geosciences

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Soil Characteristics in Private Gardens of Different City Neighborhoods: A Case Study of Taibe, Israel

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Abstract: City green areas including private gardens, provide ecological, sociological, cultural, health, and engineering advantages that motivate the urban system. Manmade impacts on the development of urban soils are of greater importance than natural ones. Soil properties were studied in an Arab city—Taibe—in Israel. Two neighborhoods in the city, which differed in time of establishment, were selected: An older residential neighborhood constructed more than 70 years ago, and a newer one built 10 years ago. In each neighborhood, 15 private gardens were randomly chosen. In total, the study was conducted in 30 gardens. In each garden, soil samples were collected from three depths: 0–2, 2–10, and 10–30 cm, respectively. In each sample, organic matter, hygroscopic moisture, calcium carbonate, bulk density, field water content, lead, copper and zinc contents, and texture were determined. The soil of the older neighborhood expressed greater values of soil properties and higher profile differentiation than the newer one. The heavy metals in the soil of the private gardens of both neighborhoods are not present in excess nor are they toxic. Under the prevailing environmental conditions, the soil of the newer neighborhood will become like that of the older one in the future unless a new soil interruption occurs. The calcium carbonate and heavy metals contents in the soil can be used as indicators of soil maturity in different areas of the city having similar environmental conditions. In addition, the gradients of these properties along profiles can be helpful in restoring the history of human activity, which prevailed in the area.

Keywords: soil properties; urban soil; private garden; human activity; heavy metals

Citation: Sarah, P.; Zhevelev, H.; Haj-Yehia, S.; Sachs, E.; Fragin, A.G. Soil Characteristics in Private Gardens of Different City Neighborhoods: A Case Study of Taibe, Israel. *Geosciences* **2022**, *12*, 217. https://doi.org/10.3390/geosciences12050217

Academic Editors: Joanna Wragg, Marc Cave, Maurizio Barbieri, Javier Lillo and Jesus Martinez-Frias

Received: 21 February 2022
Accepted: 19 May 2022
Published: 23 May 2022

1. Introduction

'Greening cities are tantamount to bringing nature back to the laps of humans who have been detached from nature but have maintained the subliminal desire to connect with nature' [1]. City gardens, both private and public ones, provide ecological, sociological, cultural, health, and engineering advantages that support the existence and operation of the urban system. Moreover, many gardens express overlap and dependence between the various beneficial elements, resulting in a synergy of advantages and making the gardens even more useful [2]. Urbanization involves the sealing of natural soil and therefore affects the hydrological systems, as well as the ecological and pedological ones. The natural hydrologic cycle shifts from an infiltration- and evapotranspiration-based system to a surface runoff dominated system [3]. In contrast, city gardens increase water infiltration and reduce runoff generation and flooding, resulting in a reduced load on the municipal drainage system. They contribute to temperature regulation and energy conservation and to preservation of biological diversity [4,5]. The evolution of urban soils is controlled by the same factors as natural soils, but the human factor imposes extremely rapid transformation cycles in comparison with those dominant under natural conditions [6,7]. Manmade forces are found to be of greater importance in urban soil development than in natural ones [8].

Construction and reconstruction activities release calcareous dust to the urban environment originated from building materials, limestone aggregate for road building, and cement. The dust enriches the soil with calcium and magnesium carbonates, which raise the soil pH level [9]. The above activities involve heavy machinery that compacts the soil by applying pressure on it, manifesting in increased soil density and reducing pore size [8]. Consequently, soil processes such as water infiltration, energy transfer, plant growth, aeration, and organic carbon accumulation are hampered [10–13]. These processes result in a decrease of soil structure, soil moisture [14], hydraulic conductivity [15], soil organic matter content, and vegetation cover [16], whereas pH level increases [17,18]. In contrast, horticulture increases soil organic matter and infiltration, thereby increasing the volume of plant-available water in soil [19].

Activities related to industry, traffic, and agriculture in the city increase the heavy metals in the soil, which threaten the environment [20–25] as well as horticulture [6]. Zn and Cu are used in most commercial metal products and are added during the manufacturing of automobile tires and brakes. Both Pb and Zn have significant emissions from coal fly ash.

Studies on the soil of private gardens in city neighborhoods are rare worldwide. In a study that focused on Arab cities in Israel, social and physical aspects were examined. The social aspect referred to the design of the gardens in terms of structure and inventory, the gardening/care interface, and the social role of the gardens [26]. The physical aspect is presented in the current study. It aimed at investigating the soil properties in the private gardens of two neighborhoods in Taibe city, Israel, which differed in time of establishment. It was hypothesized that: (i) the two neighborhoods differ in their soil properties, and (ii) these differences are modulated by exposure duration of the soil to anthropogenic activities.

