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RESEARCH ARTICLE

First national-wide survey of trace elements in Cuban urban agriculture

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Abstract Over the last three decades, urban agriculture has been improving food security in Cuba by providing fresh vegetables within and on the outskirts of cities and villages. However, organic fertilizers and substrates that are used in urban agriculture systems can be contaminated by trace elements and accordingly pose risks to human health. This study was carried out to measure the concentrations of cadmium, lead, arsenic, selenium, mercury, nickel, and chromium in composts and substrates used in Cuba's urban agriculture, as well as in vegetables grown in this cropping system to assess risks to human health. Extraction of trace elements from samples was performed with a mixture of nitric and hydrochloric acid in a microwave oven. Cadmium, lead, nickel, and chromium were determined via optical emission spectrometry, and mercury, selenium, and arsenic were measured using an atomic absorption spectrophotometer coupled with a hydride generation system. We demonstrated that the concentrations of trace elements in organic fertilizers, with the exception of compost from municipal solid waste, were within permissible values and do not pose risks to human health. The compost produced from municipal solid waste and the substrates prepared with this material presented cadmium and lead concentrations above maximum permissible concentrations. This work represents the first national-wide survey of trace elements in Cuban urban agriculture. As a result of this investigation, the use of municipal-solid-waste compost for food production was forbidden in Cuba.

Keywords Agroecology · Food security · Sustainable agriculture · Heavy metals

1 Introduction

Agriculture in urban areas has become increasingly popular worldwide and is now an essential feature of urban planning in many cities owing to the variety of benefits it provides to urban settlements (Cruz et al. 2014; Vittori Antisari et al. 2015; Dieleman 2016). These benefits include improving access to healthy food, promoting social cohesion, creating opportunities for physical activities, improving urban economic well-being and revitalizing low-income communities (Angotti 2015). In developing countries, urban agriculture is chiefly a strategy for achieving food security. Urban gardeners generally have low incomes and need to grow vegetables for their food supply and as a source of income (Saumel et al. 2012).

Urban agriculture has been practiced in Cuba for the last three decades (Febles-González et al. 2011). This farming system is part of the renovation of Cuban agriculture that took place after the collapse of conventional agriculture following the fall of the socialist bloc in the 1990s and the intensification of the economic blockade. Given this situation, Cuban

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agriculture was reoriented toward cleaner production systems based on agroecology and organic practices (Fig. 1), which enable the incorporation of urban agriculture models into the farming system as a way of establishing food production in cities and villages, with important social, economic, and environmental benefits (Palma et al. 2015).

Due to the limited availability of resources and inputs such as mineral fertilizers and pesticides, urban agriculture in Cuba is highly dependent on the use of organic amendments, particularly composts (Rodríguez et al. 2011). The use of compost as fertilizer, soil conditioner, or substrate is a sustainable recycling practice due to its beneficial effects on the biological, physical, and chemical properties of the soil, as well as on plant growth (Mylavarapu and Zinati 2009). However, composting of municipal solid wastes may result in environmental risks depending on the trace-element concentration in the raw materials that are used, which makes the final use of the compost unsuitable for food production (Hargreaves et al. 2008; Sharif et al. 2016). Therefore, the ongoing monitoring of trace elements in composts is essential to guarantee an agroecological agriculture that protects human health and the environment (Nogales et al. 2014).

The primary concerns regarding the addition of trace elements to agriculture soils are the reduction of crop productivity due to phytotoxic effects, water pollution through leaching from soils, and the entry of these elements into the food chain following plant uptake. Trace elements can enter the human body via dust inhalation, dermal absorption, and ingestion of water, soil, and food grown in contaminated sites; ingestion of contaminated vegetables can represent up to 70% of the dietary intake of trace elements (Otte et al. 2001). These elements can also have a significant impact on soil microbiota, altering microbial activity and the metabolism of microorganisms (Bolaños et al. 2016; Hongyan et al. 2016; Muñiz 2008).

