Culture and horticulture: Protecting soil quality in urban gardening

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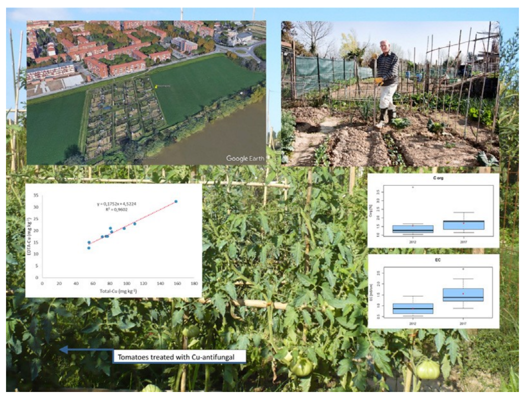
HIGHLIGHTS

- Urban cultivation for food production was investigated for soil quality.
- We surveyed the changes in soil properties of ten allotments after five years.
- The gardeners' identikit revealed their cultural background, and horticultural practices.
- Electrical conductivity, organic carbon and copper increased unevenly.
- Awareness of sustainable practices can contribute to protecting urban soil quality.

GRAPHICAL ABSTRACT



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abstract

Urban cultivation for food production is of growing importance. The quality of urban soil can be improved by tillage and the incorporation of organic matter, or can be degraded by chemical treatments. Urban gardeners have a role in this process, through the selection of various cultivation techniques. Our study focuses on an allotment area in the town of Pisa (Italy), which since 1995 has been run as a municipal vegetable garden by the residents. We analysed the soil and compared the data with those collected five years previously, to verify the possible changes in soil properties and fertility. We also interviewed the gardeners regarding their backgrounds, motivations and cultivation practices. We looked for possible changes in the soil quality attributable to the cultivation techniques. We found that the allotment holders influenced the soil quality through the cultivation techniques. Organic carbon, electrical conductivity and the content of copper increased unevenly in relation to the gardeners' cultivation practices. At the same time the study highlights that the urban gardeners were not completely aware of how to protect and enhance the fertility and the quality of urban soil. We believe that town councils should be responsible for providing correct information to the allotment holders and thus prevent the possible misuse of urban soil to grow food, as this can affect everyone's health.

1. Introduction

Urban food production has become a major topic in environmental and social sciences (Egerer et al., 2018). On the one hand the cultivation of food in urban areas can increase food security (Lal, 2017) and access

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to nutritious food, which is lacking for the poor in urban society (Gerster-Bentaya, 2013). On the other, because of urban pollution, the safety of consuming food grown in cities is a concern. Studies have investigated the contamination of vegetables grown in cities, due to soil pollution, mainly trace metals, as they are persistent and accumulate in the soil (Alloway, 2004; Hough et al., 2004; Béchet et al., 2016). The past land use (industrial, agricultural, military) can contribute to the pollution of urban soils (Hursthouse and Leitao, 2016). The translocation of metals from soil to edible parts of vegetables is negligible if the soil properties, such as pH, organic matter, texture, do not allow the mobility of metals (Sipter et al., 2008; Weeks et al., 2007; Bretzel and Calderisi, 2011). As the major sources of trace metals in cities are traffic and industries, the contamination of home-grown vegetables comes directly from the atmosphere (Amato-Lourenco et al., 2017). To tackle the pollution of home-grown vegetables, guidelines have been proposed in a recent COST action (Bell et al., 2016) indicating a series of management techniques, such as the isolation of the allotment area from atmospheric sources of pollution (i.e. traffic), the careful cleaning of produce, and cultivation in raised beds. These guidelines are intended for the widest public access, thus they can be downloaded for free from the web (Urban Allotment Gardens in European Cities - Future, Challenges and Lessons Learned, http://www.urbanallotments.eu/fact-sheets.html).