2. Materials and Methods

2.1. Study Area

The city of Taibe is located on a hilly area of 100–150 m above sea level in the central district of Israel (N326262 E350089) (Figure 1). The average annual precipitation is 550 mm, which falls from November to April. The coldest month is January, with an average temperature of 14 °C, and the hottest month is August, with an average temperature of 32 °C [27]. The population of the city is 42,400 inhabitants, and the city's jurisdiction area is 18.7 km^2. About 20% of the area is allocated to residential purposes, 10% to industry, commerce and services, and 70% to plantations, field crops, and other open areas. The soils belong to sandy soils type with a predominance of Luvisols (locally known as "Hamra") [28]. The residential area is mainly composed of houses of one or two floors. Taibe was formerly a village, but with the increase in its population, the village was declared a city in 1990.

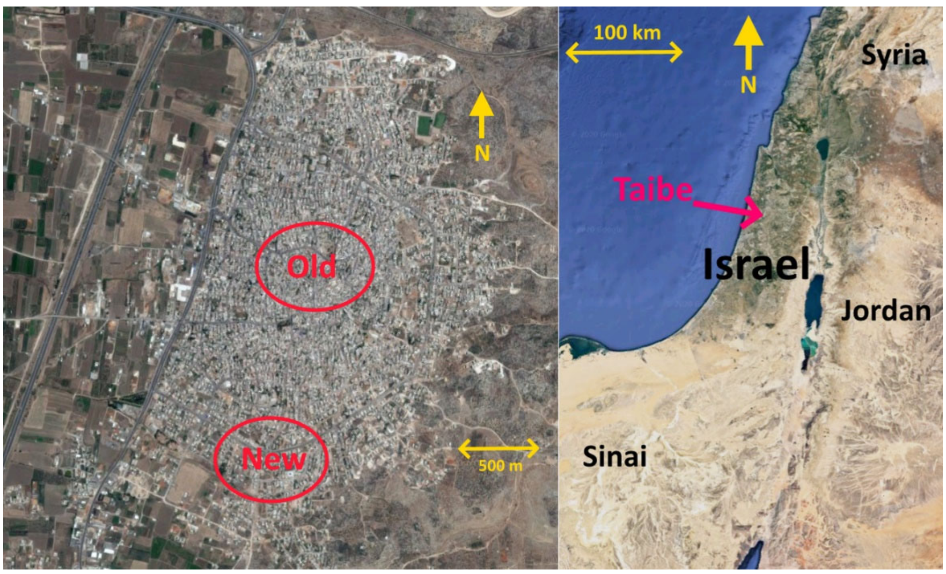

Figure 1. Map of the study site (from Google maps, Imagery ©2022 TerraMetrics, Map data ©2022 Mapa GISrael).

2.2. Field Work

Two neighborhoods in the city, which differed in time of establishment, were selected: an older neighborhood (hereafter ON) constructed more than 70 years ago, and a newer one (hereafter NN) built 10 years ago (https://taibeh.muni.il accessed on 11 January 2022) (Figure 1). In each, fifteen gardens were randomly selected. In each of the gardens, soil was sampled at an open area between trees from a 0.5 m^2 area size at three depths (0–2, 2–10, and 10–30 cm). Sampling was not done under trees to avoid the effect of tree species on soil properties. Altogether, 90 soil samples were taken. The soil sampling was carried out in September 2016. Prior to the sampling, soil compaction, expressed as the penetration depth (PD) of a stick driven into the soil by a 235-g weight falling from a height of 50 cm [29], was determined. Five repetitions were done over an area of 1 m^2, which included the above square area of soil sampling. For each garden, the average of the repetitions represents the penetration depth of the garden.

2.3. Laboratory Methods

For each soil sample, the electrical conductivity (EC) and pH were determined in a 1:1 soil:water (w/w) extract. Electrical conductivity and pH were measured with a conductometer (Cyberscan 510 CON Eutech Instruments, Singapore) and pH-meter (Cyberscan 510 pH, Eutech Instruments, Singapore), respectively. Soil organic carbon was determined by the wet combustion dichromate method [30] using a UV spectrophotometer (SHIMATZU UV1800, Kyoto, Japan). Then, the organic matter was obtained by multiplying the carbon values by 1.724. Soil hygroscopic moisture (SHM) and field water contents (FWC) were determined gravimetrically [31]. Bulk density (BD) and particle size distribution were determined by the clod and sedimentation methods, respectively [32]. Calcium carbonate (CC) was measured with a calcimeter [33,34]. All the soil samples were air-dried and sieved (2-mm sieve) before laboratory analysis.

For each upper soil layer (0–2 cm) heavy metals, lead (Pb), copper (Cu), and zinc (Zn), concentrations were measured in soil extract. Briefly, for the extracting of the metals, 4 g of air-dry soil was mixed with 25 mL of 4 N HNO_3 and left to be digested at 80 °C overnight. Then, the heavy metals concentrations were determined by an Atomic Absorption Spectrophotometer (Perkin-Elmer Model 560, Norwalk, CN, USA) [35].

2.4. Statistical Analysis

The data were subjected to Duncan's multiple range test [36] at P = 0.05 level of significance, to determine for each soil property significant differences between the city neighborhoods and between soil depths. The coefficient of variation (CV) was used to estimate the degree of variation from data series of each property between the neighborhoods and between soil depths. It represents the ratio of the standard deviation to the mean, in percent. In this study, the values of <20%, 20–50%, 50–100%, and >100% were defined as low, medium, high, and very high CVs, respectively. High values indicate heterogeneity and low ones indicate homogeneity.

