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RESEARCH ARTICLE

REMOVAL OF HEAVY METALS FROM TWO AGRICULTURAL SOILS IN ABIDJAN, COTE D'IVOIRE USING TWO PLANTS SPECIES: *JATROPHA CURCAS* AND *VETIVERIA ZIZANIOIDES*

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ABSTRACT

The study aims to investigate the removal of heavy metals, such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn) from contaminated soils using *Jatropha curcas* and *Vetiveria zizanioides* plant species. Soil samplings from the 0-20 cm depth were taken from two agricultural plots (Attécoubé and Cocody) in Abidjan, Côte d'Ivoire. The two plants species were planted in pots (25x25cm) containing 10 kg of soils. Samples were removed from pots for analysis, following 3, 6 and 9 months of growth. Physical and chemical characteristics of soil, such as: texture, cation exchanges capacity, pH, organic matter and heavy metals contents were measured before and after plant growth. Soil samples were air-dried and sieved through a 2-mm sieve according to NF X31-412. Samples were digested according to references methods used for the studies of marine pollution (UNEP). Metals were determined by atomic absorption spectrophotometer (AAS) and a Perkin Elmer 3000DV Inductively Coupled Plasma- Atomic Emission Spectrometer (ICP-AES). Results show that *Vetiveria zizanioides* and *Jatropha curcas* were effective heavy metal accumulators, making them useful in the phytoremediation of polluted soils by heavy metals. The accumulation of Pb, Cd, Cr, Cu and Zn in *Jatropha curcas* roots was found to be higher than those in leaves. However, in the case of *Vetiveria zizanioides*, Cu and Zn accumulated more in plant leaves than in roots. The results of this study clearly revealed that *Vetiveria zizanioides* was more effective than *Jatropha curcas* in reducing soil pollution by heavy metals.

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INTRODUCTION

The production of food in the city has a long history, both in the developed (in the form of allotment gardens) and developing world. Since the early 1990s, in particular, there has been increasing recognition amongst the scientific and development community of the rising importance of food production in city areas, particularly in those parts of the world that have been characterised by economic collapse (Mbiba and Van Veenhuizen, 2001). Urban and peri-urban agriculture (UPA) can offer wide-ranging benefits. It can contribute substantial amounts to the proportion of food consumed in the city: Sweet (1999), for example, has estimated that 15 -20% of the world's supply of vegetables is produced in urban areas, and FAO (1999) estimates that 800 million urban dwellers are actively engaged in UPA, 200 million providing food for markets (FAO, 1999). In some cases, UPA has faced strong opposition from city authorities, because of a range of negative health, environmental, economic and cultural aspects (Tinker, 1994), comprising contamination of crops with pathogens, chemical residues and heavy metals (Lock and Van Veenhuizen, 2001).Indeed, heavy metal contamination is a major global concern due to high persistency, potential toxicities and bioaccumulation in living organisms. The contamination by heavy metals, such as Cu, Cd, Pb, Cr and Zn in soil is especially worrisome. Heavy metals were often used in the industry and spread widely into the environment, contaminating the soil, underground water and surface water resources, causing harm to humans, animals and plants (Singh *et al.,* 2004). Moreover, heavy metals are not likely to undergo degradation and, therefore, remain almost indefinitely in the environment. Soils contaminated with heavy metals pose major environmental and human health problems that need an effective and affordable solution. Remediation of heavy metals polluted soil could becarried out using physico-chemicals processes, such asion-exchange reactions, precipitation, reverse osmosis, evaporation and chemical reduction. However, these measures are costly and leavetoxic residues in soil. Many sites around the world like urban agricultural sites

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remain contaminated because it is too expensive to clean them up with available technological know-how. Phytoremediation is an alternative emerging technique utilizing plants to reduce, remove, degrade or immobilize pollutants from a contaminated environment. The advantages of phytoremediation are well-known, eco-friendly and cost effective, as compared to other conventional techniques (Burd *et al.,* 2000). However, in order to survive and establish in highlymetal-polluted sites, plants must have the capacity to grow, produce high biomass and tolerate metal toxicities, as well as other hostile environmental conditions. With deep and dense rooting systems, *Jatropha curcas* and *Vetiveria zizanioides* are good candidates for phytoremedial investigations. The aim of this study is to compare the uptake efficiency of heavy metals (Pb, Zn, Cd, Cu, Cr) from soil, by *Vetiveria zizanioides* and *Jatropha curcas* plant species.