Fig. 1 Organic urban farm (organopónico) Jardín del Caribe, Guantánamo city, Cuba

There is a lack of information regarding human exposition to trace elements via urban agriculture in Cuba. We hypothesized that the uptake of trace elements via vegetables fertilized with some composts or substrates used in the country can pose a risk to human health. Therefore, the objectives of this work were to (1) determine the concentration of Cd, Pb, Ni, Zn, Hg, Se, and As in composts and substrates used in urban agriculture, (2) assess the uptake of Cd and Pb for vegetables cultivated in these substrates, and (3) evaluate the risks associated with the consumption of vegetables grown in urban agriculture. Our results can assist management authorities in eliminating or avoiding major metal sources in order to guarantee food quality and safety.

2 Material and methods

2.1 Compost sampling and analysis

We sampled 11 types of compost used for vegetable production on 60 organic urban farms (so-called *organoponicos*) and 11 waste-processing centers throughout Cuba. The composts were sampled in the following provinces: La Habana ($n = 56$), Guantanamo ($n = 10$), Pinar del Rio, Artemisa, Mayabeque, Matanzas, Villa Clara, Ciego de Avila, Camaguey, and Granma y Guantanamo ($n = 11$). The 10 composts sampled in Guantanamo were obtained from the waste-processing centers of Sur Isleta, Los Cocos, and Vilonio. The first two centers processes municipal solid waste without previous sorting that is then classified manually before forming the compost piles; the Vilonio waste center processes only crop residues.

Three composite samples were collected from each compost pile. Each composite sample was made up of 15 single samples collected randomly. The samples were air-dried and sieved through a 2-mm sieve. Eight replicates of each compost were analyzed for pH, electric conductivity, and percentage of organic matter according to the methodology described in ISO-11464 (1999). The values' ranges were the following: pH (6.59–7.88), electric conductivity (1.09–7.45), and organic matter (39.3–69.5).

The composts were also analyzed for Cd, Pb, Ni, Zn, Hg, Se, and As. Owing to the absence of Cuban guideline values for trace elements in fertilizers, the values were compared with a Brazilian resolution that regulates the limits of these elements in organic fertilizers in order to protect soils and crops from contamination (Brasil 2006).

2.2 Vegetable cultivation

Four species of highly consumed vegetables in Cuba were analyzed for trace-element concentrations in their edible parts: lettuce (*Lactuca sativa*), chard (*Beta vulgaris*), radish (*Raphanus sativus*), and bell pepper (*Capsicum annuum*).

These species were grown on four different substrates in single and successive croppings. These substrates were prepared with a 1:1 mixture of soil and either cow manure or municipal-solid-waste composts as commonly used in the *organoponicos*. Two soils were used. They were classified as Typic Kandiustalf (sandy loam texture) and Rhodic Eutrodox (clay texture) according to Soil Taxonomy (Soil Survey Staff 1999); these soil types are the primary agricultural soils in Cuba. Substrates with municipal-solid-waste compost were cultivated in two successive croppings: (1) lettuce followed by bell pepper and chard (Typic Kandiustalf) and (2) lettuce followed by radish and chard (Rhodic Eutrodox). Substrates with cow manure underwent a single cultivation of lettuce and chard.

For the substrates and vegetables, three composite samples made up of 20 subsamples zigzagged along each bed planting were taken. The vegetables were collected at commercial maturity. Samples of the leafy vegetables were divided into leaves and stems, and the bell pepper samples were separated into leaf, stem, and fruit parts. Vegetables were gently washed under running tap water and then rinsed with distilled water before analyses.

In order to assess the quality of vegetables produced on the substrates, the concentration of each trace element found in the edible parts of the studied vegetables was compared with the General Standard for Contaminants and Toxins in Food and Feed (Codex Alimentarius 2016).

2.3 Chemical analyses

Samples of soil, composts, substrates, and vegetables were digested in Teflon vessels with 9.0 mL of HNO_3 and 3.0 mL of HCl in a microwave oven (USEPA 1998). High-purity acids were used in the analysis (Merck, PA). Glassware was cleaned and decontaminated in a 5% nitric-acid solution for 24 h and then rinsed with distilled water. The concentrations of Cd, Pb, Ni, and Zn were determined via inductively coupled plasma (ICP-OES/Optima 7000, Perkin Elmer), and the concentrations of Hg, Se, and As were determined via atomic absorption coupled with a hydride generation system (FIAS100/Flow Injection System, Perkin Elmer).

Standard procedures for controlling the quality of the analysis, such as curve recalibration, analysis of blank samples, and analysis of standard reference material (NIST 2710—Montana Soil), were performed. The NIST recovery range of the evaluated metals was between 91 and 105%.

