Urban Soil Properties as Affected by Land Use Units and Socio-economic Levels: The Case of the City of Tel-Aviv, Israel

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Over 50 percent of the world's population lives in urban areas and affect soil properties. The aim of this study was to analyze soil properties in various urban open land use units (LUU) in two neighborhoods that differ in their socio-economic levels (High and Low). Four types of LUU (municipal parks, private gardens, derelict areas and traffic islands) with four replicas for each LUU were chosen in each neighborhood. Organic matter content, soil moisture and pH at two depths of soil (0-2 cm and 5-10 cm) and soil surface compaction by penetration depth were analyzed. Results indicate that "urbanization footprint" was significantly represented by the upper soil layer. Urbanization led to increase of organic matter and water content in the sandy soil relatively to undisturbed sandy soil that was observed at an adjacent national park. The anthropogenic impact on soil within the urban system is correlated with the socio-economic level of the neighborhood. A low socio-economic level led to a decrease in the variability of soil properties, and thus restricted the urban ecosystems' heterogeneity.

Keywords: *Urban soil; Organic matter; Penetration depth; pH; Soil moisture; Spatial heterogeneity.*

The traditional paradigm of soil formation is related to ecological factors (Jenny, 1941). However, anthropogenic impacts are not a less important factor in affecting soil structure, characteristics and pedogenetic processes (Singer and Warkentine, 1996; Yaalon, 1997). A good example for such effects on soils is urban areas.

Over 50 percent of the world's population live in urban areas with a density that ranges between an average of 3,100 (high income society) and 9,200 (middle and low income society) people per square kilometer, which is 2.74 and 8.17 times greater than the average density in the urban regions of the USA respectively (Demographia, 2000). These facts require special consideration regarding the urban

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ecosystems that have developed in view of open rural spaces. Soil is one of the significant elements of urban ecosystems that reflects the spatial and temporal impacts of man (Aey, 1990; McDonell and Pickett, 1990; Sukopp, 2004). Despite the importance of this issue, few studies have examined the impact of man on soil properties and processes within urban regions (Sukopp et al., 1979; Effland and Pouyat, 1997; Jim, 1998b; Sukopp, 2004).

The quality and quantity of organic soil matter varies spatially and temporally in urban areas (Beyer et al., 1995; Pouyat et al., 2002; Scharenbroch et al., 2005). The quantity can be higher in comparison with the adjacent natural open spaces (Blume, 1989; Zheveleva et al., 1989; Schleus et al., 1998), but it can also be lower due to the impact of trampling (Jim, 1987, 1998a). Similarly, pH values are high due to urban dust deposits enriched with calcium and magnesium carbonates, sodium chlorides and/or other anti-frost reagents (Jim, 1998b; Alexandrovskaya and Alexandrovskiy, 2000; Sukopp, 2004), as well as the influence of trampling (Kutiel et al., 2000; Andres-Abellan et al., 2005), which both cause soil alkalinity. However, the pH can also be lower due to acidified precipitations (Blume, 1989; Meshcheryakov et al., 2005). Soil moisture and water regime are also altered in urban regions as a result of a lowered water table, asphalt cover (Sukopp et al., 1979; Blume, 1989) and trampling impacts, which decrease soil moisture (Dotzenko et al., 1967; Kutiel et al., 2000). In addition soil surface compaction (Blume, 1989; Jim, 1993) and bulk density (Jim, 1998a, b) are higher in urban soils, which as a whole, lead to urban soil degradation (Jim, 1993, 1998b). In all cases anthropogenic impacts on soil properties are mainly expressed in the upper soil layer (10 cm) (Beyer et al., 1995; Sharenbroch et al., 2005; Sarah and Zhevelev, 2007; Zhao et al., 2007), which interacts and responds directly to the various stresses that occur on the soil's surface (Sarah, 2001; Zhevelev and Sarah, 2002; Zvikel et all., 2007).

Most of the above mentioned soil properties were studied in detail, particularly in rural areas (Dotzenko et al., 1967; Kuss, 1986; Marion and Cole, 1996; Kutiel and Zhevelev, 2001; Andres-Abellan et al., 2005). However, they have been investigated in a very limited manner in urban areas.