MATERIALS AND METHODS

Site description

Soils samples were collected from 2 agricultural fields in Abidjan, Côte d'Ivoire. The sites were located, respectively in Cocody (N 0519.388'; W 00336.737') and Attécoubé (N 0521.528'; W 0402.679'). The selection of these two sites was justified by the fact that they have several plant species in common and they were contaminated by heavy metals (Kouakou *et al.,* 2008). The control soil was taken far from the contaminated area located at Bessikoi (N 0524.704'; W 00357.189') Cocody, Abidjan (Figure 1).

Experimental layout

Phytoremediation studies were carried out for 3, 6 and 9 months. *Jatropha curcas* and *Vetiveria zizanioides* plants were collected from the local the agricultural agency. Healthy plants, with a height of 15-20 cm, were selected as test plants for this study. One plant was placed in each pot (25 x 25cm) containing 10 kg soil (Figure 2).

Soil samples analysis

Soilsamples were homogenized before being selected. They were then dried at ambient temperature, crushed in a porcelain crucible then sieved to a 2 mm sieve. They were digested according to references methods for the study of marine pollution (UNEP, 2007). The principle of the digestion method is based on the decomposition of the soils by hydrofluoric (HF) acid in with aqua-regia (HCl: HNO_3 = 3:1). The use of HF is essential because it is the only acid which completely dissolves the silicate lattices and all metal elements (Loring and Rantala, 1992). A 0,1g of soil was placed in Teflon tubes washed beforehand with dilute nitric acid and run through a hot mineralization process using 1 ml of aqua-regia (HNO_3:HCl =1:3) and 3 ml of concentrated (48%) HF. The Heating was done at 120°C for one hour. After cooling at ambient temperature, the residues were included in a boric acid solution (2,8 g of boric acid in 20 ml of distilled water). Final volume was brought to 50 ml with distilled water and allowed to stand overnight. The solution was cooled then filtered through a Whatman filter paper. Sample blanks were analyzed to correct for possible external contributions, while replicate samples were also prepared. All the analyses were done in triplicate to ensure reproducibility of the results. The digested samples were analyzed using a Varian AA20Atomic Absorption Spectrophotometer.