2.4 Statistical analysis

Descriptive statistics (mean, medians, minimum and maximum values, and standard deviation) for the raw data were established using the statistical package Statgraphics Plus 5.1 (StatPoint, Inc., VA, USA). Due to the high variability of data, trace-element concentrations in the composts as well as the extreme values in individual populations of each element were standardized using a logarithmic transformation (ln (c) (MP) +1); this procedure was done for homogenization reasons to achieve a more symmetrical distribution and enable a comparable graphical representation.

3 Results and discussion

3.1 Trace-element concentrations in composts and substrates

In general, the concentration of trace elements in the studied composts was within the regulatory levels (Table 1), ensuring their safe use. However, trace-element contamination in municipal-solid-waste compost raises concerns about risks to human health; all of the elements assessed exceeded the permissible limits. The concentrations of Cd, Pb, Hg, As, Se, and Ni were roughly 3, 7, 2, 3, 2, and 4 times higher, respectively, than permissible levels. The high level of Ni in the earthworm humus and in crop-residue compost is probably due to the unusually high natural concentration of Ni in soils of Cuba (Rodríguez et al. 2015). Municipal-solid-waste compost contains trace elements as a consequence of plastics, metal objects, solvents, paints, papers, wood and petroleum products, Cd-Ni batteries, and other discarded materials (Rodríguez et al. 2013). Separation of hazardous materials, such as batteries, at the source and central separation in mixed municipal solid-waste management systems could greatly decrease the trace-element concentration in the municipal-solid-waste compost (Zhang et al. 2008). However, the results indicated that the manual separation of significant trace-element-enriched materials was not effective at reducing the concentration of trace elements in the municipal-solid-waste compost.

A comparison of the trace-element concentrations of composts from municipal solid waste from Cuba and other countries corroborates the assertion that separation strategies must be improved in Cuban municipal solid-waste facilities in order to achieve lower trace-metal concentrations. The trace-element concentrations from municipal solid waste from Cuba were higher than found in municipal solid wastes from Brazil (Jordão et al. 2006), Tunisia (Achiba et al. 2009), Belgium (Soumaré et al. 2002), USA (Das et al. 2002), and Portugal (Alvarenga et al. 2007). The improvements to achieve lower metal concentrations include reducing or eliminating trace-element levels in materials destined to become municipal solid-waste compost, separating clean organic materials at the source for separate collection and composting, separating contaminants at the source for separate collection and disposal, separating contaminants from municipal solid waste at a centralized facility prior to composting, and

Table 1 Trace-element mean values, standard deviation, and range for 11 composts sampled from *organoponicos* in Cuba and regulatory levels (RL) of trace elements in organic fertilizers. *1* filter-cake compost (*n* = 5), *2* horse manure + crop-residue compost (*n* = 6), *3* horse manure + soil − 1:1 (*n* = 14), *4* rabbit-manure compost (*n* = 1), *5* cow-manure compost (*n* = 5), *6* cow manure + crop-residue compost (*n* = 3), *7* cow manure + soil − 1:1 (*n* = 5), *8* earthworm humus (*n* = 5), *9* crop-residue compost (*n* = 4), *10* crop residue + soil − 1:1 (*n* = 23), *11* municipal-solid-waste compost (*n* = 6); Brasil (2006)[a]