Planners regard urban farming, vegetable gardens, and rooftop agriculture as new forms of urban greening, thus involving citizens and improving the liveability of cities (Tappert et al., 2018). Nevertheless, at an institutional level, urban agriculture is not taken into consideration, as it does not produce an income; which results in poor services, and no training for technicians and gardeners. Moreover, municipalities tend to allocate neglected land to urban allotments that does not have much fruitful potential (Gerster-Bentaya, 2013). This often means that the physical and chemical quality of the soil is lacking. However, the role of urban farmers or gardeners is fundamental, as they can contribute to improving the quality of the soil if they are aware of the cultivation techniques required (Edmondson et al., 2014). Conversely, they can accelerate the degradation process, if they try to compensate for the lack of nutrients by the overuse of chemicals (Bretzel et al., 2016), at the same time posing a threat to their health. In any case "examining variability within local soil management systems is crucial to understanding anthropogenic impacts on soil dynamics" (Engel-Di Mauro, 2003).

People's reasons for cultivating allotments have changed through time and space, mainly in relation to historical and economic situations. Allotments became more important during war periods when they were mainly cultivated as a source of food, as happened in England and Wales (Thorpe Report, 1967). After the 1970s in northern Europe there was a revival in the cultivation of allotments, as social aspects primarily motivated most plot holders (Acton, 2011). Although there has been recent interest in Mediterranean Europe (Italy, Spain Greece), citizens of these countries have in fact cultivated vegetable gardens in cities for centuries. For example, in the Middle Ages, outside and inside the city walls of Pisa, many vegetable gardens flourished (Fischer, 1998), while during the long and drawn-out sieges, in cities across Europe the cultivation of food was the only way to avoid death from hunger. Today in low-income countries, often in the southern regions of the world, urban agriculture contributes to reducing poverty and improving food security (Mkwambisi et al., 2011; Poulsen et al., 2015). However, urban agriculture today is multi-faceted, involving socio-environmental justice (Tornaghi, 2017) and the fulfilment of ecosystem services (Langemeyer et al., 2016; Breuste and Artmann, 2014).

Although many papers have studied the soils of urban allotment, and others have studied the gardeners' profiles, very few have interviewed the gardeners in relation to the impact of the management practices on the modifications of the soil properties (Engel-di Mauro, 2003; Egerer et al., 2018; Tresch et al., 2018).

Our aim was thus to verify whether the motivation for gardening, which depends on a social, economic and cultural background of the garden holders, affects the soil quality. For example, in a previous work (Bretzel et al., 2016) we found that inappropriate anti-fungi treatments resulted in an excess of copper in the soil. In the present work, we studied an allotment area in the town of Pisa (Italy), which had been investigated five years previously (Bretzel et al., 2016). The initial holders were retired people, factory workers, living in the neighbourhood. Recently new social groups including young people and immigrants have requested an allotment. Thus, 2012 as the starting time (Bretzel et al., 2016), after five years (i.e. in 2017) the cultivation choices should have shown their effect on the soil properties, and reveal to what extent changes have occurred.

The aim of our study was to evaluate to what extent and how human actions can affect the quality of allotment soil. We thus compared the properties of the allotment soil in two different periods, 2012 and 2017, in relation to the management techniques, as revealed by interviews with the allotment holders.

2. Materials and methods

2.1. Site description

The study area is located in Pisa, Italy (90,000 inhabitants). The climate is warm and temperate, the average annual air temperature is 14.3 °C and the average annual rainfall is 900 mm. The allotment area is situated in a very populated district built in the 1960s, in the east of the town near the river Arno. The area is located in the floodplain of the river Arno, sloping 1 m in a south-north and east-west direction. It was managed for field crop production until 1995, when the municipal vegetable gardens were set up. Now the area is divided into 72 allotments, each of which is about 90 m^2, and located far from the main roads, isolated from the effects of traffic by distance and a river embankment. Ten allotments, the same ones that were selected and sampled in 2012 (Bretzel et al., 2016), were sampled to analyse the soil characteristics after five years of cultivation.