The contrast of spatial variations in soil properties within the urban area are due to the existence of various land use units (LUU) (Blume, 1989; Zheveleva et al., 1989; Beyer et al., 1995, 2001; Pouyat et al., 2002; Lorenz and Kandeler, 2005; Scharenbroch et al., 2005; Zhao et al., 2007). This term was used by Blume (1989) to define different functional elements in the urban area.

The socio-economic situation may also affect soil properties within urban systems. Although this issue was not investigated yet, it was shown that this factor affects the properties of urban green spaces (Martin et al., 2004; Pauleit et al., 2005; Ellis et al., 2006). Higher socio-economic neighborhoods were found to be characterized by large green spaces with diverse and better managed vegetation as compared to lower socio-economic neighborhoods.

The aim of this study was to analyze soil properties in various urban land use units in the city of Tel-Aviv, Israel, in relation to higher and lower socio-economic conditions. We hypothesize that low socio-economic conditions, which can be considered as the equivalent to high population density, and thus having high trampling pressures, absence of sufficient economic income and deficient management activities of the open urban areas, are followed by significant soil degradation. We focused on two questions: whether socio-economic levels affect soil properties differently at various LUU, and how much they differ from those found in adjacent less disturbed areas.

STUDY AREA

The study was conducted in the city of Tel-Aviv, Israel between 2008-2009 (N 32° 05', E 34° 45') that is located on the Mediterranean coast. The population in this 51.76 km^2 area of municipal jurisdiction is approximately 358,800 people (i.e. an average of 6,932 inhabitants per square kilometer). The predominate soil is Typic Xerochrept (locally known as "Hamra") formed from coastal sand and calcareous sandstone (Koyumdjisky et al., 1988). This soil is low in organic matter (<1%), slightly acidic to neutral pH (7-8) and low in CEC (up to 4 meq/100 g soil). The soil contains negligible percentages of clay (up to 5 %) and silt (<4 %); it is predominantly sand (> 90 %).

Table 1: Socio-economic characteristics of studied neighborhoods

Characteristic	High	Low
No. of municipal parks	28	17
Total municipal parks area (ha)	25.5	5.1
Average area per municipal park (ha)	0.91	0.3
Average Number of residents per ha	1,745	4925
Average park area per resident	0.00057	0.0002
Average apartment area (m^2)	133.4	65.5
Private car owners (%)	77.3	27.1
Computer owners (%)	46.4	10
Socio-economic Index	1.5	0.62

Note: High: High socio-economic level of neighborhood.
Low: Low socio-economic level of neighborhood.
Source: Statistical yearbook, Tel-Aviv-Yafo Municipality, the Center for Economic and Social Research, No. 42. 2002.

The climate in Tel Aviv is humid Mediterranean with rains falling between November and May. The mean annual precipitation is 530 mm, and temperatures range between 30.2 ° C (August) and 9.6 ° C (January).

Two neighborhoods were chosen in the city of Tel-Aviv that differ mainly in their socio-economic levels, based on the data supplied by the statistical yearbook of the city (Table 1). These neighborhoods will be further referred to as the Higher Socio-Economic Neighborhood (High), and the Lower Socio-Economic Neighborhood (Low).

MATERIALS AND METHODS

In each neighborhood we selected four representative types of urban land use units (LUU): municipal parks (MP), private gardens (PG), derelict areas (DA) – open and unmanaged areas, and traffic islands (TI) – open narrow green strips between roads. Each type of LUU included four replicas. Soil was sampled at the spring season.

