Journal of the Serbian Chemical Society
JSCS-info@shd.org.rs • www.shd.org.rs/JSCS

J. Serb. Chem. Soc. 78 (7) 1045–1053 (2013)
JSCS–4480

UDC 504.53:504.06+581.5+635.01:546.3
Original scientific paper

Impact of urban gardening in an equatorial zone on the soil and metal transfer to vegetables

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(Received 15 September 2012)

Abstract: This study was aimed at assessing the impact of urban agriculture on physicochemical properties of the soil and the metal uptake by some leafy vegetables cultivated in urban soils of Libreville, Gabon. Cultivated and uncultivated topsoil and vegetable samples were collected from two urban garden sites, and analyzed. The results showed that there was strong acidification and a decrease in the concentrations of nutrients and metals in soils due of agricultural practices. The metal transfer to plants was important, with the exception of iron. The non-essential metals cadmium and lead were not detectable in the plant tissues. Amaranth accumulated more metals than other vegetables. Amaranth and Roselle were vegetables that preferentially concentrated metals in their leaves and could, therefore, be used for metal supplementation in the food chain.

Keywords: soil acidification; trace metals; leafy vegetables; bioconcentration factor; translocation factor.

INTRODUCTION

Population growth forecasts for year 2030 indicate that the world population will increase and reach 9 billion inhabitants. This growth will particularly occur in the urban areas of developing countries, creating a situation of exploding alimentary needs.[1] In response to this considerable challenge, urban agriculture, which was almost insignificant thirty years ago, has developed in and around cities and has reached a phase of rapid expansion in developing countries. Therefore, it is important to assess the impact of this practice on urban soils and the nutritional quality of cultivated vegetables. International trade regulatory rules and guidelines are being developed in many countries across the world to

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doi: 10.2298/JSC120915116O

prevent, monitor and control soil pollution.[2,3] For instance, the European Economic Commission was asked to elaborate guidelines for member states and competent regional authorities to revise the EU directive on sludge and elaborate a new directive on composting. Although transfer of trace metals from the soil to plants has often been mentioned,[4,5] to date, only a few studies have been conducted on this issue in West and Central Africa.[6–8]

The mobility of metals in soils and their absorption and bioaccumulation in vegetables depend on many factors, such as the climate, the bio-physicochemical properties of the soils, the type of vegetable cultivated, *etc*.[9] In urban areas, the proximity to roads and many factories can modify the physicochemical properties of and metal speciation in soil.

The aim of this study was to assess the impact of agriculture on the properties of soils in Libreville and the transfer of metal elements from the soils to vegetables.

MATERIAL AND METHODS

This study was conducted in two market gardening areas of Libreville between January and March 2008. The city is situated in West Gabon (9°25′ east longitude and 0°27′ north latitude). The two study sites, Alibandeng and PK8, are located in the north and east of Libreville, respectively. The climate type is equatorial. The annual rainfall varies from 1,600 to 1,800 mm. The average temperatures oscillate between 25 and 28 °C with minima (18 °C) in July and maxima (35 °C) in April, with a humidity of 80 to 100 %.

The oldest sites of vegetable production around Libreville were selected (16 years old). The first one, Alibandeng is located nearby the airport, and the other one, PK8 is beside the National Road 1. Both are densely populated flat and swampy zones. The Alibandeng soil is made of raw minerals of non-climate origin, formed on marine sands from the Quaternary era, whereas the ferralitic soil of PK8 is strongly altered and desaturated.[10]

Three cultivated soil samples and three uncultivated soils samples in each area were randomly collected with a stainless steel shovel. The samples were put in plastic bags immediately and stored at −4 °C. They were air-dried, crushed in a mortar, sieved through a 100-mesh sieve (2 mm), then crushed with a tungsten-carbide blade grinder and subsequently sieved through a 0.2 mm titanium mesh. The soil properties were assessed according to Association Française de Normalisation (AFNOR) protocols.[11] They included: particle size, pH, total organic carbon (*TOC*), total Kjeldahl nitrogen (*TKN*), assimilatable phosphorus (*P*), and cation exchange capacity (*CEC*). Considering, the average content of carbon in soil organic matter of 58 %, a conversion factor of 1.724 was used to calculate the percentage of organic matter (*OM*) from the content of organic carbon.[12]

Plant samples were collected at maturation. They were washed with distilled water and with de-ionized water to eliminate air-borne pollutants and soil particles, dried in air and then at 70 °C until constant weight, finely ground (0.2 mm) and kept in plastic bags. Amaranth (*Amaranthus cruentus*) and lettuce (*Lactuca sativa*) were collected at the Alibandeng site and roselle (*Hibiscus sabdariffa*), amaranth, Chinese cabbage (*Brassica chinensis*) and lettuce at the PK8 site.