3. Results

Field observations showed that at the soil sampling area, the herbaceous vegetation cover was 30–50% in the gardens of the old neighborhood (ON), whereas less than 10% cover occupied the soil in the new neighborhood (NN).

Table 1 shows statistical parameters of the studied soil properties at the gardens of the two city neighborhoods. It can be seen that the averages and the medians of EC in all depths and PD in the upper layer decreased from the ON to the NN. For EC, the averages and medians also decreased with increasing depth. In both neighborhoods, the coefficients of variation (CVs) of EC were moderate in all three depths. The CVs of PD were moderate in ON and high in NN. At each of the soil depths, the averages and medians of pH were higher in the NN with respect to the ON (Table 1a).

Table 1. Statistical parameters of different soil properties at the gardens of two city neighborhoods. (**a**) pH, electrical conductivity (EC), and penetration depth (PD); (**b**) bulk density (BD) and calcium carbonate (CC); (**c**) field water content (FWC) and organic matter content (OM); (**d**) hygroscopic soil moisture (HSM). N = 15 for each depth and neighborhood. For each soil property, different capital letters within a column indicate significant differences between neighborhoods, and different small letters within a raw indicate significant differences between depths by Duncan's Multiple Range Test at $P = 0.05$.

(a)

Neighborhood		Soil Property						
		pH			EC (μS/cm)			PD (cm)
		Soil Depth (cm)						
		0–2	2–10	10–30	0–2	2–10	10–30	0–2
Old	Avg.	7.22 Ba	7.21 Aa	7.15 Aa	993 Aa	718 Ab	532 Ab	1.94 A
	Std.	0.41	0.35	0.32	475	432	168	0.8
	CV (%)	5.65	4.86	4.54	48	60	32	42.6
	Med.	7.04	7.15	7.11	849	540	507	1.9
	Max.	8.05	8.18	7.99	1745	1622	965	3.5
	Min.	6.68	6.72	6.74	344	260	316	0.8
New	Avg.	7.45 Aa	7.31 Aa	7.41 Aa	716 Ba	509 Ab	391 Bc	1.55 A
	Std.	0.43	0.37	0.31	163	275	137	1.2
	CV (%)	5.74	5.03	4.15	23	54	35	75.6
	Med.	7.54	7.25	7.37	713	487	339	1.1
	Max.	8.17	8.05	8.13	1012	1035	662	5.0
	Min.	6.63	6.86	6.97	480	169	200	0.5

(b)

Neighborhood		Soil Property					
		BD (g/cm^3)			CC (%)		
		Soil Depth (cm)					
		0–2	2–10	10–30	0–2	2–10	10–30
Old	Avg.	1.49 Ab	1.55 Aab	1.62 Aa	9.68 Ab	10.16 Aab	14.98 Aa
	Std.	0.11	0.15	0.12	6.85	10.98	10.10
	CV (%)	7.16	9.67	7.23	70.81	108.11	67.41
	Med.	1.48	1.56	1.62	6.71	5.16	14.86
	Max.	1.68	1.78	1.85	24.17	41.85	33.08
	Min.	1.31	1.20	1.45	2.45	0.02	1.68
New	Avg.	1.58 Aa	1.63 Aa	1.54 Aa	4.65 Aa	4.18 Aa	4.28 Ba
	Std.	0.12	0.12	0.20	6.34	6.71	7.02
	CV (%)	7.62	7.62	12.77	136.42	160.39	164.08
	Med.	1.60	1.64	1.55	2.79	1.77	2.01
	Max.	1.76	1.86	1.85	24.44	22.64	21.44
	Min.	1.36	1.46	1.19	0.00	0.00	0.00

(c)

Neighborhood		Soil Property					
		FWC (%)			OM (%)		
		Soil Depth (cm)					
		0–2	2–10	10–30	0–2	2–10	10–30
Old	Avg.	7.10 Aa	7.14 Aa	8.58 Aa	2.36 Aa	1.20 Aa	1.13 Aa
	Std.	5.85	4.74	4.59	1.58	0.68	0.50
	CV (%)	82.43	66.35	53.44	67.03	57.09	44.49
	Med.	6.28	7.25	7.06	1.92	1.23	0.99
	Max.	19.56	20.22	16.32	5.98	2.30	2.01
	Min.	0.77	2.28	2.04	0.34	0.25	0.28
New	Avg.	4.96 Aa	6.24 Aa	7.01 Aa	1.15 Ba	0.56 Bb	0.54 Bb
	Std.	4.79	6.65	6.94	0.68	0.40	0.42
	CV (%)	96.57	106.60	99.05	59.63	72.22	79.27
	Med.	3.07	3.17	3.77	0.95	0.40	0.44
	Max.	18.15	26.35	25.23	2.48	1.24	1.51
	Min.	1.28	1.73	2.40	0.24	0.06	0.07

