "reference plant" about 17- up to 30-folds (**Table 3**; **Figure 3**). The deviation in the lower parts (meristematic regions M and low parts of shoots S1) was less than zero, but upper parts of shoots S2 and S3 are higher and obtained at 120% (TB6-S2). It means that, in the shoots of vetiver, Al is concentrated in the leave top and the ratio of Al shoot: root is varied from 3 up to 8%.

The concentrations of Al in all parts of vetiver are increased by its increasing in contaminated water (**Tables 1** and **4**; **Figure 4**), and it was higher in the roots than in the shoots. The minimum concentrations are in the meristematic regions, because the amount of Al passively taken up by roots and then translocated to tops reflects the Al

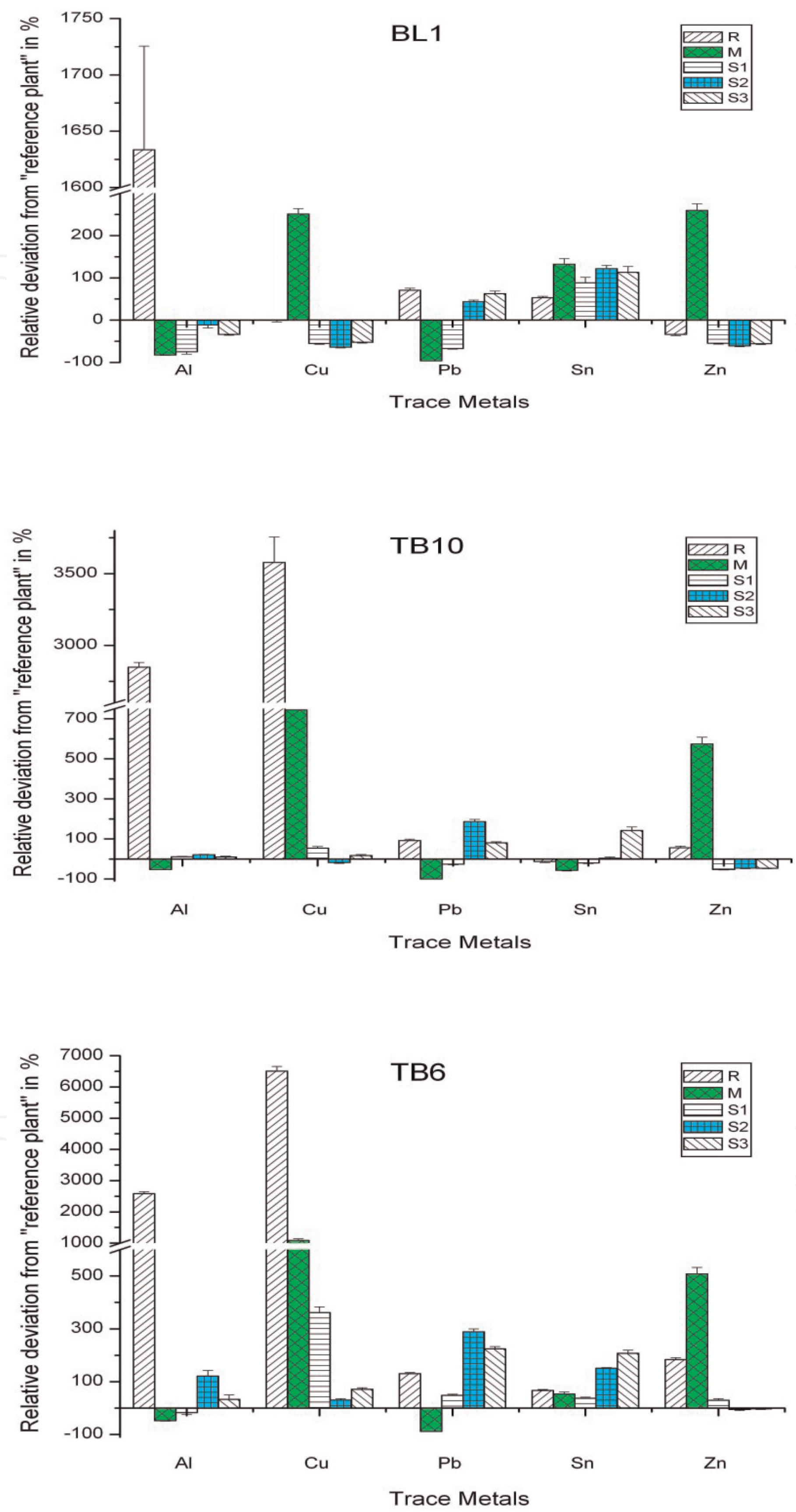


Figure 3.
Relative deviations of vetiver parts after normalization against "reference plant" [19].

