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Phytoextraction potential of three endogenous Amaranthaceae species grown on the Akouédo landfill (Abidjan, Côte d'Ivoire)

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Abstract

The selection of adequate plant species is a prerequisite for cleaning-up trace metal elements contaminated-soils by phytoextraction which is a cost-effective and environmentally-friendly technology. The potential of *Amaranthus spinosus, Amaranthus viridis* and *Alternanthera sessilis* to remove metal trace elements from the soil of the Akouédo landfill was investigated. The concentrations of metal trace elements in soil were also considered. Moreover, the accumulation of Zn, Ni, Cu, Pb and Cd was assessed based on bioconcentration factor, translocation factor and phytoextraction potential. The results showed high concentration values in the soil of the abandoned and the operation site of the landfill compare to the control site. The highest concentrations of trace metal elements in the plant shoot were observed with *A. spinosus* for Ni, *A. viridis* for Pb and *A. sessilis* for Zn. Furthermore, the highest values of bioconcentration factor (BCF) and the translocation factor (TF) for Ni, were respectively 56 and 2.6, in *A. spinosus*, suggesting that it can be considered as a Ni hyperaccumulator. Among all metal trace elements, Pb and Zn were respectively highly bioaccumulated in *A. viridis* and *A. sessilis*.

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Introduction

Metal trace elements contamination of soil and water is a major environmental problem worldwide due to the rapid development of agriculture, urbanization and industrialization. Soils contamination by metal trace elements results from land application of biosolids, waste incineration, agricultural use of low quality fertilisers and application of pesticides, mining, industrial and traffic emissions, weathering of buildings, military activities and others (Kozlov *et al.,* 2000; Sterckeman *et al.,* 2002; Sebastiani *et al.*, 2004; Walter *et al.*, 2006). Consequently, soils pollution by metal trace elements is responsible for losses in soil fertility, food contamination, ecotoxic effects and risks to human health. Unlike organic contaminants, metal trace elements cannot be degraded (Lasat, 2000; Ghosh and Singh, 2005a). In addition, as far as clean-up of soils contaminated by metal trace elements is concerned, conventional remediation techniques fall short of expectation due to their high cost (Mench *et al.* 1994), whereas phytoremediation can be considered as an economical and effective alternative in some cases of metal trace elements pollution (Lasat, 2000). Phytoremediation is a technology, where plants are used to remove and control toxic substances from polluted soil (McCutcheon and Schnoor, 2003). This offers an attractive, environmentally friendly, aesthetically pleasing, publically acceptable and cost-effective approach to remove metal trace elements from soil (Entry *et al.*, 1997; Raskin *et al.*, 1997; Zhu and Shaw, 2000). Among phytoremediation technologies, phytoextraction is widely regarded as a promising technology. In fact, phytoextraction uses hyperaccumulator and accumulator to remove contaminants from the soil (Wei *et al.*, 2009). Researchs on hyperaccumulators has led to intensive screening of many plant species (Kuzovkina *et al.*, 2004). Two main strategies are currently applied: the first one considers the use of hyperaccumulator plants with exceptional metal accumulating capacity. And the second one implies the use of high biomass producing plants which can also sometimes accumulate large quantities of metal trace elements (Angle and Linacre, 2005). In the first case, the use of hyperaccumulator plants is mainly limited by low biomass production, while in the second case plants producing high biomass concentrate low amounts of metals (Salt *et al.*, 1998; Masarovičová and Králová, 2012). Moreover, hyperaccumulators identified are non endemic to tropical areas, such as Côte d'Ivoire. To develop phytoremediation technologies, the identification and evaluation of the potential of the local plants species to accumulate metal trace elements must be done. Thus, Messou *et al.* (2013) reported that Amaranthaceae species grown on the Akouédo landfill may be suitable candidates to accumulate metal trace elements.

However, these authors did not provide any experimental data on the ability of Amaranthaceae species to accumulate metal trace elements. The aim of this study is to assess the potential of three Amarantanceae species *(Amaranthus spinosus, Amaranthus viridis* and *Alternanthera sessilis)* to accumulate metal trace elements in order to provide a scientific base for phytoextraction application.

Material and methods

Description of study area

The Akouédo landfill is located in the District of Abidjan. It is situated between 395 800 – 397 500 m N and 591 100 – 593 000 m W, and covers an area of about 153 ha (Fig. 1).

Previous studies (Kouamé *et al.*, 2006) showed that the soil of this landfill was contaminated by metal trace elements. In the superficial stratum (less than 50 cm depth), the average concentrations of zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb), iron (Fe), and copper (Cu) were respectively of 250, 50, 5, 140, 1 400 and 80 ppm. The mean value of pH was 8.25 (Kouamé *et al.*, 2006). Moreover, a control site was selected in the District of Abidjan. However, this site was relatively far from Akouédo landfill, i.e., near the Banco National Park (Fig. 1). The control site was located between 382075.466 – 384193.133 m N and 599019.676 – 600806.458 m W.