2.2. Soil analysis

Soil sampling was carried out in the tilled layer (0–20 cm depth) and each sample consisted of three sub-samples. Soil was air-dried at room temperature (20°) until constant weight, and sieved with 2 mm mesh. Texture, pH (H_2O), cation exchange capacity (CEC), organic carbon (C_{org}), total nitrogen (N_{tot}) and electrical conductivity (EC) were determined in triplicate on the 0–2 mm fraction by means of standard methods (ASA-SSSA, 1996). The concentrations of total and mobile lead (Pb), copper (Cu), nickel (Ni), chromium (Cr), zinc (Zn), cadmium (Cd) and potassium (K) were determined using ICP-OES spectrometry (Liberty Axial Varian, Turin, Italy) after acid attack (EPA 3051A). The potential mobility of soil metals and their possible translocation in plant tissues were investigated with a Sequential Extraction Procedure (SEP) (Petruzzelli et al., 2015). The first step of the SEP is with H_2O, which extracts the metal fraction free in the circulating solution of soil; the second step is with KNO_3, which is able to break the electrostatic bonds, and the third step is with EDTA, a strong organic extractant, which simulates the action of root exudates capable of breaking the covalent bonds with soil surfaces.

2.3. The survey

The survey was conducted with questionnaires presented to the allotment holders in the form of interviews conducted by the authors, in order to instantly clarify any possible doubt regarding the questions. All the sampled allotment holders were interviewed. The aims of the questionnaires were to define the typology of people, reveal the cultivation techniques and gardeners' awareness of them, and then to highlight the connections between the management choices and the soil properties possibly affected by the cultivation style. The questions were closed-ended. A first set of questions were related to personal

Table 1
Allotment soil properties in 2012 (Bretzel et al., 2016) and 2017.

		C org	N tot	pH	EC	CEC	K tot
		%	%	H_2O	mS cm^{-1}	$cmol^+ kg^{-1}$	mg kg^{-1}
Mean	2012	1.5	0.2	8.3	0.9	19	4421
	2017	1.7	0.2	7.9	1.6	16.5	2906
SD	2012	±0.82	±0.05	±0.35	±0.29	±2.10	±654
	2017	±0.35	±0.08	±0.13	±0.55	±1.52	±1168

information (sex, age, job, personal and background data), and a subsequent set focused on the socio-cultural aspects (sources of gardening information), and the last set of questions focused on the kind of cultivation practices (tillage, use of chemicals, input of organic matter) (Table B1 - Supplementary material). The questions were defined on the basis of our needs as well as taking into account the literature (Voigt et al., 2015).

2.4. Statistical analysis

In this study statistical analysis was applied to the datasets, using the statistical software R (release 3.4.0, packages readxl, MASS, stats, nortest and car), to describe the characteristics of the soils to understand the relationships between the measured variables and samples. Data normality was assessed with the R function shapiro.test and the homogeneity of variance with the R function bartlett.test. The two sample *t*-test (for normal distributions), or the Wilcoxon rank sum test (for non-normal distributions), were used to compare soil compositions between 2012 and 2017. Significant differences were considered at a p b 0.05. To show the linear dependence of Cu EDTA to total Cu, a linear standard regression curve was obtained using Excel Software, with R^2 as the Pearson correlation coefficient. We also used principal component analysis (PCA) to analyse the relationships between variables. PCA is a method of extracting a low dimensional set of features from a high dimensional data set in order to capture as much information as possible. If principal components capture 75%–80% of the total variance, the PCA can be considered a good instrument to visualize variable relationships.

3. Results

3.1. Soil characterisation

The allotment area showed a sandy loam texture, with sand ranging from 70 to 49%, silt from 43 to 20%, and clay from 15 to 7%. Electrical conductivity (EC) and cation exchange capacity (CEC) were in the typical range for a sandy loam soil; pH was moderately alkaline. The soil characterisation in the two periods of the survey is summarised in Table 1: some of the soil properties changed over time: Corg increased in some allotments, pH, CEC and K decreased, EC increased (Fig. 1).