Compost	Trace element (mg kg^{-1})						
	Cd	Pb	Hg	As	Se	Ni	Cr
1	0.7 ± 0.1	41.7 ± 13.0	0.02 ± 0.00	2.4 ± 0.5	3.3 ± 0.8	61.3 ± 11.0	40.0 ± 5.0
2	0.7 ± 0.5	34.7 ± 24.6	0.03 ± 0.02	1.7 ± 0.9	3.6 ± 2.9	34.0 ± 8.7	40.3 ± 15.2
3	0.7 ± 0.5	45.4 ± 31.0	0.02 ± 0.01	3.0 ± 2.1	4.3 ± 3.2	58.9 ± 24.5	47.8 ± 19.4
4	0.5 ± 0.0	34.9 ± 0.0	0.03 ± 0.00	2.9 ± 0.0	2.8 ± 0.0	46.9 ± 0.0	52.1 ± 0.0
5	0.8 ± 0.5	34.9 ± 6.4	0.03 ± 0.02	1.4 ± 0.9	5.7 ± 4.7	60.2 ± 22.0	57.6 ± 21.2
6	0.9 ± 0.8	58.4 ± 0.8	0.04 ± 0.02	1.2 ± 0.0	2.8 ± 0.0	26.0 ± 0.0	33.7 ± 8.0
7	1.5 ± 0.2	48.0 ± 12.5	0.04 ± 0.01	2.7 ± 1.57	3.8 ± 0.4	62.7 ± 11.2	113.0 ± 3.5
8	1.0 ± 0.5	47.8 ± 17.8	0.06 ± 0.04	14.9 ± 2.17	4.3 ± 2.0	160.4 ± 45.4	152.6 ± 40.9
9	0.4 ± 0.1	61.9 ± 7.4	0.02 ± 0.00	14.3 ± 2.8	2.5 ± 0.8	150.9 ± 21.5	177.0 ± 15.0
10	0.7 ± 0.3	45.0 ± 7.2	0.03 ± 0.02	16.3 ± 2.8	4.3 ± 0.8	206.4 ± 97.5	176.4 ± 34.8
11	4.8 ± 0.9	545.2 ± 93.8	1.90 ± 0.63	62.1 ± 2.0	141.0 ± 42.1	253.3 ± 26.5	221.7 ± 46.4
Range	0.2–6.2	13.5–1.1	ND–2.8	ND–98.0	0.8–204	10.6–455.7	16.7–297.3
RL[a]	*3*	*150*	*1*	*20*	*80*	*70*	*200*

separating contaminants from municipal-solid-waste compost at a centralized facility after composting (Richard and Woodbury 1992).

The concentrations of trace elements in soils and substrates that did not receive municipal-solid-waste compost were within permissible levels for agricultural soils (Table 2), except for Ni and Cr. The high concentrations of Ni and Cr in Cuban soils are natural and inherent to the parent soil material (Rodríguez et al. 2015). On the other hand, the use of municipal-solid-waste compost increased the concentrations of Cd, Pb, As, Se, and Hg above the limits considered safe for soil cultivation. Achiba et al. (2009) also reported that the addition of municipal-solid-waste compost increased Cd and Pb concentrations in the soil.

3.2 Cadmium and lead concentrations in vegetables

The Codex Alimentarius (2016) presents threshold values only for Cd and Pb; other trace elements were not determined in the edible parts of crops. The concentrations of Cd and Pb in the edible parts of vegetables grown on substrates that received cow manure (Fig. 2) were below the maximum allowable concentration of these elements (Codex Alimentarius 2016). Therefore, the cow manure used in Cuban urban

Table 2 Trace-element concentrations in soils and substrates (soil + organic fertilizer/compost, 1:1 ratio) used in Cuban urban agriculture. Mean of three replicates. *TK* Typic Kandiustalf, *RE* Rhodic Eutrodox, *MSWC* municipal-solid-waste compost, *PL* permissible level in soils[a] (CONAMA 2009) and substrates[b] (Brasil 2006)

Substrate	Trace-element concentration (mg kg^{-1})						
	Cd	Pb	As	Se	Hg	Ni	Cr
TK soil	0.8 ± 0.1	24.3 ± 4.3	15.1 ± 1.1	1.3 ± 0.1	0.07 ± 0.0	183.0 ± 9.6	191.9 ± 12.6
RE soil	0.4 ± 0.1	36.9 ± 5.0	6.2 ± 0.9	1.4 ± 0.2	0.03 ± 0.0	276.5 ± 8.8	154.9 ± 16.2
TK + Cow Manure	0.4 ± 0.1	66.5 ± 7.1	18.0 ± 4.3	2.4 ± 0.1	0.07 ± 0.0	178 ± 10.0	179 ± 14.6
RE + Cow Manure	0.4 ± 0.1	98.1 ± 9.1	19.4 ± 6.2	1.4 ± 0.8	0.07 ± 0.0	186 ± 7.6	198 ± 12.2
TK + MSWC	9.1 ± 1.0	352.0 ± 12.1	62.4 ± 9.1	143.1 ± 8.1	12.45 ± 1.08	285 ± 8.8	245.2 ± 23.1
RE + MSWC	8.6 ± 0.9	1501.5 ± 23.2	75.8 ± 12.1	149.0 ± 12.2	14.09 ± 1.37	298 ± 9.5	228.4 ± 32.0
PL[a]	*3*	*180*	*35*	*5*	*12*	*100*	*150*
PL[b]	*8*	*300*	*20*	*80*	*2.5*	*175*	*500*