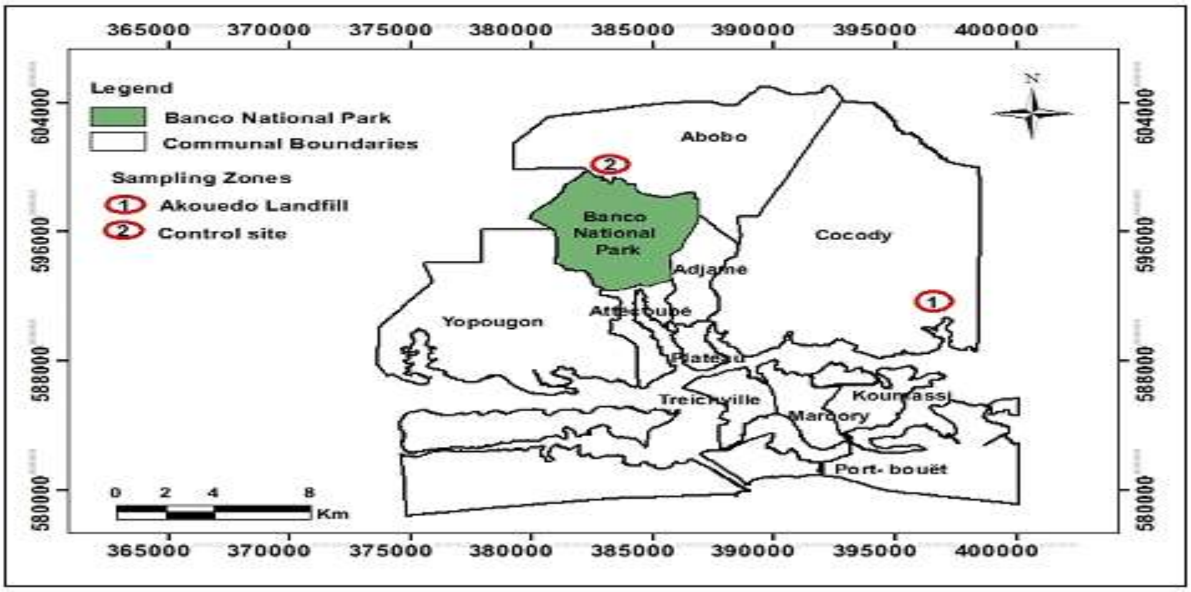

Fig. 1. Location of the sampling zones.

Plants and soil sampling

Both soils and plants were sampled at the Akouédo landfill and the control site. For the Akouédo landfill, two different sampling zones were chosen. Indeed, on this landfill there is an abandoned site (AS) which was first used for waste disposal. Since the AS was saturated, a neighboring site was chosen for waste disposal (Operating Site (OS)). For both, nine plots were established for soil sampling on the AS and OS. For the control site, three plots were defined. The plots were established as representative of the study site as possible.

This choice also aimed at getting abundant biomass when plants are harvested. For plants sampling, only mature plants were taken. 10, 20 and 40 plants, of respectively *Amaranthus spinosus*, *Amaranthus viridis* and *Alternanthera sessilis* were randomly harvested (uprooted) on each plot. The plants were separated into roots and shoots. After that separation process, the plant samples were first washed with tap water and next with distillated water, to remove surface dust and soil. Finally, the samples were oven-dried at 65° C for 72 hours. After drying, the vegetal material was milled into a homogenous powder after their dry weights were determined. Table 1 presents a list of plant samples (roots and shoots) obtained in each zone. For soil sampling, steel auger was used. The soil samples were collected at depths of 0-10 cm, 10-20 cm, 0-30 cm and 30-40 cm. On each plot, soils samples were taken at each corner (4) and one in the centre. A composite sample was prepared at the same depth on each plot. Soil samples were collected in plastic bags, air-dried and ground to pass through a 2 mm sieve. A total of 72 soil samples were collected from the landfill zones, while 12 samples were obtained from the control site.

Chemical analyses

The phytoavailable fraction of metals in the soil samples was performed with ammonium acetate - ethylenediamine tetra-acetatic acid (EDTA) according to the NFX 31-120 procedure (AFNOR, 1999). Concentrations of Cd and Pb were determined using graphite furnace atomic absorption spectrophotometer (GFAAS) and Cu, Ni and Zn were determined using a flame atomic absorption spectrophotometer (FAAS).

To determine total metals content in the plants samples, a graphite furnace atomic absorption spectrophotometer and a flame atomic absorption spectrophotometer were used post-digestion. The analytical processes for the vegetal material involved incineration and acid digestion with HCl.

Data analysis

Bioconcentration, Translocation and Phytoextraction potential evaluation

The Bioconcentration Factor (BCF) was used to determine the quantity of metal trace elements that is absorbed by the plant from the soil. This is an index of the ability of a plant to accumulate a particular metal with respect to its concentration in the soil (Ghosh and Singh, 2005b; Maldonado-Magaña *et al.*, 2011) and is calculated using the following formula:

$BCF = [Metal]_{whole\ plant} / [Metal]_{soil}$

The higher the BCF value the more suitable is the plant for phytoextraction (Blaylock *et al.*, 1997). BCF Values > 2 were regarded as high values.

To evaluate the phytoextraction potential of the plants, the translocation factor (TF) was used. This ratio is an indication of the ability of a plant to translocate metals from its roots to its shoots (Mattina *et al.*, 2003; Marchiol *et al.*, 2004; Waranusantigul *et al.*, 2008). It is represented by the ratio:

$TF = [Metal]_{shoot} / [Metal]_{root}$

Hence, metal trace elements that are accumulated by plants and largely stored in the roots of plants are indicated by TF values < 1. On contrary, when TF values > 1, this indicates that the metals are much stored in the shoot.

The phytoextraction potential (PP) represents the total amount of metal trace elements extracted per plant from soil, in a single phytoextraction cycle. This index was adapted from Kos *et al.* (2003):

$PP\ (g/plant) = [Metal]_{shoot} \times dry\ biomass.$

Statistical analysis

Statistical analysis of the data was carried out using Statistica software version 7.1. To verify the statistical significance of metal content in the vegetal biomass, data were analyzed using the parametric test (LSD Fisher) and the non parametric test (Kruskall-Wallis). Statistical significance was defined at the level of $p < 0.05$. Furthermore, the principal component analysis (PCA) was applied to classify plant species considering metal trace elements accumulation potential. This was performed with R software version 3.1.1.

