academicJournals

Vol. 9(25), pp. 1952-1960, 19 June, 2014
DOI: 10.5897/AJAR11.2082
Article Number: C0DD9E645572
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Characteristics of a manganese-rich soil and metal accumulation in edible parts of plants in the region of Moanda, Gabon

Jean Aubin ONDO[1,2]*, François EBA[1], Richard MENYE BIYOGO[1], Pascale PRUDENT[2], Magloire OLLUI-MBOULOU[1] and Joseph OMVA-ZUE[1]

[1]Laboratoire pluridisciplinaire des sciences de l'Ecole Normale Supérieure, B.P 17009 Libreville Gabon.
[2]Laboratoire Chimie Provence (UMR CNRS 6264) – Chimie Environnement Continental, Aix-Marseille Université, 3 Place Victor Hugo, Case 29, 13331 Marseille, France.

Received 27 October, 2011; Accepted 12 June, 2014

Moanda region in Southeastern Gabon is rich in manganese (Mn) ores. This study aimed to determine the physico-chemical properties of cultivated and uncultivated soils and the metal content in edible parts of 9 plants cultivated in this area. The studied soils had a sandy loam clay texture. Cultural practices induced a significant acidification, decrease in fertility and loss of metals from soils. Mn contents in soils varied from 8,672 to 17,956 mg.kg^{-1}, and were significantly higher in uncultivated than in cultivated soils. Concentration of metals in plants seemed to depend on the type of plant more than the concerned part. Except for Nkoumou (*Gnetuma fricanum*), Ca, Mg and K contents were in large amounts in all plants so they could be good sources of macronutrients for humans and animals. Mn levels in leaves of cassava and sorrel and Fe levels in the red sorrel leaves exceeded 1 g.kg^{-1}. Sorrel and amaranth showed the highest daily intake of nutrients.

Key words: Manganese-rich soil, metal nutrients, food plants, bioconcentration factor (BCF), daily nutrient intake.

INTRODUCTION

Metals naturally occur in the Earth's crust at variable concentrations and with few exceptions they undergo to biogeochemical cycles (Garrett, 2000). Among the most abundant elements, Al can be toxic to plants, animals and humans (Poschenrieder et al., 2008; Gonzalez-Muñoz et al., 2008), whereas others such as Mg and Zn are essential for growth and life of plants, animals and humans and insufficient level of essential elements cause serious human, animal and plant (Ebel and Gunther, 1980; Galdes and Vallée, 1983; Young-Eun et al., 2007).

In several world areas, metals accumulate to levels above levels of the Earth's crust and become mines exploited by men. Mining activities can lead to metal accumulation in biological tissues through inhalation, ingestion or absorption through the skin (De Miguel et al., 2007; Ferreira-Baptista and De Miguel, 2005; Lu et al., 2003). The populations in these regions sometimes practice agricultural activities for food. Leafy,

*Corresponding author. E-mail: laplus_ens@yahoo.fr, Tel: (33) 4.13.55.10.41. Fax: (33) 4.13.55.10.60.

Figure 1. Map of Moanda city location.

vegetables hold an important place in well-balanced diets, and increasing consumption of vegetable and fruits is advisable (Kawashima and Soares, 2003). Leafy vegetables represent an important source of proteins, vitamins and minerals for humans, and act as buffering agents for acidic products formed during the digestion process. However, vegetables may accumulate both essential and toxic elements (Akbar Jan et al., 2010) which may cause nutritional disorders and diseases, particularly in Africa (Odhav et al., 2007; Kwapata and Maliro, 1995) where approximately 300 million people go hungry and 31 million children less than 5 years are undernourished (Tchibambelela, 2009). Leafy vegetables are commonly edible as meals, mixed or not with fruiting vegetables and/or tubers (cassava, yam, and taro).

There is little information currently on food composition in Gabon and on metals contents in cultivated soils and their transfer to crops. The present work aims to assess the accumulation of seven major nutritional metals (Ca, Mg, K, Na, Fe, Mn, and Zn) and the non-essential metal Al, in food plants by the determination of their content in manganese-rich soil of Moanda and in the edible parts of these plants. This is complemented by the study of the impact of agriculture on the soils characteristics, by the calculation of bioconcentration factor (BCF) of metals in plants, and by the calculation of the daily nutrient intake of major nutritional metals.

MATERIALS AND METHODS

Study area

The study area is located in the areas of Moanda, Haut-Ogooué Province, South-east Gabon, 571 m [13°10' - 13°15' E, 1°25' - 1°35' S, (Figure 1)]. The area is covered by a mosaic of forest and secondary grassland savannah. The climate is transitional equatorial with an annual rainfall of 1800 to 2000 mm and an average temperature of 23 to 24°C and a small dry season (December to February) and a large dry season (June to September) (Guichard and Tercinier, 1979). Moanda is one of the most important manganese mining towns in the World, with an estimated 230 million tons of Mn, 20% of the World's deposits. The total Mn and ferromanganese ore reserve exceeds 200 Gt. They are confined to the Lower Proterozoic Franceville Formation that fills the intracratonic Franceville basin. The Franceville formation is composed of the dominant marine terrigenous rocks and the subordinate carbonate varieties, volcanics, and jaspilites. The rocks are virtually undeformed, but divided by faults into blocks. The formation is approximately 4000 m thick and is divided into several lithostratigraphic units (Kuleshov, 2011; Vizier, 1971).

