ORIGINAL ARTICLE

Analysis of an agricultural soil contaminated by cobalt, lead and zinc

Análisis de un suelo agrícola contaminado por cobalto, plomo y zinc

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ABSTRACT: In current agriculture it is necessary to control the safety of the food that is produced, for this it is vital to take into account the levels of contamination caused by heavy metals. One aspect to consider is the study of soil quality to preserve or improve its productivity, in order to guarantee environmental protection, human health and food safety. Trace elements in high concentrations in soils are food toxins with negative effects on health that manifest themselves in the long term as a result of the consumption of contaminated food and water. The objective of this work is: to study mathematical models to predict the behavior of cobalt, lead and zinc concentrations in agricultural soil, adjacent to the dumping of industrial waste in the San José de las Lajas municipality. For this, the concentration data of heavy metals cobalt (Co), lead (Pb) and zinc (Zn) were taken from the year 2005 to the year 2018 to predict their behavior from the use of statistical-mathematical tools until the year 2034. It was obtained that, according to the mathematical models obtained, these soils should not be used to grow vegetables for consumption, at least until 10 years after this investigation.

***Keywords*:** Phytoremediation, Food Safety, Toxic.

RESUMEN: En la agricultura actual es necesario controlar la inocuidad de los alimentos que se producen, para ello es vital tener en cuenta los niveles de contaminación que provocan los metales pesados. Un aspecto a considerar es el estudio de calidad del suelo para conservar o mejorar su productividad, de forma que se garantice la protección ambiental, la salud humana y la seguridad alimentaria. Elementos traza en concentraciones elevadas en suelos son tóxicos alimentarios con efectos negativos sobre la salud que se manifiestan a largo plazo como resultado del consumo de aguas y alimentos contaminados. El presente trabajo plantea como objetivo: estudiar modelos matemáticos para predecir el comportamiento de las concentraciones de cobalto, plomo y zinc en un suelo agrícola, aledaño al vertimiento de residuos industriales en el municipio San José de las Lajas. Para ello se tomaron los datos de concentración de metales pesados cobalto (Co), plomo (Pb) y zinc (Zn) desde el año 2005 al año 2018 para predecir su comportamiento a partir del uso de herramientas estadístico-matemáticas hasta el año 2034. Se obtuvo que, según los modelos matemáticos obtenidos, estos suelos no deban emplearse para cultivar hortalizas con objeto de consumo, al menos hasta 10 años después de esta investigación.

Palabras clave: fitorremediación, inocuidad alimentaria, tóxicos.

INTRODUCTION

The environmental problem is without a doubt one of the most important problems affecting 21st century society according to CEPAL (2017; 2021). The existence of environmental impacts has caused the destruction of soils available for agricultural activities.

All of this could compromise several of the Millennium Development Goals of the United Nations Organization and the National Economic and Social Development Plan until 2030 (PNDES 2030) to comply with the process of updating the economic and social model in Cuba, moving through the path of sustainable development, integrating its three dimensions: economic, social and environmental (INV-Cuba, 2021).

Therefore, the Cuban State has established in the guidelines of the Economic and Social Policy of the

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Party and the Revolution according to Gaceta Oficial de la República de Cuba (2017; 2020), that civil society in general assumes the will to undertake actions that promote and guarantee food safety, respecting the environment.

The achievement of these objectives is influenced by the development of certain industrial activities that constitute a risk of environmental contamination, not only due to atmospheric emissions but also to poor waste management, which can cause leaks of components that accumulate in the ground and as a consequence, a "contaminated soil" may appear (Goya-Heredia *et al.*, 2020).

The use of wastewater in agriculture provides benefits as a source of fertilizers for crops, but without prior treatment, it causes negative effects, which generate an impact on land use, agricultural production and human health, although its Negative effects on health manifest themselves in the long term (Doležalová-Weissmannová *et al.*, 2019).

To solve these problems that arise, there are treatment techniques based on the ability of different organisms to degrade, extract or immobilize contaminants from water or soil. These techniques are called Bioremediation and as a particular case when using different plants, Phytoremediation (Ardizzi, 2018).

The concern about having guaranteed food led man to propagate any plant species in agricultural areas close to industrialized or contaminated areas that, according to Guzmán *et al.* (2019), is a global reality and Cuba is no exception, so it is important to study the toxic effects that different groups of pollutants produce in the food chain.

The need to develop and apply methodologies that allow risk analysis to be carried out with the highest degree of precision possible is therefore established.

Despite everything stated, there are areas in Cuba where for various reasons the environmental security that is needed is not met and the accumulated experience does not take into account what is related to the soils destined for agricultural production. By taking on the challenge, the Faculty of Agronomy-UNAH continues research related to the problems of heavy metal contamination in vulnerable agroecosystems (Valdés-Carmenate *et al.*, 2017; Guzmán-Morales *et al.*, 2021).