Results

Biomass vegetal

The shoot and root biomasses of *Amaranthus spinosus* were more important than those of *Amaranthus viridis* and *Alternanthera sessilis* and (Table 2). They were 84.5 ± 9.1 g plant^{-1} and 9.4 ± 1.2 g plant^{-1} on the abandoned site (AS), respectively, for the shoot and root biomass. However, on the operating site (OS), *A. spinosus* recorded a shoot biomass of 81.7 ± 7.5 g plant^{-1} and root biomass of 11.1 ± 1.4 g plant^{-1}. On the control site (CS), *A. spinosus* presented shoot and root biomasses of respectively, 79.6 ± 6.2 g plant^{-1} and 10.7 ± 1.1 g plant^{-1}.

Soil metals concentration

Metals trace elements concentrations in the soil of landfill site were much higher than those of the control site. For the abandoned site (AS) and the operating site (OS), the metal trace elements mean concentrations ranged respectively from 86.70 ± 15.78 to 84.25 ± 14.62 mg kg^{-1} of Zn, 26.06 ± 4.51 to 17.83 ± 3.03 mg kg^{-1} of Pb, 17.98 ± 4.29 to 10.39 ± 1.84 mg kg^{-1} of Cu, 1.65 ± 0.23 to 1.40 ± 0.15 mg kg^{-1} of Ni and from 0.72 ± 0.09 to 0.62 ± 0.06 mg kg^{-1} of Cd. In contrast, the control site contained 25.86 ± 21.61 mg kg^{-1}, 2.19 ± 0.21 mg kg^{-1}, 1.23 ± 0.21 mg kg^{-1}, 0.25 ± 0.03 mg kg^{-1} and 0.02 ± 0.01 mg kg^{-1}, respectively for Zn, Pb, Cu, Ni and Cd.

Metals trace elements concentration in the plant biomass

The Zn concentration in the roots (Fig. 2) was higher than that in the shoot of *Amaranthus spinosus*, with mean values of 340 mg kg^{-1} (abandoned site) and 322 mg kg^{-1} (operating site). However, the statistic analysis revealed that the Zn concentrations in the root biomass were significantly different ($p < 0.05$), when comparing abandoned site and the operating site. The Zn concentration in the root and shoot of *A. spinosus* of the control site were not significantly different ($p > 0.05$). In contrast, with *Amaranthus viridis* and *Alternanthera sessilis*, Zn concentrations in the shoot were higher in comparison with the root concentration.

Table 1. List of plant samples (S: shoot; R: Root).

Species	Plant samples		
	Abandoned site	Operating site	Control site
A. spinosus	AmS-S1 ; AmS-R1	AmS-S2 ; AmS-R2	AmS-S3 ; AmS-R3
A. viridis	AmV-S1 ; AmV-R1	AmV-S2 ; AmV-R2	AmV-S3 ; AmV-R3
A. sessilis	AlS-S1 ; AlS-R1	AlS-S2 ; AlS-R2	AlS-S3; AlS-R3

Table 2. Shoot and root dry biomass (g.plant^{-1}; mean ± standard deviation).

Species	Abandoned site		Operating site		Control site	
	Shoot	Root	Shoot	Root	Shoot	Root
A. spinosus	84.5 ± 9.1	9.4 ± 1.2	81.7 ± 7.5	11.1 ± 1.4	79.6 ± 6.2	10.7 ± 1.1
A. viridis	3.1 ± 0.5	0.7 ± 0.1	4.2 ± 0.8	0.9 ± 0.2	4.1 ± 0.6	0.8 ± 0.2
A. sessilis	6.8 ± 1.2	0.5 ± 0.1	7.7 ± 1.4	0.5 ± 0.2	7.2 ± 0.7	0.5 ± 0.2

For Ni (Fig. 3), the highest concentrations were observed in the shoot of *A. spinosus* and the root of *A. viridis,* respectively. The Ni concentration in the shoot and root of *A. spinosus* were not significantly different ($p > 0.05$) on the three sampling sites. The results observed with *A. sessilis* on the abandoned site and the operating site were quite different. The highest concentrations of Ni were observed in the root and shoot, on the abandoned site and the operating site, respectively. These concentrations were not significantly different ($p > 0.05$).

Table 3. Bioconcentration Factor and Translocation factor values.

