Negative externalities of intensive use of organic wastes on two tropical soils in the context of urban agriculture in the region of Dakar

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Abstract
The use of organic wastes (OW) as fertilizer has negative effects on the agroecosystem due to their trace elements (TE) content. This research aimed to assess the risk of agroecosystem contamination by TE (Cd, Cr, Cu, Ni, Pb and Zn) in the context of OW recycling in market gardening on arenosol (loamy sand) and fluvisol (clay loam) from Dakar (Senegal). The inventory (conducted with 40 market-gardeners) and soil profiles analyses revealed a significant contamination in all TE on the surface layer (0-20 cm) of arenosol, where the sewage sludge (SS) is used intensively. On the fluvisol, poultry dung (PD) spreading induced only Zn contamination (an increase of the order of 22%) in the superficial layer (0-40 cm) as compared to control of the site investigated. Indeed, SS contained higher concentrations of Zn, Cu, Pb and Cr (respectively 1003, 323, 50 and 41.2 mg.kg^{-1} of dry matter) than PD (respectively 320, 22, 2.0 and 21 mg.kg^{-1} of dry matter).

Introduction
In 2025, half of the population of sub-Saharan Africa will live in cities. This urbanization increases food requirements and generates organic wastes (OW) from various origins: household waste, sewage sludge, poultry dung, slaughterhouse waste, etc. For sustainable development, agricultural recycling is a recognized alternative of these OW managements. The advantages of using OW as fertilizer and soil amendment should be assessed together with potential environmental and toxicological impacts due to the presence of pollutants such as TE (Cd, Cr, Cu, Ni, Pb, and Zn) [1, 2]. One study demonstrated that TE concentrations in OW are correlated with the size of cities or farms where the wastes are produced, and are differentiated with respect from TE origins (geogenic: Cr–Ni; anthropogenic agricultural and urban: Cu–Zn; anthropogenic urban: Cd–Pb) [3]. In the region of Dakar, where two market gardening basins (Pikine and Rufisque) coexist, our objective consists to identify and characterize the risks of suburban agrosystems pollution by TE, to develop alternative management to minimize negative impacts.

Material and Methods
Study area
This study was carried out in the urban area of Dakar, Senegal. The climate is sahelian type, with a long dry season (November to June) and a short rainy season (July to October) with an average annual rainfall of 500 mm. Irrigated urban agriculture is practiced in market gardening basins of Pikine and Rufisque, located on arenosol (on dune material) and fluvisol (on calcareous), respectively [4].

Methodological approach
To characterize the cultural practices and assess the risk of suburban agroecosystems contamination by TE, two complementary approaches were used. First, an inventory was conducted using a questionnaire with 40 market-gardeners, to identify farming systems and history of plots (e.g. types and frequency of OW use, year of plots cultivation series, etc.). The second approach consisted to identify 3 sites (2 on arenosol and 1 on fluvisol) for sampling soils prior to analysis. For each site, two plots (cultivated and uncultivated: control) were sampled at five depths (0-20, 20-40, 40-60, 60-80, and 80-100 cm). These samples were air-dried and sieved to 2 mm. Total TE (Zn, Cu, Pb, Ni, Cr, and

Cd) were determined by using ICP-AES (Inductively coupled plasma atomic emission spectroscopy). The stabilized sludge from Pikine sewage (lagoon type, established since 1973) and poultry dung from battery farming at Rufisque were sampled, dried at 40 °C, ground and sieved to 1 mm before analysis. Total carbon and nitrogen were determined by dry combustion according to the Dumas principle with Thermoquest. Major elements (P, Ca, Mg, and K) and TE were analyzed by using ICP-MS (Inductively Coupled Plasma-Mass Spectrometer). All measurements were repeated three times, with standard deviations between measurements below 5%.