The present work proposes: to study mathematical models to predict the behavior of cobalt, lead and zinc concentrations in an agricultural soil, adjacent to the dumping of industrial waste in the municipality of San José de las Lajas.

MATERIALS AND METHODS

The experimental site corresponds to an agricultural area, located 200 m away from the source of contamination (Empresa Cerámica Sanving S.A.) at 22º57'49.66" N, 82º10'13.02" W and 22º58'7.95" N, 82º10' 13.60" W, according to the North Cuba coordinate system, and adjacent to the waste dumping (GEOCUBA, 2018). It belongs to farmers who participate in the Urban, Suburban and Family Agriculture Program, of the Jamaica Popular Council, San José de las Lajas municipality, Mayabeque (Figure 1), in a soil classified as Leached Yellowish Ferralitic, according to Hernández *et al.* (2015). The crop plots produce vegetables such as: lettuce, tomato and cabbage.

Study of heavy metal content in soil

The series of data corresponding to the values of 42 concentration samples of the heavy metals Co, Pb and Zn was taken, from the year 2005 to the year 2018,

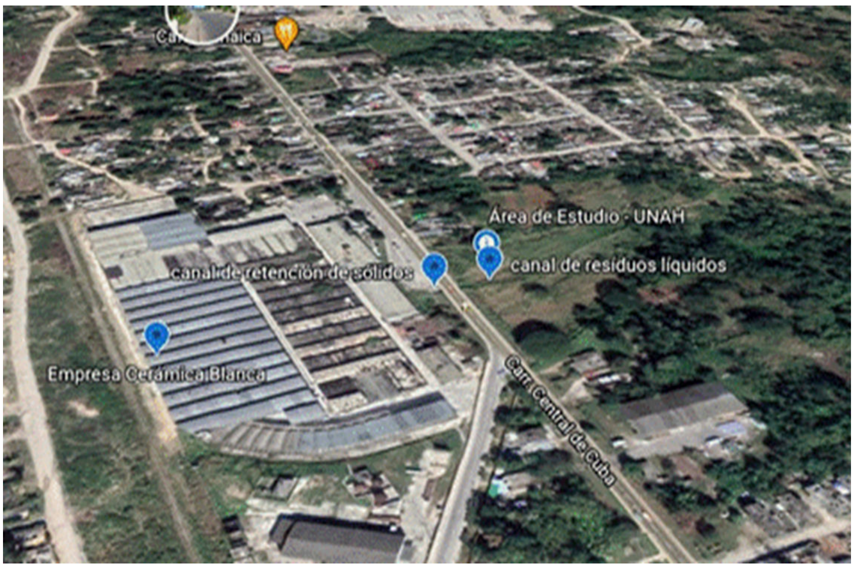

FIGURE 1. Location of the experimental research area.

from the studies carried out by the FITOPLANT Scientific group of the Faculty of UNAH Agronomy. The values were compared with the maximum permissible limits and dangerous levels for soil and plants, proposed by Fadigas *et al.* (2006) and Kabata-Pendias (2010).

Mathematical analysis to estimate decontamination in the study area by Co, Pb and Zn

Taking into account the concentration of the major elements found in the soil analyzes (Co, Pb and Zn) according to Guzmán-Morales *et al.* (2021), we proceeded to predict the time in which this soil could be decontaminated.

To characterize the behavior of the concentrations and analysis of possible decontamination, the data were tabulated in the Microsoft Excel 2003 program. Next, simple linear regression was performed with the STATGRAPHICS Centurium XVIII program (STATGRAPHICS, 2018). The estimation was carried out using the interpolation method with linear equation Y = a+bx according to del Valle-Moreno *et al.* (2022) where "Y" corresponded to the concentration of each variable and "X" years analyzed. At the same time, the behavior and trend for each case was analyzed. In addition, the averages of the annual concentrations were analyzed with respect to the Reference Values and Upper Permissible Limit.

The statistical processing for the prediction of contamination consisted of the calculation of the confidence intervals of the means by treatments of the variables evaluated, for a confidence level of 99 %. The calculated and predicted values were taken into account to prepare the prediction graphs, combining the statistical program STATGRAPHICS Plus for Windows 5.1 and the Excel program, taking into account the equations obtained from the models, predicting until the year 2034.

Economic evaluation of contamination with heavy metals in the studied area

A comparison was made of the yields of vegetables produced in the agricultural area, in the winter campaign of 2020, with data from 2018. For this, the values of planted area (SS), price of the product and others were kept fixed. expenses, making calculations in Cuban pesos (CUP) and based on direct sowing technologies in production, according to Trujillo *et al.* (2007), the yield data (kg ha^{-1}) were provided by the producer of the area and for the costs the information from the Accounting and Prices Directorate of the Minag-Cuba (2011) was used.