Sampling and sample preparation

Soil and plants analyzed in this study were collected in the forest (control soil) and plantations located 15 km from Moanda. The soil was black, a characteristic of manganese-rich soil. The crops were grown in a deforested area in the following sequence: clearing, burning, cleaning and planting.

Samples of surface soil (0 to 10 cm) were collected in five different points, according to a cross pattern, in cultivated (soil in the root zone) and uncultivated parcels. They were air-dried. The aggregates were crushed and soils were sieved to 2 mm mesh and stored in polythene bags. A part of this fraction was crushed with a tungsten-carbide blade grinder and subsequently sieved with a 0.2 mm titanium mesh.

2 to 5 kg of the edible parts of each plant species were randomly selected and collected. All collected plant samples had reached the same degree of maturation. Samples were washed 3 times with distilled water first, and with de-ionized water thereafter. They were dried in a stove at 70°C until constant weight. Samples were finely ground (0.2 mm) and kept in polyethylene bags. The selected plants are listed in Table 1.

Physico-chemical characterization of the soils

Soil properties were assessed according to the Open Systems Interconnection (ISO) protocols (AFNOR, 1994). They included: particle size (3 fractions), pH_{water}, pH_{KCl}, total organic carbon (TOC), total Kjeldahl nitrogen (TKN), available phosphorus ($P_{ass.}$), cation exchange capacity (CEC), and exchangeable bases (Ca_{exch}, Mg_{exch}, K_{exch}, and Na_{exch}). Considering that the average content of carbon in soil organic matter (OM) is equal to 58%, the conversion factor 1.724 was used to calculate the percentage of OM from the content of organic carbon (Abollino et al., 2002). The sum of exchangeable bases S was calculated.

Total metals concentrations in soils

Soil samples were mineralized in aqua regia (1/3 HNO_3 + 2/3 HCl) according the AFNOR NF X31 - 151 (AFNOR, 1994) standard using a microwave mineralizer. The mineralization products were filtered with a 0.45 µm mesh and the mineral concentrations determined by the Inductively coupled plasma atomic emission spectroscopy (ICP-AES) method (JobinYvon, Spectra 2000). Accuracy of the method was tested by analysing two reference soils (SCP-Science SS-2, Canada and SRM-2586, USA). Precision of results ranged from 3.9 to 7.6%.

Metals in plants

Plant samples were digested at 150°C for 1 h in a microwave

Table 1. Studied plants and consumed parts.

Usual name of plant	Part consumed	Scientific name of plant
Pimento	Fruits	*Capsicum frutescens*
Nkoumou	Leaves	*Gnetum africanum*
Okra	Fruits	*Abelmoschus calei*
Eggplant	Fruits	*Solanum melongena*
Lemon grass	Leaves	*Cymbopognon citratus*
Yam	Tubers	*Dioscorea* spp
Cassava	Leaves Tubers	*Manihot esculenta* Crantz
Amaranth	Leaves	*Amaranthus cruentus* L.
Sorrel with small red leaves	Leaves	*Hibiscus sabdariffa*
Sorrel with large green leaves	Leaves	*H. sabdariffa*

mineralizer using a mixture of nitric acid, hydrogen peroxide and ultra-pure water with a volume proportion ratio 2:1:1 (Nardi et al., 2009). The resulting solution was filtered with a 0.45 µm mesh and stored at 4°C before ICP-AES analysis for determination of metal concentrations.

Bioconcentration factor (BCF)

The capacity of plants to accumulate metals present in soils was assessed using BCF, defined as the ratio of their concentrations measured in plant tissues and soils, in dry weight (Komarek et al., 2007).

$$BCF = \frac{\text{Metal concentration in consumed part of plant}}{\text{Metal concentration in soil}}$$

Daily intake of metals (DIM)

The DIM was calculated by the following equation:

$$DIM = \frac{[M] \times K \times I}{W}$$

Where [M] represents heavy metal concentrations in plants (mg.kg^{-1}); K is conversion factor used to convert fresh part consumed of plant weight to dry weight, estimated to 0.085; I is daily intake of consumed plants (kg); W is average body weight.

The average adult and child body weights were considered to be 55.9 and 32.7 kg, respectively, while average daily vegetable intakes for adults and children were considered to be 0.345 and 0.232 kg/person/day, respectively (Arora et al., 2008; Wang et al., 2005).

Statistical analysis

The means and standard deviations were calculated for all data. The influence of agriculture on soil fertility parameters were analyzed through analysis of variance (ANOVA) statistical tests. Statistical significance was set at 95% ($p = 0.05$).

RESULTS AND DISCUSSION

Soil characteristics

The physico-chemical characteristics of the soils are reported in Table 2. The loam content is significantly higher in the control soil (uncultivated) than in cultivated soil ($p = 0.025$ and $F = 12.3$ - with F: variance). Furthermore, the sand concentration is significantly higher in the cultivated soil than in the control soil ($p = 0.035$ and $F = 9.8$). The cultivation increased the sand content by 41% and decreased the silt content by 24%. The loss in silt content and the gain in sand content were probably due to agricultural practices, erosion and illuviation (Igué, 2007). Several authors have also found that tillage of land affects positively or negatively the particle size of soil by ameliorating or reducing root growth, nutrient interception by roots, and soil aeration or compaction (Agoumé and Birang, 2009; Béliveau et al., 2009; Korkanc et al., 2008).

