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Evaluation of the content of metallic trace elements (MTE) in soils under market gardening in the town of Korhogo (Côte d´Ivoire)

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Abstract

The objective of this study is to assess contamination by MTE in soils under market gardening in the city of Korhogo. Three sites were chosen to conduct the study. After a soil sample, elements such as pH, C, N, clay and some MTE (Fe, Mn, Cr, Zn and Cu) were determined. The results show that the pH at the three sites is acidic (pH <6). Average CEC values and organic matter contents are low. Analysis of the soil profiles has shown that leaching, major processes that govern the distribution of chemical elements in the soil, are of low intensity. Also the affinity of MTE for clays is marked by the presence of both horizons of deep accumulations. The Mn contents are in the zone of the critical contents for the grounds, being able to involve phenomena of toxicity. However, the vertical dynamics of MTE are, on the one hand, influenced by the clay content, and on the other hand, by the organic matter content.

Key words: soils, market gardening, Trace metals, Toxicity, Leaching.

Introduction

In African countries, 40% of city dwellers are engaged in some sort of agricultural activity (Maxwel, 2000) on the outskirts and within cities. This urban agriculture then plays an important role in the fight against urban food insecurity and the population poverty in the developing countries. The work of Davis *et al*. (2017) indicates that urban agriculture provides between 20% and 80% of household consumption in Africa.

Unfortunately, lack of space and land issues lead people to cultivate on roadsides, rights-of-way and other unsupervised public areas. This results in a risk of contamination of metallic pollutants (Ondo, 2011). The work of Kouakou (2009) and Guety *et al*. (2015) indicated a high level of contamination in metallic trace elements (MTE) in urban and peri-urban soils of large African cities. These contaminations would probably be due to wastewater discharges, uncontrolled fertilization of these soils and also irrigation water used (Bouchouata *et al*., 2012). The toxic effects of MTE depend mainly on the quantities accumulated and properties of soils (Zwolak *et al.,* 2019).

The town of Korhogo is one of the major cities in the country with a growing population and market gardening is booming. Also the soils of the northern part of Côte d'Ivoire are mostly acidic, which could favor the great assimilation of certain metals by cultivated plants (Nangah *et al*., 2013) and therefore their integration into the food chain. Integrating these elements into the food chain would be likely to cause serious dangers for populations.

The objective our work is to quantify the total contents of metals and to determine the potential risks in soil hazards in the city of Korhogo. More specifically, it is about:

- Determine the MTE contents in soils under market gardening;

- Establish the relationships between the physico-chemical characteristics and the MTE in the soils under market gardening.

Methods

Study area

The town of Korhogo is located at 9°59' of latitude North et 6° 49' of longitude West, in the northern part of Côte d'Ivoire, 635 km from Abidjan, the economic capital. The vegetation is marked by grassy and wooded savannahs characterized by trees and shrubs. The climate of the Korhogo area is of the Sudano-Guinean transition mode characterized by two major seasons: a rainy one which extends from May to October and a dry one, from November to April. The dry season is accompanied by the harmattan between December and February as well as heat peaks between March and April. The average annual rainfall is between 1100 and 1230 mm, with an average annual temperature of 25.8 ° C. The relief of the area is slightly wavy and dotted with inselbergs whose altitude varies between 400 and 450 m. Several types of soil derive from the numerous geological formations encountered in the area, namely: Ferralsols, Cambisols, Fluvisols and Luvisols (N'Guessan *et al*., 2019).

Sampling

The sites sampled in the town of Korhogo are shown in Figure 1. At each site, a soil profile was opened. Each horizon was then taken and subsequently coded by distinguishing 4 classes:

- H1 (0-20), grouping all the horizons between 0 and 20 cm deep, rich in organic matter, crossed by many roots;
- H2 (20-40), covering all the horizons between 20 and 40 cm deep, with a progressive depletion of organic matter, there are many small roots;
- H3 (40-60), corresponding to horizons between 40 and 60 cm deep;
- H4 (60-120), covering all horizons between 60 and 120 cm, this class characterizes deep soils.

A total of 14 samples were sent to the Laboratory for analysis.

Laboratory analysis

The particle size was determined by the densimetric method, using the Robinson pipette. The pH was measured by the electrometric method using a glass electrode in a soil / solution ratio of 1 / 2.5. Organic carbon was determined by the method of Walkley and Black (1934). The nitrogen was determined by the method of Bremner (1996). At pH 7, the cation exchange capacities (CEC) were determined by extraction with ammonium acetate (NH4Ac, pH 7).
The trace elements were determined using an Optical Emission Spectrophotometer, Coupled with Inductive Plasma (ICP-OES).