Species	Heavy metals	BCF			TF		
		Abandoned site	Operating site	Control site	Abandoned site	Operating site	Control site
A. spinosus	Zn	3.26 ± 1.12 ^{a}	3.45 ± 1.53 ^{a}	6.74 ± 2.96 ^{a}	0.49 ± 0.06 ^{a}	0.58 ± 0.11 ^{a}	1.60 ± 0.22 ^{a}
	Ni	31.44 ± 10.27 ^{a}	56.54 ± 15.90 ^{b}	13.62 ± 0.77 ^{a}	1.48 ± 0.72 ^{a}	2.61 ± 0.93 ^{a}	1.84 ± 0.06 ^{a}
	Cu	2.96 ± 0.77 ^{a}	9.77 ± 5.86 ^{a}	3.40 ± 0.17 ^{a}	0.69 ± 0.18 ^{a}	0.90 ± 0.40 ^{a}	0.43 ± 0.04 ^{a}
	Pb	1.38 ± 1.01 ^{a}	1.17 ± 0.62 ^{a}	1.12 ± 0.09 ^{a}	1.08 ± 0.55 ^{a}	0.42 ± 0.10 ^{a}	1.04 ± 0.03 ^{a}
	Cd	0.32 ± 0.07 ^{a}	0.51 ± 0.16 ^{a}	4.58 ± 1.66 ^{a}	0.43 ± 0.05 ^{a}	0.69 ± 0.15 ^{a}	1.52 ± 0.29 ^{a}
A. viridis	Zn	2.53 ± 0.85 ^{a}	2.81 ± 1.13 ^{a}	5.07 ± 2.63 ^{a}	1.69 ± 0.18 ^{a}	1.73 ± 0.23 ^{a}	1.70 ± 0.40 ^{a}
	Ni	8.92 ± 3.94 ^{a}	5.73 ± 1.93 ^{a}	8.22 ± 2.39 ^{a}	0.46 ± 0.06 ^{a}	0.45 ± 0.09 ^{a}	2.24 ± 0.43^{a}
	Cu	1.56 ± 0.43 ^{a}	1.89 ± 0.83 ^{a}	2.32 ± 0.54 ^{a}	1.91 ± 0.37^{a}	5.51 ± 4.28 ^{a}	0.38 ± 0.02 ^{a}
	Pb	2.17 ± 0.63 ^{a}	2.53 ± 0.61 ^{a}	0.82 ± 0.13 ^{a}	1.61 ± 0.09 ^{a}	1.95 ± 0.26 ^{a}	0.82 ± 0.06 ^{a}
	Cd	2.69 ± 0.59 ^{a}	3.50 ± 0.59 ^{a}	2.55 ± 0.57 ^{a}	0.55 ± 0.07 ^{a}	1.50 ± 0.52 ^{a}	1.24 ± 0.12 ^{a}
A. sessilis	Zn	11.27 ± 3.87 ^{a}	6.69 ± 2.09 ^{a}	10.19 ± 4.82 ^{a}	2.63 ± 0.47 ^{a}	1.66 ± 0.23 ^{a}	1.08 ± 0.16 ^{a}
	Ni	25.06 ± 8.48 ^{a}	67.97 ± 30.75 ^{b}	5.75 ± 3.95 ^{a}	0.78 ± 0.16 ^{a}	1.71 ± 0.87 ^{a}	3.51 ± 1.24 ^{a}
	Cu	6.11 ± 2.50 ^{a}	5.56 ± 1.34 ^{a}	1.29 ± 0.98 ^{a}	2.04 ± 0.59 ^{a}	1.53 ± 0.79 ^{a}	0.15 ± 0.10 ^{a}
	Pb	0.44 ± 0.16 ^{a}	0.64 ± 0.19 ^{a}	0.81 ± 0.08 ^{a}	2.47 ± 1.80 ^{a}	1.11 ± 0.25 ^{a}	0.88 ± 0.11 ^{a}
	Cd	0.87 ± 0.32 ^{a}	1.04 ± 0.41 ^{a}	1.17 ± 0.59 ^{a}	0.80 ± 0.30 ^{a}	0.66 ± 0.12 ^{a}	0.46 ± 0.18 ^{a}

Regarding to Cu concentration in the plant biomass (Fig. 4), *A. viridis* and *A. sessilis*, presented similar results. The highest concentrations of Cu were observed in the shoot and the root, respectively on the abandoned site and the operating site. However, the root of *A. spinosus* accumulated the much higher concentration of Cu, with values of 66.67 mg kg^{-1} on the abandoned site and 86.89 mg kg^{-1} on the operating site. Nevertheless, the statistic analysis showed that Cu concentration in the shoot and root of *A. spinosus* were not significantly different ($p > 0.05$).

Table 4. Quantity (g plant^{-1}) of metals uptaked by the mature plant of *A. spinosus*, *A. viridis* and *A. sessilis*.

Species	Sites	Dry shoot biomass (g)	Zn	Ni	Cu	Pb	Cd
A. spinous	Abandoned site	84.45	12.18	3.37	2.79	0.87	0.02
	Operating site	81.72	12.44	4.27	4.78	0.99	0.02
	Control site	79.61	4.51	0.30	0.38	0.23	< 0.009
A. viridis	Abandoned site	3.10	0.28	0.02	0.06	0.09	< 0.009
	Operating site	4.25	0.45	0.02	0.03	0.12	< 0.009
	Control site	4.05	0.18	0.01	0.01	0.01	< 0.009
A. sessilis	Abandoned site	6.77	2.66	0.15	0.40	0.06	< 0.009
	Operating site	7.66	2.33	0.41	0.26	0.06	< 0.009
	Control site	7.16	0.62	0.02	0.02	0.02	< 0.009

For Pb concentration (Fig. 5), the root of *A. spinosus* showed the highest values, with average concentration reaching 27.13 and 26.03 mg kg^{-1}, respectively on the abandoned site (AS) and the operating site (OS), respectively. In contrast, *A. viridis* accumulated highest Pb concentration in the shoot. However, the Pb concentration in the shoot and root biomasses of *A. viridis* were not significantly different ($p > 0.05$). Compared to *A. spinosus* and *A. viridis, A. sessilis* showed highest Pb concentration in the shoot on the AS and in the root on the OS.