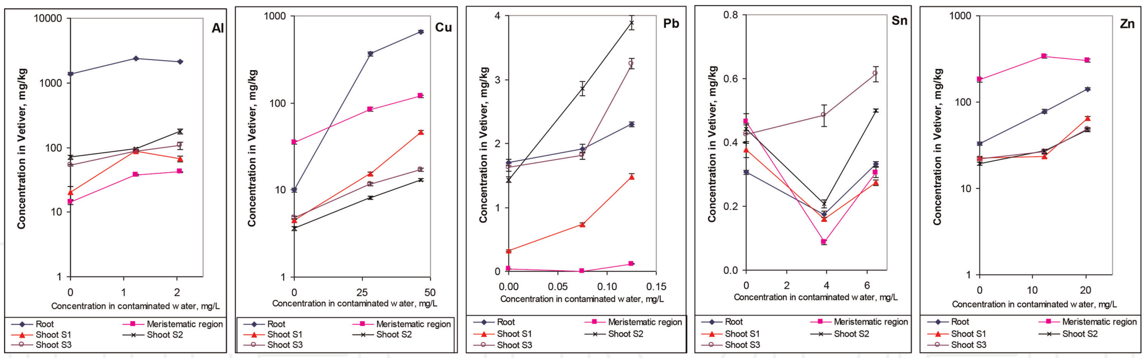


Figure 4.
Relationships between the concentrations of metals (Al, Cu, Pb, Sn, and Zn) in several parts of vetiver and those in contaminated water.

tolerance of plants, but the ability to accumulate Al in roots is not necessarily associated with Al tolerance [20].

3.2 Copper (Cu)

Copper had the major functions in plants as component of some enzymes role as catalyst [24], involved in oxidation, photosynthesis, protein, and carbohydrate metabolism, possibly in symbiotic N_2 fixation, and valence changes [20] (but it is toxic if concentration of Cu more than the plant needs). Cu is an essential element for the growth of most of aquatic organisms but is toxic at level as low as 10 mg/L [25]. In our experiment, vetiver plants were grown well in the solutions TB10 and TB6 with 27.821 and 46.369 mg/L Cu, respectively (**Table 1**).

In all parts of samples TB10 and TB6, copper concentration is higher in comparison with vetiver blank (BL1). In each vetiver sample, Cu is concentrate in root by the following order: R > M > S1 > S2, S3 (**Table 4**; **Figure 4b**) except blank BL1.

In the root tissue and the meristematic regions, Cu is almost entirely in complexed forms; it is most likely that the metal enters root cells in dissociated forms [20], and so it had strong capability to hold Cu, and Cu cannot be transported to shoots.

Chemical fingerprint: The Cu concentrations in “reference plant” are lower than in all vetiver parts, which were living in wastewater (except TB10-S2) (**Table 3**; **Figure 3**). The deviations with “reference plant” in the shoot oscillated from 16.7 (TB10-S3) to 361.5% (TB6-S1), in the meristematic region from 745 (TB10-M) to 1091% (TB6-M) and in the root from 3578 (TB10-R) up to 6507% (TB6-R). On contrary, in the root (−0.2%) and shoot (−52 ÷ −64%) of blank BL1, it is lower than zero (except meristematic region).

The trend of slope line is clearly in diagram “Cu concentration in Vetiver against Cu concentration in contaminated solution” (**Table 3**; **Figure 4b**): it is raised by increasing of Cu concentration in contaminated water. It seems that Cu concentration in vetiver is the function (in direct proportion) of its concentration in contaminated water. Cu concentrations in root (R), meristematic region, and shoots (S1, S2, S3) parts of vetiver are raised in proportion to its increasing in contaminated water. The Cu concentration increasing in root is faster than in meristematic region and in other parts M > S1 > S2, S3.

Cu has low mobility relative to other elements in vetiver, and most of this metal appears to remain in root and leaf tissues until it senesces [20].