Table 2 reports the trace metal values, showing that only Cu increased over time. Values of total Cd, and mobility test of Zn and Pb, in water and

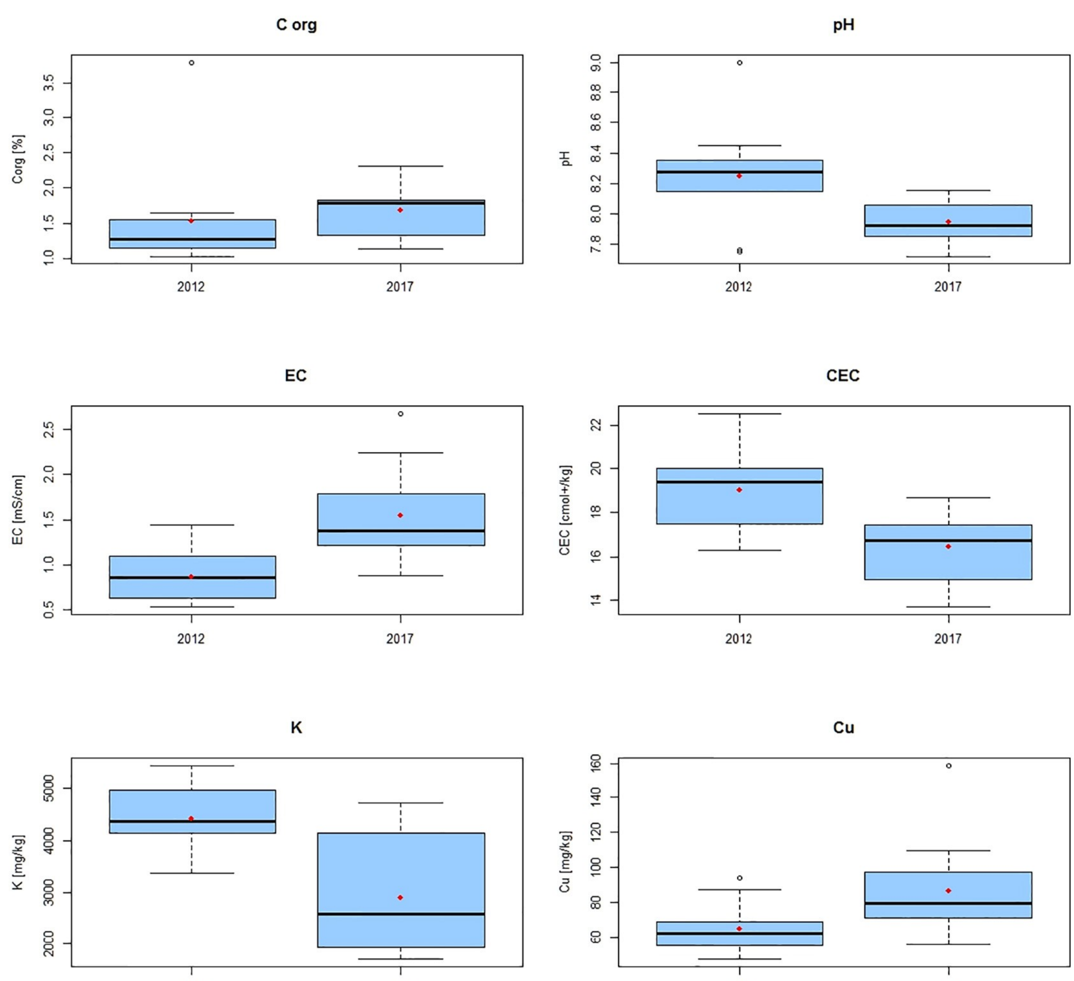

Fig. 1. Soil chemical characteristics and elements changed between 2012 and 2017: Corg (organic carbon) p-value 0,069; pH p-value 0,027; EC (electrical conductivity) p-value 0,003; CEC (cation exchange capacity) p-value 0,007; K (potassium) p-value 0,003; Cu (copper) p-value 0,035.

