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Soil quality in the urban gardens of Barcelona (Spain)

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Abstract

Purpose Urban agriculture is expanding worldwide and is being promoted by the FAO as a strategic activity because of its environmental, socio-economic, and educational benefits for citizens. In Spain, it is estimated that there are more than 20,000 urban gardens. There are many variables to take into account when starting to cultivate an urban garden, among which the quality of the soil is crucial. Nevertheless, some studies have shown high levels of contamination in soils dedicated to urban horticulture. The sources of contamination can be various, such as previous unrecognized management and irrigation with poor quality water, or the addition of polluted compost and other soil improvers. Soil contamination can migrate to vegetables and fruits, thus entering the food chain.

Materials and methods In this study, we analyzed the soils from ten urban gardens in the city of Barcelona, with a special focus on possible contaminants. Based on the possibility that irrigation water is a source of pollution, this was also analyzed in all investigated gardens.

Results and discussion Some of the waters analyzed for irrigation have a high concentration of salts, and a few of them contain nitrites, which are listed as a pollutant. The dominant texture of the soils was sandy clay loam and loamy sand, the pH was generally high, between 7.87 and 8.41, clearly carbonated, with Ca generally being the dominant exchangeable cation, but without the risk of a high percentage of active carbonates that could make it difficult to grow vegetables. The content in organic matter was very variable, but in all cases it appeared to be potentially incrementable. The three tests used to check possible soil contamination from heavy metals, do not attest to significant pollution.

Conclusions The soil quality overall is suitable for growing vegetables and allowing growers to work in these areas in complete safety. Although it would be necessary to analyze also other toxic elements, not considered in this study, some of the measured ones could come from the gases of road transport or even from the port of Barcelona.

Keywords Irrigation water · Soil contamination · Urban agriculture · Smart cities · SUITMAs

1 Introduction

Urban agriculture is an expanding activity in large cities of developed countries. An ever-increasing number of cities, which recognize the importance of this practice, are designing food policies aimed at including vegetable gardens in the urban fabric. Urban gardens are being promoted by the FAO as integral to more sustainable cities and are considered essential to tackle the effects of climate change and create new sustainable food systems (Wadumestrige et al. 2021). The functions performed by urban gardens are of different types, as underlined by Busquets Fabregas et al. (2008): (1) self-production function: urban gardens seek to combine the needs of the place and agricultural practices to increase

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productivity. (2) Environmental function: urban gardens promote ecological values. (3) Urban planning function: unused or abandoned spaces in cities are transformed into green and accessible areas. (4) Social function: cohesion and community work activities are encouraged by urban gardens, with obvious educational-therapeutic values. (5) Health function: urban gardens favor healthy nutrition and psycho-physical wellbeing. (6) Cultural function: the horticultural tradition, which is deeply rooted in the rural environment, is maintained and passed on to the urban population. (7) Esthetic function: cities have to deal with new scenarios, which demand a variety of open green spaces.

In Spain, it is estimated that there are more than 20,000 urban gardens (Puerto et al. 2021), although these have rarely been studied (Paradelo et al. 2020). Despite the multiple benefits that urban gardens can have, their soils can give rise to various environmental, ecological, and health risks (Buscaroli et al. 2021; Cheng et al. 2021). Nonetheless, to date there is no specific regulation that establishes the parameters to be respected and the threshold values for contaminating substances. The Spanish legislation actually does not have any specific section regulating urban land intended for agricultural use (MITECO 2021). For this reason, the use of urban land as a vegetable garden legally falls into the category "other land uses" (Herbón et al. 2021). In Barcelona, when the city council learns of a soil contamination problem, it must replace the contaminated soil with other uncontaminated soil. An example of these actions is the one undertaken in the urban garden of Can Cadena, also analyzed in this study. In 2018, the city council, through the Barcelona Public Health Agency, detected high levels of Pb, Cu, and Zn, and also benzopyrene. The first 150 cm of soil were removed from an area of 655 m^2 and replaced with exogenous mineral and organic soil (Ajuntament de Barcelona 2019). High levels of soil contamination make agricultural products unsuitable for human consumption (Meharg 2016; Calle Loja and Zhindón Rodríguez 2019). The pollutants found in the soil of urban gardens may have different origins, such as poor quality irrigation water, as observed in the city of Lima (Thomas 2014), or previous unrecognized soil management (Kumar and Lakhwinder 2016). According to Galán and Romero (2008), land previously used for residential purposes is more rarely contaminated than areas used for industrial or commercial purposes. The addition of soil from elsewhere (Requene et al. 2022) or poor-quality compost is another source of potentially toxic elements (PTE), such as arsenic, cadmium, copper, lead, and zinc (Izquierdo et al. 2015).

Pollutants may be deposited on the soil via emissions from neighboring or remote areas, originating from foundries, fuel combustion, waste incineration, traffic, and others (Madejón et al. 2011). Compounds that can contaminate both the soil and the plants themselves are the polycyclic aromatic hydrocarbons (PAHs). The source of emissions of PAHs in cities is mainly road traffic (Schauer et al. 2001), which is in fact the most important source in Barcelona (Van Drooge et al. 2014). A study by Martínez-Lladó et al. (2007) also identified the Barcelona Harbor as a source of PAHs, although in that study a high contamination of these ompounds was ruled out; however, the same study found contamination by TBT (tributyltin), which could reach nearby sediments. In our study, there are two urban gardens with some proximity to Barcelona Harbor. TBT is on the list of the most polluting for the European Union (EC 2001).

