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Full Length Research Paper

Long term effect of municipal solid waste amendment on soil heavy metal content of sites used for periurban agriculture in Ngaoundere, Cameroon

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An assessment of the impact of amendment using untreated municipal solid wastes on the trace element contents of periurban areas soils was carried out in Ngaoundere. Waste samples were collected in November and soil samples were collected in November, January, April and July. Heavy metal total concentrations in urban wastes differed significantly among sites and ranged from 0.48 to 7.64 mg/kg for Cd, 38.3 to 236 mg/kg for Cu, 44.06 to 58.03 mg/kg for Ni, 117 to 528 mg/kg for Pb and 270 to 2110 mg/kg for Zn. These levels were out of the critical level for agricultural use at Camp prison (for Pb and Zn), Norvegien (for Cd, Cu and Zn), and Sabongari Gare site (for Cd, Cu and Zn). The levels of Ni in urban wastes from all sites and the levels of all heavy metals in urban wastes from Douze Poteaux site were lower than the critical level. The results revealed that the soil total concentrations of Cu, Zn, Cd and Pb were below the typical agricultural soil critical level for the soil control and out of the critical level for amended soils. The levels of Ni were found to be within the normal range at all sites. The highest available concentration of Zn (139.17 mg/kg) was found in November, Fe (843.23 mg/kg) and Pb (38.82 mg/kg) in January and Cu (19.09 mg/kg) and Ni (8.98 mg/kg) in July. The available concentrations of Cd did not differ among periods. The highest bioavailable factor (BF) of Zn, Ni and Pb was found at Douze Poteaux site and of Cd and Cu at Sabongari Gare site.

Key words: Heavy metals, soils, municipal solid wastes, amendment, bioavailability factor.

INTRODUCTION

Waste management problem is one of the worrying results of rapid and anarchic urbanization of African countries (Onibokun and Kumuyi, 2001). In African cities organic material forms 50 - 90% of urban refuse and the organic fraction includes raw kitchen waste generated in the preparation and consumption of food (food leftovers, rotten fruit, vegetables, leaves, crop residues, animal excreta and bones (Asomani-Boateng and Murray, 1999). Therefore, such wastes can serve as fertilizer for urban cultivation. The practice of reusing wastes in food cultivation in Africa is not new; most African countries have traditionally utilized various types of organic materials to maintain and improve the productivity and fertility of agricultural soils (Asomani-Boateng and Murray, 1999). Today, waste reuse in urban farming in African cities can play an important role in reducing the public coast of waste management, soil and water pollution and thus providing a better living environment (Drechsel et al., 1999; Berend, 1999).

The Ngaoundere Plateau has been the location of vegetable gardening for at least 18 years (SDEAA, 1996). The expansion of dry-season irrigated vegetable production is stimulated by the growing urban and affluent population. In the peri-urban areas of Ngaoundere farmers were reported to use various types of materials as fertilizers: town refuse ash, untreated town refuse and ani-

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animal manures (Adjia, 2003). Although the nutrient content of wastes makes them attractive as fertilizers, when untreated wastes are used in crop production, consumers risk to contract the diseases like cholera and hepatitis, or to undergo heavy metal contamination (Drechsel et al., 1999). In fact, large amounts of the waste comprise organic material, but there are considerable proportions of plastic, paper, metal rubbish and batteries which are known to be real sources of heavy metals (Lisk, 1988; Zhang et al., 2002; Pasquini and Alexander, 2004). Heavy metals, non-biodegradable, can accumulate in soils to toxic concentrations that affect plant and animal life. Contamination of soils by heavy metals can be caused by many factors such as metal-enriched parent materials, mining or industrial activities, non point sources of metals, especially automotive emission, and use of metal-enriched materials, including chemical fertilizers, farm manures, sewage sludge, and wastewater irrigation (Freedman and Hutchinson, 1981). However, soil contamination by heavy metals and toxic elements due to parent materials or point sources often occurs on a limited area and is easy to identify (He et al., 2005). In agricultural production systems, soil contamination of heavy metals is mainly related to input and accumulation of these elements through repeated use of metal-enriched chemicals such as fungicides, farm manures, chemical fertilizers, and biosolids (Webber, 1981). Biosolids and/or municipal composts made of biosolids and yard wastes often contain higher concentrations of Cu, Zn, Cd, Cr, and Ni than those found in soils (He et al., 2001). Heavy metals derived from anthropogenic inputs are presents in soils in reactive forms and lead to a higher risk of toxicity compared to heavy metals derived from parent materials, generally immobilised in relatively inert forms (Baize, 1997; Kabata-Pendias and Pendias, 2001). Several works have been done in developed countries and showed excessive concentrations of heavy metals in agricultural soils and plants (Alloway, 1995). The research on the soil-to-plant transfer of heavy metals is going on in developing countries. In Nigeria, the research work of Oluyemi et al. (2008) showed high levels of As, Cd, Cr, Ni and Pb above the critical level in crop leaves in both dry and wet season. In Ngaoundere, data on soil and crops from municipal solid waste amended sites are not available. Hence, the objectives of the present paper were to provide data on the chemical properties of the municipal solid wastes used in vegetable production and to assess the pollution status ofthe amended sites.