Table 2
Allotment soil trace metals in 2012 (Bretzel et al., 2016) and 2017.

		Pb tot	Pb EDTA	Cr tot	Cr EDTA	Ni tot	Ni EDTA	Cu tot	Cu EDTA	Zn tot	Zn EDTA
		mg kg^{-1}									
Mean	2012	10.0	3.2	58.2	n.d.	46.4	1.3	64.8	15.1	74.5	6.5
	2017	7.6	4.0	43.9	n.d.	30.2	1.0	86.5	20.0	55.2	6.1
SD	2012	±1.77	±0.6	±10.1	–	±6.67	±1.3	±15.2	±2.8	±6.1	±1.7
	2017	±1.80	±0.7	±10.3	–	±1.8	±1.3	±30.2	±5.4	±9.6	±1.8

KNO_3, were below the detection limits (0.05 mg/L for all elements). The EDTA mobility test showed very low values for all the metals and did not show bioavailability phenomenon (Table. 2). EDTA Cu was strongly related to total Cu (Fig. 2), indicating that the fraction of Cu extractable with EDTA has a linear dependence on the total Cu in soil.

3.2. Allotment holders' survey

The majority of the allotment holders were men, over 65 years old, and were workers at a local factory, but now retired. They had cultivated the allotment since 1995 (Fig. A1 - Supplementary material). Their motivations for cultivating the allotment were related to health (open air activity), for relaxation and fun, and food production for themselves and the family (Fig. A2 - Supplementary material). Most of them spent many days per week and N3 h per day at the allotment, especially in spring-summer (Fig. A3 - Supplementary material). The horticultural best practices were gathered from various sources including personal experience, TV, the web, and the garden centre/nursery, where the majority of them purchased the plants and seeds. Very few of them were able to produce the vegetal material themselves (Fig. A4 - Supplementary material). They stated that they followed organic cultivation rules, but at the same time we found that they used pesticides such as slug killers, and chemical fertilisation (Fig. A5 - Supplementary material). Most of them stated that they used manure (Fig. A6 - Supplementary material). The relations with neighbours were limited, and often seen as a source of problems (Fig. A7 - Supplementary material). The family connection with agricultural cultural roots was distant and lost. They all tilled the soil, mostly by hand. Among the problems highlighted were the management of pests, the relationship with the local council, the lack of rules. Possible improvements were the installation of a common composter and dust bins, a covered space for rain and sun protection, toilets, and the allocation of the empty allotments (Fig. A7 - Supplementary material).

3.3. Relations between soil properties and cultivation

The relationship between the soil parameters and cultivation practices for each allotment and variation in time are represented in the

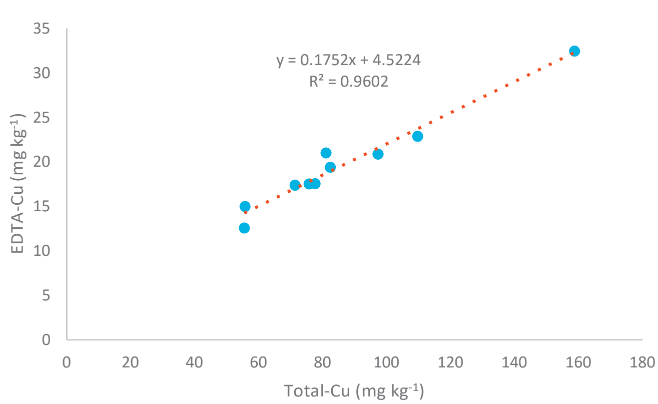

Fig. 2. Linear regression between total Cu and EDTA-Cu in the allotments' soil.

PCA bidimensional plots in Fig. 2. In our analysis we found two principal components, as linear combination of our variables, and we projected our dataset on the plan identified by these components. Total variance captured by the two principal components was 78%, 75% and 84%, respectively thus the projections on the principal components plain is a good representation of the space of variables for all three datasets. The spatial distribution of the soil parameters showed a stronger relation with the allotments in 2017 compared to 2012, highlighted by the comparison of the datasets. The allotments differed in relation to the soil parameter modifications. The analysis of the variations confirmed these findings (Fig. 3).