In the study by Van Drooge et al. (2014), the deposition of this type of pollutants in the needles of pine trees, both in the most remote, high, and forested area of Barcelona, which is considered a natural park, and in the parks from the city center, is analyzed. These authors found that environmental concentrations of PAHs were two to five times lower in the natural park compared to urban parks in the city. Of all the PAHs analyzed, phenanthrene had the highest concentration.

Regarding other types of pollutants, such as trace elements, which can be released from the traffic in large cities, a study carried out in Istanbul by Sezgin et al. (2004) concluded that there was greater variability in areas with heavy traffic than in more residential areas, and in the former, the legal concentration thresholds of some pollutants in the street dust were exceeded. It is assumed that these pollutants may reach the leaves of vegetables or also be deposited in the soil.

Pollutants can enter plant tissues at varying rates according to the type of pollutant and plant species. The assimilation process has been studied in many places, including urban gardens. Attanayake et al. (2014) conducted a field experiment in a community urban garden in the USA with a soil total Pb concentration of 60 to 300 mg kg^{-1}, finding that all vegetables had detectable amounts of Pb in their edible portions, with the highest concentrations in root/tuber crops, followed by leafy and fruiting vegetables. Another example of this type of study in urban gardens was based in Wroclaw (Poland), where the level of pollution was so high that more than 30% of the harvest was harmful to the health of consumers (Kowalska et al. 2016). Rodríguez-Bocanegra et al. (2018) found contamination by Cu, Pb, and Zn in an urban soil in Barcelona; the contamination, according to their study, can reach the plants, their roots and leaves, and in the case of Pb even in the drainage waters exceeding the values permitted by Spanish legislation. However, the authors took into account only one sampling location in the entire city of Barcelona.

Particle size can also be a pollution problem. A study by Valido et al. (2018) in the city of Barcelona analyzed the sands of 37 playgrounds and found that the most abundant trace elements were Ti, Mn, Ba, Zr, Zn, Rb, and Sr, and the only ones that could be enriched by contamination were Sb and As. For these authors, the maximum risk for children using these playgrounds is the size of particles which may cause local exceedances of PM10 European limit standards.

The aim of this study was to assess the soil quality and the possible contamination by some pollutants of ten urban gardens in Barcelona, as well as to verify the quality of the water used for their irrigation as a possible source of contamination. The rationale of this investigation lies in the fact that some of the studied gardens are located on sites where previous land uses (factories, buildings) are known to have involved pollution. The initial hypothesis is that the urban environment may have affected or is negatively affecting soil quality, thus contaminating the vegetables grown in these gardens.

2 Material and methods

2.1 Study area

Soils of ten urban gardens were sampled in various districts of Barcelona from among those not recently fertilized and undergoing similar agronomic practices (Fig. 1). According to oral communication with the managers of the urban gardens, all of them need some kind of fertilizer to be able to grow crops. In some cases, the urban gardens located in forest areas have been mixed with soil from the same area. The most produced vegetables are tomatoes, beans, potatoes, zucchini, chard, legumes, cabbages, eggplants, garlic, onions, artichokes, and lettuce. The choice of the gardens was based on their distribution throughout the city, and it influenced whether the managers were receptive to collaborating with the research. Some of the gardens are managed by the municipality and others by citizens' associations.