MATERIAL AND METHODS

Area description

The study was carried out in Ngaoundere, the country town of the Adamawa province (Cameroon). This city expands on a plateau about 2500 km. The plateau stands at altitude 1100 m and lies at latitude 07°09'N and longitude 13°01'E. It is characterised by granitic and migmatitic rocks. Total annual rainfall is superior or equal to 1400 mm; average annual temperature is 22°C. The natural vegetation of the area is a savannah (Letouzey, 1969).

Vegetable production normally takes place during the dry season, which runs approximately from November to April, and is mostly characterised by the harmattan wind and absence of precipitation, typical for the tropical climate. The onset and end of the season are obviously variable because they depend on the climatic conditions characterising a particular year. At the end of the farming season (April-Mai), immediately after the last harvest, leafy vegetables are replaced with the corn crop. Farmers abandon their land for the wet season break from July to October. During the wet season break, farm land is covered by weeds.

The dry season is long enough to allow more rounds of harvest, the first taking place in January and the last in April. The farmers tend to intercrop, mixing slowly growing species (such as cabbage, watermelon or tomatoes) with quick maturing species (such as lettuce and local leafy vegetables) in the same subplots. The four case study farms are located along the Soumsoum River which goes trough the Ngaoundere town from west to the north (Figure 1). The farmers use the Soumsoum as a source of irrigation water. The farms were chosen because the plots had been under cultivation for at least 10 years.

Sampling

Urban waste manures samples were collected from municipal waste dump sites at Camp Prison, Norvegien, Douze Poteaux and Sabongari Gare sites (Figure 1). Soil samples were collected from municipal solid waste amended gardens at the same agricultural sites. Soil control sample was equally collected from garden with no municipal solid waste. The soil samples were collected at 0 – 20 cm depth at all sites. Municipal solid waste samples were collected in November, and soil samples were collected in November (the beginning of the farming season), January (the first period of harvest), April (the latest period of harvest) and July (the wet season break).

Chemical analysis

Municipal solid waste and soil samples were air-dried, ground and sieved through 2 mm sieve. Soil and urban waste manure samples were analysed for the following parameters: pH, electrical conductivity, organic matter, Ca, Mg and heavy metals. The pH was measured using the water and KCl methods; electrical conductivity was determined using the aqueous extraction (1/5) method (Mathieu and Pieltain, 2003). Organic matter was determined using Anne method (modified Walkey-Black method) (Mathieu and Pieltain, 2003). Exchangeable Ca and Mg were extracted with ammonium acetate at pH 7 and Ca and Mg concentrations were determined by volumetric method using EDTA as the chelating agent (AFNOR, 2002).

Urban waste samples and cultivated soil samples were analysed for total and available heavy metal concentrations. Total concentrations of Cu, Ni, Zn, Cd and Pb were determined using the standard procedure of the French Normalization Association (AFNOR, 1987). A subsample (0.250 g) was gradually warmed to 450°C. After cooling, hydrofluoric acid (HF) and perchloric acid ($HClO_4$) were added to the residue, and the mixture was heated to dryness. Hydrochloric acid (HCl) was added and heated to redissolve the residue. The solution was thereafter brought to 50 ml volume with distilled water. Total concentrations were analysed by an inductively-coupled argon plasma atomic emission spectrometer (ICP), VARIAN Plasma 96. For available heavy metal content determination, Cu, Ni, Zn, Cd and Pb were also extracted with diethylene-triamine-pentaacetic acid (DTPA). The solution is made