The uncultivated soil was slightly alkaline and its pH significantly higher compared with the cultivated soil pH. Soil acidification in cropping systems in the tropics is mainly due to depletion of soil base cations by leaching due related to the impact of rainfall (Khresat et al., 2008; Sa et al., 2009; Haynes et al., 2003) or due to through use of chemical fertilizers. The decrease in pH in the surface layer also may be associated with changes in particle size and with a relative loss of soil OM. The pH_{water} value was always higher than pH_{KCl}, indicating that the soil minerals were negatively charged and could retain the free cations in soil solution.

The TOC and available P contents in the cultivated soil decreased both by about 50% mainly due to the increased OM mineralization and leaching rates (Table 2).

Available P is influenced by the mineralogy and soil texture and is concentrated in the organic fraction of most

Table 2. Physico-chemical characteristics of soils.

Characteristics of soils		Uncultivated soil	Cultivated soil
Particle size	Clay ($mg.g^{-1}$)	275.1 ± 12.9^a	234.3 ± 61.0^a
	Loam ($mg.g^{-1}$)	332.3 ± 24.5^a	252.7 ± 16.5^b
	Sand ($mg.g^{-1}$)	361.1 ± 43.4^a	511.3 ± 47.1^b
pH	pH_{-water}	7.4 ± 0.8^a	4.8 ± 0.3^b
	pH_{-KCl}	6.3 ± 0.8^a	3.7 ± 0.1^b
	ΔpH	1.1 ± 0.5^a	1.1 ± 0.1^a
Organic matter	TOC ($mg.g^{-1}$)	39.9 ± 5.8^a	24.7 ± 1.3^b
	OM ($mg.g^{-1}$)	69.0 ± 9.2^a	42.7 ± 1.4^b
	TKN ($mg.g^{-1}$)	2.9 ± 0.7^a	2.6 ± 0.2^a
	TOC/TKN	13.8 ± 0.3^a	10.7 ± 1.2^b
Phosphorus	$P_{ass.}$ ($mg.kg^{-1}$)	26.3 ± 0.6^a	13.6 ± 0.1^b
Basic exchangeable cations	Ca ($mg.kg^{-1}$)	4601 ± 837^a	64.1 ± 12.6^b
	Mg ($mg.kg^{-1}$)	460.9 ± 48.5^a	18.2 ± 11.0^b
	K ($mg.kg^{-1}$)	318.2 ± 41.4^a	3.9 ± 1.4^b
	Na ($mg.kg^{-1}$)	9.0 ± 1.5^a	2.3 ± 0.6^b
Cation exchange capacity	CEC (meq/100 g)	25.1 ± 2.9^a	13.1 ± 2.9^b
Sum of exchangeable basic cations	S (meq/100 g)	27.2 ± 2.6^a	4.9 ± 0.7^b

a, b: Means (±standard deviation) followed by different letters in a same line are significantly different at the 0.05 level.

tropical soils (McAlister et al., 1998; Kamprath and Watson, 1980). The predominant form of phosphorus in soils that contain clay minerals of type 1/1 and Fe- and Al-rich soils as soils of Moanda, is Al-phosphate which is transformed over time in Fe-phosphate (Sanchez, 1976) and reduces the availability of P by adsorption of this element on the large area of Fe-Al-(hydro) oxides (McAlister et al., 1998).

Exchangeable Ca, Mg, K and Na concentrations which also significantly decreased is higher as a result of agricultural practices. Indeed, there is a decreased by 74 to 98% in the cropped soils (Table 2). Base cation depletion of soils was related to acidification leading to a reduced availability of these essential nutrients for plant growth. In acid soils, most of the Ca^{2+} present would exist in soluble form, but both soluble and exchangeable Ca decreases with decreasing soil pH (Haynes and Ludecke, 1981). Furthermore, at low pH, the availability of Ca is further hampered in the presence of high Al concentrations (Bolan et al., 2003). Upon soil acidification, decreasing amounts of Mg remain in exchangeable form due to reduction in variable charge, and more is present in solution, liable to leaching losses. Also, since Mg is a poor competitor with Al and Ca for the exchange sites, it tends to accumulate in the solution phase and is therefore prone to leaching (Myers et al., 1988; Edmeades et al., 1985). The sum of exchangeable bases was low in cultivated soils compared to control soils (Table 2).

The CEC also significantly decreased in the cultivated soil (Table 2). The soil CEC is contributed by the SOM and clay minerals (Bewket and Stroosnijder, 2003), and therefore, soil acidification and SOM losses reduce the soil CEC.

Total metal concentration in soils

Concentrations of metals in soils are presented in Table 3. Concentrations of the measured metals were significantly higher in the uncultivated than in cultivated soil, except for Al and Fe. The Mn concentration in the uncultivated soil was larger than that of the cultivated soils. The Mn and Al concentrations along with the acidic pH value in cultivated soil could pose risks of toxicity of soil for plants (Kabata-Pendias and Mukherjee, 2007). In fact, at acidic pH free Al and Mn may be the predominant forms in soil solution, which could be readily available for plants (Gauthier, 2002; Pedro, 2007). Renella et al. (2005) reported that in Mn and Zn polluted soils, the Mn and Zn solubility was significantly higher in the presence of organic acids typically released by the plant roots than in water, thus suggesting that plants can mobilize trace elements by their root exudates.