Results

Market gardening systems and diagnosis of risks of soils contamination by TE

Almost all surveyed farms are subject to intensive use of OW, at least 20 years, in both market gardening basins. At Pikine, farms are individual type and usually cover small areas (< 0.50 ha). There is a dominant production of lettuce among the crops (eggplant, pepper, tomato, onion, and beet). Before 2008 (the year of rehabilitation of the wastewater treatment station), 90% of surveyed market-gardeners fertilized with a varied combination of OW (PD, manure from horses, sheep and cattle), mineral fertilizers (NPK and urea) and used raw wastewater for irrigation. Since 2008, there is a massive use of SS for soil amendment. In the literature, it has been demonstrated that urban wastewater are rich in nutrients and in TE. These TE come mainly from corrosion and leaching of plumbing, fungicides (cuprous chloride), pigments, larvicides (copper acetoarsenite), water-proofing products, deodorants and cosmetics (zinc chloride and oxide), antiseptics, paints, pigments (as oxides, carbonates) and printing inks [5]. Moreover, we note visible symptoms of phytotoxicity such as growth inhibition and chlorosis in some crops (lettuce and scarlet eggplant) on arenosol. According to [6], soil type, previous cropping practices and TE contents of OW spread on soil, determine the level of contamination of the agroecosystem and the plant. Symptoms of iron chlorosis noted could be due to some plot ecotoxicity. Indeed, [7] prove that the Cu phytotoxicity causes an antagonistic effect on the iron (Fe) nutrition of plants. At Rufisque, farms are family type and cover an area ranging from 0.5 to 5 ha. Crops grown are mainly cabbage, carrot, lettuce, pepper and tomato and are irrigated by pure water of consumption. To fertilize, market-gardeners are also using a diversified combination of OW such as PD, manure from horses, sheep, cattle and slaughterhouses and mineral fertilizers (NPK, urea, and rock phosphate). In all forms of combination, 70 % of market-gardeners use PD which could present potential risks of soil contamination by TE.

Characterization of dominant OW use in the both market gardening basins

The elemental analysis of OW are presented Table 1.

Table 1: Characteristics of dominant OW

OW	Ash (%)	Major elements (% of dry matter)						Trace elements ($mg.kg^{-1}$ of dry matter)					
		N	C	P	K	Ca	Mg	Cu	Zn	Ni	Cr	Pb	Cd
SS	34	5.00	35.4	1.68	0.57	4.75	0.4	323	1003	15	41	50	2.6
PD	49	2.44	26.7	1.73	2.06	7.96	0.7	22	320	7	21	2	1.4

The major and trace elements concentrations of the two OW are different. The SS contains a lower content of ash (34 %) and was richer in carbon (35.4 %) and nitrogen (5 %) than PD (49, 26.7 and 2.44 %, respectively). For PD, the C and N contents are close to the average values obtained in the chicken litter generated from different production systems [8]. Concentrations of major elements (K, Ca, and Mg) in PD are higher than those observed in the SS. While, SS is richer in TE than PD, Zn, Cu and Pb contents in SS (respectively 1003, 323, and 50 $mg.kg^{-1}$) are similar to those obtained in stabilized sludge sewage [3]. PD is characterized by low concentrations of Cu and Pb (<50 $mg.kg^{-1}$) and high concentration of Zn (320 $mg.kg^{-1}$). Zn contamination of PD comes from food additives (Zn is a factor promoting metabolism, bone growth and the immune system of chickens), and 95-99 % of this trace element (which is generally in excess of the needs of the animal) is excreted in the dung [9]. It appears that these OW can be potential sources of organic matter and macronutrients (N, P, K, Ca, and

Mg) for plants. However, the TE contents of SS could reduce its agronomic value by inducing potential risks of agroecosystem contamination.

Chemical properties of soils: variations of trace elements in the soil profiles

Figures 1 and 2 present the evolution of TE concentrations as a function of depth sampling on cultivated (CP) and uncultivated plots (UcP) from both soils. Sites 1 and 2 on arenosol are cultivated since 1973 (40 years) and 1985 (28 years). These sites (Fig.1) show same trends in terms of TE concentrations.

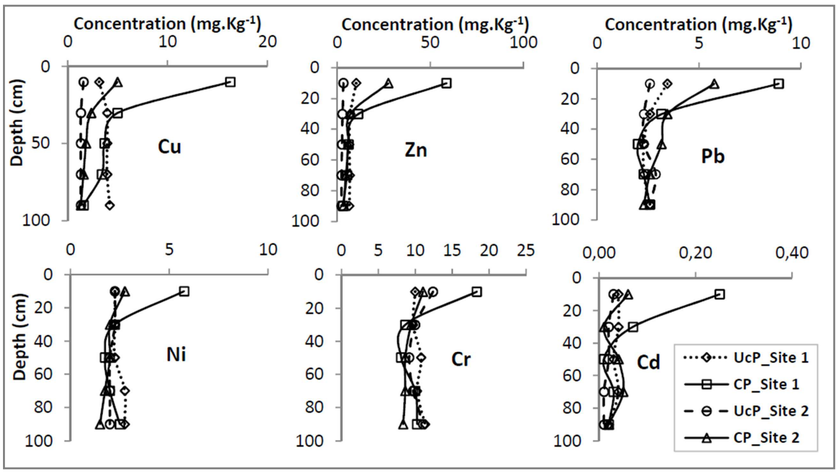

Figure 1: TE concentrations as a function of depth at sites 1 and 2 on Pikine arenosol.