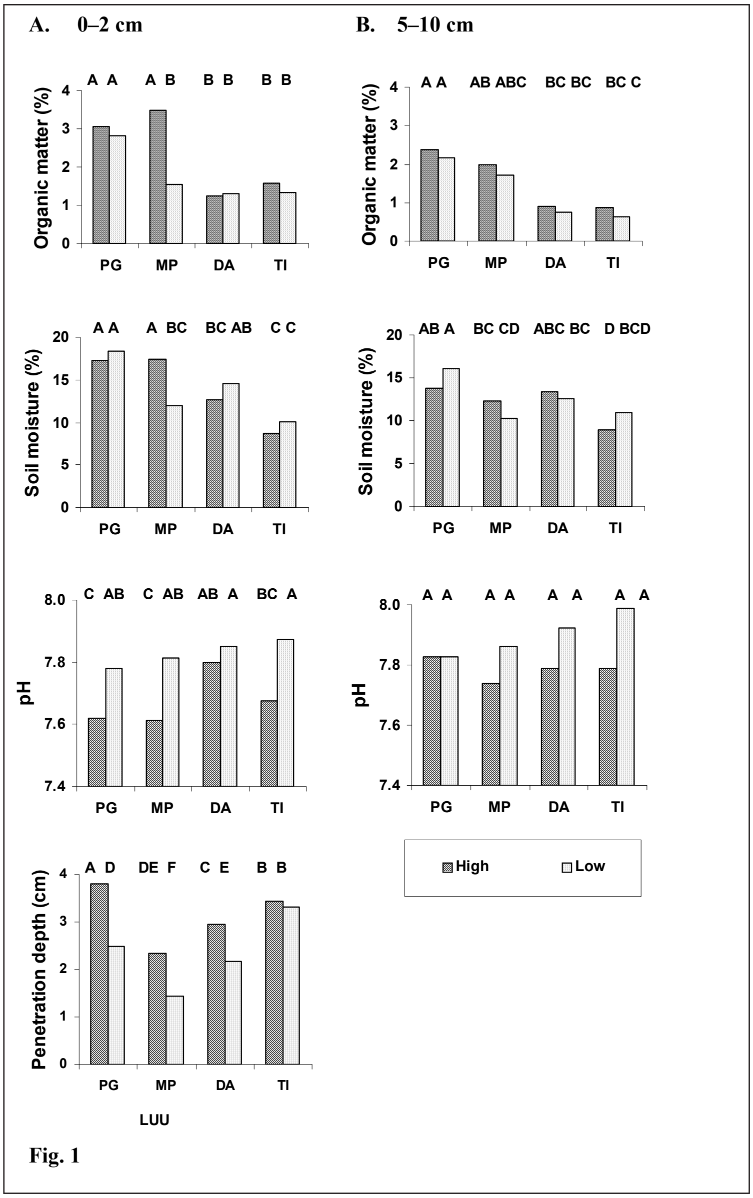
Four soil samples from a depth of 0-2 cm (after removal of the litter layer) and two samples from a depth of 5-10 cm were collected from each replica (24 samples for each LUU in each neighborhood). All 192 soil samples were analyzed for content of organic matter in the soil by using the wet combustion dichromate method (Rowell, 1994), pH (in water solution 1:1) and soil moisture using the gravimetric method. Soil surface compaction was determined by thrusting a stick into the soil. This penetration was done by means of having a weight (235 g) dropped onto the stick (from 50 cm above it) towards its base (Karpachevsky et al., 1980; Meshalkina et al., 1995; Sarah and Zhevelev, 2007). Twenty random measurements were made for each replica.

The differences between averages were statistically analyzed by Duncan's Multiple Range Test at α=0.05 significance level. The significance of correlations between the different soil properties was determined by the Pearson coefficient. Hierarchical cluster analysis by Ward's method with Euclidian distance without data transformation was performed for identification of the groups with similar LUU types.

RESULTS

The content of organic matter in the soil was higher in both soil layers (2-3%) in the private gardens of both neighborhoods as compared to other land use units (Figure 1). However, the greater difference, as well as the significant one between the two neighborhoods, was found in the upper soil layer of the municipal parks: organic matter content in the High was almost three times higher than in the Low. Non-significant differences were found between the two neighborhoods concerning all other land uses.

Figure 1: Averages of soil properties at different Land Use Units (LUU) in depths: 0–2 cm (A) and 5–10 cm (B)



Note: PG: private garden; MP: municipal park; DA: derelict area; TI: traffic island.

Different letters indicate significant differences between averages. Duncan's Multiple Range Test with α=0.05.

High and Low: High and Low socio-economic level of neighborhood, respectively.

Soil moisture content (9%-18%) revealed nearly the same pattern as for the organic matter. The correlation between both moisture and organic matter contents is very high and significant, especially for the upper soil layer (Table 2). The significant difference in soil moisture between the two neighborhoods was found in the upper soil layer in the municipal parks: soil moisture was 1.5 times higher in the High than in the Low (Fig. 1A).