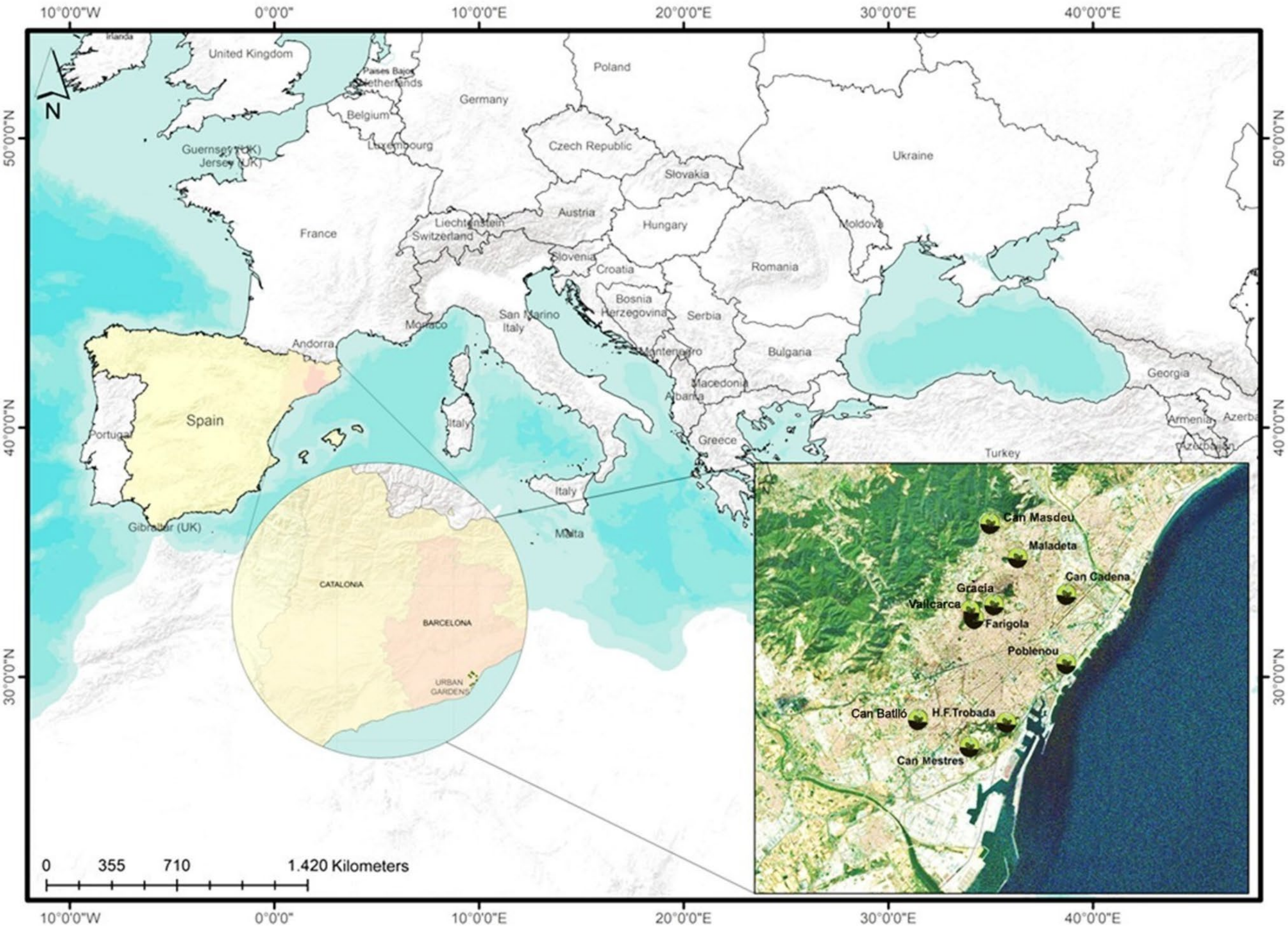

Fig. 1 Location of the urban gardens studied in Barcelona

Table 1 shows a description of the studied urban gardens. The WRB (1) classification correspond to each type of natural soil, the WRB (2) is the classification for anthropized soils (WRB 2022). The SUITMAs classification (Morel et al. 2015) collect the ecosystem services that urban gardens provide. SUITMAs correspond to Soils of Urban, Industrial, Traffic, Mining and Military Areas. According to the WRB, all of them have been classified as Anthrosols because they are now used for agricultural purposes, and in addition, some type of compost or fertilizer has been added to support plant growth. And with regard to SUITMAs, soils that have a more natural base have been distinguished, classified as "vegetated pseudo-natural", corresponding to the urban gardens located in the most forested areas of Barcelona (Collserola and Montjüic), while "vegetated engineered" are those located where previously there were buildings or factories.

More information about these urban gardens are in the supplementary material (Table S1) together with a photographic comparison before they were gardens with the current situation (2023), and information on the previous land use, the extent of the cultivated area, and the year in which each one was established as an urban garden. There is also a web link to each of the garden, where one can find additional information.

Sampling was carried out according to the guidance issued by the Gobierno de La Rioja (2003), in an area of 50 m^2 in each garden, randomly collecting four samples of 250 g each per garden. Almost cylindrical samples of the same volume were taken from the 0–30-cm-depth interval, then combined in a clean plastic bag and mixed together to make the cumulative sample homogeneous. In addition, a 1-l sample of irrigation water was collected from each studied garden. Some of the water came from the municipal aqueduct, other from rainfall collectors.

Table 1 Soil classification of each urban garden (ICGC 2019)

Urban garden	WRB (1)	WRB (2)	SUITMA
Vallcarca	Eutric Leptosols	Anthrosols	Vegetated engineered
Poblenou	Calcaric Fluvisols	Anthrosols	Vegetated engineered
Maladeta	Eutric Leptosols	Anthrosols	Vegetated engineered
Gràcia	Eutric Leptosols	Anthrosols	Vegetated pseudo-natural
Can Masdeu	Eutric Leptosols	Anthrosols	Vegetated pseudo-natural
Can Batlló	Eutric Leptosols	Anthrosols	Vegetated engineered
Can Cadena	Petric Calcisols	Anthrosols	Vegetated pseudo-natural
H.F.Trobada	Calcaric Fluvisols	Anthrosols	Vegetated pseudo-natural
Can Mestres	Calcaric Fluvisols	Anthrosols	Vegetated pseudo-natural
Farigola	Eutric Leptosols	Anthrosols	Vegetated pseudo-natural

2.2 Laboratory methods

2.2.1 Water

Nitrites, nitrates, phosphates, HCO_3^-, Cl^-, and hardness (mg $CaCO_3$/l) in the water samples were determined using colorimetric methods at the Physical Geography Laboratory of the University of Barcelona following Buurman et al. (1996) and Úbeda et al. (2002). Electrical conductivity (EC) and pH were analyzed with a conductivity meter and a pH meter. Other chemical analyses of irrigation water (Table 3) were done by CCiTUB (Scientific and Technical Services of the University of Barcelona) using Induction Couple Plasma (ICP) with a PerkinElmer Elan-6000 spectrometer and a PerkinElmer Optima-3200 R spectrometer.

