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Effects of Soil Fertilization Using Compost of Solid Household Waste on the Heavy Metals Content of the Productions

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Authors' contributions

The present study was carried out in collaboration between all the authors. The author FGBZ designed the study, performed the statistical analyzes, analyzed and interpreted the results and wrote the first draft of the manuscript. Authors KBK and VK provided the technical support. Author AYK supervised the research. All authors read and approved the final manuscript.

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ABSTRACT

This study was conducted to evaluate the chemical quality and fertilizing value of naturally occurring compost in the City of Daloa landfills. The treatments consist of i) lettuce culture on unfertilized soil or control, ii) lettuce culture on soil supplied with 250 kg/ha of NPK mineral fertilizer of formula 12-22-22 and iii) lettuce culture on soil amended with 40 t/ha of compost, laid out in a Randomized Complete Block Design (RCBD) with three replicates. Results indicate that the

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compost used contained significant amounts of N (0.88±0.09 g/kg), P_2O_5 (0.173±0.021 g/kg) and K_2O (0.278±0.016 g/kg). This compost also contains, but in small amounts, toxic heavy metals such as copper (233.183±3.21 mg/kg), lead (113.775±2.55 mg/kg) and zinc (141.783±3.03 mg/kg). Regarding the crops, the analyzes revealed that lettuce grown in the presence of NPK and compost absorbed more heavy metals than those grown on the control soil. With NPK, heavy metal concentrations increased steadily in crops during all the crop cycles when, with compost, these concentrations remained almost stable between the first and second crop cycles before growing during the third cycle. It was concluded that fertilization, whether mineral or organic, can promote heavy metal accumulation in crops. Thus, the fertilization of agricultural soils should be conducted with great care.

Keywords: Organic fertilizer; mineral fertilizer; metal trace elements; lettuce; crops; Daloa.

1. INTRODUCTION

In sub-Saharan African countries, the supply of fresh produce to cities is mainly provided by urban and peri-urban agriculture actors [1,2]. These growers are increasingly using composts as alternatives to chemical fertilizers because of the high costs of these fertilizers. However, composts, in general, can lead to an accumulation of heavy metals in the soil and then in the plant. This risk is much higher with composts produced naturally in the open air in municipal dumps with garbage that has not been sorted [3,4]. Thus, the use of garbage compost makes it essential to determine its quality before it is used in agriculture [5]. This quality of compost is determined by several criteria, the main ones concerning its maturity, its impurities, its content of metallic trace elements, pathogenic micro-organisms, and organic pollutants. Some physical characteristics (granulometry) and chemical (pH, C/N ratio, the content of organic matter, etc.) are very often determined also to evaluate the quality of the composts. However, the maturity of the compost, which determines its degree of stability, remains the most important characteristic to be taken into account when testing compost quality [6]. This study is part of the dynamic to promote the use of composts. It aims, on the one hand, to determine the quality of compost produced naturally in the open air in public landfills and, on the other hand, the effect of this compost on the absorption of heavy metals by crops.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was conducted in Daloa located in the Haut-Sassandra region of Côte d'Ivoire (Fig. 1). The climatic regime of this region is that of the Guinean domain characterized by an equatorial and subequatorial regime with two maximum rainfall. The month of June represents the peak of the great rainy season and that of September, the peak of the short rainy season. These two maxima are separated by one or two months more or less rainy [7]. According to [8], the forest landscape of the study area varies progressively from moist semi-deciduous forest to mesophilic cleared forest. The relief of the zone is little contrasted and little varied, dominated by plateaus of 200 to 400 m of altitude [9]. The geological formations of the zone are those of Middle Precambrian mainly dominated by granites, to which are added some schist and flysch intrusions. Soils are generally ferralitic moderately leached or desaturated [10]. However, the soil of the experimental site in the Tazibouo district of Daloa is sandy soil [11].

Socio-economic activities are quite diversified in the study area. However, agriculture remains the primary income generating activity. Agricultural dynamics in rural areas is based mainly on perennial cash crops (coffee, cocoa, rubber, oil palm); in the cities, on the other hand, it is food crops, especially market gardening, which play a predominant role.