Table 2: Coefficients of linear correlation (Pearson test) between different soil properties at two soil depths

	OM1	pH1	SM1	PD	OM2	pH2	SM2
OM1	_	-0.589**	0.809**	0.263	0.751**	-0.200	0.403*
pH1		_	-0.354*	-0.210	-0.415*	0.497**	-0.093
SM1			_	-0.093	0.657**	0.061	0.735**
OM2					_	-0.415*	0.380*
pH2						_	0.181
SM2							_

OM: organic matter; SM: soil moisture; PD: penetration depth; pH

* Significant at the 0.05 level (2-tailed)

** Significant at the 0.01 level (2-tailed)

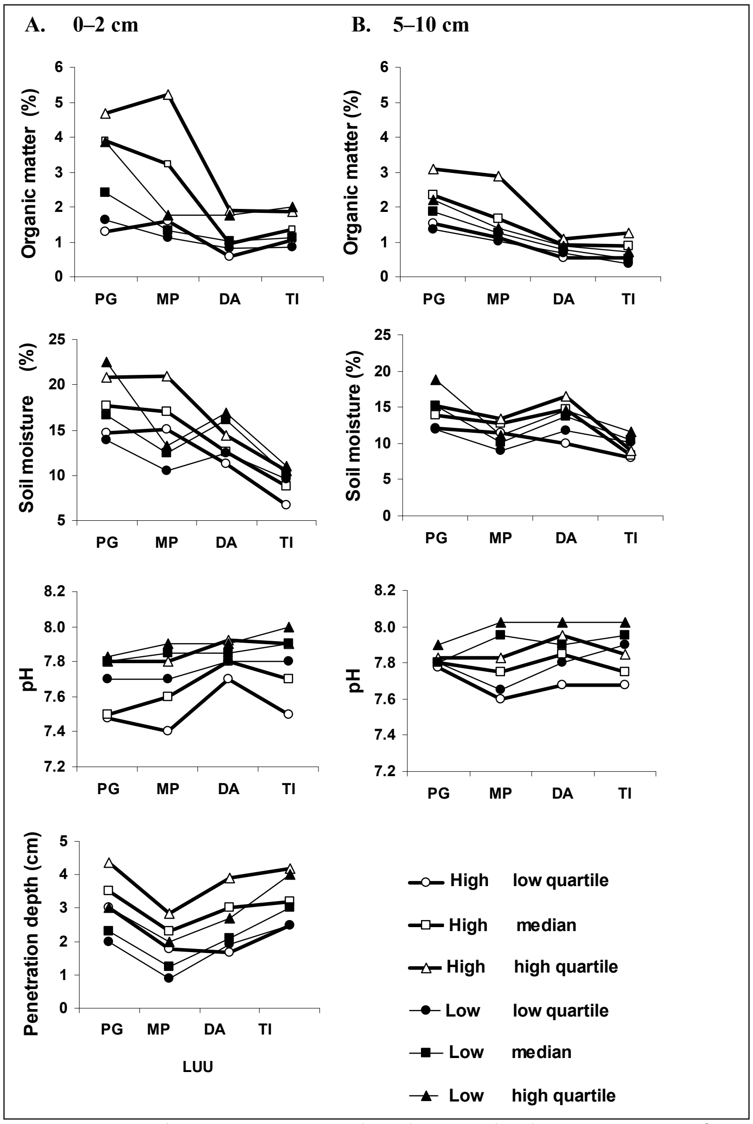
1: 0–2 cm; 2: 5–10 cm.

The pH values ranged between 7.6 and 8. There were differences within this extremely narrow range of values - the pH in the upper soil layer was significantly more alkaline in the Low than in the High in the following LUU: private gardens, municipal parks and traffic islands (Figure 1A).

Penetration depths (1.5-3.8 cm) were found to be significantly higher in all LUU in the High than in the Low, except for the traffic islands. Likewise, lower values were obtained for both neighborhoods in the municipal parks (Figure 1A).

Data analysis based on percentiles of the observed values for the soil properties, supports an indication for the variability level in each LUU as compared between the two neighborhood types, and was reflected by inter quartiles interval (Figure 2). Variability level of organic matter content in the upper soil layer in the private gardens and mainly in the municipal parks located in the High were higher than that in the Low. However, private gardens in the Low also showed a high variability as compared to the other LUU in this neighborhood type. Similar trends were obtained for the lower soil depths of both neighborhoods (Figure 2B). Variability was small and especially obvious in the Low.