Statistical analysis

STATISTICA 7.0 software was used for data processing. The Kruskal-Walis nonparametric test, followed by a multiple pair comparison according to the Dunn procedure, was used for the structuring of the means of the different parameters. The Pearson correlation test was performed between MTE and soil parameters.

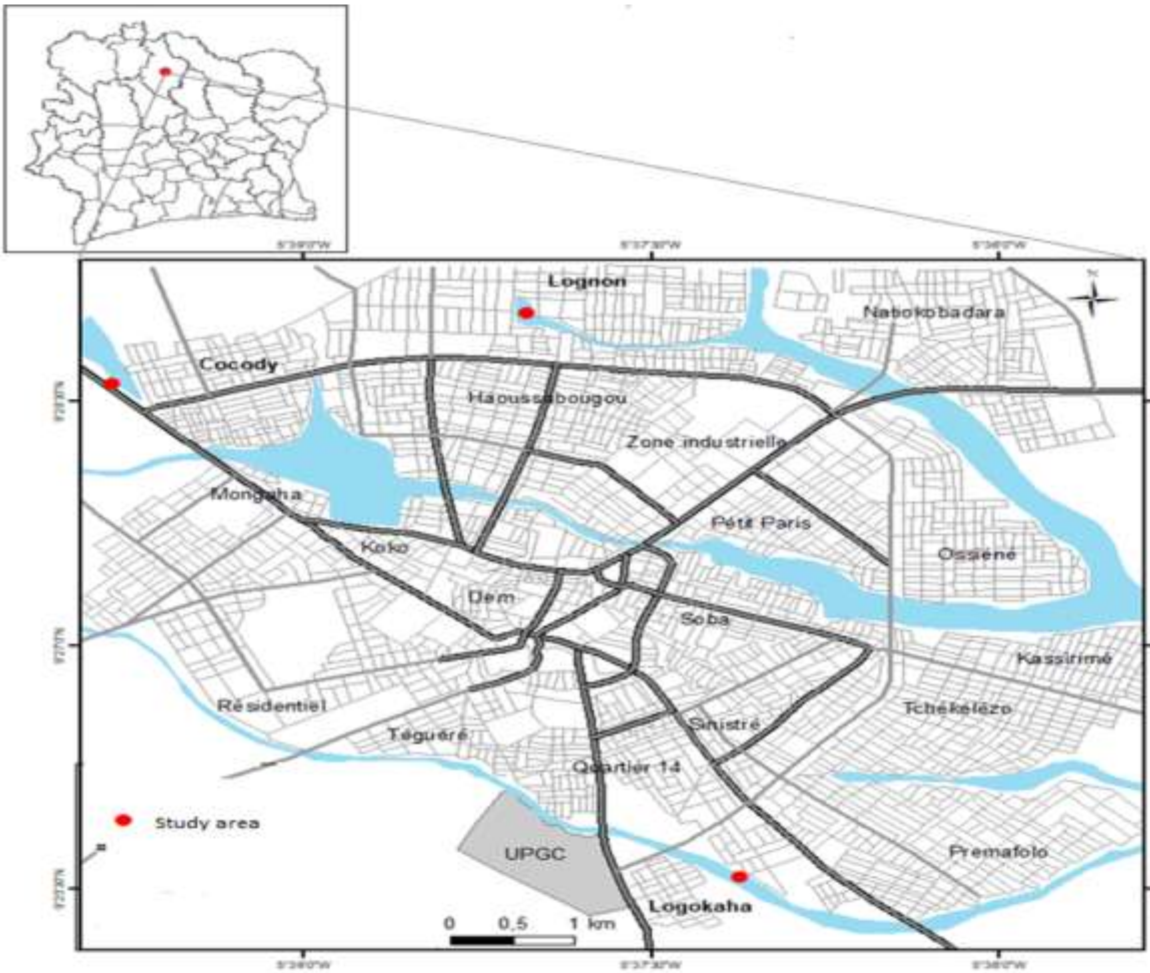

Figure 1: Location map of study sites in the city of Korhogo

Results and discussion

Physico-chemical characteristics of soils and evolution of MTE according to the study sites