2.2 Planting Materials

For this study, three basic types of equipment were used: fertilizer material, plant material, and technical equipment.

The fertilizer material consists of a garbage compost naturally formed in the open air in a public dump in the city of Daloa. As regards plant material, it is lettuce of the species *Lactuca sativa*. It has been used as an indicator of the risks of heavy metal toxicity by accumulation in leaves intended for human consumption. Indeed,

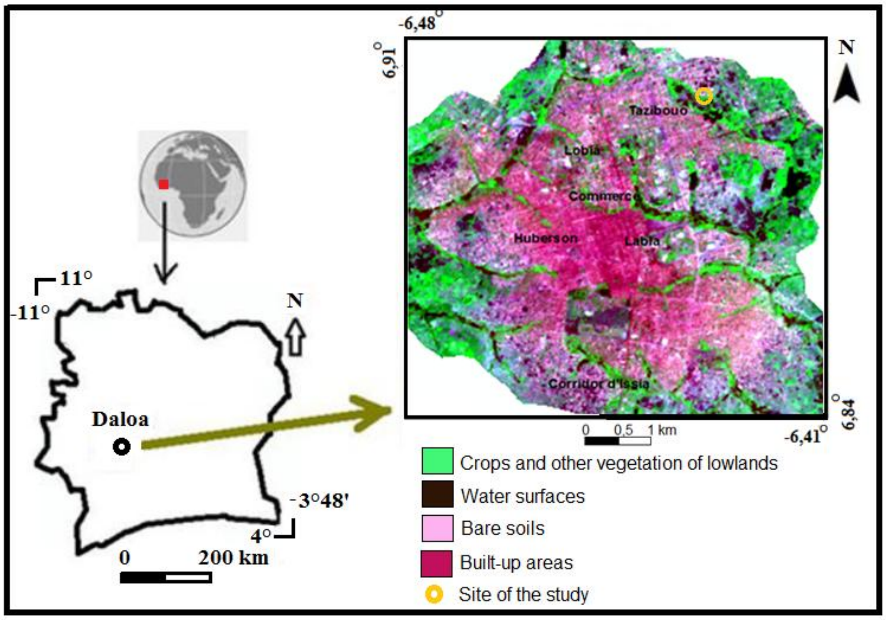

Fig. 1. Location map of the study area

several studies confirm the cumulative nature of lettuce for heavy metals compared to other vegetable species grown in market gardening [12,13,14]. Regarding the technical equipment used, it consists of several tools, including:

i) A Roberval scale, for the measurement of the quantities of fertilizers, brought to the soil;
ii) A tape measure for distance measurements on the plot;
iii) A machete, for the cleaning of the plot;
iv) A soil scientist's knife and plastic bags for the collection and preservation of soil and compost samples;
v) Statistica 7.0 Software (Statsoft, Tulsa, USA) for data analysis.

2.3 Field Experiment

The experimental configuration implemented was a Randomized Complete Block Design (RCBD) with three replicates [15]. This trial included three treatments: (i) control or culture of lettuce on unfertilized soil, (ii) growing lettuce on soil supplied with 250 kg/ha of NPK mineral fertilizer of formula 12-22-22 and (iii) growing lettuce on a soil amended with 40 t/ha of compost.

Each block was 16 m long and 4 m wide. The basic plot was an 8 m² board (4m x 2m). The plants were transplanted on five lines at the rate of 0.3 m between the lines and 0.3 m on the line, ie 6 plants per m^2 or 60,000 per hectare. An aisle of one meter in width was observed around each block and thus around the entire plot. The transplanting of the plants on the elementary plots was carried out after a nursery of these plants which lasted 15 days. Throughout their development cycle, the plants were watered daily, morning and evening.