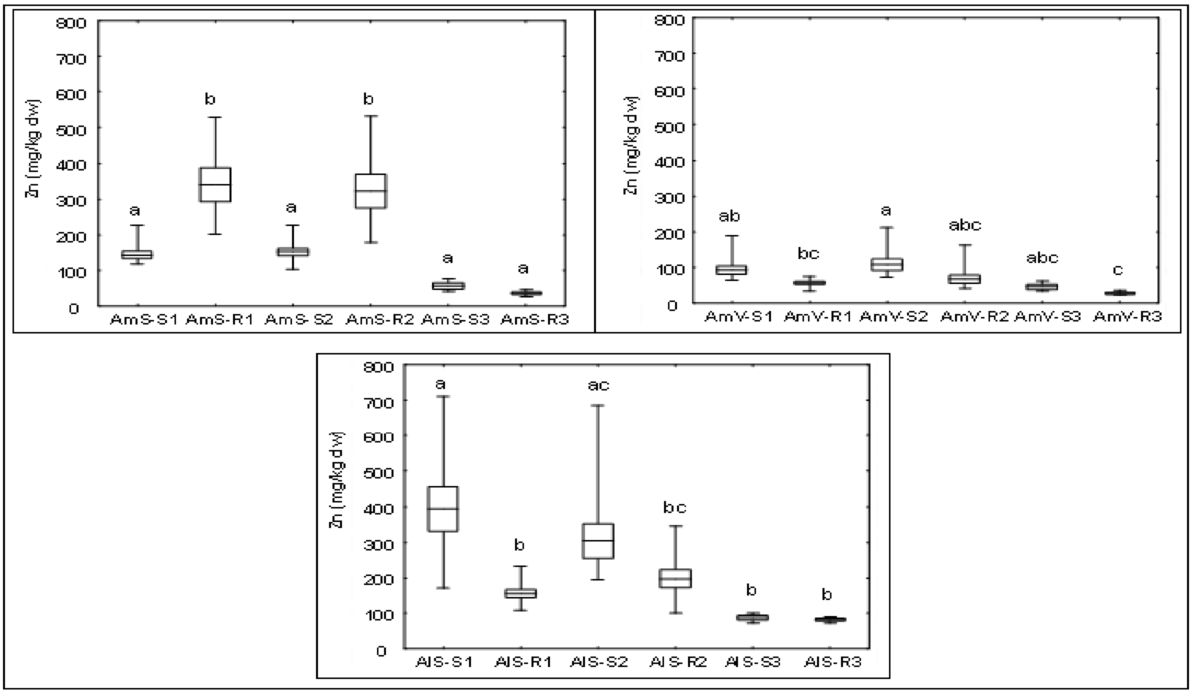

Fig. 2. Zn concentration in the shoot (S) and root (R) of *A. spinosus* (AmS), *A. viridis* (AmV) and *A. sessilis* (AlS).

The Cd concentration in the root of *A. spinosus*, *A. viridis* and *A. sessilis* was higher than that in the shoot (Fig. 6). Compared to the shoot concentration, the Cd levels in the root biomass were significantly different ($p < 0.05$) on the abandoned site, with *A. spinosus* and *A. viridis*.

Furthermore, metal trace elements concentrations in the all plant sampling biomasses from the control site were much lower than those recorded on the abandoned site and the operating site.

Bioconcentration and Translocation factor

The average BCF of *Amaranthus spinosus* ranged from 0.32 ± 0.07 to 56.54 ± 15.90 (Table 3). On the landfill site (abandoned site and operating site), the lowest BCF was observed with Cd and the highest with Ni. On the control site, the average BCF values were above 1. For *Amaranthus viridis*, the average BCF ranged from 0.82 ± 0.13 (Pb) to 8.92 ± 3.94 (Ni). The results showed that, the BCF values were above 1 on the abandoned site and the operating site. Furthermore, the average BCF of *A. spinosus* were lower than 1with Pb. The highest values were observed with Ni on the abandoned site (25.06 ± 8.48) and on the operating site (67.97 ± 30.75). The BCF were not signifcantly different on the sampling site with *A. viridis* and *Alternanthera sessilis* ($p > 0.05$).

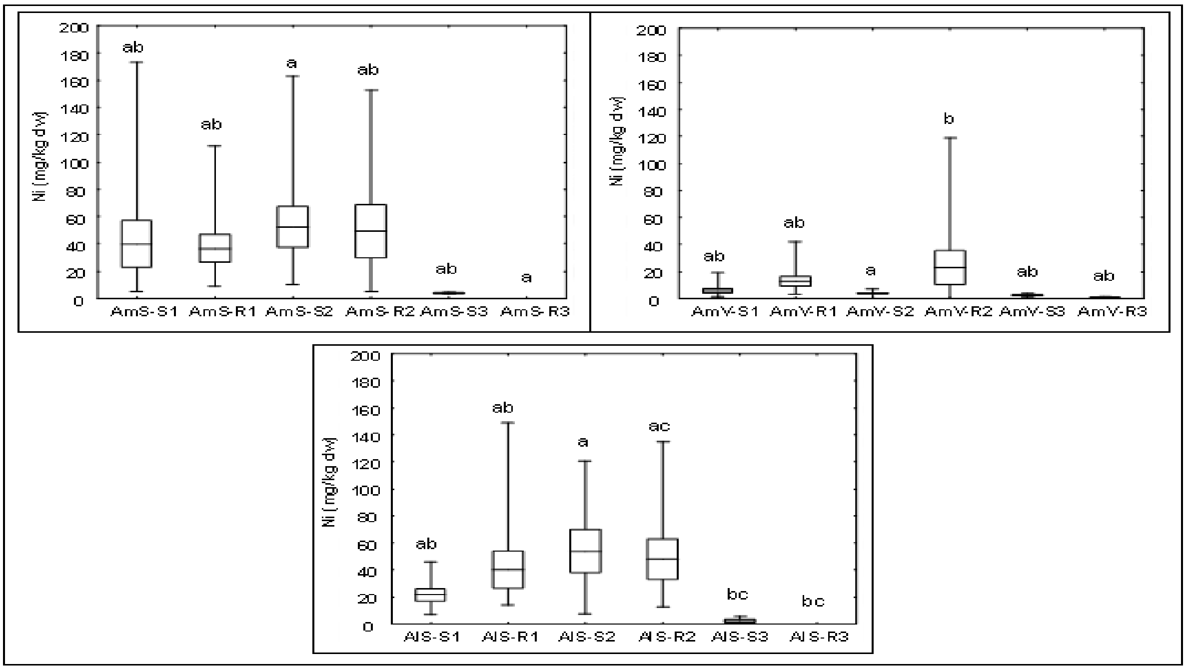

Fig. 3. Ni concentration in the shoot (S) and root (R) of *A. spinosus* (AmS), *A. viridis* (AmV) and *A. sessilis* (AlS).