Figs. B1–6 report the bar-graphs of the soil properties of each single allotment, in the two survey periods. By comparing the 10 selected gardens in 2012 and 2017, some soil properties increased and others decreased, depending on the cultivation techniques adopted by each gardener; e.g. Corg and N increased in six allotments, Cu in seven, EC increased in nine, CEC and K decreased in nine. The graphs show that although the overall variations are small, at the single allotment level, they differed significantly between the years in terms of soil quality.

4. Discussion

Our results showed that in 2017, five years after the first survey, the soil properties had changed in relation to the gardeners' cultivation practices: organic carbon and nitrogen had increased in some of the allotments, and dissolved salts (EC) had increased almost everywhere; and total and EDTA-extractable copper values had changed in relation to the use of anti-fungal treatments. Other metals (Pb, Zn, Cr, Cd) had not changed on a temporal and spatial basis.

The changes in the soil properties were due to the addition of organic matter (manure) and partially, the burying of the cultivation residues. Copper-spraying, especially on tomatoes also played a role, which in some allotments led to the accumulation of copper into the soil. Although the average of the parameter variations in time can be limited, it can be remarkable in the case of some allotment, as the result of the single gardener choices.

Sandy-loam texture is ideal for horticulture, as many vegetables need to develop large root apparatus, but in these conditions the organic matter is unprotected and rapidly oxidates, due to the scarce presence of clay (Miles et al., 2008). This should be counteracted by regularly adding compost or manure, and thus improving the amount of organic carbon and nitrogen input. Moreover, regular tillage exposes SOM to more rapid oxidation, leading to its decline if it is not reintegrated (Miles et al., 2008). The very low C/N shows that carbon, although improved in some allotments, was still lacking in the soil, while there was an excess of nitrogen. All the gardeners stated that they buried crop residuals at the end of the cultivating season, but probably the quality or the quantity of the residuals was not sufficient to increase the amount of organic carbon, and to balance the N fertilisation. Egerer et al. (2018) found that mulching was an indicator of soil fertility in US community gardens; the garden accessibility favoured the transport of organic material and gardeners who had easier access were at an advantage. Accessibility is an important aspect that can make the difference to the cultivation, also due to the advanced age of many allotment holders.