TE concentrations were constant in the uncultivated soils profiles. Sewage sludge amendment and wastewater for irrigation on CP increased significantly Zn, Cu, and Pb concentrations of surface layer (0-20 cm) at both sites as compared to controls. Ni, Cr, and Cd contaminations in the surface layer of CP on the site 1 were significantly higher than the site 2. This result could be explained by the different durations of sites cultivation on the one hand, and by the slight levels of these TE in SS, on the other hand. At 20 –100 cm depth, the organic amendment did not have a significant effect on TE contents in the soil. Similar results were obtained by [10].

The site 3 on fluvisol (Fig.2), have been cultivated from 1988 (25 years).

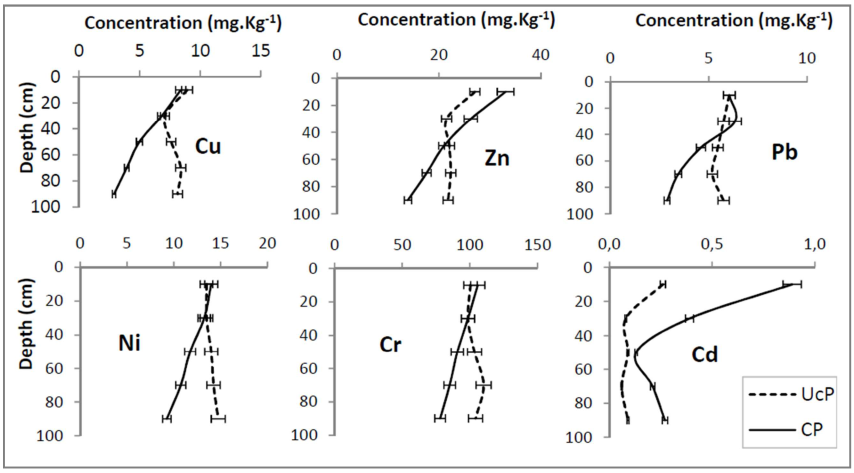

Figure 2: TE concentrations as a function of depth at site 3 on fluvisol at Rufisque.

The TE concentrations vary slightly within profile of UcP (control). The concentrations of Cu, Pb, Ni, and Cr obtained in the surface layer (0 - 40 cm) of CP are not significantly different from the control. This indicates an absence of the contamination from these elements. The Zn concentration increased in the order of 22 % in surface layer (0 – 40 cm) of CP compared to control. Zn contamination on surface layer of CP could be explained by the spreading of PD, which were rich in Zn (320 mg.kg^{-1}). For Cd concentration, there is a significant contamination of the whole profile of CP. This concentration decreases from 0.89 to 0.13 $mg.kg^{-1}$ in the superficial layer (0 - 50 cm). This contamination would come from the rock phosphate, which is also used as fertilizer on the site (200 $kg.ha^{-1}$ every two years). Indeed, increased Cd content in soils related to the use of phosphate fertilizers has been clearly demonstrated by [11]. In the deep horizons (40 - 100 cm), all concentrations in TE except Cd of CP are decreasing and lower than those obtained to control. This decrease could be explained by dissolution due to the variation of the shallow groundwater (at 80 cm), which induces redox processes in the middle layer (40 - 80 cm) from CP, and in the most deep layer (80 - 100 cm) from UcP. Indeed, the CP and the UcP situated respectively in the bottom and the upper part of the site. It has been reported in the literature that the topography is the ultimate key factor that controls the fluctuating groundwater levels, which leads to changing redox conditions in soils and provoking dissolution of iron and manganese oxyhydroxides, releasing heavy metal bound to them [12].

Conclusion and perspectives

Environmental and toxicological impacts resulting from intensive use of OW depend of (i) cultural practices and (ii) soil type. The comparison of profiles contents in cultivated plots with uncultivated plots revealed that only the surface horizons have been affected by TE contamination on arenosol. To evaluate the potential phytotoxicity of OW used in tropical suburban agroecosystem, we intend to test the environmental availability of TE by Diffusive Grandient in Thin films technique, and their phytoavailability with a biotest (RHIZOtest) [13].

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