Table 1. *Cont.*

(d)							
Neighborhood		**Soil Property**					
		HSM (%)					
		Soil Depth (cm)					
		0–2		**2–10**		**10–30**	
Old	Avg.	2.19	Aa	1.57	Aa	2.02	Aa
	Std.	2.04		1.74		2.05	
	CV (%)	93.22		110.60		101.83	
	Med.	1.41		0.80		1.21	
	Max.	5.52		6.20		6.15	
	Min.	0.40		0.40		0.20	
New	Avg.	1.45	Aa	1.46	Aa	1.82	Aa
	Std.	0.99		1.76		2.35	
	CV (%)	68.43		120.48		129.10	
	Med.	1.21		1.01		0.40	
	Max.	3.71		6.61		7.44	
	Min.	0.20		0.10		0.20	

The averages and medians of CC at all depths in the old city area were higher than those in the new one. The CV values in the old neighborhood were lower than the new one in all depths. The averages and medians increased with increasing depth in the old neighborhood, whereas in the new one no such trend was seen. The CVs were high and very high in ON and NN, respectively. The averages and medians of BD in the old neighborhood were lower than those in the new one (Table 1b).

The means and medians of the FWC at all three depths were higher in the ON with respect to the NN. In both neighborhoods, average FWC increased with depth. The medians showed similar trend. CVs of both neighborhoods were high.

In the ON, at each depth, the averages and medians of OM were higher than those in the NN. In both neighborhoods, the averages and medians decreased with increasing depth. In general, the CVs of both neighborhoods were high (Table 1c).

The differences in HSM between neighborhoods and depths were very small. The CVs are high to very high (Table 1d).

Table 2 shows that in both the old and new areas, at each of the soil depths, averages and medians of the sand percentage were about four 4 times higher than the combined clay and silt percentages. The CVs of the sand was low for both neighborhoods. The 10–30 cm layer expressed less sand with respect to the upper layers.

Table 2. Statistical parameters of Grain Size Fractions at three soil depths in the gardens of two city neighborhoods. N = 6 for each depth and neighborhood. For each depth, different capital letters within a column indicate significant differences between neighborhoods, and different small letters within a raw indicate significant differences between depths by Duncan's Multiple Range Test at P = 0.05.

Neighborhood		**Grain Size Fractions (%)**							
		Soil Depth 0–2 cm							
		Clay		**Fine Silt**		**Coarse Silt**		**Sand**	
Old	Avg.	8.39	Aa	5.37	Aa	4.33	Aa	81.91	Aab
	Std.	5.40		2.26		4.60		8.40	
	CV (%)	64.33		42.02		106.33		10.26	
	Med.	5.61		5.41		2.40		85.22	
	Max.	17.59		8.62		12.42		91.30	
	Min.	4.66		2.63		1.42		72.73	
New	Avg.	9.57	Aa	3.99	Aa	0.77	Aa	85.68	Aa
	Std.	1.48		3.39		0.64		3.43	
	CV (%)	15.44		84.90		83.91		4.01	
	Med.	9.95		2.46		0.49		86.62	
	Max.	11.08		9.95		1.88		88.89	
	Min.	7.16		1.95		0.24		79.85	

Table 2. *Cont.*

Neighborhood		Grain size fractions (%)							
		Soil Depth 2–10 cm							
		Clay		Fine Silt		Coarse Silt		Sand	
Old	Avg.	8.19	Aa	4.09	Aa	2.35	Aa	85.37	Aa
	Std.	4.26		2.28		1.80		7.38	
	CV (%)	52.09		55.76		76.42		8.64	
	Med.	8.35		3.41		2.02		84.44	
	Max.	13.88		7.13		5.09		95.23	
	Min.	2.78		1.19		0.80		77.55	
New	Avg.	9.81	Aa	1.94	Aa	1.37	Aa	86.88	Aa
	Std.	4.11		0.93		0.66		5.45	
	CV (%)	41.91		47.96		48.53		6.27	
	Med.	8.19		1.74		1.22		89.33	
	Max.	16.82		3.55		2.13		90.73	
	Min.	6.59		1.24		0.74		77.49	
Neighborhood		Grain size fractions (%)							
		Soil Depth 10–30 cm							
		Clay		Fine Silt		Coarse Silt		Sand	
Old	Avg.	10.86	Aa	5.64	Aa	4.55	Aa	78.95	Ab
	Std.	5.73		3.28		2.63		7.37	
	CV (%)	52.76		58.20		57.77		9.34	
	Med.	10.16		4.80		3.80		79.31	
	Max.	19.04		10.10		8.04		86.40	
	Min.	5.00		2.61		2.19		68.04	
New	Avg.	15.20	Aa	3.84	Aa	2.23	Aa	78.73	Aa
	Std.	8.64		5.00		1.65		13.73	
	CV (%)	56.85		130.36		74.19		17.44	
	Med.	18.75		2.00		1.44		78.37	
	Max.	24.70		12.59		4.84		91.77	
	Min.	5.24		0.00		0.98		57.87	

The averages and medians of Pb, Cu, and Zn concentrations were higher in the ON with respect to the new one. Generally, the CVs were high to very high. NN showed greater and smaller CVs of Pb and Zn, respectively, than those of ON (Table 3).