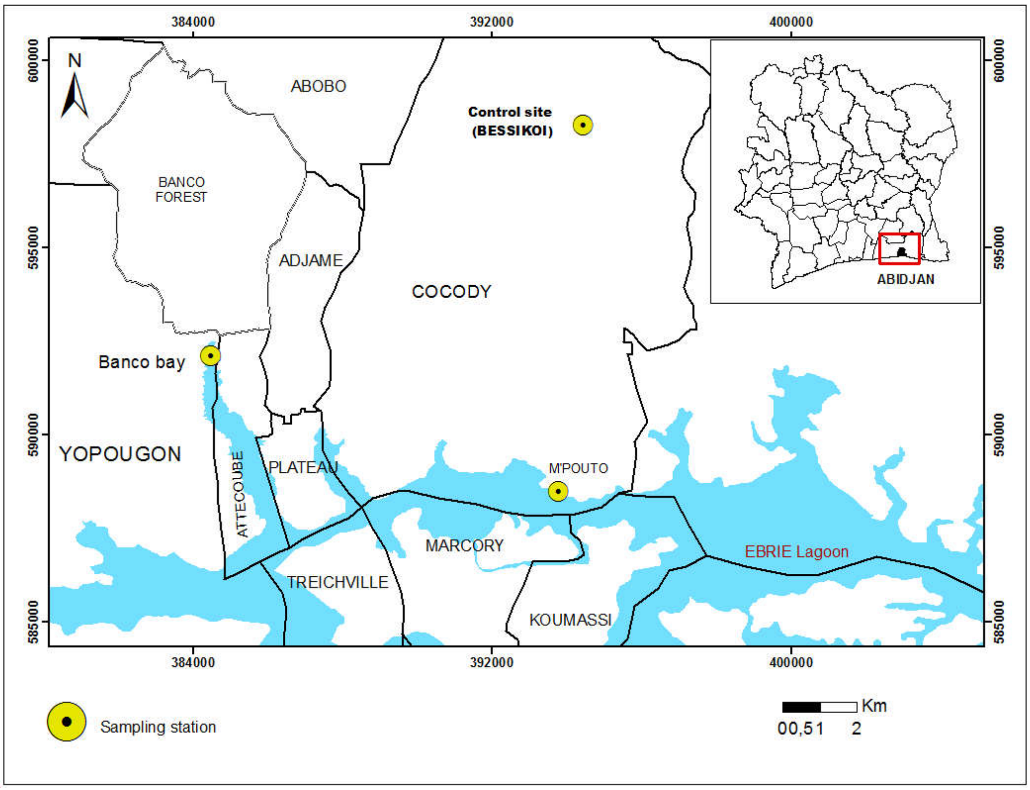


Figure 1. Map showing sampling sites

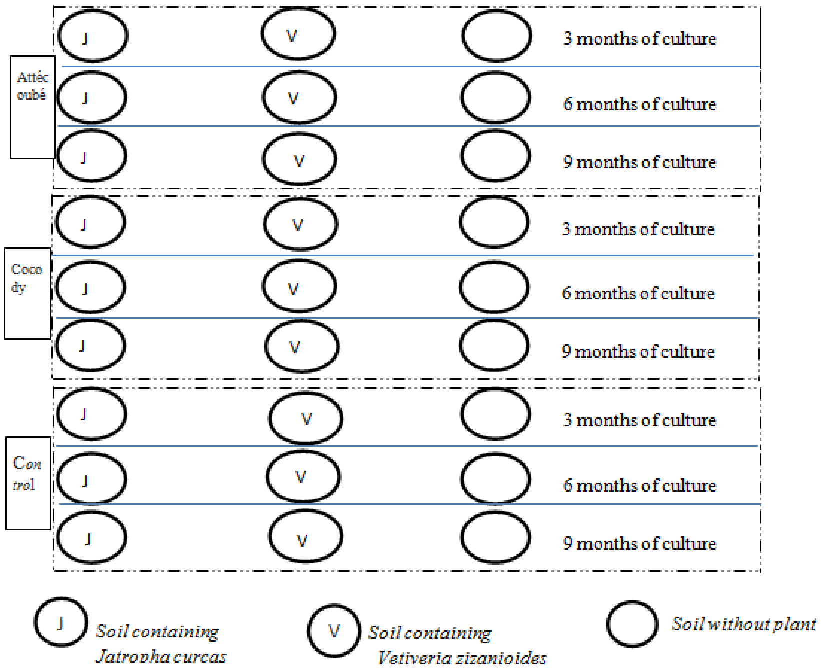


Figure 2. Schematic of experimental culture of *Jatropha curcas* and *Vetiveria zizanioides*

Plant samples analysis

The plant samples were separated into root and leaves to determine the accumulation trend from water to root and to the leaves. They were each dried in an oven at 60 °C till well dried. The dried samples were ground before digestion. Five hundred milligrams of dried weight of each fraction were digested with 10 mL of $HClO_4$ and HNO_3 mixture (1:3) at about 80 °C for 4 h. The resulting cleared colored solutions were made up to a mark in a volumetric flask (25 mL) with distilled water. All the reagents that were used were of analytical grade and all the reaction vessels were treated well to avoid external contributions of the metals. Sample blanks were analyzed to correct the possible external contributions while replicate samples were also evaluated and all the analyses were done in triplicate to ensure reproducibility of the results. The digested samples were analyzed for five metals (Pb, Zn, Cu, Cd and Cr) by a Perkin Elmer 3000DV Inductively Coupled Plasma- Atomic Emission Spectrometer (ICP-AES).

Bioaccumulation factor

The Bioaccumulation factor (BCF) is an index defined using the following formula (Yoon *et al.,* 2006):

$$\text{BCF} = \frac{\text{Heavy metal concentration in roots } (\text{mg}.Kg^{-1})}{\text{Heavy metal concentration in soil} (\text{mg}.Kg^{-1})}$$

Cluis (2004) reported that the BCF for hyper accumulators is > 1, and, in some cases, can increase up to 100.

Translocation factor

The translation factor (TF) is the capability of plants to take up heavy metals from their roots and to translocate them to their above-ground parts. Thus, TFis defined using the following formula according to Liu *et al.*, 2010:

$$\text{TF} = \frac{\text{Heavy metal concentration in leaves } (\text{mg}.Kg^{-1})}{\text{Heavy metal concentration in roots} (\text{mg}.Kg^{-1})}$$

A value of TF greater than1 (TF > 1) indicatesa higher translocation of metals from the root to the shoot part of the plant. In contrast, TF values of less than 1 (TF < 1) mean that metals are more stored in the roots part of plants. Therefore, it can be concluded that this criteria is more crucial in phytoextraction. Baker and Whiting (2002) reported that excluders can be identified by a TF < 1, whereas, accumulators are characterized by a TF > 1.