The soil and plants samples were mineralized at 150 °C for 1 h in a microwave mineralizer using *aqua regia* (1/3 HNO_3+2/3 HCl) and a mixture of nitric acid, hydrogen peroxide and ultra-pure water with a volume proportion ratio 2:1:1, respectively. The mineralization products were filtered through a 0.45 μm mesh and the metals were analyzed by ICP-AES (Spectra 2000 Jobin Yvon).

The mobile fraction of the metal in the soils was extracted with 0.05 M EDTA at pH=7 and analyzed by ICP-AES.[13]

The capacity of plants to uptake metals from soils can be assessed using the bioconcentration factor (*BCF*), defined as:[14]

$$BCF = \frac{\text{Metal concentration in dry plant (mg kg}^{-1}\text{)}}{\text{Metal concentration in soil (mg kg}^{-1}\text{)}} \tag{1}$$

The transfer capacity of metal elements between the roots and aerial parts of a plant can be defined by the translocation factor (*TF*) given by:[15]

$$TF = \frac{\text{Metal concentration in aerial part (mg kg}^{-1}\text{)}}{\text{Metal concentration in roots (mg kg}^{-1}\text{)}} \tag{2}$$

Statistical tests were realized with the XLSTAT package under EXCEL. Similarity between samples was verified with a one-way analysis of the variance (ANOVA). A 0.05 level of probability was used for the statistical significance level.

RESULTS AND DISCUSSION

The physicochemical characteristics of the soil samples are presented in Table I. The two control soils were neutral. Alibandeng soil is sandy with low elevated organic matter (*OM*), nitrate test kit (*NTK*) and *P* levels. The water retention capacity of this soil is lower than that of the PK8 soil, which is siltier and exhibits more *OM*, *NTK* and *P* levels. Thus, the PK8 site seems more appropriate for agriculture than Alibandeng. In each site, the agricultural practices have led to a significant soil acidification. The cultivated soils are more acidic, and have higher levels of *NTK*, silt, *OM*, *P* and clay than the control soils. The fertilizers used were urea, and nitrate, phosphate and potassium (NPK) salts. These data agree with a comprehensive review of from 57 studies in Africa that showed a trend of negative balances for nutrients due of agricultural practices.[16]

TABLE I. Physicochemical properties of soils of Alibandeng and PK8; numbers followed by the same letter, a, b, c, d, e, f, g, h, i or j, in each row are not significantly different at $p < 0.05$ by the Student's *t*-test

Soil		pH	*CEC*	Sand	Silt	Clay	*OM*	*NTK*	*P*
			meq/100 g			g kg^{-1}			mg kg^{-1}
Alibandeng	Control	6.9^{a}	2.8^{d}	914^{a}	53^{b}	39^{a}	25.7^{c}	0.80^{b}	0.10^{b}
	Cultivated	4.3^{b}	4.8^{c}	935^{a}	22^{b}	35^{c}	22.2^{c}	0.66^{bc}	< 0.05
PK8	Control	7.1^{a}	13.6^{a}	545^{b}	278^{a}	178^{b}	68.3^{a}	3.07^{a}	5.6^{a}
	Cultivated	4.1^{b}	7.5^{b}	587^{b}	268^{a}	135^{c}	29.8^{b}	0.49^{c}	< 0.05

In urban soils, trace metals such as cadmium, copper, manganese, lead and zinc are good indicators of soil contamination arising from gasoline, vehicle exhausts, car components, industrial emissions, *etc*.[17,18] Pseudo-total and EDTA-extractable metal levels in the soils are presented (in mg kg^{-1} of dry weight) in Table II. They were higher in the PK8 soils than the Alibandeng soils and were significantly decreased at Alibandeng for Pb and Zn ($p < 0.001$), and at PK8 for Cu, Fe, Mn, Pb and Zn ($p < 0.001$). Metal levels in the cultivated soils were lower than or in ranges of those found in other agricultural soils of West African countries.[7,8] The soil acidity, as well as erosion and mineral fertilizers (particularly urea) have a strong influence on the mobility of ions and their uptake by plants, and decrease the soil metal concentrations.[19,20]