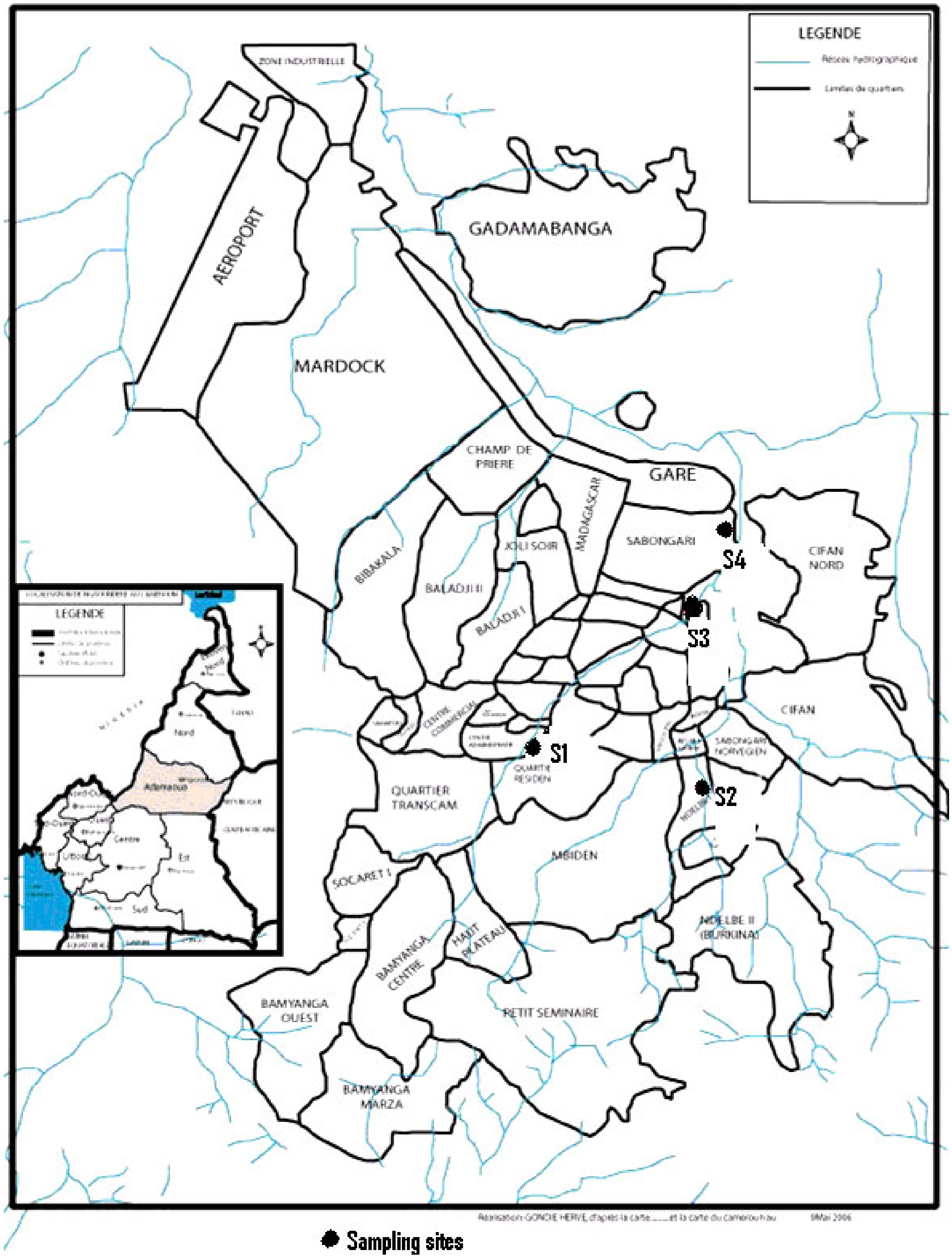

Figure 1. Map of Ngaoundere showing the sampling locations (S1 = Camp Prison; S2 = Norvegien; S3 = Douze Poteaux; S4 = Saongari Gare).

up of a mixture of 0.005 M DTPA, 0.1 M triethanolamine (TEA) and 0.01M $CaCl_2$, adjusted to pH 7.3 (Mathieu and Pieltain, 2003). The concentrations in extracts were analysed using an atomic absorption spectrophotometer (AAS), model of VARIAN Spectr AA.20. The wave lengths for Cu, Cd, Zn, Fe, Pb, Ni are 324.8, 22.8 213.9, 248.3, 217.0, 232.0 nm, respectively.

Statistical analysis

The analysis of variance was carried out using Stat Graphics 3.0.

Table 1 : Some physico-chemical parameters of municipal solid wastes

Sites	pH-eau	pH-KCl	$CE_{1/5}$ (dS/m)	OC (%)	Ca (g/100g)	Mg (g/100g)
S1	8,55±0,03^{c}	7,87±0,01^{b}	2,96±0,10^{d}	15,71±0,01^{c}	18,21±0,45^{d}	2,80±0,06^{a}
S2	7,98±0,11^{a}	7,33±0,04^{a}	1,33±0,00^{a}	4,71±0,01^{a}	15,89±0,28^{c}	3,70±60,04^{c}
S3	8,34±0,06^{b}	7,96±0,02^{c}	1,84±0,10^{b}	5,89±0,56^{a}	13,54±0,27^{b}	3,67±0,04^{bc}
S4	9,40±0,02^{d}	8,86±0,01^{d}	2,07±0,05^{c}	10,21±1,11^{b}	12,59±0,27^{a}	3,50±0,10^{b}

Means with the same letters are not significantly different at P<0.05 according to Duncan Range Test.
OC = Organic Carbon ; S1 = Camp Prison ; S2 = Norvegien ; S3 = Douze Poteaux ; S4 = Sabongari Gare

Table 2 : Heavy metal total concentrations (mg/kg) of municipal solid wastes

Sites	Cd	Cu	Ni	Pb	Zn
S1	1.91±0.04^{b}	52.3±6.36^{a}	44.06±2.12^{a}	528±8.20 ^{c}	705±7.64^{b}
S2	7.64±0.78^{d}	236.00±11.96^{c}	65.60±3.25^{c}	216±4.67^{b}	1 140±13.96^{c}
S3	0.48±0.01^{a}	38.30±5,80^{a}	46.0±1,98^{a}	117±4.38^{a}	270±17.25^{a}
S4	3.18±0.06^{c}	159.00±8.65^{b}	58.30±2.40^{b}	216±3.25^{b}	2 110±21.21^{d}
EEC*	3	140	75	300	300

Means with the same letters are not significantly different at P < 0.05 according to Duncan Range Test.
*Maximum permissible levels according to the Council Directive 86/278/EEC (Pasquini, 2004)
S1 = Camp Prison; S2 = Norvegien; S3 = Douze Poteaux; S4 = Sabongari Gare

Significant differences were considered at $P < 0.05$ and mean values were separated using the Duncan's multiple range test.