RESULTS

Heavy metal content in the sites

Table 1 presents the physicochemical characteristics of the soils.In both agricultural sites, Pb and Zn are above the safe limits given by Kabata-Pendias and Pendias (2001),whereas, Cu, Cd, and Cr contents were below the safe limits. The highest concentration for lead was recorded from the Attécoubé site, with a mean value of 496.54 ± 58.5 $mg.kg^{-1}$.

Heavy metals concentration during phytoremediation

Figure 3 shows a significant decrease in Pb, Cd, Cr, Cu and Zn concentrations in soils under going phytoremediation. The lower concentrations were obtained after 9 months. In all cases, the final concentration of each metal in soils containing *Vetiveria zizanioides* was lower than those in soils containing *Jatropha curcas*.

Table 1. Physicochemical parameters and heavy metals concentrations in soils

	Sites			
	Attécoubé (n=15)	Cocody (n=15)	Bessikoi – control (n=15)	MAC
pH_{eau}	7.60 ± 0.12^{a}	7.41 ± 0.17^{a}	5.47 ± 0.14^{b}	
pH_{KCl}	7.03 ± 0.12^{a}	6.89 ± 0.21^{a}	4.82 ± 0.24^{b}	
CEC (cmol.kg^{-1})	8.35 ± 0.98^{a}	12.25 ± 3.05^{b}	10.77 ± 1.57^{b}	
COT(mgkg^{-1})	335.57 ± 50.92^{a}	468.56 ± 157.04^{b}	211 ± 55.88^{c}	
$CaCO_3$ (gkg^{-1})	14.64 ± 0.83^{a}	12.8 ± 1.09^{b}	14 ± 0.26^{ab}	
N (mgkg^{-1})	43.04 ± 8.26^{a}	44.15 ± 1.3^{a}	34.1 ± 7.2^{a}	
Pb (mg kg-1)	496.54 ±58.5^{a}	37.13 ± 8.42^{b}	6.77 ±1.98^{b}	20-300
Cd (mg kg-1)	1.56 ± 0.22^{a}	1.84 ± 0.37^{a}	0.75 ± 0.16^{b}	1-5
Cr (mg kg-1)	1.72 ± 0.17^{a}	1.62 ±0.35^{a}	1.57 ±0.19^{a}	50-200
Cu (mg kg-1)	70.96 ± 14.25^{a}	72.94±8.83^{a}	15.14 ±1.21^{b}	50-140
Zn (mg kg-1)	1749 ± 177.5^{a}	1002.45 ±95.31^{b}	39.46 ± 7.8^{c}	150-300

Value in the same line with different superscript are significantly different at $p < 0.05$.MAC: Maximum Allowable Concentration in agricultural soil (mg.kg^{-1})Kabata-Pendias and Pendias(2001).n = number of analyzed soils sample

Table 2.Heavy metals accumulation in the roots and leaves of both plants after 9 months of growth