TABLE II. Pseudo-total and mobile metals in soils of Alibandeng and PK8 (expressed in mg kg-1 of dry weight); numbers followed by the same letter, a, b, c or d, in each row are not significantly different at $p < 0.05$ by the Student's *t*-test

Metal		Alibandeng control	Control PK8	Cultivated Alibandeng	Cultivated PK8
Cu	Pseudo-total	3.15^{c}	22.24^{a}	2.72^{c}	9.81^{b}
	Mobile	0.39^{c}	2.03^{a}	0.06^{c}	1.08^{b}
Fe	Pseudo-total	15011^{bc}	44841^{a}	8856^{c}	16332^{b}
	Mobile	2587^{b}	4225^{a}	208^{c}	1646^{b}
Mn	Pseudo-total	55.6^{c}	448.4^{a}	39.6^{c}	278.9^{b}
	Mobile	2.8^{b}	30.5^{a}	2.3^{b}	22.9^{a}
Pb	Pseudo-total	55.0^{b}	110.6^{a}	7.3^{c}	19.6^{c}
	Mobile	4.9^{b}	11.7^{a}	0.3^{b}	2.5^{b}
Zn	Pseudo-total	75.5^{b}	218.2^{a}	8.2^{c}	25.4^{c}
	Mobile	7.5^{b}	21.3^{a}	0.4^{c}	1.7^{bc}

The rate of element absorption by a plant depends on the cultivated plant, the soil properties and the mobility of the metals in the soil.[21] The results showed that the mobile (or EDTA-extractable) metal levels in this study followed the order Fe > Mn ≈ Zn > Pb > Cu in the control soils and Fe > Mn > Zn > Cu > Pb in the cultivated soils. The mobile metal levels varied from 0.4 to 10.9 mg kg^{-1} for Cu, from 31 to 361 mg kg^{-1} for Fe, from 2.3 to 95.0 mg kg^{-1} for Mn, up to 19.9 mg kg^{-1} for Pb and from 0.5 to 41.5 mg kg^{-1} for Zn. These values showed an important mobile fraction of Cu (13.7–46.8 % of its pseudo-total concentration in the soil), a moderate mobile fraction for Mn (3.9–30.3 %), Pb (3.6–19.2 % in the control soils), Zn (6.7–17.8 %) and a low value for Fe (0.2–2.5 %). It is possible that the addition of EDTA to the soils increased the phytoavailability of the metals by forming water-soluble chelate–metal complexes.[21,22] Cu, Pb and Zn were more mobile in the control soils, and Fe and Mn were more mobile in the cultivated soils than in the uncultivated soils. With the exception of Fe in the cultivated soils, the metals were more mobile in the silty soils than in the sandy soils. This result does not reflect the capacity of retention of metals, which is more important in loamy soils than in sandy soils. Indeed, Zhang and Zhang found that the contents of clay, organic carbon, total P, total Pb, total Cu and total Zn in silty soils were higher than sandy soils.[23]

The metal concentrations in the vegetables based on their dry weight are given in Table III. The concentrations of Cd and Zn were below the detection limits (0.30 and 2.36 mg kg^{-1}, respectively). Moreover, the Cd and Pb concentrations were low in the studied plants and these non-essential metals could not contaminate the food chain. The concentrations of Cu, Fe, Mn and Zn in vegetables ranged from 3.4 to 21.6 mg kg^{-1} for Cu, 319 to 3.777 mg kg^{-1} for Fe, 34 to 555 mg kg^{-1} for Mn and 29 to 176 mg kg^{-1} for Zn. The differences in the metal concentrations between the vegetables implied that the uptake capacity of the metals depended on the vegetable and the soil. The highest concentrations were found in the roots of lettuce from Alibandeng and the cabbage from PK8 for Cu and Fe, respectively; in amaranth leaves from Alibandeng for Mn; in amaranth leaves and roots from Alibandeng for Zn (Table III). Zinc concentrations were significantly higher in the vegetables from Alibandeng than those from PK8 were. These results confirmed the high uptake capacity of amaranth as was found previously in other studies.[14,21] The capacity of amaranth to accumulate more Mn and Zn than lettuce when grown on Alibandeng soil but not on PK8 soil probably reflects differences in the inherent crop growth characteristics.[7] The order of metal accumulation in the different parts of the plants depended on the studied species. When the entire plant is considered, the metal concentrations were Fe > Mn > Zn > Cu.