RESULTS AND DISCUSSION

Physico-chemical composition and heavy metal contents of urban wastes

Physico-chemical composition of urban wastes: The mean distribution of some physico-chemical parameters of urban solid wastes at different periurban sites are summarized in table 1. The urban waste pH differed significantly ($P < 0.05$) among the periurban sites. The value of pH-water ranged from 8.55 units to 9. 40 units while pH-KCl ranged from 7.33 to 8.86 units. These values were higher than those of Ramachandran and D'souza (1998) recorded on City compost and sewage sludge (7.7 and 6.2, respectively) in India, but lower than those of Pasquini and Alexander (2004) on town refuse ash used for urban agriculture in Jos. The difference could be due to the origin, nature (raw material contrary to ash material) or the degree of waste decomposition. Electrical conductivity differed significantly ($P < 0.05$) among periurban sites. It ranged from 1.84 to 2.96 dS/m and the highest value was found at S1. The organic carbon (OC) content of municipal solid wastes ranged from 4.71 to 15.71%. Ramachandran and D'Souza found out similar values on sewage sludge (15.1%) and city compost (10.4%) used in India for urban agriculture. The highest values were found at S1 and at S4. The variability of OC content of municipal solid wastes is expected because of their nature. Municipal urban wastes from S1 and S4 showed large amounts of waste food and waste manure.

Ca and Mg contents differed significantly among the periurban sites. The levels of Ca ranged from 12.59 to 18.45 g/100 g whereas the levels of Mg ranged from 2.80 to 3.5 g/100 g. These values were similar to those of Pasquini and Alexander (2004) on town refuse ash (1.33 - 61.85 g/100 g for Ca; 0.16 - 3.34 g/100 g for Mg) used in Jos for urban agriculture.

Total concentrations of heavy metal in municipal solid wastes: According to table 2, the range of Cd, Cu, Ni, Pb and Zn total concentrations in the urban waste sample from the study sites were 0.48 - 3.18, 38.30 - 236.0, 44.06 - 65.60, 117.00 - 528.00 and 270.00 - 2110.00 mg/kg, respectively. The municipal solid urban wastes can be classified into 3 types:

i.) Single Zn pollution, for example, solid waste samples from S2.
ii.) Combined Pb-Zn pollution, including solid waste samples from S1.
iii.) Combined Cd-Cu-Zn pollution, including at S2 and S4.

However, no solid waste could be classified as Ni-polluted. Solid waste samples from S3 were out of the classification because they did not present heavy metal critical level. However, except Cu, the levels of Zn, Ni, Pb, and Cd were generally above the USA maximum

Table 3. Some physico-chemical parameters of cultivated soils.