Table 3. Statistical parameters of lead (Pb), copper (Cu), and zinc (Zn) at 0–2 soil depth in the gardens of both city neighborhoods. N = 15 for each metal in each neighborhood. For each soil's heavy metals, different letters indicate significant difference between the neighborhoods by Duncan's multiple range test at $P = 0.05$.

Neighborhood		Heavy Metals (mg/kg Soil)					
		Pb		Cu		Zn	
Old	Avg.	19.7	A	18.8	A	157.9	A
	Std.	13.3		12.1		250.7	
	CV (%)	67.7		64.5		158.7	
	Med.	17.9		14.2		87.5	
	Max.	59.8		48.3		1050.0	
	Min.	7.8		6.0		37.5	
New	Avg.	13.4	A	9.1	B	50.2	A
	Std.	14.9		5.2		18.8	
	CV (%)	111.4		57.0		37.4	
	Med.	9.3		9.1		45.3	
	Max.	61.7		18.9		84.4	
	Min.	6.7		2.9		25.0	

4. Discussion

4.1. Differences between the City Neighborhoods

The two city neighborhoods of the present study differed in the time period passed since their establishment; the old one was constructed over more than 70 years ago and the newer one in the last 10 years. Therefore, the former experienced urban environment, including human activities, for a longer period. Compared to the old neighborhood (ON), the soil of the new neighborhood (NN) expressed lower hygroscopic moisture, field water content, electrical conductivity, organic matter, penetration depth and calcium carbonate, and higher pH (Table 1). The averages of soil properties in each soil layer were not significantly different between the neighborhoods, but rather show trends. The medians reinforce the average trends. Soil properties are closely interrelated and are well understood in terms of the dynamics of plant litter cycling and anthropogenic involvement. The latter affects soil properties via construction and destruction, industry, traffic, and horticulture activities. Early on in the recent decade, NN has undergone severe construction activities that compacted the soil. Compaction led to fewer macropores, those through which roots could generally proliferate readily [37], resulting in fewer plants. Shortly after soil compaction ceased, vegetation re-occupied the area. Presumably, this vegetation would have spread in the following years so that the vegetation cover would have risen and resembled the cover in the ON. Field observations showed lesser herbaceous vegetation cover at the NN than that seen in the ON. The difference is mainly attributed to the nature of performing gardening chores in the neighborhoods. In the gardens of the present study, another study examined the gardening/treatment interface and the social role of the gardens and determined an inventory of each garden's components [38]. They found that compared to the ON, in the NN more gardens are treated by professional gardeners that remove natural herbaceous vegetation; hence small amounts of vegetation residues remain on the soil. In contrast, in the ON, gardening is done by family members who leave most of the natural herbaceous plants in situ, among the ornamental plants. The lower vegetation cover of the NN probably encourages stronger raindrop impact on the soil surface, formation of mechanical crust, soil sealing [38,39], and loss of soil water [40–42]. Both the lower soil water content and lower litter supply limit soil faunal activity of transforming the organic residues into soil organic matter [43]. Hence, OM was lower and BD was higher in NN. This agrees with many authors that found negative relationships between OM and BD [44–47]. To sum up, the anthropogenic activities in the NN drives a causal chain of lower herbaceous production, litter production and soil organic carbon, and greater soil bulk density. The lower OM possibly restricted the FWC values, as absorptive capacity to retain water in the soil depends on OM and clay contents [48]. It is worth noting that the texture of both areas was sandy and similar, so it can't account for the difference in field water content.

OM and CC have an opposite effect on soil pH; increasing OM and CC were associated with decreasing and increasing pH, respectively. OM lowers soil pH by releasing hydrogen ions that were associated with organic anions or by nitrification [49]. The CC reacts with carbon dioxide and water in the soil to yield bicarbonate, which is able to take H^+ and Al^{3+} out of the solution, thereby raising the soil pH. The OM was significantly higher in ON and imposed lower pH in this neighborhood.

There were not distinct differences in spatial heterogeneity of soil properties between neighborhoods. In all layers, in both neighborhoods, pH and BD showed low spatial heterogeneity (CVs up to 13%). In general, higher and similar heterogeneity was found for EC, SM, PD, FWC, and OM in both neighborhoods. In contrast, CC, which is considered as a stable feature, showed CV values 1.5–2 times higher in NN than those in ON, although the average of NN was lower than ON. This means a higher degree of variation in the NN. This might indicate that the gardens of NN did not reach a phase of excessed input (urban calcareous dust) over output (leaching) processes of CC. The longer these processes take place, the higher the possibility of CC urban dust accumulation.