The average values of the physico-chemical parameters of each site are presented in Table 1. The clay proportions are higher in Lognon (24.37%) compared to the other sites (Cocody and Logokaha, respectively 14.16% and 15.01%). No significant difference between the sites, regarding the clay contents, was revealed by the Kruskal-Walis test. Table 1 shows that the cation exchange capacity varies from one site to another. This is corroborated by the Kruskal-Walis test which highlights a highly significant difference between the CEC values of the three sites ($P < 0.01$). These values range from 3.73 cmol.kg-1 to 5.917 cmol.kg-1 with the highest recorded in Lognon. Measured pH values indicate that the soil pH at the three sites is acidic (pH <6). These values show a significant in the Kruskal-Walis test ($P < 0.02$). The organic matter contents of the analyzed soils are 0.80% to 1.38%. The highest rate is found in Lognon (1.38%), followed by Logokaha (0.84) and Cocody (0.80). None of the soils analyzed have values in the range of normal organic matter rates (1.5-2.5%) according to Thiagalingam (2000).

ETM content at site level

The total concentrations were measured for the MTE studied (Table 2), based on each site selected for the study. The Cocody site has the highest levels of Mn (2334.16 mg.kg^{-1}) and Fe (4580 mg.kg^{-1}). Next comes that of Logokaha (Mn = 1798 mg.kg^{-1}; Fe = 3257 mg.kg^{-1}) and Lognon (Mn = 1528, 25 mg.kg^{-1}; Fe = 2700 mg.kg^{-1}). No significant difference was found after comparison of values by site by the Kruskal-Walis test. The average Zn contents are increasing from Cocody to Logokaha and range from 29.3 mg.kg-1 to 56.9 mg.kg-1. Logokaha has the highest levels followed by Lognon (45.25 mg.kg^{-1}).

No significant difference was noted between the Zn contents on all the sites. Cu levels range from 12.66 mg.kg-1 to 27 mg.kg-1 at all three sites. The amount of Cu at Logokaha is the highest with a value of 27 mg.kg-1 while that of Cr for the same site is the lowest with 15.25 mg.kg-1. The Cr contents are however the highest in Cocody. The Kruskal-Walis test gives no significant result between the Cu and Cr values at the three sites.

Table 1: Physical and chemical characteristics of the soils studied according to the sites

Site	Clay (%)	CEC (cmol.kg^{-1})	pH	Organic matter (%)
Cocody	14,16 ± 4,18a	3,73 ± 1,11a	5,8 ± 0,16a	0,80 ± 0,41a
Lognon	24,37 ± 9,82a	5,91 ± 0,87b	5,1 ± 0,33b	1,38 ± 0,32a
Logokaha	15,01 ± 4,91a	3,9 ± 0,46ab	5,6 ± 0,22ab	0,84 ± 0,45a
P of Kruskal-Walis	0,16	0,01	0,02	0,16
Effect	NS	HS	S	NS

Table 2: Average MTE levels in the soils studied at the three sites

Site	Mn	Fe	Zn	Cu	Cr
Cocody	2334,16 ± 145,65a	4580 ± 244,61a	29,3 ± 3,03a	12,66 ± 0,56a	49,15 ± 2,41a
Lognon	1528,25 ± 193,87a	2700 ± 123,045a	45,25 ± 3,09a	7,25 ± 0,92a	35,7 ± 3,05a
Logokaha	1798,00 ± 110,55a	3257,5 ± 215,99a	56,9 ± 3,13a	27 ± 1,32a	15,25 ± 0,90a
P of Kruskal-Walis	0,6	0,33	0,38	0,11	0,06
Effect	NS	NS	NS	NS	NS

Characteristics of soils according to horizons

The average clay contents as a function of the depth of the horizons studied show a saw tooth evolution (Figure 2). The values are increasing from H1 to H2 then from H3 to H4. There is also a strong accumulation of clay in H4.

The average amount of CEC and the pH value recorded show an identical evolution at all points (Figure 3 and Figure 4). This trend is marked by a gradual decrease from H1 to H3. There is then an increase in values from H3 to H4 with a value in H4 that is slightly higher than the value observed in H1.

The evolution of the organic matter rate over all the horizons of the study sites is marked by a sharp decrease from H1 to H3 so that the value recorded in H3 is half that of H1 (Figure 5). Then there is a weak growth from H3 to H4 but this value is lower than that obtained in H2. However, none of the average levels observed are significantly different after application of the Kruskal-Walis test.