The TF values of the 3 Amaranthaceae species ranged from 0.15 ± 0.10 to 5.51 ± 4.28 (Table 3). *A. spinosus* and *A. sessilis* presented low TF values (<1) for Cd on the abandoned site and the operating site. Furthermore, the results showed that the high TF values were observed with *A. spinosus* for Ni (2.61 ± 0.93), with *A. viridis* for Cu (5.51 ± 4.28) and with *A. sessilis* for Zn (2.63 ± 0.47). However, the TF values were not signifcantly different on the sampling site ($p > 0.05$).

Phytoextraction potential

The amounts of metal trace elements accumulated in the average dry-ground biomass showed that *Amaranthus spinosus* presented the highest amounts of Zn, Ni, Cu and Pb on the abandoned site and the operating site (Table 4). The lowest amounts of accumulated metals were recorded on the control site for all the plant species. Furthermore, Cd is the weak accumulated metal by plant species tested.

Discrimination of the plant species

For the principal component analysis (PCA), the first two axes (F1 and F2), yielding in 36.65% of the total variance, were selected for the discrimination of tested plant species (Fig. 7). The results showed that *Amaranthus spinosus* accumulated Zn, Cu, Ni, Pb and Cd. However, *Amaranthus viridis* showed potential for the accumulation of Pb while *Alternanthera sessilis* is more suitable for Zn phytoextraction.

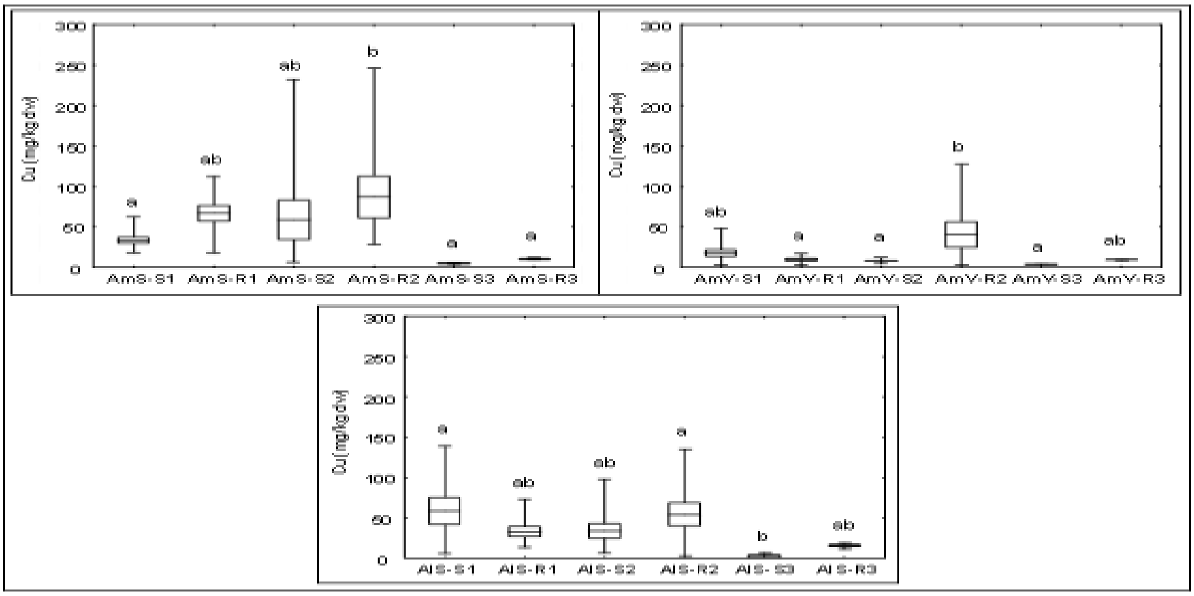

Fig. 4. Cu concentration in the shoot (S) and root (R) of *A. spinosus* (AmS), *A. viridis* (AmV) and *A. sessilis* (AlS).

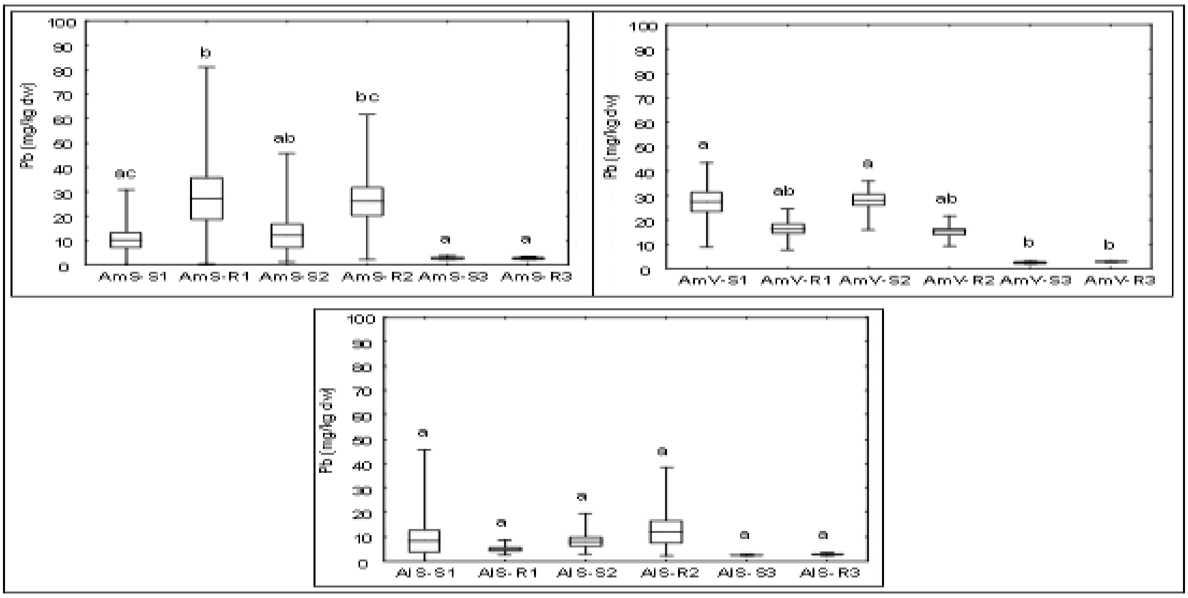

Fig. 5. Pb concentration in the shoot (S) and root (R) of *A. spinosus* (AmS), *A. viridis* (AmV) and *A. sessilis* (AlS).