2.4 Data Collection

The data collection was carried out in three phases: first, the initial conditions of the soil used were determined in the laboratory by carrying out on six samples of this soil the laboratory analyzes summarized in Table 1. For this purpose, soil sampling was carried out in the soil layer explored by the roots of lettuce plants set up (0-40 cm deep), at several locations in the plot (center, east, west, north, and south). These samples were air-dried on newsprint for one week, sieved and stored in plastic bags before being sent to the laboratory. Then, the fertilizing properties and the chemical quality of the compost used were also determined on six samples of this compost by the same laboratory tests carried out on the soil. Compost sampling consisted of taking several samples and randomly choosing the samples to be analyzed [19]. These samples were packaged in plastic bags and kept cool before being sent to the

Table 1. Synthesis of laboratory analyses performed on samples of compost and soil used

Properties	Variables	Methods
Acidity	pH (1 : 2.5: Soil : Water)	Glass Electrode pH Meter [16]
Organic matters	Carbon (C)	Walkley and Black Method [16]
	Total Nitrogen (N) C/N	Modified Kjeldahl Method [16]
Phosphorus	Assimilable phosphorus	Modified Olsen method [17]
Exchangeable bases	Calcium (Ca^{2+})	Spectrophotometry of Atomic Absorption Method [16]
	Magnesium (Mg^{2+})	
	Potassium (K^{+})	
	Sodium (Na^{+})	
Heavy metals	Copper (Cu^{2+}) Lead (Pb^{2+}) Zinc (Zn^{2+})	Mass spectrometry Method [18]

laboratory. Finally, the chemical quality of the lettuce produced was determined by measuring their levels of copper, lead, and zinc, which are toxic heavy metals. To do this, two lettuce plants were arbitrarily selected by treatment at the end of each crop cycle, for a total of 18 plants. The leaves of these plants were removed and dried in the open air for a week; preserved in newsprint, these sheets were transported to the laboratory where their copper, lead and zinc contents were determined by the mass spectrometry technique [18]. All these analyzes were carried out at the Plants and Soils Analysis Laboratory of the National Polytechnic Institute Félix Houphouët-Boigny.

2.5 Data Analysis

The mean values of the chemical parameters of lettuce obtained were subjected to a one-way analysis of variance (ANOVA) to compare the treatments (Effects of fertilization on heavy metal accumulation in lettuce). Fisher's LSD post hoc test was performed to form homogeneous groups. This method was used to compare the levels of heavy metals assayed in the cultures resulting from the different cycles of a same treatment.

3. RESULTS

3.1 Properties of Soil and Compost Used

The results of laboratory tests carried out on soil and compost of household waste used are recorded in Table 2. It appears that the soil is acidic (pH = 5.13±0.93). It contains on average 0.836±0.12% organic matter with 0.486±0.13 and 0.086 ± 0.01% organic carbon and total nitrogen, respectively, resulting in an average C/N of 5.65±1.21. Its phosphorus content is estimated at 0.133±0.008 $g.kg^{-1}$ whereas exchangeable bases, namely calcium, magnesium, potassium and sodium are respectively: 0.219±0.011, 0.212±0.01, 0.038±0.012 and 0.039±0.02 $cmol.kg^{-1}$. For copper, lead and zinc, which are the only heavy metals measured, their respective contents found in the soil are: 13.12±1.23, 6.185±1.01 and 27.147±2.22 $mg.kg^{-1}$. All these soil properties are different from those of the compost used very significantly ($p < 0.001$). Indeed, this compost, with a pH of 7.3±0.2 is basic. It contains at least ten and eighteen times the total amount of nitrogen and organic carbon or organic matter in the soil. It is almost the same for the levels of exchangeable minerals, especially the heavy metals dosed (copper, lead and zinc) which are, in this order, about seventeen, eighteen and five times more abundant in the compost.

Table 2. Properties of soil and compost used

Variables	Soil	Compost
pH	5.13±0.93	7.3±0.2
C (%)	0.486±0.13	9.05±1.07
N (%)	0.086±0.01	0.88±0.09
C/N	5.65±1.21	10.28±1.98
Pass ($g.kg^{-1}$)	0.113±0.008	0.173±0.021
Ca^{2+} ($cmol.kg^{-1}$)	0.219±0.011	0.353±0.05
Mg^{2+} ($cmol.kg^{-1}$)	0.212±0.01	0.281±0.013
K^{+} ($cmol.kg^{-1}$)	0.038±0.012	0.278±0.016
Na^{+} ($cmol.kg^{-1}$)	0.039±0.02	0.475±0.11
Cu^{2+} (mg.kg-^{1})	13.12±1.23	233.183±3.21
Pb^{2+} (mg.kg-^{1})	6.185±1.01	113.775±2.55
Zn^{2+} (mg.kg-^{1})	27.147±2.22	141.783±3.03