Sites	Periods	pH-eau	pH-KCl	$CE_{1/5}$ (dS/m)	CO (%)	Ca (g/100g)	Mg (g/100 g)
T	November	$6.23{\pm}0.06^{b}$	$4.95{\pm}0.01^{b}$	0.09±0.00a	$4.22{\pm}0.54^{a}$	$3.66{\pm}0.05^{c}$	$0.75{\pm}0.21^{a}$
	January	$5.61{\pm}0.05^{a}$	$5.00{\pm}0.01^{b}$	$0.13{\pm}0.01^{b}$	$5.19{\pm}0.16^{a}$	$3.09{\pm}0.09^{ab}$	$0.81{\pm}0.04^{ab}$
	April	$5.74{\pm}0.04^{a}$	$4.67{\pm}0.01^{a}$	$0.14{\pm}0.01^{c}$	$4.58{\pm}0.54^{a}$	$3.05{\pm}0.22^{a}$	$0.77{\pm}0.01^{a}$
	July	$6.10{\pm}0.06^{b}$	$4.70{\pm}0.04^{a}$	0.09±0.00a	$4.40{\pm}0.21^{a}$	$3.41{\pm}0.06^{bc}$	$1.09{\pm}0.07^{b}$
S1	November	$6.58{\pm}0.06^{c}$	$5.44{\pm}0.04^{b}$	$0.14{\pm}0.01^{b}$	$3.81{\pm}0.54^{a}$	$4.24{\pm}0.08^{b}$	$1.46{\pm}0.25^{b}$
	January	$6.37{\pm}0.06^{b}$	$5.37{\pm}0.01^{b}$	$0.12{\pm}0.01^{a}$	$7.20{\pm}0.54^{c}$	$3.49{\pm}0.05^{a}$	$0.71{\pm}0.08^{a}$
	April	$5.71{\pm}0.04^{a}$	$5.23{\pm}0.01^{a}$	$0.46{\pm}0.03^{d}$	$5.08{\pm}0.32^{b}$	$4.82{\pm}0.24^{c}$	$0.95{\pm}0.16^{a}$
	July	$6.32{\pm}0.03^{b}$	$6.54{\pm}0.03^{c}$	$0.19{\pm}0.01^{c}$	$3.79{\pm}0.00^{a}$	$5.19{\pm}0.12^{c}$	$1.05{\pm}0.09^{ab}$
S2	November	$6.91{\pm}0.10^{b}$	$5.41{\pm}0.02^{b}$	$0.09{\pm}0.01^{a}$	$4.17{\pm}0.54^{b}$	$3.37{\pm}0.00^{a}$	$0.83{\pm}0.07^{b}$
	January	$6.99{\pm}0.00^{b}$	$5.20{\pm}0.02^{a}$	$0.12{\pm}0.01^{b}$	$1.42{\pm}0.16^{a}$	$3.42{\pm}0.15^{a}$	$0.48{\pm}0.01^{a}$
	April	$6.96{\pm}0.06^{b}$	$6.14{\pm}0.04^{c}$	$0.28{\pm}0.01^{d}$	$1.53{\pm}0.54^{a}$	$4.31{\pm}0.07^{b}$	$1.00{\pm}0.12^{bc}$
	July	$6.66{\pm}0.08^{a}$	$6.31{\pm}0.02^{d}$	$0.25{\pm}0.01^{c}$	$4.45{\pm}0.22^{b}$	$4.91{\pm}0.09^{c}$	$1.14{\pm}0.05^{c}$
S3	November	$7.36{\pm}0.03^{b}$	$6.23{\pm}0.04^{b}$	$0.16{\pm}0.01^{b}$	$2.99{\pm}0.11^{b}$	$7.48{\pm}0.08^{b}$	$1.21{\pm}0.03^{b}$
	January	$7.29{\pm}0.62^{b}$	$6.12{\pm}0.02^{a}$	$0.15{\pm}0.01^{a}$	$1.53{\pm}0.54^{a}$	$5.68{\pm}0.26^{a}$	$0.80{\pm}0.14^{a}$
	April	$6.32{\pm}0.03^{a}$	$6.54{\pm}0.03^{c}$	$0.30{\pm}0.02^{c}$	$3.24{\pm}0.27^{b}$	$7.70{\pm}0.03^{b}$	$1.42{\pm}0.21^{b}$
	July	$7.16{\pm}0.03^{ab}$	$6.64{\pm}0.02^{d}$	$0.39{\pm}0.03^{d}$	$5.53{\pm}0.27^{c}$	$10.75{\pm}0.06^{c}$	$1.56{\pm}0.08^{b}$
S4	November	$6.55{\pm}0.13^{a}$	$5.54{\pm}0.04^{b}$	$0.11{\pm}0.00^{a}$	$5.75{\pm}0.54^{c}$	$5.60{\pm}0.12^{a}$	$1.08{\pm}0.21^{a}$
	January	$6.37{\pm}0.01^{a}$	$5.69{\pm}0.01^{c}$	$0.14{\pm}0.00^{b}$	$5.19{\pm}0.22^{b}$	$5.39{\pm}0.23^{a}$	$1.18{\pm}0.22^{a}$
	April	$7.62{\pm}0.37^{b}$	$5.27{\pm}0.03^{a}$	$0.26{\pm}0.01^{c}$	$2.80{\pm}0.38^{a}$	$5.30{\pm}0.28^{a}$	$0.86{\pm}0.03^{a}$
	July	$7.52{\pm}0.03^{b}$	$6.61{\pm}0.02^{d}$	$0.28{\pm}0.00^{d}$	$2.68{\pm}0.54^{a}$	$6.82{\pm}0.10^{b}$	$1.08{\pm}0.07^{a}$

Means with the same letters are not significantly different at $P < 0.05$ according to Duncan Range Test in different periods for one site.
T = Control; S1 = Camp Prison; S2 = Norvegien; S3 = Douze Poteaux; S4 = Sabongari Gare.

limits of heavy metal concentrations for use of biosolids in agriculture which are: Cu (463 mg/kg), Zn (725 mg/kg), Ni (29 mg/kg), Pb (106 mg/kg), and Cd (7 mg/kg) (Walker, 2001). Repeated use of biosolids or composts has been reported to contaminate the soils (Chander and Brookes, 1993).

The levels of all heavy metal differed significantly among the periurban sites. The variation of the level of heavy metal could be due to the composition of solid waste. The municipal solid wastes showed large amounts of plastics, paper, accumulators and batteries. It's known that batteries can be a source of Cd, Ni, Pb and Zn; dust, dirt and clay particles in paper can be a source of Ca; magazine paper is a notable source of Fe, Pb and Zn; other papers can be a source of Cu and Mg (Lisk, 1988).

Physico-chemical composition and heavy metal contents of cultivated soils

Physico-chemical composition of cultivated soils: The physico-chemical parameters of cultivated soils determined in the present study are shown in Table 3. The soil pH differed significantly among the periurban sites and from one period to another. There were also interactions between the effects of site and period ($P < 0.05$). The soil pH of amended sites was significantly greater than the pH of the control site with no waste. This may be because of high pH and neutralising potential (due to high contents of Ca and Mg) of municipal solid wastes used as fertilizers. The highest levels of pH were Registered in November and July. This could be attributed to the amendment practice in November and the effect of run off which is responsible for waste deposit in the Soumsoum valleys in July. pH is one of the factors which influence the bioavailability and the transport of heavy metal in the soil and according to Smith (1996) heavy metal mobility decreases with increasing soil pH due to precipitation of hydroxides, carbonates or formation of insoluble organic complexes. The soil electrical conductivity (EC) also differed among the periurban sites and from one period to another. There were also interactions between the effects of site and period ($P < 0.05$) for EC.