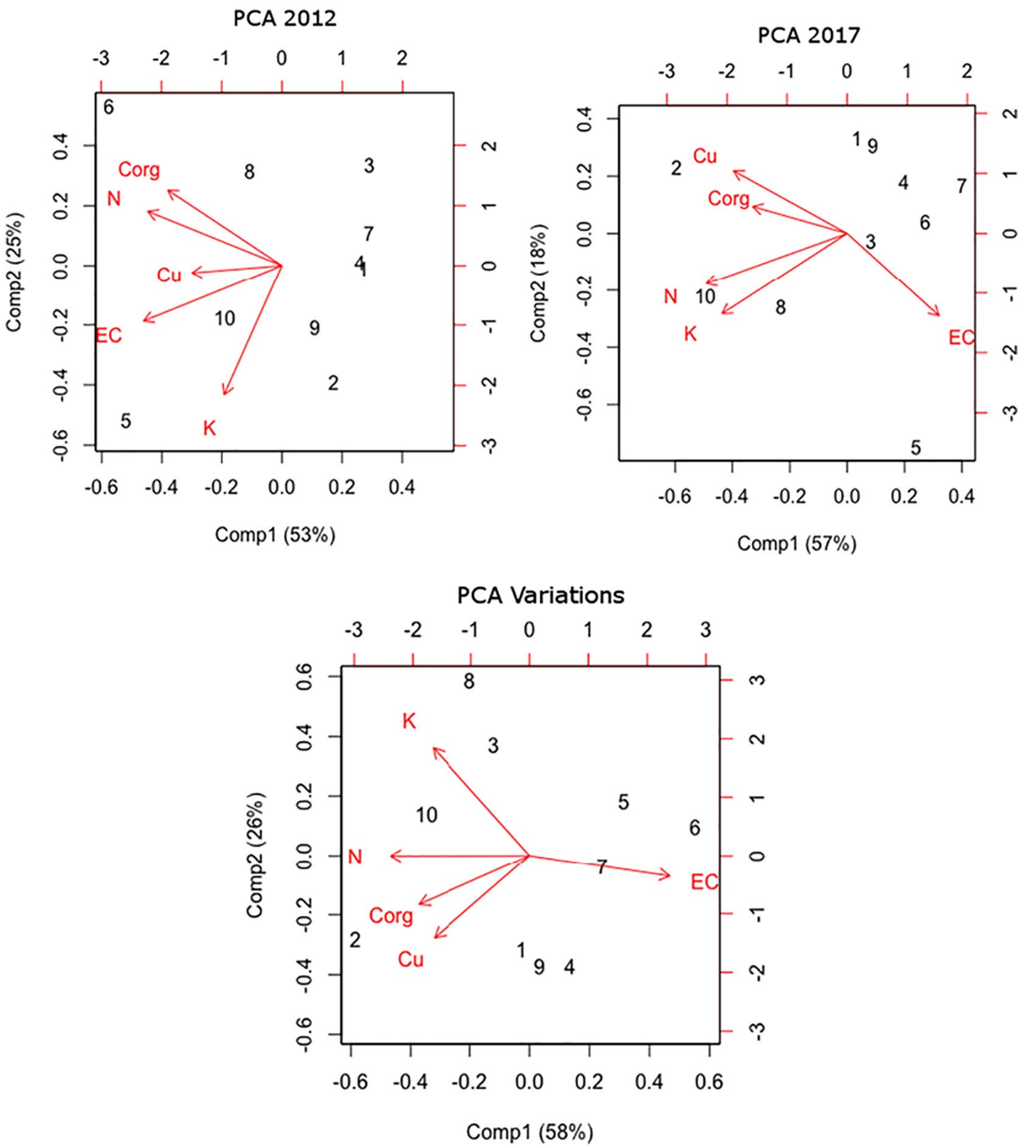

Fig. 3. PCA values of the most significant parameters for the study (Corg, pH, EC, N and K) in 2012, in 2017 and their variations from 2012 and 2017.

Vegetables grown in the allotments were consumed by a small number of people (often the family is just one person), so low levels of fertilisation were feasible. This would prevent the risk of the leaching of nitrogen and other elements, which is increased by the coarse texture and frequent irrigations, often occurring in urban agriculture (Cameira et al., 2014). The interviews showed how the fertilisation technique differed: some holders preferred to fertilise with manure and some with chemicals, others used both, which was reflected in the differences in soil properties in the different allotments.

Electrical conductivity is a soil property that greatly affects vegetable growth and the EC test provides a reliable method to monitor nutrients (Corwin and Lesch, 2003). The increase in this parameter in nine out of ten allotments, was related to the addition of salts due to the fertilisations by the gardeners, and to the pest treatments with copper sulphate. However, as the area is very close to the river mouth, there may have been some input of saline water in the vadose zone, especially in 2017 when a drought made the river flow very low. The EC values (0.1 mS cm^{-1}) can be tolerated by many species of vegetables, which have a different adaptation to salinity. For example, onions, lettuce, peppers, carrots are sensitive to 1.0–2.0 mS cm^{-1}, while Chenopodiaceae such as spinach and Swiss chards are tolerant to 4.0–6.0 mS cm^{-1} (Shannon and Grieve, 1998). Potassium is one of the cations that neutralises the negative charges in soil particles and contributes to the CEC, with other cations, i.e. Mg^{++} and Ca^{++}. Potassium reduction is consistent with the reduction of CEC, however 10–20 $cmol^{+}$ kg^{-1} is considered a good average value of CEC for agricultural soils (Gessa and Ciavatta, 2000). The modifications over time of the soil properties were related more to the management of each allotment, as evidenced by the component analysis (PCA), as in 2017 the properties were much more related to the allotments. The urban soil properties modifications carried out by the gardeners' cultivation can lead to new pedological ecosystems which are very different from the original (Egerer et al., 2018).