2.2.2 Soils

Soil samples were air-dried and then sieved to 2 mm to remove rock fragments (> 2-mm particles). Soil samples were analyzed for conductivity and pH with a conductivity meter and a pH meter, respectively. For the extraction of the four major cations (Ca, Mg, Na, and K), and P (Table 5), given the high pH of the samples, barium chloride was chosen as a reagent. For the minor elements (Table 6), diethylenetriaminepentaacetic acid (DTPA) reagent was used. The extracts were analyzed by CCiTUB using induction couple plasma (ICP) with a PerkinElmer Elan-6000 spectrometer and a PerkinElmer Optima-3200 R spectrometer following the methods described by Knudsen et al. (1983), Buurman et al. (1996), and Burt (2014). All analyses were carried out on fine earth, i.e., the < 2-mm particles. The particle size distribution was determined using the Bouyoucos densimetric method. Soil organic carbon (C) and inorganic carbon (IC) were determined by the LOI (loss on ignition) method (Heiri et al. 2001). Nitrogen (N) was measured by ICP (inductively coupled plasma mass spectrometry) (Nelson and Sommers 1980). Calcium carbonates (CaCO3) and active carbonates were analyzed by the Bernard calcimeter. To determine active carbonates, the sample was mixed with calcium oxalate prior to analysis.

Table 2 Basic characteristics of irrigation water

		pH	EC (µS/cm)	NO$_2^-$ (mg/kg)	PO4^{--} (mg/kg)	NO$_3^-$ (mg/kg)	mgCaCO$_3$/l (mg/kg)	HCO$_3^-$ (mg/kg)	Cl$^-$ (mg/kg)	SAR
1	Vallcarca	7.79	451	**0.05**	0.4	5	319	142	46	0.71
2	Poblenou	7.54	1430	**0.05**	0.7	10	408	234	206	2.03
3	Maladeta	7.78	395	0	0.5	5	266	117	46	0.59
4	Gràcia	7.64	483	**0.05**	0.4	5	355	200	149	2.09
5	Can Masdeu	8.06	695	**0.05**	0.5	5	355	176	74	1.02
6	Can Batlló	7.58	1153	0	0.3	5	355	190	174	1.92
7	Can Cadena	7.50	1252	*0.1*	0.3	**10**	461	234	174	1.68
8	H.F.Trobada	7.20	*2171*	0	1	**10**	*797*	307	355	1.75
9	Can mestres	7.38	1257	**0.05**	0.5	5	408	190	202	1.86
10	Farigola	8.18	649	0	0.5	5	337	156	92	1.35

Numbers in bold mean that the concentrations are above the recommended levels. Numbers in italics denote contamination

2.3 Contamination indexes for trace elements

To test the level of trace element contamination, three indices have been established (Charzyński et al. 2017), which take into account the data of the samples analyzed in mg/kg. The geochemical background in our study was determined on the basis of Puig et al. (1999), Bech et al. (2015), Bech et al. (2008), and Tumé et al. (2006). For the enrichment factor (EF) calculation, the reference elements for normalization for cultivated soils in urban areas have been used (Cenci et al. 2001).

I_{geo} (Muller 1969) is computed using the following equation:

$$I_{geo} = \log_2[Cn/1.5 * Bn],$$

where Cn is the measured concentration of the element in environment and Bn is the geochemical background value in soil. The constant 1.5 allows to analyze natural fluctuations in the content of a given substance in the environment and to detect very small anthropogenic influences.

The EF calculation is expressed as:

$$EF = [Cx/Cref]_{sample}/[Cx/Cref]_{background},$$

where Cx is the concentration of the element of interest and Cref is the concentration of reference element for normalization.

The PLI (pollution load index) (Tomlinson et al. 1980) is expressed as follows (using the trace elements analyzed for this study):

$$PLI = [CF_{Cr} * CF_{Al} * CF_{Cu} * CF_{Zn} * CF_{Pb} * CF_{Mn} * CF_{Fe}]^{1/7}$$

3 Results and discussion

3.1 Water

The concentration of the variables measured in the irrigation water used in the ten urban gardens is shown in Tables 2 and 3. Their interpretation is based on Moliner and Masaguer (1996), Úbeda et al. (2002), ASP (2012), and FAO (2018).

Table 3 Concentration of selected chemicals in the irrigation water of the studied gardens

		Zn	Fe	Mg	Mn	Na	Si	Cr	B	Al	K	SO4	Ca	Pb
1	Vallcarca	0.05	0.01	11.45	0.00	22.27	2.65	0.00	0.08	0.09	3.91	15.46	60.92	0.00
2	Poblenou	0.01	0.00	16.59	0.00	64.82	1.55	0.00	0.11	0.05	**13.26**	25.87	56.54	0.00
3	Maladeta	0.01	0.00	10.16	0.00	17.69	2.56	0.00	0.04	0.08	3.27	13.62	56.40	0.01
4	Gràcia	0.01	0.01	20.92	0.00	78.28	2.35	0.00	0.12	0.08	**13.93**	33.19	81.08	0.01
5	Can Masdeu	0.00	0.01	20.34	0.00	38.16	4.73	0.00	0.06	0.05	1.91	23.59	82.51	0.01
6	Can Batlló	0.00	0.00	12.09	0.00	53.89	0.77	0.00	0.10	0.03	9.98	19.33	44.92	0.00
7	Can Cadena	0.00	0.01	15.63	0.00	50.57	1.62	0.00	0.07	0.03	4.34	24.91	48.79	0.00
8	H.F.Trobada	0.00	0.01	28.02	0.00	74.83	**6.72**	0.00	0.07	0.06	1.91	37.80	103.76	0.00
9	Can Mestres	0.02	0.00	12.60	0.00	53.25	0.79	0.00	0.07	0.09	10.30	20.65	46.22	0.00
10	Farigola	0.00	0.01	14.34	0.00	44.32	2.20	0.00	0.06	0.07	7.96	21.63	64.84	0.00