The soil electrical conductivity was greater at the amended sites than at the control site. The EC increased from November to April, but decreased in July. The decomposition of organic materials in municipal solid wastes could be accelerated by agricultural activities from November to April releasing ions in soil.

The organic carbon (OC) contents of soil differed significantly among sites and periods. There were also interactions between the effects of site and period. The soil OC of the control site was high compared to amended sites. This could be attributed to the soil origin. For periods, the lowest OC content was found in April. This could be attributed to the decomposition of organic matter due to the agricultural activities. Moreover, the high temperature in April must have favoured the activeties of microorganisms on soil organic matter. In fact, the precipitation, the temperature and the relative humidity recorded in Ngaoundere were respectively 0 mm, 20.53°C and 44.59% in January, and 117.58 mm, 24.64°C and 69.3% in April (meteorological data from the Ngaoundere airport). Thus, the meteorological conditions in April compared to January were favourable to the activities of microorganisms involved in the decomposition of organic matter. The Organic matter plays an important role in soil structure, water retention, cation exchange and in the formation of complexes (Alloway and Ayres, 1997).

The concentrations of exchangeable Ca and Mg in soils differed significantly among sites and periods and there were also interactions between the effects of site and period. The Ca and Mg contents of the amended sites were significantly higher compared to the control site with no waste. This may be connected to the heterogeneous nature of wastes received by different periurban sites, which is expected to impact differently on soil properties (Oyedele et al., 2008).

Heavy metal contents of the soils

Heavy metal total contents: The distribution of heavy metals in the cultivated soils is shown in Table 4. The sequence of heavy metal total concentrations in soils was Zn > Pb > Cu > Ni > Cu. The heavy metal total concentrations of the cultivated soils were significantly higher on the periurban sites amended with untreated solid wastes compared to the control site with no waste. According to the table 4, the range of Cd, Cu, Ni, Pb and Zn total concentrations in the cultivated soil samples from the study sites were 0.28 - 3.3.97, 39.00 - 137.25, 31.03 - 47.11, 30.00 - 307.2 and 59.2 - 484.6 mg/kg, respecttively. According to the EU guide values (European Union, 2000) of heavy metal in soil used for agriculture purposes, the soil control was not polluted, however, the cultivated soils amended with untreated urban wastes can be considered as combined Cd-Cu-Zn-Pb polluted. However, no soil could be classified as Ni-polluted because Ni total concentrations at all sites were below the critical levels. Total heavy metal concentrations obtained in this study were higher than those of Anikwe and Nwobodo (2002) and of Oyedele et al. (2008) recorded at dump sites in Nigeria. Moreover, the heavy metal concentrations of municipal solid waste amended sites were above the average concentrations of Cu, Zn, Ni, Pb, and Cd in worldwide soils which are 20, 10 – 300, 40, 10 – 150, 0.06 mg/kg, respectively (He et al., 2005). However, some of our results were lower than those of Oluyemi et al. (2008) reported at a landfill in Nigeria. The amount of heavy metals mobilized in soil environment is a function of pH, properties of metals, redox conditions, soil chemistry, organic matter content, clay content, cation exchange capacity, and other soil properties (Arun and Mukherjee, 1998; Kimberly and William, 1999; Sauve et al., 2000). Heavy metals are generally more mobile at pH < 7 than at pH > 7. The pH of the soils from the municipal solid waste amended sites ranged from 5.71 to 7.62. This is therefore hazardous for agricultural purposes since crops are known to take up and accumulate heavy metal from contaminated soils in their edible portions (Wei et al., 2005).

Heavy metal available concentrations: The sequence of heavy metal available concentrations in soil at the periurban sites was Zn > Pb > Cu > Ni > Cd. This is in good agreement with total concentrations. It's known that the bioavailability of metals in soil depend on pH, organic matter and total metal content (Sauve et al., 2000). The available concentrations of all metals in soil differed significantly among sites and periods, except Cd for which no significant difference ($P > 0.05$) was found among periods. The mean pH of the soils at the four periods ranged from 6.47 to 6.75. It seems that the lower and the slight variation of the soil pH have favoured the bioavailability of Cd at all periods of sampling. These findings are in agreement with Bingham et al. (1980), Mahler et al. (1980), Hooda and Alloway (1994), and Ramachandran and D'Souza (1998) who reported that Cd and Zn availability and uptake was higher from low pH than higher pH soils. Although, Cd concentrations of the soils did not differed significantly among periods, there were interactions between the effects of site and period for all metals. The available concentrations of heavy metals were significantly higher in amended soils than in the control. This is in agreement with the total concentrations of heavy metals in soils.