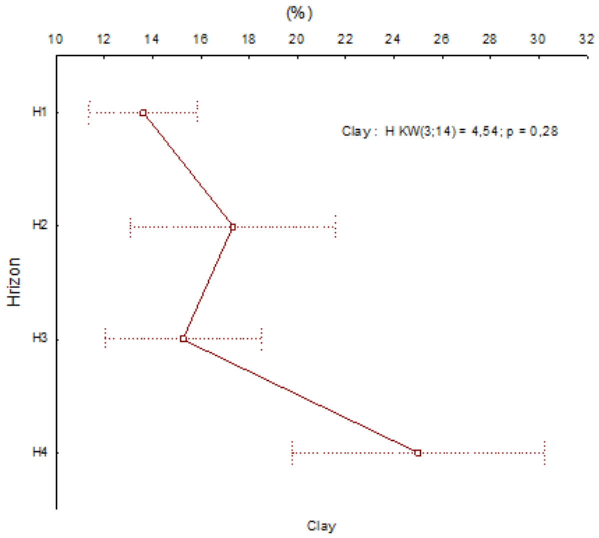

Figure 2: Average clay evolution over all three sites based on depth

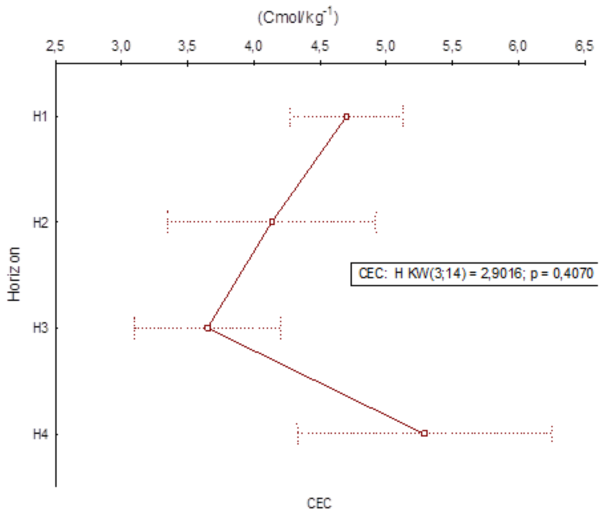

Figure 3: Average CEC evolution over all three sites based on depth

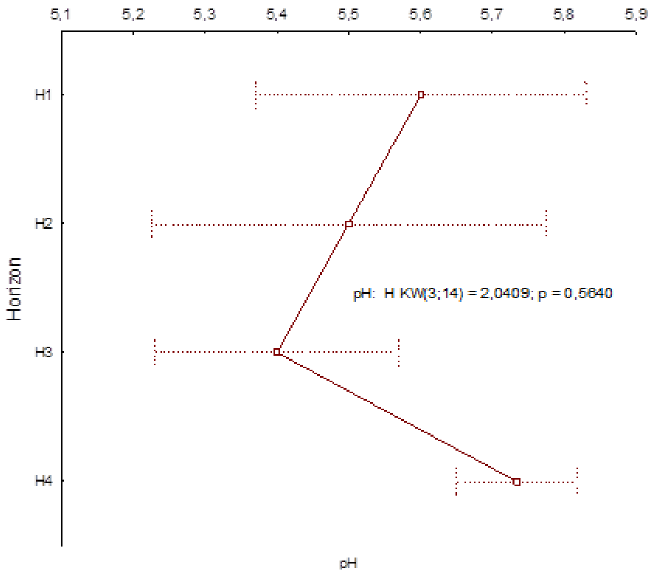

Figure 4: Average pH evolution over all three sites based on depth

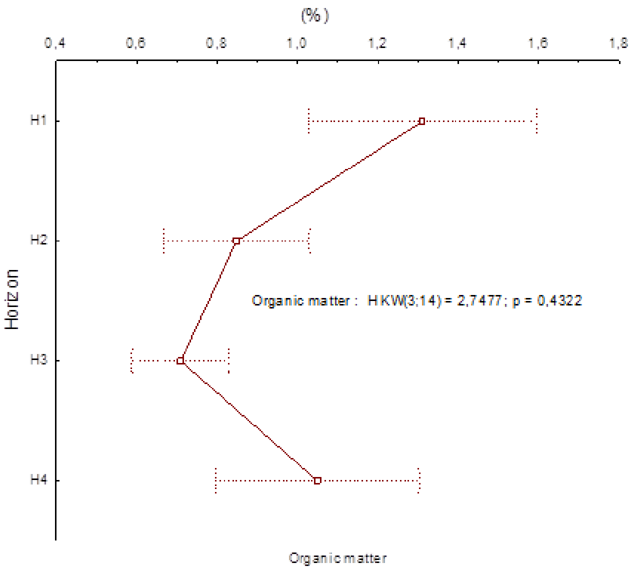

Figure 5: Average organic matter evolution over all three sites based on depth

Evolution of MTE according to horizons

The mean values of Mn show a sawtooth evolution from H1 to H3 (Figure 6). However, the variations are minimal as they are between 1400 and 1600 mg.kg-1. However, a strong accumulation of Mn in H4 is observed. All the recorded values are in the critical content level zone. Figure 6 highlights the Fe contents obtained over all the horizons of the sites. The contents are very high and decreasing from H1 to H3 then from H3 to H4. However, they grow between H2 and H3. Unlike Mn, it is this time the depth horizons which record the highest Fe contents with H3 as accumulation horizons.

The evolution of Zn and Cr is show in Figure 7. Zn has a high H1 and H2 content and a decrease from H2 to H4. H2 play the role of accumulation horizon. Also the quantities of Zn in H3 and H4 are substantially equal but both greater than those recorded in H1. The Cr changes in saw tooth from H1 to H3 but the growth from H1 to H2 and the decline from H2 to H3 are very small amplitude. However, values drop in H4. None of the levels measured in terms of horizons as a whole shows any significant difference.