Table 3. Total metals Concentrations in soils.

Metal ($mg.kg^{-1}$)	Uncultivated soil	Cultivated soil
Ca	36.823 ± 3.847[a]	178.6 ± 24.8[b]
Mg	4.380 ± 694[a]	1.037 ± 430[b]
K	14.940 ± 1.464[a]	8.796 ± 785[b]
Na	1.323 ± 319[a]	891.1 ± 247.2[a]
Al	14.823 ± 1.673[a]	36.529 ± 3.508[b]
Fe	15.210 ± 1.498[a]	20.869 ± 1.124[b]
Mn	15.725 ± 2.231[a]	10.070 ± 1.398[b]
Zn	463.3 ± 53.2[a]	248.3 ± 37.9[b]

a, b: Means (±standard deviation) followed by different letters in a same line are significantly different at the 0.05 level.

Fertility parameters of soils

Based on the classification of Landon (1991) of different parameters of agricultural tropical soils, levels of TOC and TKN in cultivated soils are still significant for a good agricultural performance (23 to 58 and 2 to 5 g/kg, respectively. However, all parameters indicated that cropping was not environmentally sustainable, leading to the lowering of important indicators of fertility such as TOC, OM, TKN, $P_{ass.}$, exchangeable base cations. This observation was also made by Guichard (1975) who analyzed soil samples from gardens in this study area. Fertilizers applied to soils are almost exclusively minerals, mainly urea and NPK. EdouEdou (2006) observed also that the organic fertility of cultivated land was renewed through an annual or temporary abandonment of cultivated area. This practice only occurred after the observation of infertility signs, including the decline in yield. The levels of OM and nutrients then could decrease greatly depending on the duration of the operation of the cultivated plot.

Ca mobility is more elevated than Mg mobility in cultivated soil. Exchangeable Ca and Mg represent about 36 and 2%, respectively of the total concentration of these elements in the cultivated soil. This is consistent with the results of Guichard and Tercinier (1979) and Guichard (1975), which showed that the proportion of illitic clays, manganese, calcium and magnesium carbonate complexes was important in these soils. In these complexes, Ca is relatively mobile, while Mg is poorly soluble (Legros, 2007).

Metal concentrations in plants

The concentrations of metals in edible parts of plants are shown in Figure 2. The ranking order of the measured metals in plants was: Ca > K > Mg > Mn > Na > Fe > Al > Zn. These concentrations seem to depend on the type of plants more than the edible part concerned. All plants accumulate significant amounts of Ca, Mg and K. Only Nkoumou accumulated small concentrations of metals, and had a very poor nutritive intake. The plants studied in the region of Moanda could be an important source for the intake dietary of these nutrients for humans and animals. Bartlett (1999) described Mn as a "key of life" because of its importance in photosynthesis, the vital link in a large amount of processes occurring in human or animal organism. The Mn levels in several parts of plants (Okra fruits, Cassava leaves, Amaranth leaves and Sorrel leaves) are higher than plant toxic level of 500 mg/kg proposed by Kabata-Pendias and Mukherjee (2007). Here, cassava and sorrel leaves accumulate values above 1000 $mg.kg^{-1}$ of Mn. Ascher et al. (2009) reported that Ca, P, Fe, Mn and Zn concentrations in the edible parts of lettuce grown on polluted soils depended on the pollution level and that soil remediation reduced the potentially toxic Mn and Zn concentrations in the edible parts of lettuce.

Bioconcentration factor (BCF)

The rate of elements absorption by the plant depends on the plant cultivated and soil properties such as pH, cation exchange capacity and distribution of metals in different soil fractions (Kos et al., 2003; Cui et al., 2004). The metal BCF in plants is used to describe the extent of the accumulation of a compound in a biological system identified. Table 4 presents the BCF values of metals in consumed parts of studied plants. Al and Fe are less accumulated than other elements. Their BCF ranged from 0.0003 to 0.0265 for Al and from 0.0010 to 0.0519 for Fe. Zn is more accumulated than other metals. Values of Zn BCF are in the ranges from 0.0306 to 0.6033. Nkoumou is the leafy vegetable that accumulates the least amount of metal. However, this traditional leafy vegetable is the most popular and most consumed by people in the Moanda region. The best accumulators are sorrel with small red leaves for Al, Fe and Mn, and sorrel with large green leaves for Zn. Ondo (2011) indicated that sorrel or *Hibiscus sabdariffa*, was a plant that preferentially