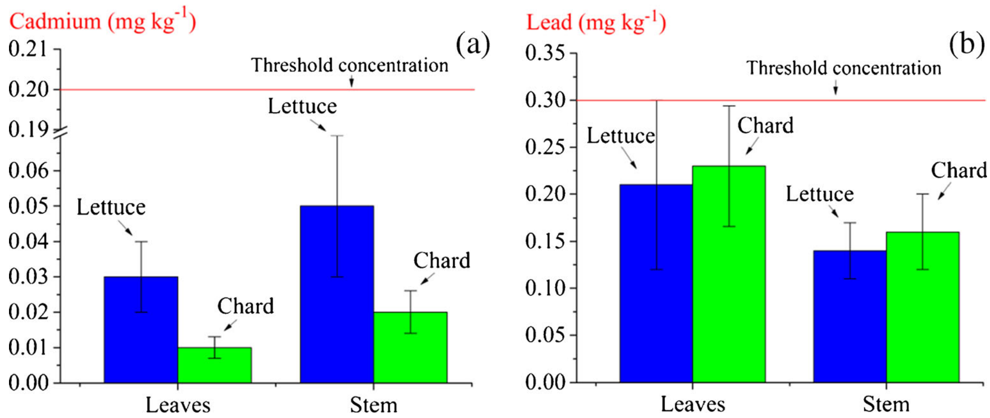

Fig. 2 Concentrations of cadmium (**a**) and lead (**b**) in edible parts of lettuce and chard grown on the substrate with cow manure. *TC* threshold concentration (Codex Alimentarius 2016)

agriculture does not pose risks regarding the uptake of Cd and Pb by vegetables. Clemente et al. (2007) reported that cow manure did not change the available concentrations of trace elements in soil or their uptake by plants compared with controls. In general, cow manure presents low concentrations of potentially toxic elements, and it can even be used to alleviate phytotoxicity and trace-element uptake in plants (Rehman et al. 2016).

We found that the use of municipal-solid-waste compost obtained from the three waste-processing centers studied poses a serious risk to human health due to the transfer of trace elements present in the municipal-solid-waste compost (Table 1) into the edible parts of vegetables cultivated in