The levels of Fe ranged from 391.98 to 907.41 mg/kg in November; 509.26 to 1299.38 in January; 191.36 to 873.36 in April; and 154.17 to 1018.52 in July (Figure 2). The levels of Cu ranged from 3.30 to 33.52 mg/kg in November; 3.01 to 15.83 in January; 3.63 to 23.63 in April; and 2.90 to 27.46 in July. The levels of Ni ranged from 2.09 to 8.59 mg/kg in November; 2.09 to 8.68 in January; 1.57 to 21.78 in April; and 2.09 to 22.09 in July. The levels of Zn ranged from 9.98 to 276.60 mg/kg in November; 10.09 to 141.65 in January; 11.81 to 161.36

Table 4. Total concentrations (mg/kg) of heavy metals in the soils from periurban sites.

Site	pH_{eau}	Cu	Ni	Zn	Cd	Pb
T	6.23	39.00±0.8^{a}	31.03±1.5^{a}	59.2±4.7^{a}	0.28±0.01^{a}	30.0±1.3^{a}
S1	6.58	99.80±7.7^{c}	37.42±2.2^{ab}	380.8±5.3^{d}	3.50±0.49^{bc}	307.2±16.3^{d}
S2	6.91	50.19±4.3^{a}	43.94±1.7^{b}	200.1±4.6^{b}	2.92±0.18^{b}	99.38±6.1^{b}
S3	7.36	137.25±7.6^{d}	40.85±4.0^{b}	245.4±18.8^{c}	3.85±0.11^{c}	120.7±7.9^{b}
S4	6.55	81.49±2.3^{b}	47.11±3.5^{c}	484.6±11.1^{e}	3.97±0.03^{c}	190.9±7.4^{c}
	5 < pH < 6	20	15	60	0.5	70
UE*	6 < pH < 7	50	50	150	1	70
	pH > 7	100	70	200	1.5	100

Means with the same letters are not significantly different at P<0.05 according to Duncan Range Test.
T = Control; S1 = Camp prison; S2 = Norvegien; S3 = Douze poteaux; S4 = Sabongari gare.
*Maximum permissible levels according to the EU Directive (European Union, 2000).

Table 5. The bioavailabilty factor of heavy metals in cultivated soils.

Sites	Metal bioavailable concentration / Metal total concentration				
	Cu	Ni	Zn	Cd	Pb
T	0.08	0.07	0.14	0.13	0.10
S1	0.09	0.16	0.46	0.30	0.10
S2	0.15	0.06	0.43	0.32	0.22
S3	0.23	0.18	0.66	0.29	0.35
S4	0.41	0.14	0.54	0.43	0.31

T = Control; S1 = Camp Prison; S2 = Norvegien; S3 = Douze Poteaux; S4 = Sabongari Gare.

in April; and 10.05 to 170.83 in July. The levels of Cd ranged from 0.04 to 1.69 mg/kg in November; 0.01 to 1.18 mg/kg in January; 0.03 to 1.57 in April; and 0.09 to 1.48 in July. The levels of Pb ranged from 3.11 to 58.33 mg/kg in November; 5.22 to 58.33 in January; 3.11 to 42.22 in April and 3.11 to 42.22 in July. The highest level of Zn was recorded in November; Fe and Pb in January; and Cu and Ni in July. This could be attributed to the affinity of metals for the soil organic matter content, the soil pH and the selective absorption of the metals by plants.

Bioavailability factor of heavy metals: The bioavailability factor was expressed as the ratio of the available concentration of a metal in soil to its total concentration. It shows the potentials of a particular metal from the soil matrix to enter the soil solution from which it can be absorbed by plants.

The Bioavailibility factor (BF) varied significantly among the periurban sites and the species of the heavy metals. Many soil factors such as pH, organic matter content, amounts and forms of oxides and carbonates, charge characteristics, as well as mineral composition influence the bioavailability, and transport of trace elements in the soil and within the agroecosystem (Fageria et al., 2002). Then the variation of the BF among sites could be attributed to the soils factors which varied among sites. This can be illustrated by the significant variation of the physico-chemical characteristics of agricultural soils analysed in this study. The least BF values were generally recorded on the control soil despite the lowest pH recorded at the same soil (table 5). This could be linked to the high organic carbon content recorded in this soil which can lead to the formation of insoluble complex compounds limiting the bioavailability of heavy metals. These findings are in agreement with Sauve et al. (2000) who reported that heavy metals are capable of forming insoluble complex compounds with soil organic matter. The general order of affinity for metal cations complexed by organic matter follows: Cu^{2+} > Cd^{2+} > Fe^{2+} > Pb^{2+} > Ni^{2+} > Co^{2+} > Mn^{2+} > Zn^{2+} (Adriano, 2001). The results showed highest BF of Zn (0.66), Pb (0.35) and Ni (0.18) at S3; Cd (0.43) and Cu (0.41) at S4. The sequence of BF was: Zn > Cd > Cu > Pb > Ni. Trace elements in soils can be divided into water soluble, exchangeable, oxide-bound, carbonate-bound, organic matter-bound, and residual that is occluded in the resistant minerals and non-extractable (Shuman, 1991).