The typical background values in Luvisols are 6 mg kg^{-1} for Pb [50], 10 mg kg^{-1} for Zn [51], and 2 mg kg^{-1} for Cu [52]. These heavy metals are released into the environment due to several factors, such as industry, traffic, and agricultural practices [53–55]. In both neighborhoods of Taibe, the HMs concentrations in the upper soil were higher than their background but far below the permissible values for agricultural and urban areas. Threshold values for soil contaminants in agricultural and for residential use are 100, 250, and 100 mg kg^{-1} and 250, 300, and 150 mg kg^{-1} for Pb, Zn, and Cu, respectively [56]. However, one can see that the soil HMs were lower in NN. The industrial area of Taibe, mainly consisting of car garages, is located 2 and 5 Km south of NN and ON, respectively. Thus, the soil HMs are mostly attributed to traffic rather than to industry. Since the NN establishment, most of the vehicles already used Pb-free gasoline. In contrast, the ON was exposed to emissions of gasoline with Pb for many years before the regulations of the Israeli governmental were installed [50]. The differences in Zn and Cu concentrations between the neighborhoods represent a different duration of exposure to traffic as was explained for Pb in this section. Additionally, the higher Zn and Cu in ON can be attributed to fossil-fuel combustion in Taibe, especially when the city was still a rural village [57] and to longer durations of horticultural practices [6], respectively.

It can be argued that HMs in the neighborhoods are affected by the distance between houses (sink) and roads (source). Previous studies have found that heavy metals in the upper layer were inversely related to the distance from the source [58]. In the ON and NN, most of the gardens are located at a distance of 9–11 m and 10–18 m from the road, respectively. Studies on the change of soil Pb with the distance from the road in Luvisols under similar climatic conditions have shown a negligible impact of the road starting from a distance of 6 m [50]. Therefore, the increase in HMs from the NN to the ON is caused by the age of the soil and can be considered as an indicator of soil age.

In order to get a deep insight into the structure of the values that build the averages of the soil properties, the value distribution of each sub-population was analyzed. It can be seen that for most properties (CC, HSM, EC, OM, PD, FWC, Zn, Pb, Cu) the interquartile intervals in ON are greater than those of the NN, especially in the upper soil depth (Figure 2). This shows that the differences between the neighborhoods are caused by the higher values in the ON compared to the NN. It is expected that in the future, under the prevailing environmental conditions, the NN will develop high values of soil properties. For example, CC in NN will increase because of longer exposure to city calcareous dust, as well as more supply of litter residues that in turn increase OM composition. The increased OM and CC will be accompanied by increasing HMs. Such changes in the future are based on previous studies that found positive relations between HMs and these properties [59]. The OM adsorb metals through ion exchange and specific adsorption [60,61] and calcium carbonate reduces the solubility of heavy metals [62]. This means that under the current conditions of garden care, the soils of both neighborhoods will become similar in a few decades unless a new soil interruption occurs. Interruption such as landslides and volcanic eruption mix the soil profile and destroy the vegetation, thus bringing about a rapid halt to an existing course of soil development.