– *Pass: Assimilable phosphorus*

3.2 Levels of Heavy Metals Observed in Crops

The levels of copper, lead and zinc observed in cultures from one crop cycle to another are shown in Table 3. Fig. 2 shows the evolution of these concentrations. It should be noted that fertilization has accelerated the absorption of heavy metals by lettuce. In fact, lettuce grown in the presence of NPK and compost absorbed more heavy metals than those resulting from the control treatment. With NPK, heavy metal concentrations have increased steadily and significantly ($p<0.05$) in crops as crop cycles follow each other. With compost, these concentrations remained almost stable between the first and second crop cycles before growing significantly ($p<0.05$) in the third cycle. The control treatment did not affect the rate of heavy metal uptake by lettuce. In sum, significant differences emerged between treatments in the first crop cycle for zinc, in the second cycle for lead and only in the third cycle for copper.

4. DISCUSSION

The soil that provided the framework for carrying out this experiment is not very fertile like most of the sandy soils of Côte d'Ivoire [10]. In fact, its low levels of calcium (0.219 ± 0.011 cmol.kg^{-1}), potassium (0.038 ± 0.012 cmol.kg^{-1}), sodium (0.039 ± 0.02 cmol.kg^{-1}) and phosphorus (0.113 ± 0.008 g.kg^{-1}) makes it unfit for crops in general. These poor properties are explained by its low clay content (less than 10%) coupled with its very high sand content (over 80%), which increases the risk of loss of minerals by the leaching phenomenon [11]. For optimal fertilization of such soil, organic fertilizers, especially compost, seem to be better suited than mineral fertilizers. But before using compost, it is recommended to evaluate its quality [5].

The physicochemical parameters generally used to evaluate the fertilizing value and the chemical quality of waste compost have been detailed by [20]. More than 60% of these parameters were taken into account in this study. These are, precisely, the pH and the contents of organic carbon, total nitrogen, phosphorus, potassium, sodium, magnesium and heavy metals.

It has been obtained that the pH of 7.3 ± 0.2 of the compost used is alkaline. This reflects the maturity of this compost. In fact, composting is always accompanied by alkalization so that at the stage of maturation, the composts are generally non-acidifying [21]. Its C/N ratio also reflects the maturity of the compost. In this respect, a study of composts of green waste, selectively collected bio-waste and residual household waste showed that composts generally reach their most important fertilizing value when their C/N ratios are comprised between 11.6 and 16.3 [22]. The one obtained here, which is equal to 10.28 ± 1.98, is slightly weaker than these thresholds. Also, taking into account the standards used by [20], the $15.57\pm1{,}82\%$ of organic matter content in the compost used, deduced from its estimated organic carbon content of $9.05\pm1.07\%$ is slightly weak in contrast to its total nitrogen content which is $0.88\pm0.09\%$. Indeed, the respective thresholds of these parameters in urban composts are at least 20% and 3% at most. The weaknesses noted here constitute a limit to the valuation of the compost used. They would be due to inappropriate conditions in which the compost was formed, namely, formation in open places exposed to all kinds of weather, so that nitrogen can be lost through evaporation or that organic matter can be washed away by runoff. Obviously, in this case, it is the loss of organic matter that has predominated. In addition, concentrations of copper (233.183 ± 3.21 mg.kg^{-1}), lead (113.775 ± 2.55 mg.kg^{-1}) and zinc (141.783 ± 3.03 mg.kg^{-1}) found in the compost used are very high relative to those revealed by several studies on urban composts [23,24]. However, these concentrations are low in relation to the critical thresholds in urban composts in general, which are set at 1000 mg.kg^{-1} for zinc and 800 mg.kg^{-1} for copper and lead [20]. These weaknesses are rather an added value to the chemical quality of the compost used.