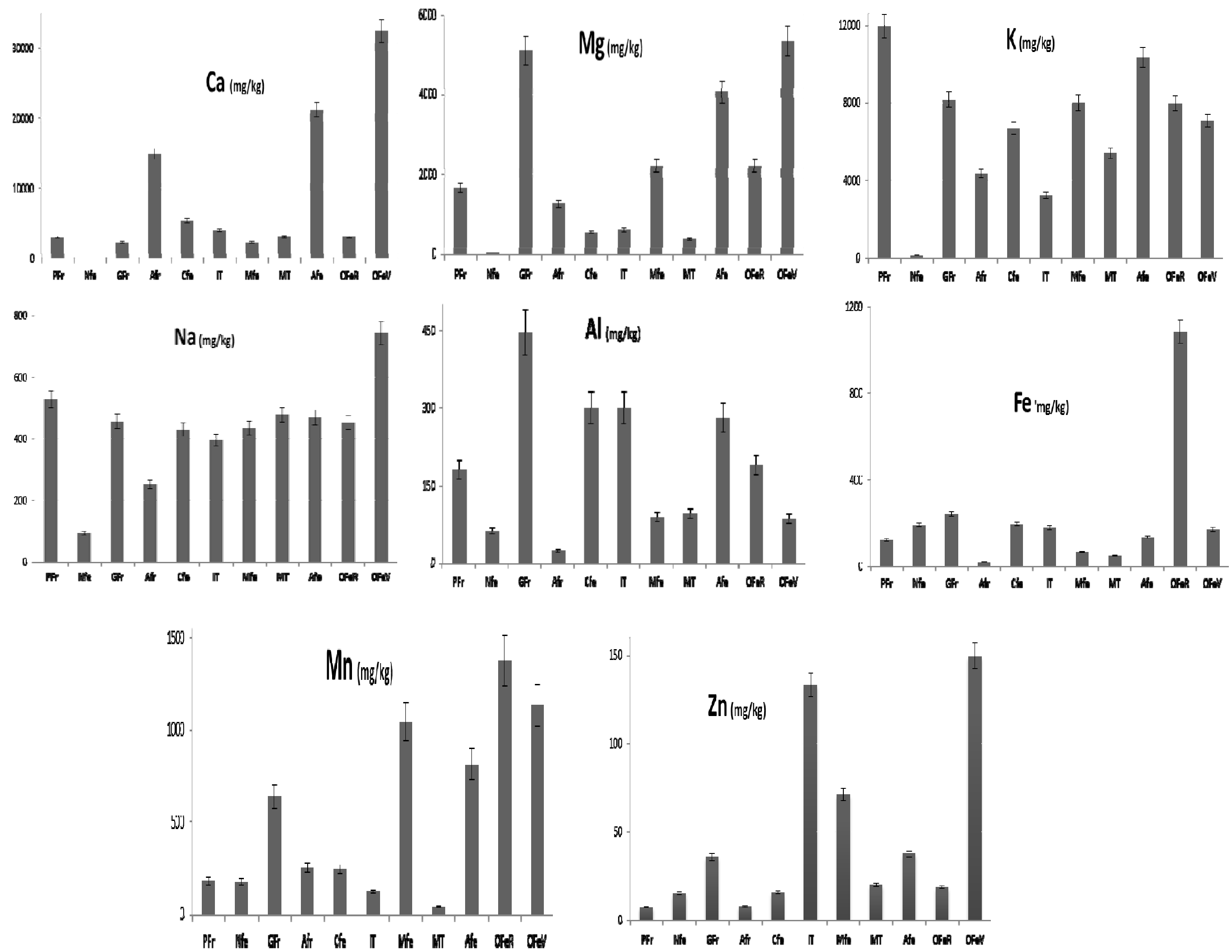

Figure 2. Metal concentrations in consumed parts of dry plants (mg.kg^{-1}). **PFr,** Pimento fruits; **NFe,** Nkoumou leaves; **GFr,** okra fruits; **AFr,** eggplant fruits; **CFe,** lemon grass fruits; **IT,** yam tubers; **MFe,** cassava leaves; **MT,** cassava tubers; **AFe,** Amaranth leaves; **OFeR,** Sorrel red leaves; **OFeV,** Sorrel green leaves.

Table 4. Bioconcentration factor of metal in consumed parts of plants.

Usual name of plant	Al	Mn	Fe	Zn
Pimento	0.0025	0.0220	0.0058	0.0306
Nkoumou	0.0009	0.0211	0.0093	0.0616
Okra	0.0062	0.0777	0.0116	0.1442
Eggplant	0.0003	0.0308	0.001	0.0322
Lemon grass leave	0.0042	0.0298	0.0093	0.0636
Yam	0.0042	0.0149	0.0086	0.5373
Cassava leave	0.0012	0.1265	0.0031	0.2872
Cassava tuber	0.0013	0.005	0.0024	0.0818
Amaranth	0.0039	0.0991	0.0066	0.1518
Sorrel with small red leaves	0.0265	0.1673	0.0519	0.0761
Sorrel with large green leaves	ND	0.1379	0.0081	0.6033

ND: Not determined.

Table 5. Estimated daily intake of nutritional metals.