All data are in mg/kg

Numbers in bold mean that the concentrations are above the legal limits (Junta de Extremadura 1993; Moliner and Masaguer 1996; Úbeda et al. 2002)

According to these authors, the observed concentrations were within the legal contents for irrigation water. Nonetheless, although the concentration of nitrites fell within the range considered normal for irrigation, in the long term, it may imply pollution (Úbeda et al. 2002). Four out of ten gardens, i.e., # 3, 6, 8, and 10, were being irrigated with nitrite-free water.

The irrigation water of garden # 8 had a very high conductivity compared to the others (2170 µS/cm), and although it contained nitrates within the limit (10 mg/kg), it was harder than recommended (797 mg$CaCO_3$/kg).

We did not find any potentially toxic elements in the irrigation water in concentrations exceeding their TLV (threshold limit values) (Table 3). Water used in gardens # 2 and 4 showed a slightly higher potassium content than the recommended limit, but it does not represent a contamination risk, as potassium is a macronutrient with a wide spectrum of acceptable content (Úbeda et al. 2002). It is necessary to take into account the characteristics of irrigation water and to understand how these can affect the condition and safety of the food grown (Lupia and Pulighe 2015). Many studies carried out worldwide have provided information on contamination from irrigation water (Döll and Siebert 2002; Morison et al. 2008; Puy et al. 2021). Bauder et al. (2011) pointed out the impact of a very high or very low pH of irrigation water and the effect that excessive salinity can have in soils. The latter situation was observed in our urban garden # 8 where, according to these authors, extreme values of EC could imply contamination. Although in our study there were no extreme values, it is recommended that periodic analyses be carried out in order to observe possible variations in the quality of the irrigation water and, if necessary, take corrective measures as soon as possible. Other authors have pointed out that understanding the effect of irrigation water on the soil in both the short and long term is essential to ensure food safety. This is also important in view of global climate change, which in the future is expected to cause scarcity of water resources for irrigation and higher concentrations of contaminants (Malakar et al. 2019). Therefore, analyzing the chemical characteristics of irrigation water (e.g., nitrites, nitrates, hardness, chlorides, and minor and major nutrients) is essential to avoid the contamination of food grown on irrigated soils (Jackson et al. 2001; Zaman et al. 2018).

Irrigation water from garden # 1, 2, 4, 5, 7, and 9 contain nitrites, which are a contaminant. The biggest contamination problem is in the water from garden # 7, which reaches 1 mg/kg. Irrigation water receives inputs from different sources and its quality is dynamic; hence, it should be monitored over time (Favero et al. 2022). Isolated increases in contaminants may be due to multiple factors, such as the time and place of sampling, the time since the last rain or internal events inherent to the dynamics of the city (do Espírito Santo Silva et al. 2020). In the gardens studied here, except for NO_2^-, the irrigation water contained potential contaminants in a so low concentration that the impact of this water on the soil would be very low.

3.2 Soils

Samples # 3, 7, 8, and 10 were characterized by a clay content higher than 20%, and they can thus be classed as sandy clay loam, according to the USDA (United States Department of Agriculture) criteria (Table 4). All other soils were sandy loam, with a lower clay content. Such textural classes are particularly suitable for the cultivation of vegetables. Clay gives soils greater water availability, providing crops with an important water reservoir when water is scarce.

All investigated urban gardens had alkaline soils (Table 5), which is in line with the most productive agricultural soils in Catalonia (e.g., in Maresme, a Catalan region near Barcelona), where the average soil pH is between 7.9 and 8.2 (Bech Borràs et al. 1981). This pH range reveals the presence of carbonates, partly in the active form, as actually found in all samples.

A high pH decreases the availability of P and B and often leads to Cu, Fe, Mn, and Zn depletion, increasing the risk of ferric chlorosis (Porta et al. 1994).

The average electrical conductivity was 424 µS/cm, with lowest and highest values of 211 and 786 µS/cm (gardens 1 and 8, respectively). According to Villar and Arán (2008), for crops, the soil EC should not exceed 500 µS/cm. However, concentrations below this threshold were recorded in all cases except at sites 4 and 8, with the higher values in the latter being due to the high conductivity of the irrigation water (Table 2); high EC can lead to some absorption of sodium, which is bad for plants, while EC below 1000 µS/cm are in practice save for agricultural and horticultural crops with exception to some ornamental plant species. The soils we

Table 4 Particle size distribution (on a percentage basis) and textural class of the analyzed soils

		Sand	Clay	Silt	Soil texture
1	Vallcarca	75.5	8.5	16	Loamy sand
2	Poblenou	75.5	16.5	8	Loamy sand
3	Maladeta	69.5	20.5	10	Sandy clay loam
4	Gràcia	77.5	17.5	5	Loamy sand
5	Can Masdeu	65.5	10.5	24	Loamy sand
6	Can Batlló	77.5	14.5	8	Loamy sand
7	Can Cadena	75.5	20.5	4	Sandy clay loam
8	H.F.Trobada	67.5	20.5	12	Sandy clay loam
9	Can Mestres	76.5	16.5	7	Loamy sand
10	Farigola	71.5	20.5	8	Sandy clay loam