Sample vetiver blank BL1										
Element	**R**		**M**		**S1**		**S2**		**S3**	
Al	1633.5	±91.9	−82.3	±1.3	−74.6	±6.1	−11.6	±6.5	−33.9	±2.2
Cu	−0.2	±4.5	250.9	±13.4	−55.4	±2.2	−63.9	±1.8	−52.3	±1.8
Pb	70.6	±4.8	−96.1	±0.2	−67.4	±1.2	43.4	±4.3	62.7	±5.9
Sn	53.2	±3.4	132.4	±13.1	88.4	±12.6	121.8	±8.4	112.9	±14.1
Zn	−33.6	±2.6	259.5	±16.4	−54.8	±2.2	−61.1	±1.7	−55.9	±1.6
Sample vetiver TB10										
Element	R		M		S1		S2		S3	
Al	2847.8	±32.9	−53.0	±1.5	10.4	±2.2	20.6	±3.0	10.2	±4.5
Cu	3578.3	±177.0	744.5	±44.9	53.9	±7.7	−18.1	±3.9	16.7	±4.7
Pb	91.9	±7.1	−100.0	±0.2	−26.4	±2.6	186.0	±11.0	80.9	±5.5
Sn	−12.5	±5.1	−56.8	±2.7	−20.2	±2.7	3.5	±5.9	142.2	±16.7
Zn	56.4	±8.0	573.9	±33.9	−52.7	±2.2	−46.0	±2.6	−46.7	±2.3
Sample vetiver TB6										
Element	R		M		S1		S2		S3	
Al	2585.4	±66.1	−47.9	±0.8	−16.7	±7.5	120.8	±21.0	32.7	±17.3
Cu	6506.7	±152.2	1091.0	±45.8	361.5	±21.8	30.5	±4.7	70.9	±5.8
Pb	130.3	±3.8	−88.3	±0.5	48.2	±4.2	288.5	±10.9	224.5	±8.1
Sn	66.5	±4.1	52.9	±7.8	37.1	±4.4	150.5	±2.6	207.0	±12.1
Zn	183.3	±7.6	507.6	±24.6	29.6	±6.2	−5.3	±3.9	−2.3	±3.3

Table 3.
Relative deviation concentration in parts of vetiver from "reference plant" (mean ± standard deviation) in %.

In the other plants, the excessive or toxic concentration of Cu is 20–100 mg/kg [20], but in vetiver plant it is much more, from 11 up to 660 mg/kg (**Table 4**).

The ratio of Cu in shoot: Root is low (4–7%) during living in the wastewater, and being higher (36–48%) in cleaning water that indicated the absorption capacity of vetiver root.

During the living in the difference concentrations of Cu in solution, the shoot of vetiver was uptake copper to the top. It seems to be raised by increasing of concentrations Cu in contaminated water (**Figure 4b**). For other plants, the level 10 mg/L of Cu in contaminated water is toxic, but vetiver can withstand and be alive at 46 mg/L.

The maximum Cu concentration in shoot of sample TB6 is 46.2, in meristematic region is 119.1, and in root is 660.7 mg/kg, which were much more than the previous results by the authors [3, 17, 26] (thresholds to shoot of Vetiver is 13–15, and root is 68 mg/kg).

In the contaminated water, there were both high Cu and Al contents, and its antagonism leads to reduction of Cu uptake by roots under high Al concentration [20].

3.3 Lead (Pb)

Pb is necessary for plant at the level of 2–6 μg/kg [27]. Pb received much attention as a major chemical pollutant of the environment and as the toxic element to plants [20].

Sample ID	Blank BL1 - Root		Blank BL1 - Meristematic region		Blank BL1 – Shoot S1		Blank BL1 – Shoot S2		Blank BL1 – Shoot S3	
Element	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Al	1386.78	73.52	14.142	1.029	20.289	4.843	70.735	5.222	52.912	1.724
Cu	9.978	0.448	35.089	1.337	4.460	0.220	3.614	0.180	4.770	0.183
Pb	1.706	0.048	0.039	0.002	0.326	0.012	1.434	0.043	1.627	0.059
Sn	0.306	0.007	0.465	0.026	0.377	0.025	0.444	0.017	0.426	0.028
Zn	33.188	1.301	179.735	8.191	22.612	1.077	19.463	0.842	22.060	0.801
Sample ID	TB10 – Root		TB10 - Meristematic region		TB10 - Shoot S1		TB10 - Shoot S2		TB10 - Shoot S3	
Element	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Al	2358.22	26.35	37.619	1.166	88.288	1.784	96.455	2.386	88.158	3.572
Cu	367.833	17.696	84.453	4.491	15.386	0.768	8.189	0.395	11.672	0.474
Pb	1.919	0.071	n.d.	n.d.	0.736	0.026	2.860	0.110	1.809	0.055
Sn	0.175	0.010	0.086	0.005	0.160	0.005	0.207	0.012	0.484	0.033
Zn	78.187	4.003	336.966	16.948	23.649	1.108	27.021	1.316	26.628	1.170
Sample ID	TB6 – Root		TB6 - Meristematic region		TB6 - Shoot S1		TB6 - Shoot S2		TB6 - Shoot S3	
Element	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Al	2148.32	52.91	41.668	0.604	66.628	6.035	176.675	16.775	106.164	13.811
Cu	660.674	15.220	119.105	4.578	46.151	2.177	13.053	0.471	17.095	0.583
Pb	2.303	0.038	0.117	0.005	1.482	0.042	3.885	0.109	3.245	0.081
Sn	0.333	0.008	0.306	0.016	0.274	0.009	0.501	0.005	0.614	0.024
Zn	141.641	3.777	303.817	12.303	64.808	3.086	47.334	1.971	48.860	1.669

n.d. = not detected.