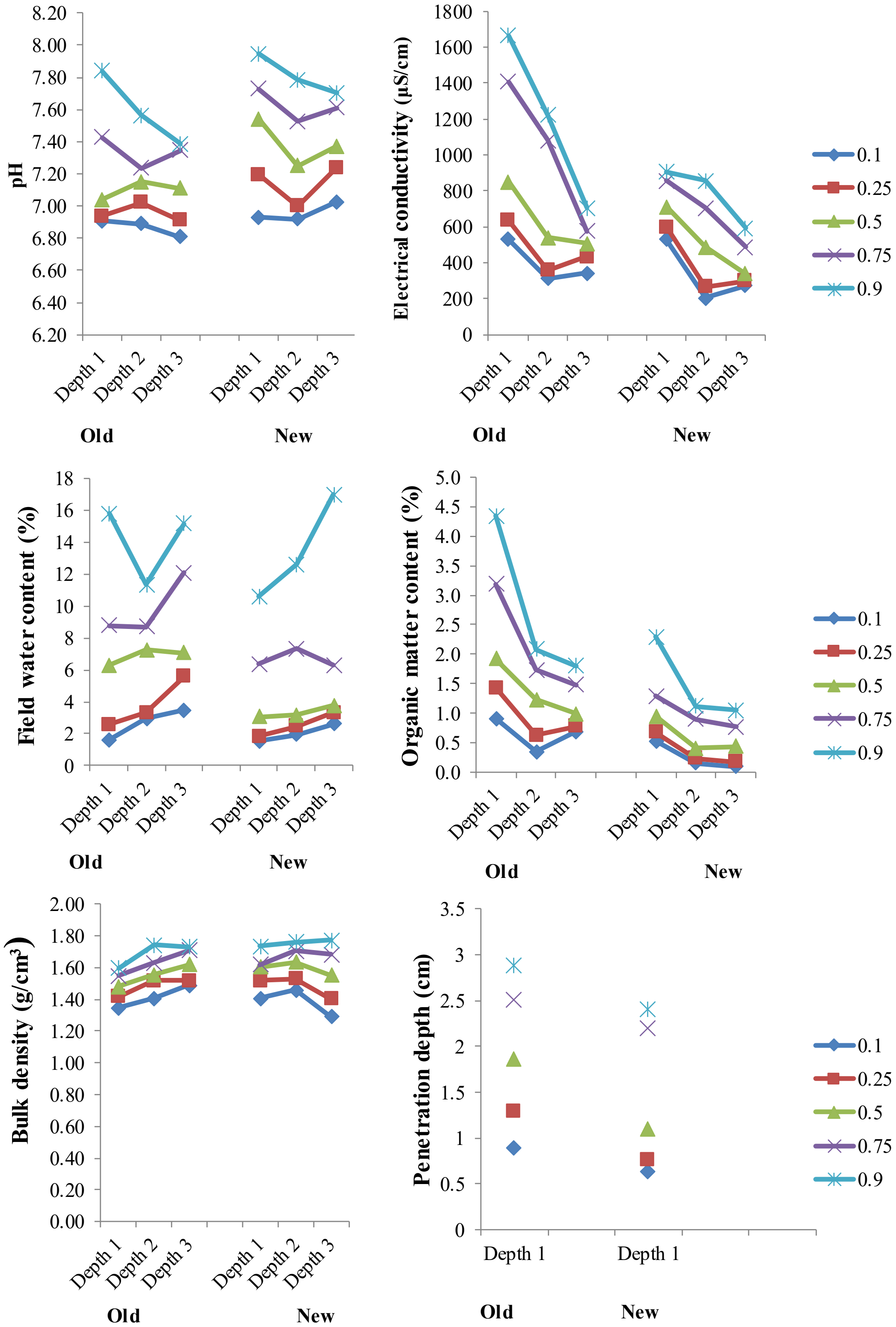

Figure 2. *Cont.*

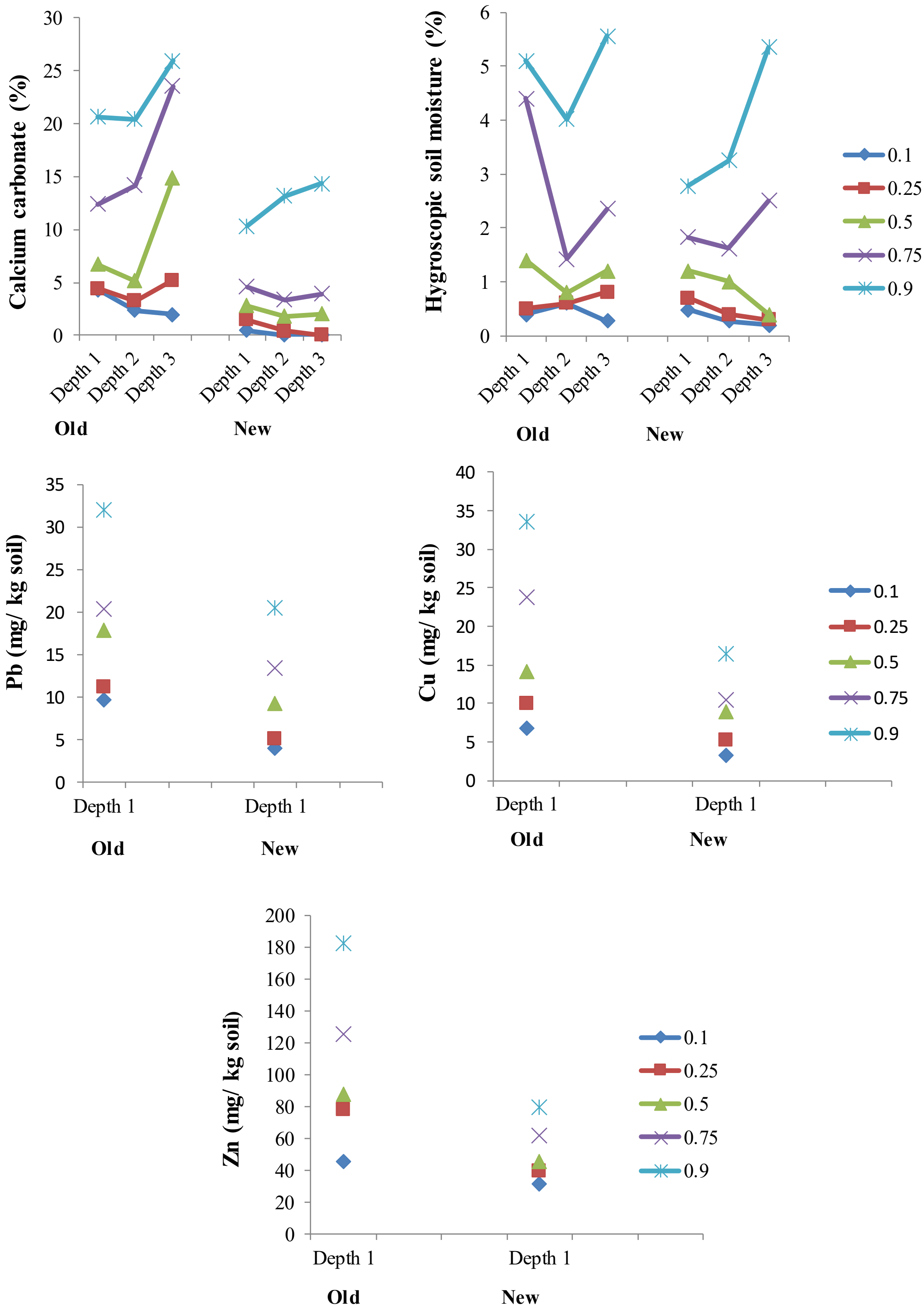

Figure 2. Deciles of soil properties for each neighborhood. EC = electrical conductivity, PD = penetration depth; BD = bulk density, CC = calcium carbonate, FWC = field water content, OM = organic matter, HSM = hygroscopic soil moisture, Pb = lead, Cu = copper, and Zn = zinc.