Figure 2: Distribution of soil properties at different Land Use Units (LUU) in depths: 0–2 cm (A) and 5–10 cm (B), as expressed by various percentiles



PG: private garden; MP: municipal park; DA: derelict area; TI: traffic island. High and Low: High and Low socio-economic level of neighborhood, respectively.

Soil moisture also showed a high variability in both neighborhoods for the upper soil layer in the private gardens. Furthermore, a high variability was found for the same soil layer in the municipal parks in the High. The trends obtained for the lower soil layer were similar in the Low, but with much smaller variability. However, the highest variability for the lower soil layer was obtained in the derelict areas of the High (Figure 2B).

The pH trends obtained for the upper soil layer of both neighborhoods were similar; still variability was higher in the High. On the other hand, in the lower soil layer variability was generally higher in the Low than those in the upper soil layer and particularly obvious in the municipal parks. The variability level in the lower soil layer in the High was smaller than those in the upper layer and again much higher in the municipal parks and the derelict areas as compared to the other LUU (Figure 2).

The penetration variability was found to be high in the derelict areas in the High where in all other LUU variability levels were similar. The variability levels in the Low were similar in all LUU (Figure 2A).

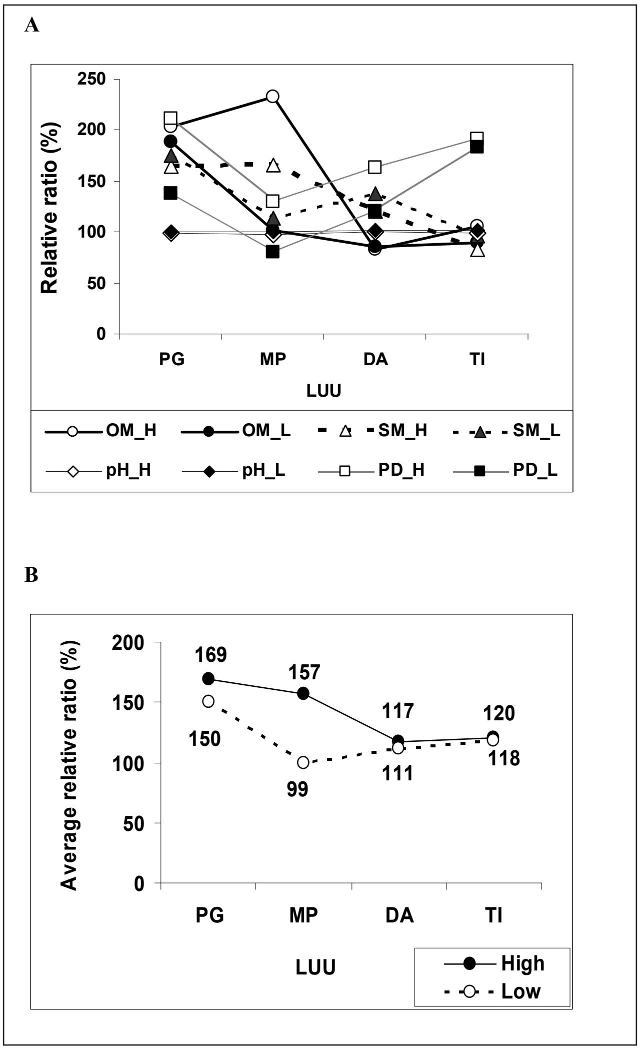
Our results were compared with those obtained in another study, conducted at the Ha'Sharon National Park adjacent to Tel-Aviv that has the same soil type (1.5 % of organic matter, 10.5 % of soil moisture, pH ~7.75 and 1.8 cm of penetration depth; Kutiel et al., 2000). The average value for each soil property was transformed into a percentage of the average value of the same property at the national park, and was represented as a "Relative Ratio" for each LUU (Figure 3A). This comparison indicates the differences between the urban and the semi-natural ecosystem as well as the differences between the two types of neighborhoods.

The organic matter content in the private gardens of both neighborhoods was almost twice that of the national park. However, the organic matter in the municipal parks in the Low was similar to that of the national park, while in the High the municipal parks were more than twice that of the national park. The organic matter in other LUU for both neighborhoods was similar to that of the national park. The remarkable difference between the two neighborhoods was again obtained for the municipal parks (Figure 3A).