Table 4.
Concentrations of trace metals in vetiver parts, (mean ± standard deviation), mg/kg.

Chemical fingerprint: Pb is concentrated in the roots of vetiver and deviation to compare with "reference plant" is 70.6 (BL1-R) up to 130% (TB6-R) (**Table 3**; **Figure 3**). But in the meristematic regions, the deviation is lower than zero and obtained −100% (TB10-R). Concentrate Pb in the shoots parts has the following order: (S2, S3) > S1, M, R, and it followed its concentrations in contaminated water and obtained fourfold more than "reference plant."

For other plants, the translocation of Pb from roots to tops is greatly limited, only 3% (Zimdahl R.L. 1975), but by our experiment for the vetiver, the translocation to shoot is obtained from 23 to 41%.

The trend of slope line is clearly in diagram "Pb concentration in Vetiver against Pb concentration in contaminated solution" (**Figure 4c**): It is raised very fast by increasing of concentration Pb in contaminated water.

The stimulating effect of Pb on Cd uptake by root may be an effect of the disturbance of the transmembrane transport of ions [20].

3.4 Tin (Sn)

Tin is very toxic to both higher plants and fungi [20].

Chemical fingerprint: The deviation of Sn to compare with "reference plant" in the low part of TB10 (R, M and S1) is lightly less than zero, but the upper parts (S2, S3) are higher and obtained 142%, and when the contaminated water raised (TB6), it is increased in all parts of vetiver and obtained to 207% (**Table 3**; **Figure 3**).

In the vetiver shoots TB10 and TB6: Concentrations of Sn are higher than in the root and meristematic region by the following order: S3, S2 > S1 > M, R (**Figure 4d**).

Not like to other plants, most of absorbed Sn remains in roots [28], the vetiver has the trend of uptake Sn, and it is accumulated in upper parts with ratio shoot: root varied from 82% (TB6-S1) to 277% (top of vetiver TB6-S3), and increased to the top by order S3/R > S2/R > S1/R.

3.5 Zinc (Zn)

The major functions of Zn in plants are: activates enzymes, regulates sugar consumption [24], and is involved in carbohydrate and protein metabolism [20].

As Kabata-Pendias Alina and Pendias Henryk suggest, soluble forms of Zn are available to vetiver and the uptake of Zn from soil to be linear with concentration in the contaminated water (**Figure 4e**).

Chemical fingerprint: The deviation of Zn concentration in meristematic regions is always higher than zero in comparison with the "reference plant," and it is obtained of 508 ÷ 574%, and root and shoot parts are obtained only lightly more than zero (**Table 3**; **Figure 3**).

Zn is concentrate much more in meristematic regions than in the roots. Roots and meristematic regions contain much more Zn than shoots, the ratio shoot: root obtains 30 up to 46%. It means Zn may be translocated from roots and accumulate by the shoots of vetiver. Vetiver has higher tolerance to Zn and Pb than other species [18]. The Zn-Pb antagonism adversely affects the translocation of each element from root to shoot [20].

4. Conclusions

In order to assess the uptake capacity of metals (Al, Cu, Pb, Sn, Zn) in contaminated water by *Vetiveria zizanioides* in laboratory condition, we have the conclusions as follows: Vetiver has higher tolerance to Al, Cu, Pb, Sn, and Zn than other species plants:

1. The roots are hyperaccumulated Al and much more than "reference plant" about 17- up to 30-folds, and the upper parts of shoots S2 and S3 are higher 1.2-folds.

2. In the other plants, the excessive or toxic concentration of Cu is 20–100 mg/kg, but in vetiver plant, it is much more and obtained up to 660 mg/kg in root, and 46.2 mg/kg in shoot, and it can withstand and be alive at 46 mg/L of contaminated water.

3. The translocation of Pb from root to shoot reached to 41%.

4. Sn is accumulated in upper parts with ratio shoot: In the root Sn, it varied from 82% up to 277% in the leave chop and increased to the leave chop by order S3/R > S2/R > S1/R.

5. Zn may be translocated from the roots and accumulated by the shoots of vetiver. The ratio shoot: the root obtains up to 46%.

The results of this study show that vetiver had the high tolerance to trace metals Al, Cu, Pb, Sn, and Zn in upper parts of shoot, and it can be used for wastewater treatment from "metal production trade village Dong Xam" and in many other trade villages of Vietnam and other countries.

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