Apart from Cu, the total metal values in soils were generally low for urban soils and compared to other studies in the same urban area (Bretzel and Calderisi, 2011). The low concentrations of metal mobile forms extracted in EDTA, which mimics the action of the root exudates with some overestimation, do not involve translocation phenomena (Petruzzelli et al., 2015); the alkaline reaction of the soil greatly reduces the mobility of the elements analysed (Hough et al., 2004). Some allotments showed a high value of soil total Cu, employed as an antifungal agent (Tresch et al., 2018), and its EDTA fraction was strongly related to the total; which confirms the anthropogenic origin of this element (Bretzel et al., 2016). A strong detrimental effect was found regarding the total abundance of fungal biomass exerted by Cu in the soil (Keiblinger et al., 2018). All the gardeners stated that they used Cu as an anti-fungal agent, especially on tomatoes, which are a very popular crop. However sometimes they spread it inappropriately (e.g. with a paint brush), as they do not have the knowledge of how to do it, thus they disperse an excess of this element in the environment, unaware of the effects.

As far as the choice of varieties and species is concerned, the allotment holders were not adventurous, as they plant the same type every year, purchased from the local shops. They were scarcely aware of landraces and local cultivars, which can be self-propagated and are more suitable for the local conditions. The use of local vegetable species, instead of new ones, can be an advantage because they adapt to the local pedo-climatic conditions, have better pest resistance, and their cultivation would contribute to preserving the agrobiodiversity (Bretzel et al., 2017). Moreover, due to soil alkalinity (pH N 8.5), micro deficiencies in Fe, Zn, Ca, Cu, N can create problems for the cultivation, for example a typical Ca-deficiency symptom on tomato (blossom end root), was observed by the allotment holders, which may also be related to the excess of nitrogen (NH_4) (Taylor and Locascio, 2004).

The interviews contributed significantly to the environmental survey (Voigt et al., 2015). The gardeners' motivations were linked with practical and personal reasons and were not supported by subsequent gardening practices (Kirkpatrick and Davison, 2018). In some cases, interviews revealed that the gardeners did not come from a rural background and they were lacking in basic gardening information, such as the fate of chemicals in the environment or the differences between organic and chemical agriculture.

Urban gardening provides a great opportunity to raise awareness about ecological issues, which could be improved by linking the allotment gardening practices to a wider vision regarding nature and sustainability (Clayton, 2007; Egerer et al., 2018). From a social cohesion point of view, cultivating an allotment does not seem to provide great benefits, since the gardeners were really only interested in their own allotments and complained about their neighbours' allotment mismanagement. Failing to meet the aims of social agriculture, can be also due to the indifference on the part of the short-sighted local council in the peri-urban fringes of the city (Dieleman, 2017).

5. Conclusions

Our study highlights that the management of urban allotments involves some changes in urban soil properties over a period of five years, and that these changes are heterogeneous, in relation to the individual management practices of the allotment holders. In particular, EC increased, organic carbon was modified, increasing in some cases and decreasing in others. The low C/N revealed that there was an excess of nitrogen fertilisation. The Cu-residuals in the soil were high in some allotments due to the improper use of anti-fungal treatments and to the accumulation over time, which could be a possible risk for the quality of soil, damaging the soil biota and the cycle of nutrients. The questionnaires given to allotment holders revealed the cultivation practices, highlighting that combining an environmental survey with a human survey is necessary in order to understand the anthropogenic impact on the soil. Local councils should be encouraged to provide educational support and information for the gardeners.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2018.06.289.

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