Statistical processing of primary data

For the analysis of the variables under study in all cases, descriptive statistics were used that included measures of central tendency and measures of dispersion. Similarly, Analysis of variance was used to compare means and multiple comparison tests (Duncan) if necessary, a 99 % confidence level was assumed. For the organization and processing of the information, the Microsoft Office 2010 Excel program was used and STATGRAPHICS Plus version 5.1 was used as statistical software.

RESULTS AND DISCUSSION

It was obtained that the MP concentrations in the contaminated soil samples are much higher than those determined in the standard soil, which is presented in Table 1.

TABLE 1. Concentration of Co, Pb and Zn in the soil used for growing lettuce, cabbage and tomato under production conditions.

Sample	Co ± std	Pb ± std	Zn± std
		mg/kg^{-1}	
Pattern	15± 4	90± 27	117± 40
Contaminated	20± 38	173± 31	415± 24
VR^{a}	9	85	140
VI^{a}	240	530	720
LSP^{b}	50	100	300
CT^{c}	25	13	70

a- Reference (VR) and Intervention Values (VI) of Dutch Standards.

b- Upper Permissible Limit in soils.

c- Values reported for the Earth's Crust.

The decreasing order that follows in contamination contributions is Zn > Pb > Co, with values of 298, 83 and 36 units of differences respectively between the contaminated soil and the standard soil, which in each case exceed the reference value and for the cases of lead and zinc concentrations also exceed the upper permissible limit, reported by Guzmán-Morales *et al.* (2021) as a soil moderately contaminated by these elements as reported in the Dutch Soil Standards (Swartjes, 1999 cited by (Guzmán *et al.*, 2019).

The analysis of this situation that occurs in the area is important, because it shows the concentration of elements present in these soils despite the distance they are from the source of contamination, which corroborates the results of previous works that analyze the agroecosystem according to Guzmán-Morales *et al.* (2021) where it was proposed that the elements detected as contaminants directly related to the waste from the Cerámica Blanca Company increase in depth and distance.

All these results have a chemical-biological influence on the crops that are produced in these areas since, as can be seen, the values affect the safety of the foods that are produced in these areas Muñiz *et al.*

(2015); Gaceta Oficial de la República de Cuba (2020) property that takes interest in local food security, in addition to ratifying the importance of these studies because under normal conditions these elements are essential for the growth and development of crops.

Analysis of statistical-mathematical models for the description of decontamination in the study area

Figure 2 presents the mathematical statistical models for predicting the minimum time necessary for the recovery of contaminated soil or the possible decrease in PM concentrations under the study conditions presented. To achieve this, it is necessary for the company to regulate its waste discharges abroad, taking the necessary measures to meet that objective.

The results obtained for Co and Zn, along with Pb, characterize the area as moderately contaminated and these first two metals have already been decreasing in content since 2019, however, Pb does not begin until after 2025. to decrease below the permissible limits and the intervention values that identify the negative actions of these elements on human health.

In the case of Pb, its decrease depends on the productive volume of the company, since this element is found mainly in the pigments that affect the coloring of the finish of the sanitary articles that are produced (information obtained according to a report from the Company valued as a source of pollution INV-Cuba (2021), which are mostly white, which also agrees with what was reported by Alarcón *et al.* (2015).

Based on all this analysis carried out, it can be concluded that these areas dedicated to vegetable crops must remain for at least 10 years without being used for these purposes, because their use threatens the food security of the locality by producing non-safe vegetables. according to Decree Law No.9 (2020) (Gaceta Oficial de la República de Cuba, 2020).

The above must be taken into account since, according to Alloway (2012; 2013), one of the most serious problems presented by contamination by heavy metals is their half-life, which ranges from 15-5,900 years depending on the metal. This author suggests that, for example, in the case of lead (Pb) it ranges between 310 to 1,500 years; therefore, the effects due to accumulation are more drastic than those produced by pollution caused at a specific moment.

Economic assessment of the impacts of PM contamination on vegetable yields in the agricultural area

From the analysis presented, the environmental value of the damage is estimated in monetary terms.

Table 2 presents the results of the yields obtained in two crop production campaigns and the losses obtained due to the presence of heavy metals in the area are assessed.

The greatest productive losses between the years evaluated were in the cultivation of cabbage, with a difference of 4,000 kg ha-1, followed by tomato and lettuce, influencing their economic losses.