Soil moisture showed very similar trends as that of the organic matter. It was roughly 1.6 times higher in the private gardens in both neighborhoods and in the municipal parks of the High when compared to the national park. Soil moisture in other LUU for both neighborhoods was almost similar to that in the national park. The remarkable difference between the two neighborhoods was where the soil moisture found in the municipal park was higher in the High (Figure 3A).

In all LUU of both neighborhoods the pH was found to be similar to that of the national park (Figure 3A). Penetration depths in all LUU, except for the municipal parks of the Low, were higher than that of the national park (Figure 3A). However, the values obtained for all LUU, except for the traffic islands, in the High were higher than those in the Low.

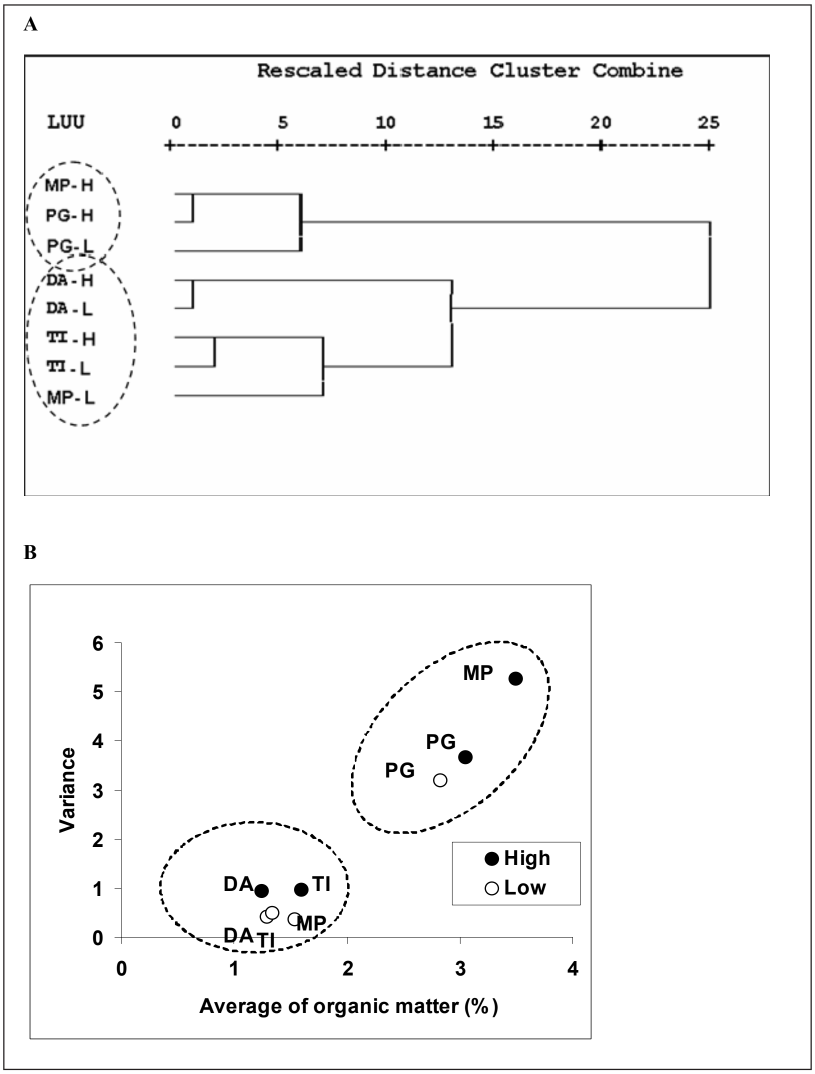
Figure 3: Soil properties relative ratio between each Land Use Units (LUU) and an adjacent national park (A), and average of the entire relative ratios for all soil properties for each LUU (B)



PG: private garden; MP: municipal park; DA: derelict area; TI: traffic island. H/High and L/Low: High and Low socio-economic level of neighborhood, respectively.

All the relative ratio values that were obtained for all properties were averaged per LUU. This was done in order to obtain one integrated number that evaluates the soil at each LUU, and indicates the difference between LUUs and the national park, and between the two neighborhoods (Figure 3B). The values obtained were either almost identical to the national park values (for instance, close to 100%, in the municipal parks at Low) or higher (>100%, such as in the private gardens of both neighborhoods). Likewise, the highest difference between the two neighborhoods was particularly distinct in the municipal parks (Figure 3B).