Discussion

The phytoremediation potential of *Amaranthus spinosus*, *Amaranthus viridis* and *Alternanthera sessilis* growing on the Akouédo landfill was investigated. Regarding to the soil metal pollution, previous studies reported the concentration of metal in the soil of the Akouédo landfill (Kouamé *et al.*, 2006; Adjiri *et al.*, 2008; Akessé *et al.*, 2013). The results of Akessé *et al.* (2013), which focused on the available fraction, were in the same order as those recorded in the present study on the abandoned site and the operating site. Metals content in soils may be due to the dumping of industrial, household and hospitals waste. In addition, atmospheric emissions and pesticides used for crops could contribute to soil contamination by metal trace elements. Furthermore, the high metals concentrations in the shoots and roots of *A. spinosus, A. viridis* and *A. sessilis* might be due to their tolerance and accumulation capacity. The tolerance and bioaccumulation are possible by an adaptation of the plant species, with new physiological capacities (Mejare and Bulow, 2001; Clemens *et al.*, 2002). This property was observed with the Amaranthaceae, which presented metals accumulators, including *A. spinosus, A. viridis* and *A. sessilis* (Prasad, 2001; Moodley *et al.*, 2007; Abe *et al.*, 2008).

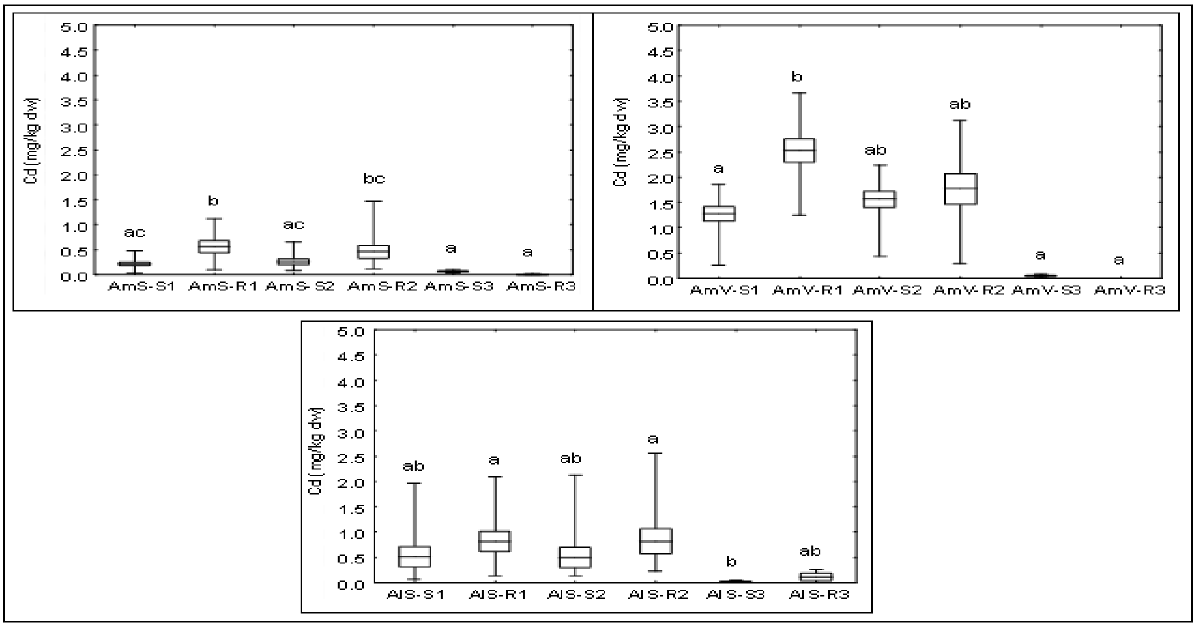

Fig. 6. Cd concentration in the shoot (S) and root (R) of *A. spinosus* (AmS), *A. viridis* (AmV) and *A. sessilis* (AlS).

The Zn concentrations in the biomass of *A. spinosus, A. viridis* and *A. sessilis* are largely higher than those reported by Prasad (2001) and Abe *et al.* (2008). This difference is due to the site nature and metals concentrations. Abe *et al.* (2008) worked on artificially contaminated soil with a specific pollutant concentration (0.17 mg / kg dry soil). Moreover, the high accumulation of Zn, Cu Pb and Cd in the roots of *A. spinosus*, Ni and Cd in those of *A. viridis* and *A. sessilis* might be due to the high concentrations of metals in the soil and the low transfert from the roots to the shoots. Additionally, the synthesis of metallothioneins and phytochelatins, which was produced in the root exudates rhizosphere promote metals sequestration in roots.

The metals content in the biomass of the species on the control site would be due to the accumulation capacity of the plant. According to Baker (1981), the accumulator and hyperaccumulator species accumulate metals in their shoot regardless of the concentration of the soil.