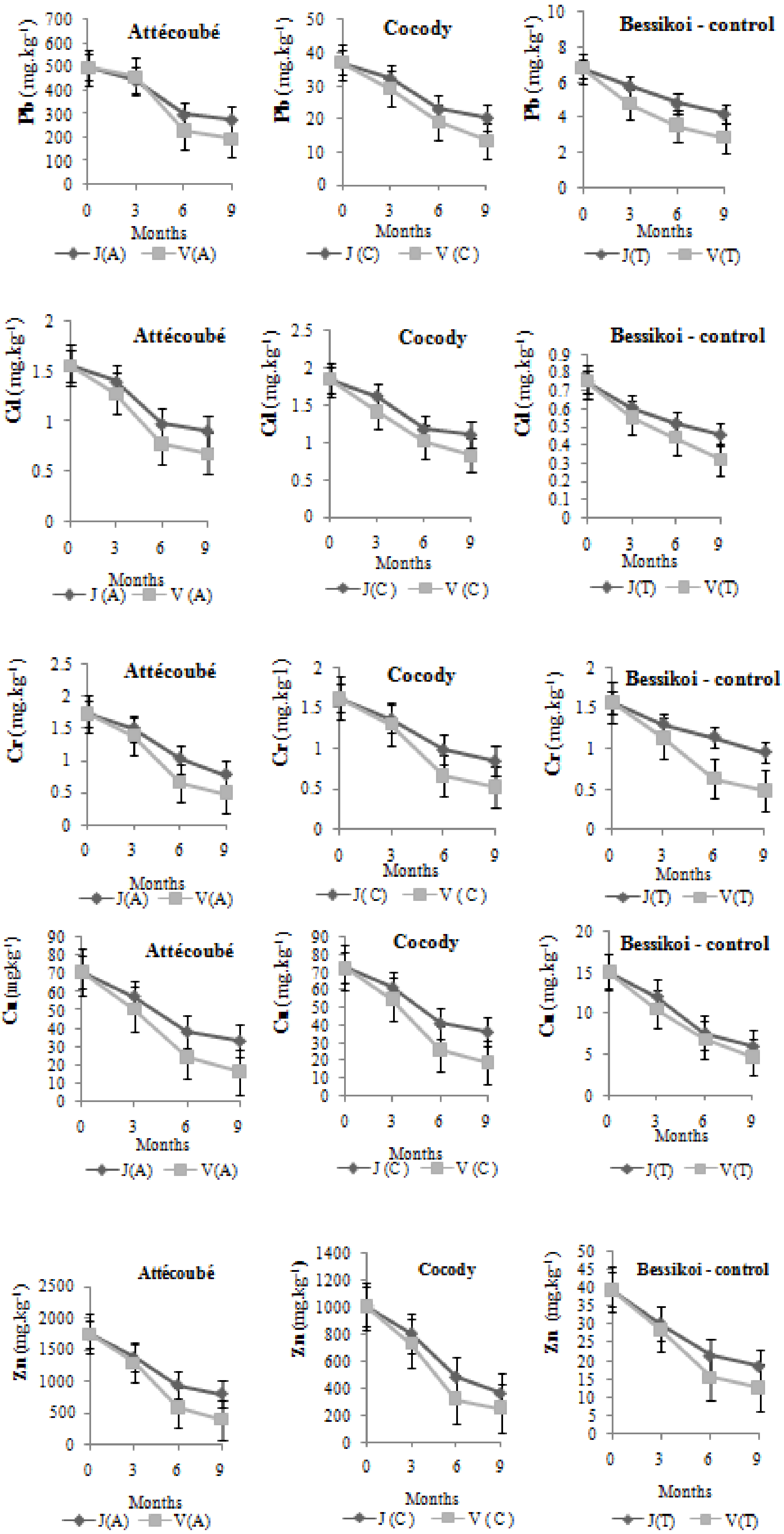
Attécoubé				
	Jatropha curcas		*Vetiveria zizanioides*	
(mg.Kg^{-1})				
Metals	Roots	leaves	Roots	leaves
Pb	382.33± 11.09^{a}	49.7± 8.62^{b}	933.49± 25.24^{a}	1512.25±15.07^{a}
Cd	1.28± 0.22^{a}	0.58± 0.06^{a}	2.7±0.2^{a}	2.75± 0.28^{a}
Cr	1.93± 0.41^{a}	1.4± 0.2^{a}	7.08± 0.09^{a}	22.08± 0.23^{b}
Cu	222.1± 12.3^{a}	184.34± 6.32^{a}	366.15± 9.42^{a}	1578.1± 82.5^{b}
Zn	2990.8± 271.5^{a}	962.14± 27.92^{a}	2763.42± 33.77^{a}	2772.22± 69.46^{a}
Cocody				
	Jatropha curcas		*Vetiveria zizanioides*	
(mg.Kg^{-1})				
Metals	Roots	leaves	Roots	leaves
Pb	25.24± 3.95^{b}	12.87± 0.19^{a}	61.26± 1.47^{b}	58.8±2.9^{b}
Cd	1.6± 0.19^{b}	0.51± 0.07^{a}	4.45± 0.53^{b}	3.53± 0.10^{b}
Cr	3.51± 0.47^{b}	2.74± 0.08^{a}	5.8± 0.47^{b}	12.41± 0.26^{c}
Cu	212.98± 5.84^{b}	185.29± 6.64^{b}	223.92± 3.9^{c}	618.02± 6.21^{c}
Zn	1754.28± 52.29^{a}	631.54± 7.57^{b}	3719.1± 31.75^{c}	3793.48± 56.28^{b}
Bessikoi - control				
	Jatropha curcas		*Vetiveria zizanioides*	
(mg.Kg^{-1})				
Metals	Roots	leaves	Roots	leaves
Pb	4.8± 0.5^{c}	1.3± 0.06^{a}	11.71± 0.47^{b}	5.03± 0.07^{bc}
Cd	0.46± 0.11^{c}	0.20± 0.05^{c}	0.77± 0.25^{b}	0.51± 0.02^{b}
Cr	2.08± 0.14^{c}	0.32± 0.03^{c}	4.02± 0.12^{b}	6.15± 0.15^{b}
Cu	34.06± 5.81^{c}	20.78± 1.87^{c}	41.03± 4.81	46.77± 5.04
Zn	123.11± 52.29^{a}	59.1± 2.4^{b}	113.25± 1.73^{a}	277.46± 7.82^{c}