Figure 4: Dendrogram of hierarchical cluster analysis of urban Land Use Units (LUU) (Ward Method, using average linkage between groups) (A), and variance of organic matter as a function of the average at various LUU (B)



PG: private garden; MP: municipal park; DA: derelict area; TI: traffic island.
H and L: High and Low socio-economic level of neighborhood, respectively.

Hierarchical cluster analysis was performed for the entire complex of soil properties that were found in all types of LUU (averages of all soil properties for the two depths) (Figure 4A). Two main sub-clusters were identified: (1) private gardens of both neighborhoods and municipal parks in the High, and (2) derelict areas and traffic islands of both neighborhoods, and municipal parks in the Low. A similar result was obtained for the relationships between the average organic matter content and the variance for the upper soil for each LUU (Figure 4B).

DISCUSSION

Open spaces are a very important component within urban ecosystems (Jim, 1987; Chiesura, 2004; Pauleit et al., 2005; Jim and Chen, 2006), thus their planning, conservation and management policies are particularly crucial for urban environment optimization (Thompson, 2002; Pickett et al., 2004). One of the indicators of an ecosystem's health is its soil properties (Aey, 1990; Sukopp, 2004); some of them, such as organic matter, express long term soil processes (Tisdall and Oades, 1982; Lavee et al., 1996, 1998; Craswell and Lefroy, 2001).

Our study attempted to evaluate the anthropogenic impact as affected by the socio-economic level of an urban population on soil characteristics at various types of urban open spaces. Four soil properties were analyzed. Two of them, pH and soil compaction, showed significant considerable differences between the Low and High neighborhoods independent of LUU type (Figure 1). This indicates the direct impact of the socio-economic situation of the neighborhood on soil. However, the other two, organic matter and soil moisture, showed different trends which were dependent on the LUU type. This fact, therefore, indicates the indirect effect of the socio-economic situation of the neighborhoods.

The differences in the pH between the two neighborhoods were found in all LUUs. We relate it to higher building density in the Low, which increases the urban dust deposits and leads to more soil alkalinity (Zheveleva et al., 1989; Jim, 1998b; Alexandrovskaya and Alexandrovskiy, 2000; Sukopp, 2004). The fact that the changes in pH between High and Low neighborhoods were systematically the same regardless of any relation to LUU type indicates the homogeneous deposition of urban dust as related to building density is the main factor affecting pH at all LUU (Figures 1, 2).

Penetration depth was also much higher in the High (except for the traffic islands) than in the Low, i.e. the soil in the Low was more compacted in all LUUs (Figure 1). This may be a result of high trampling impacts (Dotzenko et al., 1967; Kutiel et al., 2000; Andres-Abellan et al., 2005) due to higher population density in the Low and, presumably, the lack of sufficient municipal parks (Table 1).

The highest soil surface compaction in the municipal parks and the lowest in the private gardens in both neighborhoods are due to their different functions: recreation areas, and areas with predominant aesthetic and other objectives, respectively (Sukopp and Werner, 1983; Jim, 1998a; Chiesura, 2004; Smith et al., 2006). Andres-Abellan et al. (2005) found a positive correlation between soil compaction and pH. Therefore, higher soil compaction in the Low may be an additional reason for a systematic increase in the pH.

Soil organic matter and soil moisture are more dependent on the LUU type (Figure 1). Organic matter and soil moisture differ significantly between the two types of neighborhoods only in the case of municipal parks, where they were higher in the High than in the Low. Private gardens in both neighborhoods were very similar in organic matter and soil moisture content. Those gardens are treated and controlled by individuals while municipal parks are under municipality responsibility. In the case of Low, the park's soil properties are affected by trampling pressures and presumably by a lack of sufficient municipal management. In the Low there are 17 public parks and gardens in an area that is only 20% of that in the High. Furthermore, population density in the Low is almost three times that of the High (Table 1).

In addition, the average apartment area of the Low is more than 50% smaller than that of the High. We assume that in semi-arid countries, such as Israel, people (and primarily children) who live in small apartments tend to spend most of their time outdoors. A study conducted in Turkey (Erkip, 1997) showed that children of poor neighborhoods spend more time playing outdoors in the parks than children of rich neighborhoods. We also assume that the people who live in the Low have less money to invest and, therefore, less power in order to convince the municipalities to develop more gardens and to manage them properly (Erkip, 1997), contrary to those who live in the High (Ellis et al., 2006).