The results of BCF showed a high accumulation of Zn, Ni and Cu by *A. spinosus*. Hence, this plant species would be considered as suitable plant for metal contaminated-soil phytoremediation. According to Chaney *et al.* (1997), the ideal plant for metal phytoextraction has to be able to accumulate and tolerate high concentrations of metals in harvestable parts, while having a fast growth and high biomass. *A.*

spinosus presented the highest shoot biomass and also showed BCF values greater than 2 for Zn, Ni and Cu. Compared to the TF values, it should be noted that only Ni has a high TF >1 with *A. spinosus* on all the sampling sites. Furthermore, the combination of BCF and TF suggested that *A. viridis* present great potential for Zn, Ni and Pb accumulation. Considering *A. sessilis*, the values of BCF and TF indicated accumulation of Zn, Ni and Cu. The three species discrimination confirmed the great potential of Ni, Pb and Zn phytoextraction, with *A. spinosus, A. viridis* and *A. sessilis,* respectively. Concerning *A. spinosus,* it could be considered as a Ni hyperaccumulator, because it showed a BCF values ranged from 31 to 56 and a TF values ranged from 1.5 to 2.6, on the abandoned site and the operating site, respectively. It was noted that Ni has a large number of hyperaccumulators reported in 317 species and 37 families (Brooks *et al.*, 1998; Baker *et al.*, 2000). In addition, two-thirds of the Ni hyperaccumulators are found exclusively in tropical regions (Reeves, 2003; Proctor, 2003). Moreover, the accumulation of Zn and Cu is likely related to their nutrient character.

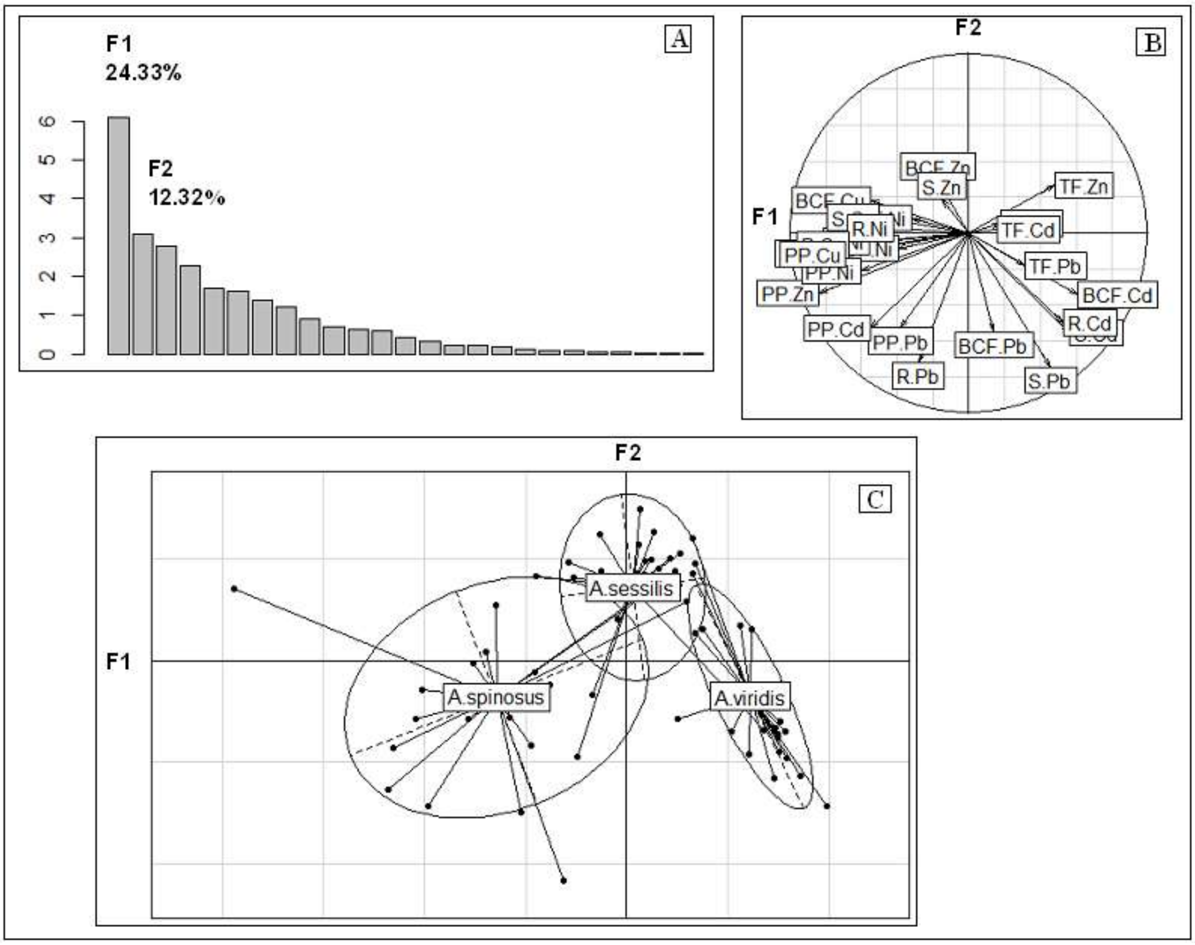

Fig. 7. Principal component analysis (PCA) on the potential of metals accumulation by *A. spinosus*, *A. viridis* and *A. sessilis*; A) values of the axes; B) correlation circle on the factorial F1 × F2; C) factorial map of the species on the factorial F1 × F2.

Conclusion

The study showed high contamination of the soil of the Akouédo landfill by metal trace elements. Furthermore, the plants species showed metals accumulation potential. For the metals accumulation in the plant shoot biomass, Ni and Zn were high uptaked by *Amaranthus spinosus* and *Alternanthera sessilis*, respectively. And *Amaranthus viridis* showed the highest values in the shoot for Zn and Pb. The BCF and TF values indicated the higher ratio for Ni with *A. spinosus*. Among the tested plants, *A. spinosus,* presented phytoextraction capability for Ni and Zn, *A. viridis* for Pb and *A. sessilis* for Zn. Only *A. spinosus* behaved as a Ni hyperaccumulator and it is good candidate for application to the phytoremediation of metals-contaminated soils.

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