In total, the compost used has a good fertilizing value and a satisfactory chemical quality. The properties measured on this compost are all very different from those of the soil used ($p<0.001$). This suggests a sensitivity of this soil to the effects of compost, including the accumulation of heavy metals in the soil. In fact, the increase in the level of heavy metals in the soil is one of the most frequent undesirable effects that may result from the application to the soil of compost produced from unsorted municipal waste [3,4]. This accumulation of heavy metals in the soil has adverse effects on the growth of crops and especially on the chemical quality of production when the plants absorb them very massively [25].

Table 3. Results of the comparison of heavy metals levels measured in crops according the different cycles of culture and treatments

	Cu^{2+} (mg.kg-1)				Pb^{2+} (mg.kg-1)				Zn^{2+} (mg.kg-1)			
	Control	**NPK**	**Compost**	**P-value**	**Control**	**NPK**	**Compost**	**P-value**	**Control**	**NPK**	**Compost**	**P-value**
Cycle 1	4,20±0,35a	4,32±0,21a	4,13±0,15a	0,78ns	0,01±0a	0,03±0a	0,04±0,01a	0,09ns	10,91±1,17a	11,32±1,28a	12,01±1,12b	0,04*
Cycle 2	4,22±0,31a	4,52±0,33a	4,23±0,25a	0,66ns	0,02±0,009a	0,05±0,01b	0,037±0,01b	0,03*	9,88±1,11a	12,52±2,01b	9,88±1,11a	0,04*
Cycle 3	4,14±0,21a	4,84±0,14b	5,44±0,31b	0,02*	0,01±0,02a	0,09±0,01c	0,098±0,02b	0,01**	10,01±1,17a	12,91±1,11b	15,01±2,17c	0,007**
P-value	0,39ns	0,04*	0,03*		0,21ns	0,02*	0,03*		0,53ns	0,04*	0,008**	

– Means on a same line or column followed by different letters are significantly different at P≤0.05;
*– **: High significant difference at P≤0.05;*
*– *: Significant difference at P≤0.05;*
– ns: not significantly different at P≤0.05.

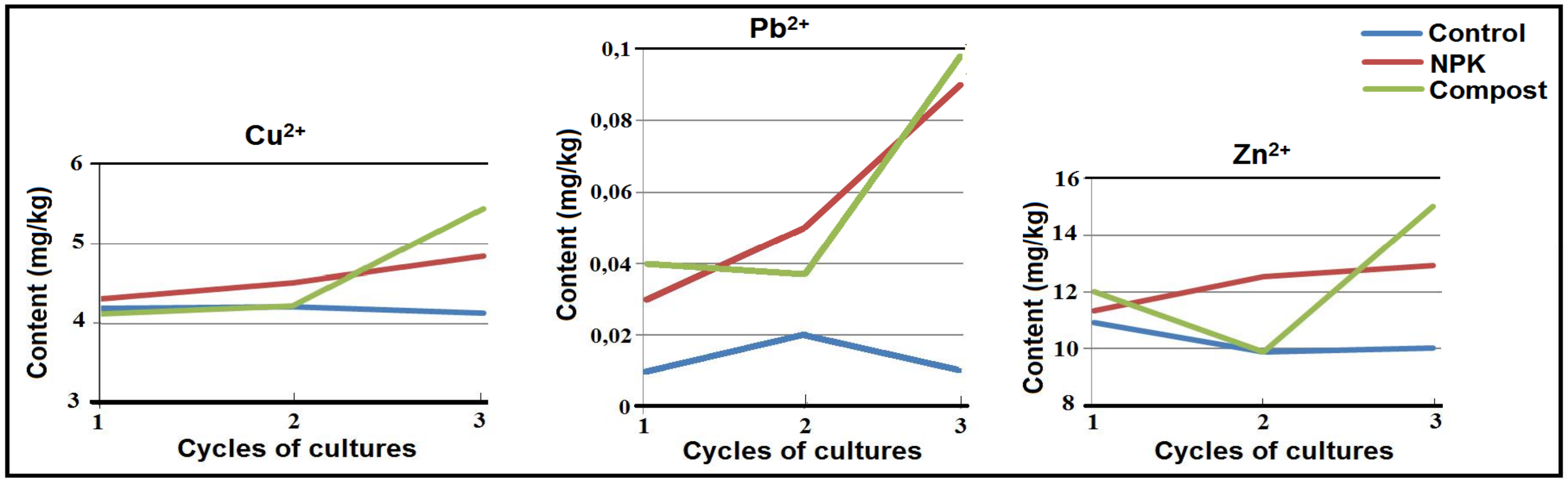

Fig. 2. Evolution of copper, lead and zinc contents in crops according to cycles of culture