Table 3.Bioaccumulation factors (BCF) of *Jatropha curcas* and *Vetiveria zizanioides*

	Attécoubé		Cocody		Bessikoi - control	
	Jatropha	*Vetiveria*	*Jatropha*	*Vetiveria*	*Jatropha*	*Vetiveria*
Pb	0.77	1.88	0.68	1.65	0.71	1.73
Cd	0.82	1.73	0.87	1.92	0.62	1.03
Cr	1.12	4.12	2.17	3.58	1.33	2.56
Cu	3.13	5.16	2.92	3.07	2.25	2.71
Zn	1.71	1.58	1.75	3.71	3.12	2.87

Table 4.Translocation factor (TF) of*Jatropha curcas*and*Vetiveria zizanioides*

	Attécoubé		Cocody		Bessikoi - control	
	Jatropha	*Vetiveria*	*Jatropha*	*Vetiveria*	*Jatropha*	*Vetiveria*
Pb	0.13	1.62	0.51	0.96	0.27	0.43
Cd	0.45	1.02	0.32	1.26	0.40	0.66
Cr	0.73	3.12	0.78	2.14	0.15	1.53
Cu	0.83	4.31	0.87	2.76	0.61	1.14
Zn	0.42	2.17	0.36	1.02	0.48	2.45



J:sol containingJatropha curcas, **V**: sol containing Vetiveria zizanioides
(A): Attécoubé, **(C)**: Cocody), **(T)**: Bessikoi –control

Figure 3. Heavy metals concentrations in soil samplesin Attécoubé, Cocody and Bessikoi-control

Heavy metals accumulation in plants

The total heavy metals concentrations removed by each plant during 9 months are given in Table 2. In the 3 sites (Attécoubé, Cocody and Bessikoi-control), heavy metals are more accumulated in the roots of *Jatropha curcas* than in the leaves. Metals concentrations in the leaves of *Vetiveria zizanioides* were greater than those accumulated in the roots. However, Pb and Cd were more concentrated in the roots of *Vetiveria zizanioides* in Cocody and the control site**.** Cadmium is the metal that less accumulated in the two plants, while Zn was the most accumulated.

Bioaccumulation factor

The Table 3shows the bioaccumulation factors (BCF) of *Jatropha curcas* and *Vetiveria zizanioides*. The BCF of *Vetiveria zizanioides* ranged from 1.58 to 5.16 in Attécoubé, from 1.65 to 3.71 in Cocody and from 1.03 to 2.87 in the control site. For *Jatropha curcas,* BCF ranged from 0.77 to 3.13 in Attécoubé, 0.68 to 2.92 in Cocody and from 0.62 to 3.12 in Bessikoi control site.

Translocation factor

Vetiveria zizanioides was capable of accumulating heavy metals (Cr, Cu, Zn) higher in the leaves part than in the root part, with the maximum translocation capability observed for Cu in Attécoubé (TF = 4.31) (Table 4).With *Jatropha curcas*a TF value of less than 1 indicated that *Jatropha curcas* accumulated heavy metals in roots rather than in leaves.

DISCUSSION

The three sites (Attécoubé, Cocody and control) were highly affected by various anthropic activities. Heavy metal concentrations observed were due to the nature of the soil, waste water and municipal sludge, agrochemicals and rain water. These results were revealed by work of Kouakou *et al.* (2008), who found that agricultural sites in Abidjan were contaminated by heavy metals. That could be explained by the geographical situation of the sites. Indeed, the sites are subjected to significant road traffic. These heavy metals, once in the atmosphere, can. Other particles can also be carried by the wind before settling on the ground.