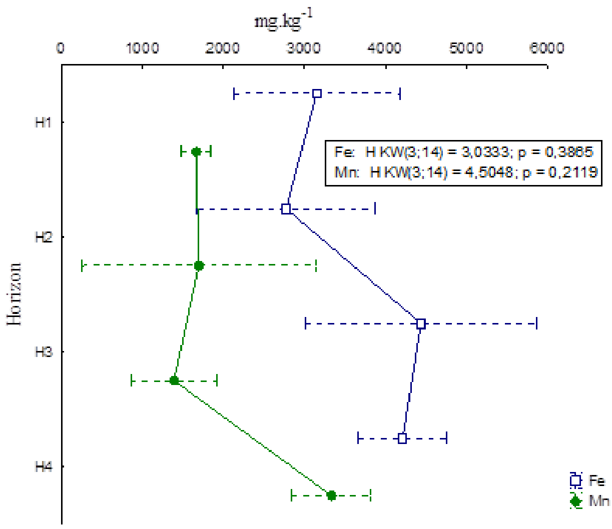

Figure 6: Average Fe and Mn evolution over all three sites based on depth

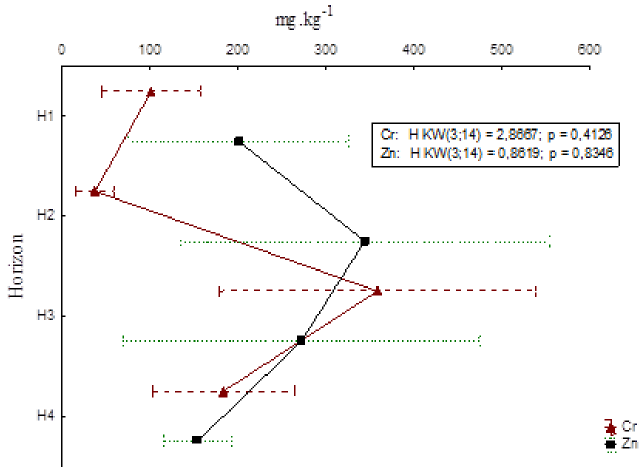

Figure 7: Average Cr and Zn evolution over all three sites based on depth

Correlation between MTE and soil parameters

The various correlations involving the physico-chemical parameters of the soils and the metal trace elements are presented in Table 3. It is observed that of all the MTE studied, only Fe and Cr have a highly significant affinity between them (0.818). The pH is significantly correlated with Al and Mn (respectively 0.638 and 0.572). The significant correlation revealed between O. M and Cu is negative, indicating that their evolution is inversely proportional (-0.639). The CEC, on the other hand, expresses a significant and positive correlation with O. M (0.824) and clay (0.724).

Discussion

The pH of the soils studied is generally between 5 and 6, which according to Deruelle (2014), is the recommended pH for market gardening. Lowering the pH to a very acidic gradient (5.5 <) promotes the increase exchangeable Al3 + which is very toxic to plants and soil organisms. The same toxic ionic release phenomenon is also observed for Mn, Fe and Zn, which also record lower contents when the pH is lower than 5.5 (Rengel, 2015).