In general, it is the variation of soil's pH which is the factor whose action on the mobility of the metals is the most decisive: its lowering favors the mobility of the heavy metals by the dissolution of the metallic salts, forms of retention of heavy metals in the soil [26]. Thus, during the first and second crop cycles, the inputs of NPK to the acidic soil used (pH = 5.13±0.93) increased its acidity. As a result, heavy metals have been massively absorbed by lettuce. Elsewhere, on plots amended with compost, the organic matter content and the soil pH were reported. The rise in pH would have caused the immobilization of heavy metals by the formation of metal salts, hence the low concentration of metals observed at the end of the first and second crop cycles in the crops of the plots concerned.

On the same plots, repeated inputs of compost to the soil since the beginning of the agronomic trials would have resulted, in the third cycle of cultivation, in the enrichment of soils with heavy metals, in particular, the mobile forms of these metals, which are easily accessible to plants. This is responsible for the increase in heavy metal concentrations observed in crops at the end of this cycle. However, the levels of heavy metals observed in the cultures (copper: 4.6±0.23 $mg.kg^{-1}$, lead: 0.058±0.01 $mg.kg^{-1}$, zinc: 12.3±1.46 mg kg^{-1}) are far from reaching their critical thresholds in food products (15 $mg.kg^{-1}$ for copper [27], 0.1 $mg.kg^{-1}$ for lead and 17 $mg.kg^{-1}$ for zinc [28]).

5. CONCLUSION

This study led to the fact that the compost used is mature and therefore contains significant quantities of organic matter and exchangeable bases necessary for crop development. In addition, the low values of heavy metals it contains are an added value to its quality. However,a strong growth of heavy metal levels was observed in harvests at the end of the third crop cycle after applying successively three doses of 40 $t.ha^{-1}$ of compost to the cultivated soil. This raises the risk of accumulation of heavy metals in the soil and then in crops due to the regular application of compost on the soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bricas N, Seck PA. L'alimentation des villes du Sud: Les raisons de craindre et d'espérer. Cahiers Agricultures. 2004; 13(1):10-14.
2. Lesafre B. L'alimentation des villes: Un nouveau défi pour la recherche. Cahiers Agricultures. 2004;13(1). Éditorial.
3. Amir S. Contribution à la valorisation des boues de station d'épuration par compostage: Devenir des micropolluants métalliques et organiques et bilan humique du compost. Thèse de doctorat, Institut National polytechnique de Toulouse, Toulouse, France. 2005;302.
4. Weber J, Karczewska A, Drozd J, Liczinar, Jamroz E, Kocowicz A. Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. Soil Biology and Biochemistry. 2006;39(6):1294-1302.
5. Mondini C, Insam H. Community level physiological profiling as a tool to evaluate compost maturity: A kinetic approach. European Journal of Soil Biology. 2003; 39:141-148.
6. Said-Pullicino D, Kaiser K, Guggenberger G, Gigliotti G. Changes in the chemical composition of water-extractable organic matter during composting: Distribution between stable and labile organic matter pools. Chemosphere. 2007;66:2166-76.
7. Brou YT. Climat, mutations socio-économiques et paysages en Côte d'Ivoire. Mémoire de synthèse des activités scientifiques. Habilitation à Diriger des Recherches, Université des Sciences et Technologies de Lille, France. 2005;212.
8. Brou YT. Variabilité climatique, déforestation et dynamique agrodémographique en Côte d'Ivoire. Sécheresse. 2010;21(1):1-6.
9. Avenard JM. Aspect de la géomorphologie in: Milieu naturel de Côte d'Ivoire. Mémoire ORSTOM, Paris, France. 1971;50:8-73.
10. Dabin B, Leneuf N, Riou G. Carte pédologique de la Côte d'Ivoire au 1/2.000.000. Notice explicative. ORSTOM. 1960;39.
11. Zro BGF, Guéi AM, Nangah KY, Soro D, Bakayoko S. Statistical approach to the analysis of the variability and fertility of vegetable soils of Daloa (Côte d'Ivoire). African Journal of Soil Science. 2016;4(4): 328-338.