The yield losses may be given because although the MPs evaluated are essential microelements for plants according to Aminiyan-Mirzaei *et al.* (2018), it is known that in high concentrations they can cause a reduction in root growth and in the frequency of

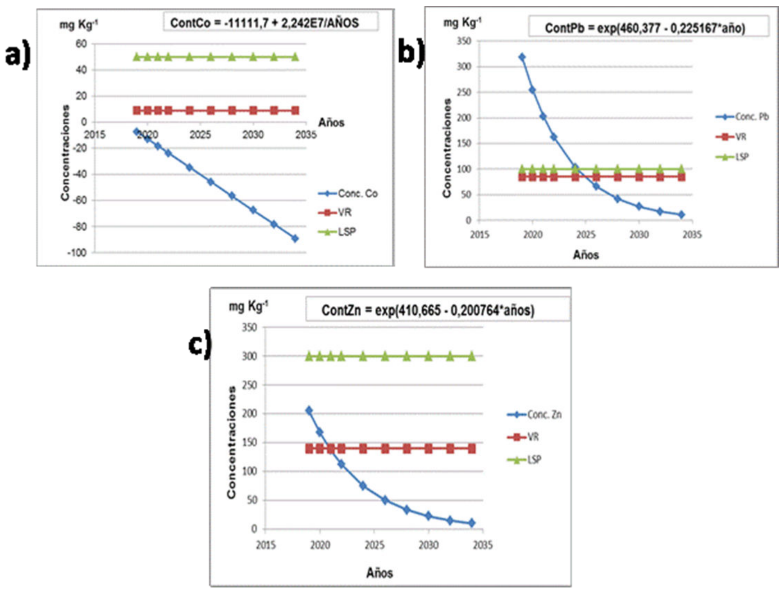

FIGURE 2. Mathematical models adjusted for the prediction of metals have decontamination in the study area. Trend lines (blue color), Reference value (pink color), Upper permissible limits (red color) at 99% confidence level (a-Cobalt, b-Lead and c-Zinc).

TABLE 2. Comparison of vegetable yields in 2018 and 2020 in the cultivated area near the Cerámica Blanca Company.

Crops	Agricultural yields (kg/ha^{-1})		Price (\$/kg^{-1})	Comercial production (\$/ha^{-1})		Lost (\$/ha^{-1})
	2018	2020		2018	2020	
Tomato	12 500	10 000	17	212 500	170 000	42 500
Cabbage	16 500	12 500	7	115 500	87 500	28 000
Lettuce	6 500	5 000	7	45 500	35 000	10 500
Total				373 500	292 500	81 000

mitotic cells, a decrease in the length of its roots and biomass, without showing signs of visible toxicity. This situation agrees with Malpeli (2018), who states that hyperaccumulator plants generally have low biomass because they use more energy in the mechanisms necessary to adapt to the high concentrations of metal in their tissues.

If in 2020 the producer presented losses estimated at 81,000 \$/ha^{-1}, it could be inferred that by 2028 the losses will reach approximately a total value that is equivalent to approximately 147,272 \$/ha^{-1} in each campaign, as proposed by Coronel & Marcelo (2018) working with two vegetables for direct consumption, broccoli and white onion.

However, this economic analysis, more than the monetary losses, which are important for the owners, insists on the fact of the concern that local authorities must have, since this plot, like many others according to ONEI-Mayabeque-Cuba (2019), has due authorization by the Delegation of Urban Agriculture and the Councils of Municipal Administrations Alarcón *et al.* (2015); NC 493 (2015), for the marketing of surplus products from the plot, at the points of sale established for this purpose.

Consequently, the excessive accumulation of heavy metals in soils leads to a high absorption of them in crops, more accentuated in vegetable crops and therefore affects the safety and quality of food according to FAO-OMS (2010 ; Soto-Benavente *et al.* (2020), and its consumption can cause the ingestion of toxic substances in the human body to not manifest immediately, but over several years depending on the exposure Díaz-García & Almeida-Maldonado (2018), so it is would be failing to comply with Decree Law No. 9 (2020) according to the Gaceta Oficial de la República de Cuba (2020) on food safety.

Therefore, it is considered that the evaluation of the risk of transfer of contaminants to the food chain, their accumulation in agricultural fruit and the toxic effects on animal and human health should constitute one of the objectives to be prioritized by the Ministry of Health. Agriculture and other OACE entities (MINSAP, MINDUS, MINEM) for decision making according to Alarcón *et al.* (2015); NC 493 (2015); since there are still agricultural areas close to polluting sources that constitute a threat to food security, due to insufficient treatment of waste the soil and accumulate in plants and organic tissues (Valdés- Carmenate *et al.*, 2017; Bünemann *et al.*, 2018).

CONCLUSIONS

The inclusion of mathematical models in pollution studies made it possible to evaluate agricultural areas contaminated with heavy metals and define the moment from which the soils could be suitable for agricultural production for consumption, showing that they should not be used for commercial purposes. agricultural (at least to grow vegetables) in the next 10 years.

The economic valuation related to the agricultural yield of crops showed that producers can have losses of approximately 147,272 \$/ha^{-1} in each campaign.

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