Daily intake of nutritional metals		Pimento	Nkoumou	Okra	Eggplant	Lemon grass	Yam	Cassava leaves	Cassava tuber	Amaranth	Sorrel with small red leaves	Sorrel with large green leaves
Mn (mg.day^{-1})	Children	0.114	0.109	0.402	0.159	0.154	0.077	0.654	0.026	0.512	0.865	0.713
	Adult	0.095	0.091	0.335	0.133	0.128	0.064	0.545	0.021	0.427	0.721	0.594
Fe (mg.day^{-1})	Children	0.077	0.122	0.152	0.013	0.123	0.112	0.041	0.031	0.086	0.682	0.107
	Adult	0.064	0.101	0.127	0.01	0.102	0.094	0.034	0.026	0.072	0.568	0.089
Zn (mg.day^{-1})	Children	0.005	0.01	0.023	0.005	0.01	0.084	0.045	0.013	0.024	0.012	0.094
	Adult	0.004	0.008	0.019	0.004	0.008	0.07	0.037	0.011	0.02	0.01	0.079
Mg (mg.day^{-1})	Children	1.052	0	3.225	0.795	0.352	0.39	1.399	0.241	2.568	1.405	3.363
	Adult	0.877	0	2.69	0.663	0.293	0.325	1.166	0.201	2.142	1.172	2.804
Ca (mg.day^{-1})	Children	1.895	ND	1.465	9.404	3.404	2.506	1.445	1.931	13.363	1.904	20.447
	Adult	1.58	ND	1.222	7.843	2.838	2.09	1.205	1.611	11.144	1.587	17.052
K (mg.day^{-1})	Children	7.526	0.106	5.141	2.755	4.206	2.034	5.042	3.419	6.493	5.018	4.452
	Adult	6.277	0.089	4.287	2.297	3.508	1.696	4.205	2.851	5.415	4.185	3.713
Na (mg.day^{-1})	Children	0.333	0.059	0.286	0.159	0.271	0.249	0.273	0.301	0.295	0.285	4.673
	Adult	0.278	0.049	0.239	0.133	0.226	0.208	0.228	0.251	0.246	0.238	3.897

ND: Not determined.

concentrated metals in its leaves, the consumable part of the plant.

Daily intake of physiologically active metals

The daily intake of physiologically active was estimated (Table 5) and was compared with the recommended daily intakes (World Health Organization, 1996; Institute of Medicine from United States, 2007). Comparisons with the recommended daily intakes present results in the range of 0.53 to 21.62% for Mn, 0.06 to 3.41% for Fe and less than 2% for other nutritional metals. The highest contributions come from the sorrel and amaranth. The high potassium values for pimento were not significant because this fruit-vegetable is used only in very small quantities because of his prickly flavor. In general, these values are higher than those found by Arora et al. (2008). The results of this study suggest that daily intakes of physiologically active from plants cultivated in manganese-rich soils of Moanda are high, and could be free of risk because the recommended daily intakes were much higher: 270 to 1200 mg/day for Ca, 10 to 30 mg/day for Fe, 75 to 420 mg/day for Mg, 1 to 6 mg/day for Mn, 700 to 2000 mg/day for K, 200 to 500 mg/day for Na, 5 to 19 mg/day for Zn (World Health Organization, 1996; Institute of Medicine from United States, 2007).

Conclusion

The agricultural practices on manganese-rich soil of Moanda significantly led to a strong acidification, a reduction of fertility index and a loss of metals in soil. Mn concentrations in several consumed parts of plants are higher than toxic level for plants (500 $mg.kg^{-1}$). The increasing consumption of vegetables in the region of Moanda could be a significant source of essential metals for animals and humans. But dietary intake of food results in long-term low level body accumulation of heavy metals and the detrimental impact becomes apparent only after several years of exposure. The determination of more toxic metals in agricultural soils, like Pb or Cd, and their transfer in consumed plants, is thus necessary. Regular monitoring of these toxic metals in soils, plants and human or animal bodies are essential to prevent their excessive build-up in the food chain. Other studies, such as education on food requirements, tillage, and new methods of conservation and preservation of agricultural soils, are of prime importance to improve crop yields. Laboratory studies and experiments carried out in cultivated field would be necessary to determine the capacity accumulate toxic metals such as Pb or Cd of sorrel, the best accumulator plant in this study and because of his importance in the alimentation in West Africa.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

Many thanks to Laurent VASSALO and Jean Félix NDZIME for their technical assistance in laboratory analysis.

REFERENCES

Abollino O, Aceto M, Malandrino M, Mentasti E, Sarzanini C, Petrella F (2002). Heavy metals in agricultural soils from Piedmont, Italy.Distribution, speciation and chemometric data treatment.Chemosphere 49:545–557. http://dx.doi.org/10.1016/S0045-6535(02)00352-1

AFNOR (1994). Qualité des sols. Recueil de normes françaises. AFNOR, Paris France P. 533.

Agoumé V, Birang AM (2009). Impact of Land-use Systems on some Physical and Chemical Soil Properties of an Oxisol in the Humid Forest Zone of Southern Cameroon.Tropicultura 27(1):15-20.

Akbar Jan F, Ishaq M, Khan S, Ihsanullah I, Ahmad I, Shakirullah M (2010). A comparative study of human health risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir), J. Hazard. Mater. 179(1-3):612-621. http://dx.doi.org/10.1016/j.jhazmat.2010.03.047

Arora M, Kiran B, Rani S, Rani A, Kaur B, Mittal N (2008). Heavy metal accumulation in vegetables irrigated with water from different sources. Food Chem. 111(4):811-815.http://dx.doi.org/10.1016/j.foodchem.2008.04.049

Ascher J, Ceccherini MT, Landi L, Mench M, Pietramellara G, Nannipieri P, Renella G (2009). Composition, biomass and activity of microflora, and leaf yields and foliar elemental concentrations of lettuce, after in situ stabilization of an arsenic-contaminated soil. Appl. Soil Ecol. 41:351–359.http://dx.doi.org/10.1016/j.apsoil.2009.01.001

Bartlett RJ (1999). Charaterizing soil redox behavior, in: Sparks DL (ed) Soil Phys. Chem. 2nd ed., CRC Press, Boca Raton, FL, pp. 371-397.