12. Pruvot C, Douay F, Hervé F, Waterlot C. Heavy metals in soil, crops and grass as a source of human exposure in the former mining areas. Journal Soils Sediments. 2006;6(4):215-220.
13. Douay F, Pelfrêne A, Planque J, Fourrier H, Richard A, Roussel H, Girondelot B. Assessment of potential health risk for inhabitants living near a former lead smelter. Part 1: Metal concentrations in soils, agricultural crops, and homegrown vegetables. Environmental Monitoring and Assessment. 2013;185(5):3665-3680.
14. Roba C, Roşu C, Piştea I, Ozunu A, Baciu C. Heavy metal content in vegetables and fruits cultivated in Baia Mare mining area (Romania) and health risk assessment. Environmental Science and Pollution Research. 2016;23(7):6062–6073.
15. Magel R, Ndungu A. Nonparametric tests for ordering in completely randomized and randomized block mixed designs. J. Biomet. Biostat. 2013;4:170-4.
16. CEAEQ. Détermination du pH: méthode électrométrique. MA. 100-pH 1.1, Rév. 3. Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec. 2005;11.
17. Pétard J. Les méthodes d'analyse. Tome 1: Analyses de sols. Laboratoire Commun d'analyses. 1993;5:200.
18. Menet MC. Principes de la spectrométrie de masse. Revue Francophone des Laboratoires. 2011;2011(437):41-53.
19. Chabalier PF, Van de Kerchove V, Saint Macary H. Guide de la fertilisation organique à la Réunion. CIRAD. 2006;166.
20. Aoun J, Bouaoun D. Etude des caractéristiques physico-chimiques et contribution à la valorisation agronomique du compost des ordures ménagères. Revue Francophone D'écologie Industrielle. 2008;50:18-25.
21. Steger MF, Frazier P, Oishi S, Kaler M. The Meaning of Life Questionnaire: Assessing then presence of and search for meaning in life. Journal of Counseling Psychology. 2006;53:80-93.
22. Houot S, Francou C, Lineres M, Le Villio M. Gestion de la maturité des composts: conséquence sur leur valeur amendante et la disponibilité de leur azote - seconde partie. Echo-MO. 2002;35:3-4.
23. Compaoré E, Nanéma LS. Compostage et qualité du compost de déchets urbains solides de la ville de Bobo-Dioulasso, Burkina Faso. TROPICULTURA. 2010; 28(4):232-237.
24. Waas E. Valorisation des déchets organiques dans les quartiers populaires des villes africaines. SKAT centre de coopération suisse pour la technologie et le management. 1996;143.
25. Redon PO. Rôle de champignons mycorhiziens à arbuscules dans le transfert du cadmium (Cd) du sol à la luzerne (*Medicago truncatula*). Thèse de Doctorat, Université Henri Poincaré, Nancy. 2009;182.
26. Perrono P. Les micropolluants métalliques des boues de stations d'épuration urbaine et l'épandage agricole. Mém. D.U.E.S.S., D.E.P., Univ. Picardie, Amiens. 1999;62.
27. Kassaoui H, Lebkiri M, Lebkiri A, Rifi EH, Badoc A, Douira A. Bioaccumulation de métaux lourds chez la tomate et la laitue fertilisées par les boues d'une station d'épuration. Bull. Soc. Pharm. Bordeaux. 2009;148:77-92.
28. Temgoua E, Tsafack HN, Pfeifer H-R, Njine T. Teneurs en éléments majeurs et oligoéléments dans un sol et quelques cultures maraîchères de la ville de Dschang, Cameroun. African Crop Science Journal. 2015;23(1):35-44.

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