TABLE III. Metal levels in leaves, roots and entire plant cultivated at Alibandeng and PK8 (expressed in mg kg^{-1} of dry weight); numbers followed by the same letter, a, b, c, d, e, f, g, h, i or j, in each row are not significantly different at $p < 0.05$ by the Student's *t*-test

Soil	Plant	Part	Cu	Fe	Mn	Zn
Alibadeng	Lettuce	Leaves	8.64^{bcdef}	701.4^{cde}	170.7^{c}	117.1^{b}
		Roots	21.56^{a}	2229.1^{b}	69.5^{hi}	122.1^{b}
		Entire plant	11.47^{b}	1034.8^{cd}	149.4^{cd}	118.6^{b}
	Amaranth	Leaves	9.69^{bcde}	318.5^{e}	554.5^{a}	156.0^{a}
		Roots	10.83^{b}	2108.6^{b}	114.2^{ef}	175.7^{a}
		Entire plant	9.08^{bcdef}	678.7^{de}	370.1^{b}	152.1^{a}
PK8	Lettuce	Leaves	5.86^{fgh}	478.6^{e}	62.3^{hij}	45.0^{c}
		Roots	10.33^{bc}	1867.8^{b}	79.4^{ghi}	49.4^{c}
		Entire plant	6.58^{efgh}	749.6^{cde}	63.6^{hij}	44.4^{c}
	Amaranth	Leaves	11.46^{b}	1044.1^{cd}	89.7^{fgh}	49.3^{c}
		Roots	9.01^{bcdef}	2122.8^{b}	77.4^{ghi}	42.9^{c}
		Entire plant	9.82^{bcd}	1136.3^{cd}	75.6^{ghi}	45.2^{c}
	Cabbage	Leaves	3.42^{h}	479.8^{e}	48.1^{ij}	28.7^{c}
		Roots	7.47^{cdefg}	3776.9^{a}	92.6^{fgh}	42.9^{c}
		Entire plant	4.26^{fgh}	1206.2^{c}	57.1^{hij}	31.3^{c}
	Sorrel	Leaves	6.00^{fg}	705.9^{cde}	133.4^{de}	30.8^{c}
		Roots	7.08^{defg}	756.7^{cde}	34.2^{j}	30.0^{c}
		Entire plant	6.16^{fgh}	679.5^{cd}	106.3^{efg}	31.7^{c}

A comparison between the determined metal concentrations based on plant dry weight with those in the literature showed that the lowest Zn concentration in vegetables from Alibandeng found in the present study was obviously higher than those reported elsewhere.[24–26] In addition, the highest Mn concentration in found in this study was higher than those reported elsewhere.[24,25] The amount of Fe in the leaves of vegetables of Libreville gardens was higher than the vegetable Fe in other urban gardens in Africa.[25,26] However, the Cu concentration in the leaves was within the ranges of Cu concentrations in Africa and China.[7,24–26]

Cu, Fe, Mn and Zn are essential metals and have known biological functions. Zinc is well known to be essential for the somatic growth of children.[27] It constitutes about 33 mg kg^{-1} of an adult body mass and it is essential as a constituent of many enzymes involved in several physiological activities, such as protein synthesis and energy metabolism.[28] Manganese ions activate numerous enzymes in plant cells. The most important role of this element in green plants is its involvement in the process of decomposition of water molecules with the release of oxygen. Copper is essential for photosynthesis and mitochondrial respiration, carbon and nitrogen metabolism, oxidative stress protection and is required for cell wall synthesis. Iron is one of the key elements for normal enzyme functions, especially those involved in redox processes, such as the synthesis of porphyrin, reduction of nitrite and sulfate, and N_2-fixation.[29]