Table 5 Chemical and physico-chemical properties of soils

		pH	EC (μS/cm)	ESP (%)	CaCo3 (%)	Active carbonates (%)	N (%)	OC (%)	C/N	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	K/Mg	Ca/Mg
1	Vallcarca	8.39	211	2.374	24.60	2.33	0.05	0.33	6.80	104	490	3215	209	0.72	9.33
2	Poblenou	8.10	473	4.286	19.25	2.00	0.29	3.24	11.28	113	379	3590	359	0.32	6.06
3	Maladeta	7.87	471	2.485	16.04	2.00	0.35	3.43	9.91	145	538	2715	268	0.62	6.14
4	Gràcia	7.99	616	3.945	5.35	0.67	0.14	2.04	14.33	141	500	4422	301	0.51	8.91
5	Can Masdeu	8.09	292	2.987	8.56	1.67	0.36	3.34	9.30	246	679	2542	572	0.36	2.69
6	Can Batllo	8.36	275	3.245	16.04	2.50	0.17	1.76	10.26	108	464	2764	301	0.47	5.57
7	Can Cadena	8.41	447	4.574	7.49	1.17	0.17	2.04	12.27	13	385	4604	259	0.46	10.78
8	H.F.Trobada	7.92	786	6.454	9.63	0.83	0.35	4.99	14.29	23	770	3134	563	0.42	3.37
9	Can Mestres	8.02	390	4.256	18.72	2.33	0.24	2.85	11.60	23	412	3114	320	0.40	5.90
10	Farigola	8.39	281	3.282	16.58	1.17	0.18	2.02	11.53	26	350	3466	313	0.34	6.71

pH, electrical conductivity (EC), exchangeable sodium percentage (ESP), calcium carbonates ($CaCO_3$), and active carbonates, total nitrogen (N), organic carbon (OC), C/N ratio, available phosphorus (P), extractable potassium (K), extractable calcium (Ca), extractable magnesium (Mg), and K/Mg and Ca/Mg ratios of the soils are reported in the columns, respectively.

analyzed contained between 5.35 and 24.60% of calcium carbonate (corresponding to total carbonates); therefore, they fall within the range "slightly calcareous" to "calcareous" (Villar and Arán 2008). In general, when total carbonates exceeds 8%, it is advisable to refer to what is called "active carbonates," which is the real quantity of carbonates that can affect crops because of very fine particle size. Almost all samples had a low content of active carbonates, with only those from gardens 1, 6, and 9 exceeding 2%, which is unlikely to cause problems for plant nutrition (Garrido-Valero 1994).

Total nitrogen ranged from 0.05 to 0.35% (Table 5), which means a "medium" to "high" supply for most plants. All other macronutrients (P, K, Ca, and Mg) were abundant but without reaching high levels, according to the scales by Villar and Arán (2008). None of these nutrients was below the threshold considered necessary for a soil for agricultural use; the levels of phosphorus and calcium were between "normal" and "very high"; and magnesium and potassium exceeded values considered "high" (Costantini 2006). Potassium was generally high, and thus, no related fertilization would be necessary for most of the horticultural species grown in the gardens (Espinoza et al. 2012). The abundance of nutrients in the analyzed soils may be due to the habit of adding manure and self-produced compost to already fertile soil (Garrido-Valero 1994).

A low C/N ratio is crucial for soil fertility. The values obtained for organic carbon and nitrogen were low in urban garden #1 and medium to high in the others. According to Darwish and Kawy (2014), a ratio between 8 and 12 is optimal in agricultural soils, because it indicates a good balance between humification and mineralization. Only one of the gardens had C/N values below 8, and three had values under 12. Based on the results obtained, the studied urban gardens therefore had satisfactory values of C/N (Table 5).

For a balanced exchange complex, each cation should be present within a certain limit in order not to saturate the surface and not to prevent the absorption of other cations. According to Villarroel (2000), a balanced exchange complex should be distributed as follows: calcium (Ca) 60–80%, magnesium (Mg) 10–20%, potassium (K) 2–6%, and sodium (Na) 0–3%. The percentages of calcium and magnesium we measured were "normal", while sodium was higher than recommended levels in 8 out of 10 samples, particularly in the H.F. Trobada urban garden (#8), where it was more than double the suggested level, probably due to the high EC of the irrigation water.

The K/Mg ratio, which should be between 0.2 and 0.3 (and not exceed 0.5 because this can lead to magnesium deficiency due to the antagonistic effect of potassium), was much higher than 0.5 in a couple of cases, i.e., at sites 1 and 3 (Table 5). None of the sites had a ratio close to 0.1, which would have an opposite effect, namely, a potassium deficiency induced by magnesium (Villarroel 2000). It is known that an excess of exchangeable calcium can interfere with the absorption of magnesium, which is assumed to occur when the Ca/Mg ratio is greater than 10. In our soils, this was only the case of the Can Cadena garden (#7), due to the high amount of Ca.