Also, chemical parameters, such as pH and of organic matter content of the soil affect heavy metal adsorption and retention in soil. Similar results were reported by Kouakou *et al*. (2008) in Abidjan (Côte d'Ivoire) and Kapungwe *et al. (*2013) in urban area in Lusaka (Zambia). Kissao *et al.* (2014) reported the same trend in Lomé (Togo).After 9 month of phytoremediation, heavy metal contents of the 3 sites were less than the maximum permitted concentrations (Kabata-Pendias and Pendias, 2001). *Vetiveria zizanioides* and *Jatropha curcas* accumulated more Zn and Cu because they are key micro-nutrients for these plant species. Cu is a component of an electron carrier called plastocyanin that is active during photosynthesis. The same results were reportedby Qihang *et al.* (2011). Moreover, the rapid growths of *Jatropha curcas* and *Vetiveria zizanioides* require an average nutrient consumption, which could also explain the accumulation of Cu and Zn in the different soils. In addition, the root system of the two plantspecies containing a larger number of fine roots could oxygenate largely the rhizosphere there by facilitating heavy metalaccumulations. The results of the present study showed that *Vetiveria zizanioides* and *Jatropha curcas* were good accumulators of Zn, Cr, Cu and Cd. which were consistent with those of Chen *et al.* (2000), which confirmed the tolerance of *Vetiveria zizanioides* to these metals. Similar results were reported by Santosh *et al.* (2009) on *Jatropha curcas* when grown in pots containing soil contaminated with heavy metals.

The low concentration of Pb absorbed by both plants could be justified by the low mobility of this metal in the ground. According to these authors, Pbis less mobile in soil. Some metals, such as Cd and Pb formorganic complexes in soil that reduce their availability to plants (Senou *et al.,* 2002). The differences in tolerance indices to the different metals used in this study indicate that genetically based tolerance may exist in plants that could survive in heavy metal contaminated habitat. Highest removal of these heavy metals may be due to fast growth and, mainly to bioaccumulation (Maria *et al*., 2004). The uptake of all metals is higher in the roots than in the leaves of *Jatropha curcas*, which agrees with several other studies (Mehra *et al.*, 2000). The translocation factor values of less than 1 (TF < 1) mean that the roots of these plants accumulated heavy metals more than the leaves. This shows that metals accumulated by *Jatropha curcas* were largely retained in roots. Lower accumulation of metals in leaves than roots of *Jatropha curcas* can be associated with protection of photosynthesis from toxic levels of heavy metals (Landberg *et al.,* 1996). For *Vetiveria zizanioides,* the translocation factor was greater than1 (TF > 1). This plant species had a higher capacity to concentrate higher quantities of metals than the surrounding environment and preferentially accumulate higher levels of Pb, Zn, Cd, Cr and Cu. The root system of *Vetiveria zizanioides* is much more developed than that of *Jatropha curcas*. *Vetiveria zizanioides* could accumulate more heavy metals than *Jatropha curcas*. Total metal concentrations stored by *Vetiveria zizanioides* exceed those stored by *Jatropha curcas* in the three soils.

Conclusion

Phytoremediation is a promising alternative method for environmental cleanup. However, it requireshyper accumulator plants such as *Vetiveria zizanioides* and *Jatropha curcas,* as these plant species concentrate high levels of heavy metals. *Vetiveria zizanioides* and *Jatropha curcas* were found to be suitable for taking up heavy metals from polluted soils. In addition, heavy metals removal rate of both species increased with time. *Jatropha curcas* accumulated more Pb; Cd, Cr, Cu and Zn in the roots than in the leaves. However, with *Vetiveria zizanioides*, Cu and Zn accumulated more in leaves than in roots. Therefore, *Vetiveria zizanioides* was more effective than *Jatropha curcas* for the remediation of soils polluted by heavy metals. The long and dense roots system of *Vetiveria zizanioides* allow for heavy metals transfer from deepersoil horizons, to the aerial part of plants.

After 9 months of growth, the rate of heavy metalsin soilwas less than the maximum permitted concentrations (pb (300 $mg.kg^{-1}$), Cd (5 $mg.kg^{-1}$), Cr (200 $mg.kg^{-1}$), Cu (140 $mg.kg^{-1}$), Zn (300 $mg.kg^{-1}$)).

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