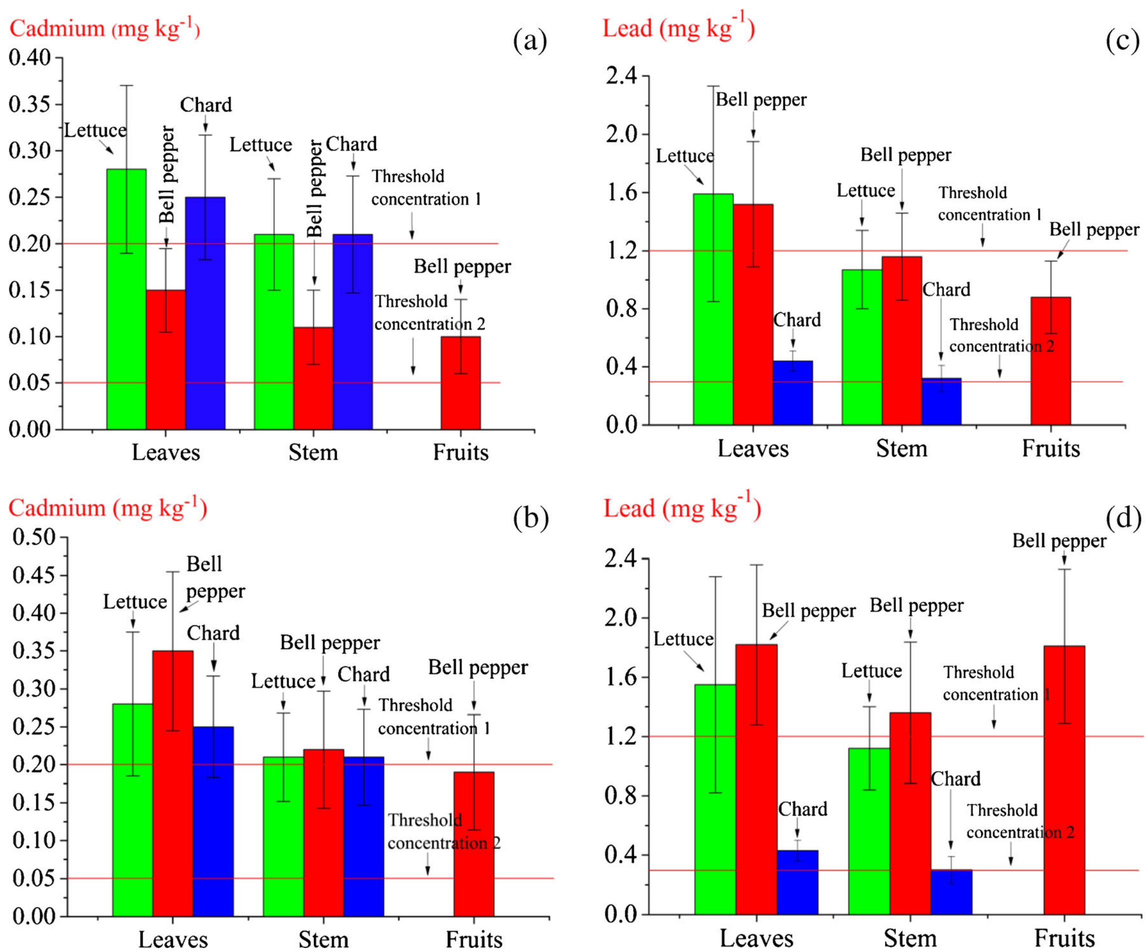

Fig. 3 Concentration of cadmium (**a** and **c**) and lead (**b** and **d**) in edible parts of vegetables grown successively (lettuce—bell pepper—chard and lettuce—radish—chard) on substrate with municipal-solid-waste compost. *TC* (*1*) and *TC* (*2*) threshold concentration in leaves and fruits, respectively (Codex Alimentarius 2016)

successive cropping: lettuce, bell pepper, and chard (Fig. 3a, b) and lettuce, radish, and chard (Fig. 3c, d).

In all cases, the highest concentrations of Cd and Pb were observed in leaves. With the exception of bell pepper fruits, the lowest metal concentrations were found in plant stems. However, the concentrations of Cd and Pb in leaves of lettuce and chard and the fruits of bell peppers were above the permissible limits set by the Codex Alimentarius, which renders these edible parts unsuitable for human consumption. Murray et al. (2011) also reported unacceptably high concentrations of Cd and Pb in lettuce and green-bean pods grown on soils amended with compost consisting of decomposed clippings and leaves collected from lawns and flower gardens. Lima et al. (2015) reported that the Pb concentrations in the edible parts of vegetables cultivated in a soil contaminated by battery recycling wastes were similar to the concentrations found in this work and also above threshold limits. It is important to point out that unacceptably high concentrations of Pb and Cd associated with municipal-solid-waste compost application in our work were observed in leaves and fruits harvested, even in the third cropping. This fact clearly highlights the potential health risks associated with the use of such composts for food production.

4 Conclusions

Given the reorientation of Cuban agriculture toward cleaner production systems based on agroecological practices, it is of paramount importance to assess the concentration of trace elements in organic agricultural inputs used in Cuba. Our data indicated that the concentrations of Cd, Pb, As, Se, Hg, Ni, and Cr in organic fertilizers used for composting in Cuban urban agriculture (filter cake, horse manure, rabbit manure, cow manure, crop residue, and earthworm humus) were within permissible limits. Therefore, these fertilizers do not constitute a risk to human health. On the other hand, composts produced from municipal solid waste yielded values above the permissible concentrations in organic fertilizers for all of the trace elements that we studied. Plants cultivated with municipal-solid-waste composts absorbed Cd and Pb in concentrations higher than the limits considered safe for human health. As a result of our study, municipal-solid-waste composts have been forbidden by Cuban authorities for food production until strategies to achieve lower trace-element concentrations in municipal-solid-waste compost from waste-processing centers are implemented.

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