All the microelements of the analyzed soils were below the safety levels and the European average levels (Table 6) (Thapa et al. 2021). In other areas of Spain, for example, in the Andalusian Community (*Real Decreto* 9/2005), the maximum levels allowed for agricultural land with $pH > 7$ are $Cr < 100$ mg/kg, $Pb < 200$ mg/kg, and $Zn < 300$ mg/kg (Fernández-Caliani et al. 2009). The values found for some metals as intermediate values for agricultural soils in Europe are Cr 53 mg/kg, Mn 663 mg/kg, Pb 39 mg/kg, and Zn 68 mg/kg (Cenci et al. 2001). In agricultural soils, Zn is mostly unevenly distributed, and its content varies between 10 and 300 mg/kg (Barber 1995), while the average is around 50–55 mg/kg (Kiekens 1995). The average content of Zn found in the soils of the various European countries varies from 7 to 89 mg/kg, with lowest values in Denmark and highest in Italy (Angelone and Bini 2017). Half of our samples were in line with the Zn limits in European agricultural soils (Hanson 1996); in the other half, the Zn content was below 7 mg/kg. Only soil from gardens #9 (47.96 mg/kg) and 10 (56.37 mg/kg) contained amounts of Zn considered suitable for horticultural crops, i.e., 20–250 mg/kg (Hanson 1996).

According to Huinink (1998) and the Netherlands Soil Protection Legislation, Zn, Pb, and Cr must not exceed 50 mg/kg. In our study, no urban garden exceeds these limits except "Farigola urban garden," which has a Zn concentration of 56.37 mg/kg.

The total boron (B) content in the investigated soils was highly variable and ranged from 24 to 214 mg/kg. For many crops, B is toxic at levels close to the optimum: some species show symptoms of toxicity just beyond 200 mg/kg. The analyzed soils were within the adequate range, except at site 2, where B content was 214.84 mg/kg. In calcareous soils, there could be some deficiency of B (Gillespie et al. 2021; Sleep et al. 2022). According to Alarcón (2001), only 5% of B can be uptaken by plants.

Manganese is generally considered deficient in a soil if its quantity is less than 3.5 mg/kg (Ortiz 2018), which was not the case of the soils we analyzed. Exchangeable manganese decreases as soil pH increases (Barber 1995), and soil microorganisms reach their maximum effectiveness when the soil pH ranges between 6.0 and 8.5 (Ramos and Romero 2016). Mn starts to become toxic as pH decreases below 5.5 (Salinas 1979), which rules out Mn toxicity in our urban gardens.

In soils with a high pH, Fe is often immobilized, and symptoms of deficiency ("ferric chlorosis") may appear at a pH higher than 6.5. According to Carrow et al. (2002), an iron concentration below 2.5 mg/kg is considered too low for most crops while higher concentrations are generally fine, although Römheld and Marschner (1986) reported that in well-aerated soils, iron values around 4 mg/kg can be insufficient for many plant species. Overall, our analyzed soils contained low extractable iron concentrations, except those from Can Cadena and Poblenou. According to Barahona-Amores et al. (2019) and Ríos-Ramírez et al. (2021), aluminum in small quantities can be beneficial to plants, even though it is not considered an essential nutrient. However, the pH is decisive, since for pH below 4.5) Al can be very assimilable and toxic (Forero-Pineda et al. 2022). The pH of the soils analyzed in this study was in the basic range, and therefore, there is no risk of Al toxicity.

Soil Cr has no direct relation to pH, and is also mobile at pH values > 8. What most influences the mobility of Cr is its oxidation state, since Cr (VI) is highly mobile and toxic, while Cr (III) has much lower mobility and availability because it is strongly retained by soil particles. Most Cr in soils is in the reduced form; however, oxidation of Cr (III) to Cr (VI) is frequent in alkaline soils that are poor in organic matter and have a high water content (Vásquez-Ibarra et al. 2021). The high pH in the analyzed soils would not hinder the availability of Cr, as it would for other metals; however, since Cr was present at low concentrations in our samples, it should not cause any toxicity to vegetables. The level of Pb we found was so low that, according to Alloway (2012), it was comparable with that of soils not affected by human activity. In general, an acceptable amount of Pb is < 200 mg/Kg (Romero et al. 2006; Cabrera et al. 2008). Culbard et al. (1988) found Pb concentrations between 298 and 580 mg/kg in soils of urban gardens in the UK, most probably due to paint from old houses and the deposition of contaminated dust. In any case, in a study of urban gardens in the USA, Brown et al. (2016) concluded that Pb contamination of food is very unlikely due to the limited uptake by edible plants.

The three indexes data are in Table 7. According to Muller (1969), $I_{geo} \leq 0$ is classified as uncontaminated, $0 < I_{geo} \leq 1$ is uncontaminated to moderately contaminated, and $1 < I_{geo} \leq 2$ is moderately contaminated. In our study,

Table 6 Extractable micronutrient concentrations in the investigated urban garden soils

Micronutrients (mg/kg)		Zn	Fe	Mn	Cr	B	Al	Pb
1	Vallcarca	0.94	0.48	14.62	0.04	129.61	1.55	29.37
2	Poblenou	4.27	19.64	36.19	0.40	214.84	48.69	0.96
3	Maladeta	3.64	1.20	43.06	0.20	176.37	12.64	1.69
4	Gràcia	2.27	1.52	42.50	0.12	123.10	12.34	0.73
5	Can Masdeu	7.53	1.02	16.02	0.18	107.26	10.34	0.58
6	Can Batllo	5.03	1.25	35.28	0.55	54.52	12.32	1.55
7	Can Cadena	6.42	3.74	81.02	0.31	24.21	9.51	0.65
8	H.F.Trobada	12.09	1.42	160.40	0.29	42.44	10.23	0.00
9	Can Mestres	47.96	0.79	164.03	0.23	49.28	11.25	3.96
10	Farigola	56.37	0.29	336.79	0.29	71.09	12.84	4.39