These two properties - soil moisture and especially the organic matter - were the main features that dictated the two obtained sub-clusters: municipal parks of the High together with the private gardens of both neighborhoods as one cluster, and municipal parks in the Low together with derelict areas and traffic islands as the second sub-cluster (Figure 4).

High spatial heterogeneity of organic matter content (~0.8-5.3%) and soil moisture (~7-23%) was expressed by the significant differences between the various LUUs and by a wide inter quartile interval (Fig. 2). A similar trend was obtained in other studies regarding urban areas (Zheveleva et al., 1989; Schleus et al., 1998; Scharenbroch et al., 2005; Lorenz et al., 2006), and was explained by the existence of a wide spectrum of functions, constructions, and intensity of urban area usage. A decrease of spatial heterogeneity of soil, as a result of different human disturbance, was described by Kutiel and Zhevelev (2001) and Jim (2003). Sarah and Zhevelev (2007) found that high visitors' pressure increased spatial homogeneity of soil and vegetation characteristics in urban areas. Thus, the potential resilience of disturbed urban ecosystems should be very low (Bengtsson et al., 2003; Alberti and Marzluff, 2004; Fisher et al., 2006). Higher spatial heterogeneity of soil moisture and organic matter content in private gardens (in both High and Low), and in municipal parks (High) relative to other LUUs, and the behavior of pH (in all LUU in High compared to Low), is evidence for the decrease of soil heterogeneity under anthropogenic impacts. The soil features in the Low parks were very homogeneous. Thus, the high sensitivity of soil in municipal parks (by both property values and heterogeneity) makes it the best "key type of LUU" for indicating the socio-economic level at a particular neighborhood.

The comparison between the urban soil characteristics and those found in the adjacent national park showed practically the same trend, in which private gardens and municipal parks express the most remarkable impacts of man on soil (Figure 3A). Organic matter and soil moisture in private gardens (High and Low) and in municipal parks (High) were about twice and even higher than those in the national park. In other LUUs within both neighborhoods pedo-genetic processes did not add nor decrease organic matter or soil moisture relative to the natural baseline level.

The integrated comparison between soil properties in each LUU and the national park indicates that urbanization under semi-arid conditions, characterized by sandy soils that underwent "improvement" of soil properties, at least does not affect the soil properties negatively (Figure 3B). The analysis of the relationship between the studied properties revealed not only the well described significant positive correlation between organic matter and soil moisture (Zwikel et al., 2007) or negative correlation between organic matter and pH (Doichinova et al., 2006) (Table 2), but also the negligible anthropogenic impact on the deeper sandy soil layer (5-10 cm). On the other hand, a high significant positive correlation for the same properties, between the depths, confirmed the horizontal connectivity between the two depths due to soil pedo-genetic processes and their dependence on the urban environments (a fact that is not trivial for urban soils).

CONCLUSION

Urban soils are affected by man's direct impact, such as urban planning, which defines the type and intensity of usage. However, indirect impact is a function of the socio-economic level of an urban population. The main impact on urban soils is expressed in the upper soil layer (0-2 cm). In the case study of the city of Tel Aviv, it was found that urbanization led to an increase in organic matter and soil moisture content as compared to natural conditions existing in an adjacent national park. The maximal increase of these properties was characterized at the private gardens without any significance of the socio-economic level of the neighborhood, and at municipal parks located in the High.

The observed LUUs were divided into two clusters based on their soil properties: (1) private gardens and municipal parks at the High, versus (2) derelict areas and traffic islands at both neighborhood types, together with the municipal parks at Low. The municipal parks were found to be highly dependent on the socio-economic situation. An analysis of soil properties indicated that organic matter and soil moisture contents were significantly lower, and the pH and the compaction level were significantly higher in the municipal parks at the Low than at the High. Likewise, the spatial variability in soil properties at the Low municipal gardens was much lower than that in the High. These results may be based on the fact that in the Low there is a limited municipal park area in relation to its high resident density and high outdoor usage, which resulted in high trampling pressures on the soil as compared to the High. Conversely, soil properties in the private gardens were found to be in the best state relative to other LUUs, regardless of the socio-economic level of their location. Thus, for the improvement of areas characterized by a Low socio-economic level, the main focus for the management of urban soils must be accomplished by standards of municipal parks area optimization.

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