The amount of organic matter observed on the sites is very low. The levels of O.M range from 0.8 to 1.4%. The intensive market gardening in the town of Korhogo does not allow any respite on the ground which is constantly sought during the year between the staggered crops of vegetable products and rice. Thus, the soils studied have lost the characterization of good market gardening soil because Deruelle (2014) situates the optimal rate of organic matter between 2 and 5%.

Table 3: Pearson correlation between physico-chemicals parameters and the MTEmeasured on all the sites.

	Cr	Cu	Zn	Fe	Mn	O.M	pH	CEC	Clay
Cr	1								
Cu	-0,121	1							
Zn	0,094	0,258	1						
Fe	0,818	-0,008	0,003	1					
Mn	-0,009	-0,069	-0,005	0,279	1				
O.M	-0,115	-0,639	-0,230	-0,036	-0,031	1			
pH	0,148	0,217	0,182	0,346	0,572	-0,383	1		
CEC	-0,180		-0,372	-0,169	-0,013	0,824	-0,425	1	
Clay	-0,170	-0,129	-0,362	-0,246	0,019	0,206	-0,265	0,724	1

The cation exchange capacity (CEC) of the soils studied is considered low according to Martin and Nolin (1991), and does not present any significant differences according to the sites. The CEC actually reflects the size of the soil reservoir of positively charged nutrients, which depends, mainly particularly, on its clay content, as well as on the nature of the organic matter (Masmoudi et al., 2011). The clay content is positively correlated with the organic matter content. Indeed, the presence in sufficient quantity of organic matter helps to stabilize clays, limit leaching and increase CEC (Singh *et al*., 2018).

Of the MTE contents, Fe, Zn, Cr and Cu appear to be typically found in most soils of the world. In contrast, the levels of Mn at the three sites are in the zone of critical levels for soils, which may lead to toxicity (Colinet, 2003). This author situates the critical contents in soils, for Mn, between 1000 and 3000 mg.kg -1. Statistical analysis has shown that Fe and Cr are significantly correlated, linearly, which could suggest that these MTE coexist as constituents of minerals in soils, consistent with the results obtained by Nangah *et al*. (2013) and Benahmed *et al.* (2016).

The MTE accumulation horizons were the clay-rich horizons. Indeed, the surface charge of the clay layers is composed on the one hand, of the permanent charges due to isomorphic substitutions in the sheets and on the other hand, variable charges having for origin the presence of hydroxyl groups at the edge of the clays on silanol (-SiOH) and aluminol (-AlOH) type sites. Standing charges give the whole sheet a negative charge and create exchange sites with cations in solution (Citeau, 2004).

The MTE concentrations of a soil undergoing leaching must increase with depth, at least until the accumulation horizon. The importance of leaching in the dynamics of MTE, as observed in the market garden soils studied, has been reported by several authors working on various types of soil (Arby *et al.,* 2010).

The highest concentrations in the surface horizons reflect the affinity of the MTE for the carbon present in the surface horizons (Schneider, 2016).

The surface horizons concentrate a large part of the contents of most of the MTE studied. This could be explained by the low intensity of the leaching phenomena that govern the vertical and horizontal dynamics of MTE. These phenomena are largely influenced by the rainfall which is low in the town of Korhogo. Indeed, the sheet of water crossing the soil profiles has the capacity to dissolve the most labile elements, and to drive them in depth (Sparks, 2003). Cr and Zn, which are elements liable to be toxic at certain levels, are essentially concentrated in the surface horizons and are bioavailable for cultivated plants.

Conclusion

The Mn contents determined at the three sites are in the zone of critical contents for soils, which can lead to toxicity. The intensive market gardening practiced on the impoverished sites by reducing the organic matter contents and the CEC. The major phenomena of the MTE distribution, leaching is weak, which has led to large concentrations of certain trace elements in the surface horizons. Also, the MTE accumulation horizons have been fairly rich in clay, the main constituents of which have large areas for fixing metal cations. The physico-chemical characteristics of vegetable soils such as organic matter, pH, CEC and clay content, when they reach certain values, greatly influence the retention and the dynamics of MTE in vegetable soils. Market gardening in Korhogo is increasingly degraded by pratices.

It would therefore be necessary to complete this evaluation of contamination in MTE from market gardening systems in Korhogo by specifying the speciation and the mobility of MTE, quantifying their enrichment rate in these soils and studying the availability and bioavailability of these MTE for cultivated plants.

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