Table 7 I_{geo}, EF, and PLI indexes in the gardens studied

Urban garden	I_{geo}						EF				PLI
	Zn	**Fe**	**Mn**	**Cr**	**Al**	**Pb**	**Zn**	**Mn**	**Cr**	**Pb**	
Vallcarca	-6.96	-6.44	-3.04	-9.90	-5.41	-0.77	1.15	0.12	0.48	0.85	0.057
Poblenou	-4.77	-1.08	-1.72	-6.57	-0.43	-5.70	1.15	0.12	0.48	0.85	0.190
Maladeta	-5.01	-5.11	-1.47	-7.57	-2.34	-4.88	1.15	0.12	0.48	0.85	0.103
Gràcia	-5.59	-4.77	-1.49	-8.31	-2.41	-6.09	1.15	0.12	0.48	0.85	0.082
Can Masdeu	-3.96	-5.34	-2.90	-7.72	-2.67	-6.42	1.15	0.12	0.48	0.85	0.080
Can Batlló	-4.54	-5.05	-1.76	-6.11	-2.42	-6.42	1.15	0.12	0.48	0.85	0.120
Can Cadena	-4.19	-3.43	-0.56	-6.94	-2.79	-6.26	1.15	0.12	0.48	0.85	0.128
H. F. Trobada	-3.27	-4.87	0.41	-7.03	-2.68	-4.32	1.15	0.12	0.48	0.00	0.094
Can Mestres	-1.29	-5.71	-0.45	-7.37	-2.55	-3.65	1.15	0.12	0.48	0.85	0.193
Farigola	-1.05	-7.16	1.48	7.03	-2.36	-3.50	1.15	0.12	0.48	0.85	0.202

garden H. F. Trobada was uncontaminated or moderately contaminated and garden Farigola showed moderate contamination, both by manganese.

The EF index for all the urban gardens is less than 2, which according to Duzgoren-Aydin et al. (2006) and Sezgin et al. (2004) means deficiency to minimal enrichment.

The PLI index was evaluated to assess the mutual contamination effects of the six metals measured in this study, and according to Charzyński et al. (2017), values less than 1 mean that there is not metal contamination. In our study, all the study sites actually showed PLI below 1.

In this study, we do not consider either Cd or Cu, as do some other studies, or other variables, such as PAHs. Therefore, we cannot exclude that the gardens studied may be contained by these or even other pollutants.

It should also be said that it is necessary to regularly control the soil parameters, since it has been found that over time there may be an accumulation of contaminants coming from irrigation water or precipitation of particles suspended in the air due, above all, road traffic.

It is also interesting, knowing that there may be contamination in the soil, to opt for some type of remediation. Bayona et al. (2018) suggest incorporation of biochar obtained by pyrolysis of vegetable waste at moderate temperatures (550–850 °C) in an oxygen-poor environment. The high adsorption capacity of organic pollutants and metals by biochar causes them to be sequestered on the surface of biochar and to not be bioavailable anymore to plants. The incorporation of native bacteria into the soil through specific fertilizers can increase biodiversity and thus also the biodegradation rate of contaminants (Bayona et al. 2018).

At the end of 2022, the city council of Barcelona commissioned a report from CREAF scientists (Ecological Research Center and Forestry Applications) on the possible contamination by eight pollutants of vegetables in urban gardens with more or less proximity to road traffic. This report is not yet available for consultation, but the main researcher of the study has communicated orally that they did not find differences in concentration in the leaves of the vegetables between one place and another and that the concentrations found did not in any case pose a risk to the health of the consumers.

For future research, the study could be expanded by increasing the number of urban gardens taken into account, properties analyzed, as well as the number of samples in each garden. Furthermore, it would be interesting to characterize the properties of any fertilizers used, to relate these to the soil quality. Since the values of the variables measured in the current study do not suggest significant problems, it would be interesting to focus future work on other toxic elements or compounds that could affect urban agriculture and be a possible risk for human health. Establishing clear standards and guidelines for irrigation water quality in different countries is essential to avoid the contamination of humans through food intake. All this information should be communicated to local administration and managers to establish controls, limitations, and possible remediations in case of contamination of soils.

4 Conclusions

The urban gardens of Barcelona that have been chosen for this study represent part of the characteristics of this type of green infrastructure in the city of Barcelona. It is clear that they fulfill a social role, but it is also important to check if they pose a risk to the population based on the possible contamination of their soils. The water used to irrigate these soils, which has been analyzed for each of the orchards, despite having, in some cases, a high concentration of salts, should not imply major contamination problems. The soils are very alkaline, although do not not present problems due to the excessive concentration of active carbonates. The texture of the 10 soils was between sandy clay loam and loamy sand, with a high percentage of sand. The relationship between potassium and magnesium showed a possible lack of magnesium absorption in three of the gardens studied. Potentially toxic elements were not abundant and, anyway, did not exceed the limits imposed by current regulations. The soils of the urban gardens analyzed for this study and for the variables studied do not show significant signs of contamination. However, other contaminants should be analyzed to affirm unequivocally that the soils of these gardens are healthy. It would be necessary to carry out studies of the properties of the soil and of the vegetables produced regularly and increase the number of analyzed variables.

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