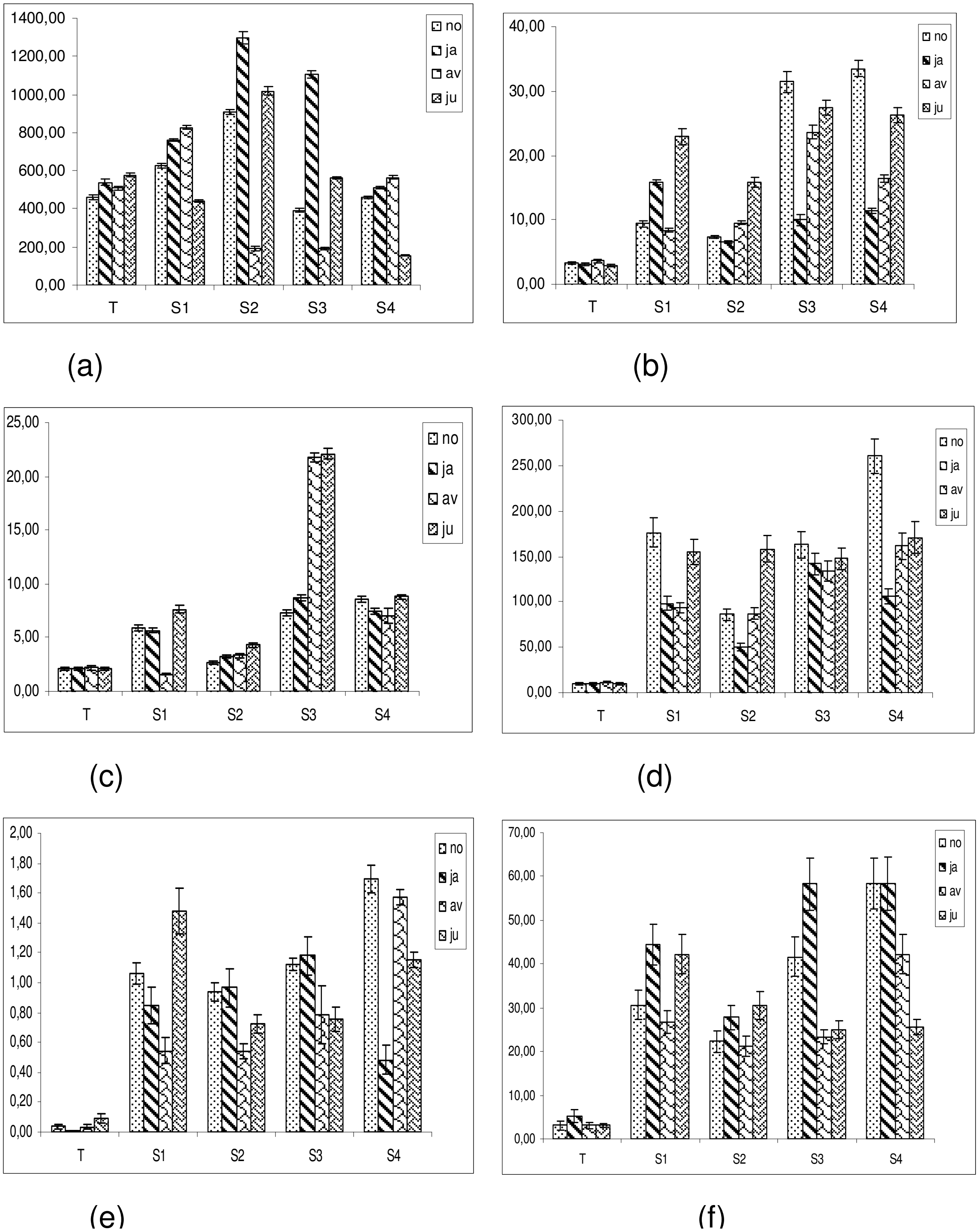

Figure 2. Available concentrations (mg/kg) of Fe (a). Cu (b). Ni (c). Zn (d). Cd (e). Pb (f) in cultivated soils (no = november; ja = january; av = april; ju = july; T = Control; S1 = Camp Prison; S2 = Norvegien; S3 = Douze Poteaux; S4 = Sabongari Gare)

Water soluble and exchangeable fractions are considered to be bioavailable, oxide-, carbonate-, and organic matter-bound fractions may be potentially bioavailable, but the residual fraction is mainly not available to either plants or microorganisms (He at al., 2005). Thus, for the control soil, the residual fraction seems to contain more heavy metals than the bioavailable fraction. Besides, the high BF for Zn at S3 and S4 suggests that the bioavailable fraction contains more Zn than the residual fraction at these sites.

Conclusion

The results of this study showed that municipal solid wastes used as fertilizer offers important benefits as a liming material because of its high pH and high organic carbon, Ca and Mg contents. However, it is clear that there is a potential problem of heavy metal contamination because of the excessive concentrations of Cu, Zn, Cd and Pb recorded in the municipal solid wastes used in periurban agriculture in Ngaoundere. The results revealed that the amended sites were polluted with Cu, Zn, Cd and Pb. This is therefore hazardous for agricultural purposes since the bioavailability of heavy metals depends also on their total concentrations in soil. The highest available concentration of Zn was found in November, Fe and Pb in January and Cu and Ni in July. The use of Douze poteaux site and Sabongari gare site is particularly hazardous due to the high BF value recorded for Zn, Pb, Ni, Cu and Cd especially that these metals may be easily taken up by crops from the soil matrix.

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