4.2. Soil Properties Gradients

High temperatures prevail in the study site in the summer. Consequently, water evaporates from the soil, especially from the upper soil layer that borders the atmosphere. Evaporation also enhances the upwards transfer of soluble salts by capillary rise. Thus, the trends of increasing FWC and decreasing EC with increasing depth in both neighborhoods was found. Such a trend was found in studies in natural areas with more than 200 mm annual rainfall [63].

Organic matter decreased with soil depth in both neighborhoods. This is expected because the main source of organic material is the above soil litter, which is transformed into OM. However, in the ON, the OM gradient was more intense and sharper. BD showed an opposite trend for reasons explained in Section 4.1. As a result, the hydraulic connectivity was better in the upper layer and encouraged downwards leaching of CC. This is clearly seen in the increasing CC with depth in ON. In NN, neither the BD nor the CC showed clear trends.

To summarize, the ON is characterized by a mature soil profile in which gradients of many soil properties can be seen, providing a clear distinction between the soil layers. In contrast, in the NN, the soil profile is young and change with depth may be observed based on OM alone, whereas the other properties have yet to develop a clear visible change.

4.3. Urban Soil Development

Pedogenic processes are classically defined by pedologists as the soil forming processes of weathering, organic matter breakdown, translocation, and accumulation [64]. Yaalon and Yaron [65] proposed the use of the term "metapedogenesis" to differentiate natural pedogenic processes from human-induced processes. Effland and Pouyat [66] proposed a conceptual model for urban soil development that was a modified version of Yaalon and Yaron's one. In brief, the model suggests that urban soil can be developed in different directions. The direction depends on the length of time that metapedogenic processes occur. Pedogenesis begins when the parent material is exposed to environmental conditions that promote natural soil formation, whereas metapedogenesis begins when humans become a factor in soil genesis. When the soil profile is rapidly disturbed, soil genesis begins at a new time zero. If such a disturbance is episodic, then pedogenic processes can again dominate and a natural profile becomes reestablished. At time scales such as natural soil formation, metapedogenesis is likely to work in combination with pedogenic processes, and thus are interdependent, resulting in less conspicuous changes in soil properties.

One can ask whether the soils in the gardens of Taibe express specific pathways of Effland and Pouyat's model. A natural soil profile, which represents pedogenesis, is absent in the vicinity of Taibe due to many years of agricultural use.

In the NN, metapedogenesis began 10 years earlier when manual and/or machinery work mixed the natural soil profile, destroyed the natural vegetation and compacted the soil. However, this was not a short episode of soil disturbance followed by pedogenesis, rather a continuous period of human intervention. The soil of the NN underwent human activities, horticultural/gardening, and recreational works (e.g., planting, hoeing, and food consumption), which resulted in the breakdown of organic residues and accumulation of organic matter in the upper soil layer. Nevertheless, the short time of active metapedogenic processes revived low structures, organic matter content, and calcareous carbonate with respect to the ON. The ON represents a longer time of metapedogenesis in which the soil recovered from the initial interruption that took place over more than 70 years earlier. A long duration of human-induced activities enabled the following processes and accelerated them. Compared to the NN, the ON experienced more cycles of irrigation resulting in a greater number of wet and dry cycles. Long durations of supplying organic residues, water, and calcareous dust enabled more net organic matter composition and calcium carbonate accumulation, alongside less bulk density. The higher organic matter, CC and HMs, indicates that the soils of the ON developed a specific soil profile that can be seen as mature urban soil with respect to that of the NN. At time scales such as natural soil formation, metapedogenesis is likely to work in combination with pedogenic processes, and thus they are interdependent. Consequently, the soil profiles in the NN will become similar to those in the ON, and their soils will be characterized with less conspicuous changes in soil properties.

5. Conclusions

It is possible to identify the soils of the NN neighborhoods as recently disruptive soils. Comparison of these soils to those of the ON shows the recovery potential of the former soils within a few to several decades. This means that the soil properties of the NN will change/develop towards the current level of properties in the soils of the ON.

The differences in the heavy metal concentrations within the city are related to anthropogenic activities and their duration.

Calcium carbonate, organic matter, and heavy metals can be used as indicators of soil maturity in city areas, which are under similar environmental conditions, such as climate, texture, and distance from industrial areas. Moreover, in old city areas, soil profiles with these properties can be helpful in understanding the history of the anthropogenic activities in the environment.

Author Contributions: Conceptualization, P.S.; Formal analysis, H.Z. and A.G.F.; Investigation, S.H.-Y. and E.S.; Methodology, P.S. and H.Z.; Writing—original draft, P.S.; Writing—review & editing, P.S. and E.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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