The metal concentrations in plants depend mainly on their concentrations in the soil on which they grew or were cultivated.[29] Thus, it is important to assess the transfer from soil to plant. The *BCF* and *TF* values for metal concentrations in the entire plants are presented in Table IV. The metal *BCF* values differed between vegetable species and between sites for a same species. This indicates a difference in uptake selectivity. The *BCF* values for Mn and Zn were 34 and 10 times higher for amaranth from Alibandeng than for amaranth from PK8, respectively. For all metals, high *BCF* values were measured in the plants from Alibandeng. This suggested that the metals were more bioavailable in the Alibandeng soils than in the PK8 soils. Alibandeng has mostly sandy soils. Sandy soils are most likely to release metals, such as Mn and Zn. Brazauskiene *et al*.[30] showed that soils with sandy texture savannas had low retention capacity of metals, such as Zn and Cu. It is thus probable that metal leaching is more important at Alibandeng than at PK8. The *BCF* data obtained in the present study followed the order Zn > Mn > Cu > Fe > Pb in Alibandeg and Zn > Cu > Mn > > Fe > Pb in PK8 (Table IV). The soil–plant metal transfer seems enhanced in Alibandeng compared to PK8. Accumulator plants exhibited *BCF* values > 1. The high *BCF* values for Cu, Mn and Zn for amaranth confirmed that this vegetable accumulates metals and could be used as food crop for the supplementation of Zn for example in the case of deficiency in this metal. Indeed, in many parts of the developing world, most Zn is provided by edible parts of plants with high phytic acid, a potent inhibitor of Zn absorption.[31] Zn deficiency is widespread in developing countries, but it is under-recognized due to lack of sensitive biomarkers of the Zn status.[32]

The ranges of *TF* values were 0.4–1.3 for Cu, 0.1–0.9 for Fe, 0.5–4.9 for Mn, and 0.7–1.0 for Zn. The *TF* of Mn was generally near to or above 1, showing that Mn could be taken up more readily in vegetables leaves than other metals. On the other hand, with exception of Fe in amaranth, the *TF* values for the metals in roselle and amaranth were near to or above 1, showing an easy metal uptake in these leafy vegetables. Both the *BCF* and *TF* values were near to or above 1 for Cu in amaranth from PK8, Mn in lettuce and amaranth from Alibandeng, and Zn in all plants, with exception of cabbage from PK8 (Table IV). It is, therefore, probable that amaranth, lettuce and roselle are useful plants for metal phytoextraction.[33] A study on plants cultivated in jars under controlled conditions is foreseen to verify this hypothesis. However, these are edible plants, so attention must be paid to the toxic levels of metals in these plants.

CONCLUSIONS

Agricultural practices in the market gardens of Libreville have led to a high acidification of the soils, a decrease in the soil fertility parameters and a loss of metal elements. These practices did not increase the levels of toxic metals in the soils. Arranged in decreasing order, the concentrations of the metals in the entire plants were Fe > Mn > Zn > Cu > Pb. All these concentrations are below the toxicity tolerance thresholds for leafy vegetables. Of the studied plants, *Amaranthus cruentus* and *Hibiscus sabdariffa* exhibited the best metal accumulation and translocation to the leaves, the consumable part of these plants. As these vegetables are widely consumed throughout West Africa, laboratory and field studies would be necessary to determine the capacity of these plants to accumulate toxic metals, such as Pb or Cd in polluted area.

Acknowledgements. Financial assistance to the first author by the Gabonese Government is acknowledged. The authors thank Prof. Patrick Höhener and Dimitra Ondo for their constructive comments.

ИЗВОД

УТИЦАЈ ГРАДСКОГ БАШТОВАНСТВА НА ЗЕМЉИШТА И ТРАНСФЕР МЕТАЛА КОД ПОВРЋА У ЕКВАТОРИЈАЛНОЈ ЗОНИ

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Циљ ове студије је оцена утицаја обраде земљишта у граду на физичкохемијске карактеристике земљишта и узимања метала од стране неког лиснатог поврћа узгајаног у земљишту у градској средини Либервила у Габону. Сакупљени су и анализирани узорци биљака и узорци површинског слоја култивисаног и некултивисаног земљишта из градских башта на две локације. Резултати су показали да је дошло до снажне ацидификације и смањења концентрација нутријената и метала у овим земљиштима, због начина обраде земљишта. Пренос метала је био значајан, осим у случају гвожђа. Неесенцијални метали кадмијум и олово нису били детектовани у ткивима биљака. Амарант је акумулирао више метала него друго поврће. Испоставило се да амарант и хибискус преференцијално концентришу метале у лишћу, те стога могу бити коришћени као суплементи метала у ланцу исхране.

(Примљено 15. септембра 2012)

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