Béliveau A, Lucotte M, Davidson R, Lopes LO, Paquet S (2009). Early Hg mobility in cultivated tropical soils one year after slash-and-burn of the primary forest, in the Brazilian Amazon. Sci. Total Environ. 407(15):4480-4489.http://dx.doi.org/10.1016/j.scitotenv.2009.04.012 PMid:19428050

Bewket W, Stroosnijder L (2003). Effects of agroecological land use succession on soil properties in Chemoga watershed, Blue Nile basin, Ethiopia. Geoderma 111:85–98.http://dx.doi.org/10.1016/S0016-7061(02)00255-0

Bolan NS, Adriano DC, Curtin D (2003).Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. Advances in Agronomy 78:215-272.http://dx.doi.org/10.1016/S0065-2113(02)78006-1

Cui YJ, Zhu YG, Zhai RH, Chen DY, Huang YZ, Qiu Y, Liang JZ (2004). Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. Environ. Int. 30:785–791.http://dx.doi.org/10.1016/j.envint.2004.01.003

De Miguel E, Irribarren I, Chacon E, Ordonez A, Charlesworth S (2007). Risk-based evaluation of the exposure of children to trace elements in playgrounds in Madrid (Spain). Chemosphere 66:505–513.http://dx.doi.org/10.1016/j.chemosphere.2006.05.065 PMid:16844191

Edmeades DC, Wheeler DM, Crouchley G (1985). Effects of liming on soil magnesium on some soils in New Zealand.SoilSci. Plant Anal. 16:727–739.http://dx.doi.org/10.1080/00103628509367640

EdouEdou G (2006). Etude des systèmes maraîchers urbains et périurbains de Libreville (Gabon), Rapport de l'Institut Gabonais d'Appui au Développement (I.G.A.D.) P. 126.

Ferreira-Baptista L, De Miguel E (2005). Geochemistry and risk assessment of street dust in Luanda, Angola : a tropical urban environment. Atmos. Environ. 39:4501–4512. http://dx.doi.org/10.1016/j.atmosenv.2005.03.026

Garrett RC (2000). Natural sources of metals to the environment. Hum. Ecol. Risk. Assess. 6:945–963. http://dx.doi.org/10.1080/10807030091124383

Gauthier C (2002). Contribution à l'étude du fractionnement de l'aluminium libéré dans des solutions de sols forestiers : Influence de la quantité et de la nature de la matière organique. Thèse de Doctorat Université de Limoges, France P. 184.

Gonzalez-Munoz MJ, Meseguer I, Sanchez-Reus MI, Schultz A, Olivero R, Benedi J, Sanchez-Muniz FJ (2008). Beer consumption reduces cerebral oxidation caused by aluminum toxicity by normalizing gene expression of tumor necrotic factor alpha and several antioxidant enzymes,Food Chem. Toxicol. 46(3):1111-1118. http://dx.doi.org/10.1016/j.fct.2007.11.006. PMid:18096288

Guichard E (1975). Prélèvement d'échantillons de terre dans les jardins de la COMILOG en bordure de la rivière Makima–Moanda. ORSTOM Outremer Centre de Libreville. Rapport P. 6.

Guichard E, Tercinier G (1979). Les oxydisolsalumino-manganésifères du plateau d'Okouma au Gabon. Contribution à l'étude cristallochimique et géochimique des phénomènes de ferrallitisation. Cahiers de l'ORSTOM, série Pédologie 17(1):9-35.

Haynes RJ, Dominy CS, Graham MH (2003). Effect of agricultural land use on soil organic matter status and the composition of earthworm communities in KwaZulu-Natal, South Africa. Agron. Ecosyst. Environ. 95(2-3):453-464.http://dx.doi.org/10.1016/S0167-8809(02)00223-2

Haynes RJ, Ludecke TE (1981). Effect of lime and phosphorus applications on concentrations of available nutrients and on P, Al and Mn uptake by 2 pasture legumes in an acid soil.Plant Soil 62:117–128.http://dx.doi.org/10.1007/BF02205031http://dx.doi.org/10.1007/BF02374088

Igué AM (2007). Impact of land use effect on chemical and physical soil characteristics in Colline Department of Benin. INRAB, pp. 1-12, http://www.rivertwin.de/assets/igue_abstract_icld4.pdf.

Institute of Medicine from United States (2007). DRI values definitions in: Food and Nutrition Board, Institute of Medicine, National Academies, http://www.iom.edu/CMS/54133.aspx.

Kabata-Pendias A, Mukherjee AB (2007).Trace Elements from Soil to Human.NewYork : Springer-Verlag .82:550. http://dx.doi.org/10.1007/978-3-540-32714-1

Kamprath EJ, Watson ME (1980). Conventional soil and tissue tests for assessing the phosphorus status of soils, in F. E. Khasawnek Editor, The Role of Phosphorus in Agriculture. Am. Soc. Agric. Madison, WI, pp. 433–469.

Kawashima LM, Soares LMV (2003). Mineral profile of raw and cooked leafy vegetables consumed in Southern Brazil. J. Food Compos. Anal. 16(5):605-611.http://dx.doi.org/10.1016/S0889-1575(03)00057-7

Khresat S, Al-Bakri J, Al-Tahhan R (2008). Impacts of land use/cover change on soil properties in the Mediterranean region of northwestern Jordan. Land Degrade. Dev. 19:397–407.

Komarek M, Chrastny V, Stichova J (2007). Metal/metalloid contamination and isotopic composition of lead in edible mushrooms and forest soils originating from a smelting area. Environ. Int. 33:677–684. http://dx.doi.org/10.1016/j.envint.2007.02.001

Kos B, Greman H, Lestan D (2003). Phytoextraction of lead, zinc and cadmium from soil by selected plants, Plant Soil Environ. 49(12):548–553.

Korkanc SY, Ozyuvaci N, Hizal A (2008). Impacts of land use conversion on soil properties and soil erodibility. J. Environ. Biol. 29(3):363-370.PMid:18972693

Kuleshov VN (2011). Manganesedeposits: Communication 1. Genetic models of manganese ore formation. Lithol. Miner. Resour+. 46(5):473-493. http://dx.doi.org/10.1134/S0024490211050038

Kwapata B, Maliro MF (1995). Indigenous vegetables in Malawi: germplasm collecting and improvement of production practices, in L. Guarino, Editor, Traditional African Vegetables. Proceedings of the IPGRI International Workshop on Genetic Resources of Traditional Vegetables in Africa: Conservation and Use, IPGRI, Kenya, pp. 132–135.

Landon JR (1991). Booker tropical soil manual, Harlow, UK.Longman P. 474.

Legros JP (2007). Les grands sols du monde. Presses Polytechniques et Universitaires Romandes (PPUR) P. 592.

Lu Y, Gong ZT, Zhang GL, Burghardt W (2003). Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China.Geoderma 115:101–111.http://dx.doi.org/10.1016/S0016-7061(03)00079-X

McAlister JJ, Smith BJ, Sanchez B (1998). Forest clearance: impact of land use change on fertility status of soils from the Sao Francisco area of Niteroi, Brazil. Land Degrad. Dev. 9:425–440. http://dx.doi.org/10.1002/(SICI)1099-145X(199809/10)9:5<425::AID-LDR306>3.0.CO;2-Z

Myers JA, McLean EO, Bingham JM (1988). Reductions in exchangeable magnesium with liming acid Ohio soils.SoilSci. Soc. Am. J. 52:131–136. http://dx.doi.org/10.2136/sssaj1988.03615995005200010023x

Nardi EP, Evangelist ES, Tormen L, Saint-Pierre TD, Curtius AJ, de Souza SS, Barbosa JrF (2009). The use of inductively coupled plasma mass spectrometry (ICP-MS) for the determination of toxic and essential elements in different types of food samples, Food Chem. 112(3):727-732. http://dx.doi.org/10.1016/j.foodchem.2008.06.010

Odhav B, Beekrum S, Akula U, Baijnath H (2007). Preliminary assessment of nutritional value of traditional leafy vegetables in KwaZulu-Natal, South Africa. J. Food Compos. Anal. 20(5):430-435. http://dx.doi.org/10.1016/j.jfca.2006.04.015

Ondo JA (2011). Vulnérabilité des sols maraîchers du Gabon (région de Libreville): Acidification et mobilité des éléments métalliques. Thèse de Doctorat, Université de Provence, France P. 317.

Pedro G (2007). Cycles biogéochimiques et écosystèmes continentaux. Acad. Sci. Paris P. 482.

Poschenrieder C, Gunsé B, Corrales I, Barcelo J (2008). A glance into aluminum toxicity and resistance in plants.Sci. Total Environ. 400(1-3):356-368. http://dx.doi.org/10.1016/j.scitotenv.2008.06.003.

Renella G, Mench M, Gelsomino A, Landi L, Nannipieri P (2005). Functional activity and microbial community structure in soils amended with bimetallic sludges. Soil Biol. Biochem. 37:1498-1506. http://dx.doi.org/10.1016/j.soilbio.2005.01.013

Sa JCM, Cerri CC, Lal R, Dick WA, Piccolo MC, Feigl BE (2009). Soil organic carbon and fertility interactions affected by a tillage chronosequence in a Brazilian Oxisol.Soil Till. Res. 104(1):56-64. http://dx.doi.org/10.1016/j.still.2008.11.007

Sanchez PA (1976). Properties and Management of Soils in the Tropics, Wiley Intersci.New York, Tchibambelela B (2009). Le Commerce Mondial de la Faim : Stratégie de Rupture Positive au Congo-Brazzaville. L'Harmattan, Paris P. 530.

Wang X, Sato T, Xing B, Tao S (2005). Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Sci. Total Environ. 350:28–37. http://dx.doi.org/10.1016/j.scitotenv.2004.09.044.PMid:16227070

Vizier JF (1971). Etude de l'état d'oxydoréduction du sol et de ses conséquences sur la dynamique du fer dans les sols hydromorphes. Cah. ORSTOM, Ser. Pédol. 9(4):373-397.

World Health Organization (1996). Health criteria other supporting information, in: Guidelines for Drinking water Quality 2 (2nd ed.) pp. 31–388.