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IMPACTS OF HUMAN ACTIVITIES ON SOIL PHYSICAL PROPERTIES OF URBAN GREEN AREAS: A CASE STUDY IN THESSALONIKI CITY, GREECE

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Abstract: Selected soil physical properties, mainly texture, structure and soil compaction through bulk density and penetration resistance, along with other soil characteristics, were studied in three forested urban parks in the Municipality of Thessaloniki city in order to examine the human impacts on them and the possible management practices. Eight soil profiles and samples from seventeen sites showed that soils are *Technic Anthrosols*, there is lack of natural soil horizons, unnatural stratification, limited soil fauna's activity, loamy texture greatly varied along soil profiles and between them, immature structure, platy type of structure at sites with intense use by visitors or maintenance machinery, weak or moderate grade of structure where sand is dominant and low organic matter content. Soil compaction plays a significant negative role on the growth of urban green as maximum bulk density (BD) values were measured at topsoils and mean penetration resistance (PR) values greater than 3 MPa were recorded close to playgrounds or areas with intense use and trampling, even at 5 cm depths in some cases. Also, high PR values were recorded in all soil profiles below 35 cm depth because of heavy machinery use during earlier earthworks. Suggested management practices include field observations, soil analysis, selection of the proper filling material and minimum use of heavy machinery during reconstruction of parks, as well as improvement of existing soil conditions combined with an increase of organic matter content in order to have functional and ecologically sustainable parks.

Keywords: urban parks, *Technic Anthrosols*, soil compaction, management practices

1. INTRODUCTION

Urban parks and open green spaces are of strategic importance for the quality of life of our increasingly urbanized society. Increasing empirical evidence, in fact, indicates that the presence of natural assets (i.e. urban parks and forests, green belts) and components (i.e. trees, water) in urban contexts contributes to the quality of life in many ways (Chiesura, 2004).

Soil is one of the major factors in urban ecosystems. Urban soils are anthropogenically altered soils characterized by contamination, compaction, soil sealing, as well as deposition, removal, or mixing of technogenic and natural substrates (Nehls & Wessolek, 2011). The soil conditions drastically affect the sustainability of these ecosystems which in turn affects human communities (Reshotkin, 2003). Therefore, there is the need to gather information about this kind of soils as well as the possibilities and the limitations placed by the soil conditions in the landscape design and planting in the urban environment.

Among the general characteristics of urban soils are high heterogeneity (horizontal and vertical), altered physical properties (such as structure, low aeration, compaction), chemical properties (e.g. usually elevated pH, contamination), and biological properties (alterations to the size and diversity of microorganism populations), the man-made and re-deposited natural materials, the changed or newly created soil profile (layers instead of diagnostic horizons) (Penižek & Rohoškova, 2006).

Human activity within cities alters the physical character of soils. With the constant changes and additions made to the urban ecosystem, it is no surprise that soils located within urban areas are unique. The physical characteristics of soils include texture (particle size), bulk density, structure (type of peds), plasticity, permeability, porosity, temperature, and moisture content (Marcotullio et al., 2008).

Soil texture influences plant health by affecting drainage, field capacity and rooting depth; it also contributes significantly to other soil physical characteristics such as compactibility (Gregory et al., 2006; Millward et al., 2011). Soil structure is one criterion of soil quality. It is vulnerable to change by management and degradation processes like compaction and erosion, and its preservation is a key to sustaining soil function. Visual soil structure refers to macromorphological features of soil structure that can be detected and evaluated in the field (Müller, 2011).

Compaction is the process of reduction of the specific volume (or porosity) of a soil (Marcotullio et al., 2008). While soil compaction in agriculture has been intensively studied, there are no systematic studies investigating the extent of compaction in urban ecosystems, despite the repercussions for ecosystem function. Urban areas are the fastest growing land-use type globally, and are often assumed to have highly compacted soils with compromised functionality (Edmondson et al., 2011). In urban parks, soil compaction is usually the result of human traffic and vehicles operated for events and for park maintenance (Millward et al., 2011). Heavily compacted soil has been found in urban parks proximate to paths and roadways (Jim, 1998a,b), sometimes as deep as the first half meter (Toleti, 2011). It is in the upper meter of soil where 90% of tree roots are located (Craul, 1999) and of these the majority of water and nutrient absorbing roots grow even closer to the surface (Millward et al., 2011).

Craul (1992) identified six conditions within urban areas that promote compaction including partial destruction of soil structure and horizon arrangement within the profile, low organic matter content - which acts as an aggregating, structure forming agent - and therefore limited soil organism populations which in turn promote soil structure and increase porosity, elevated soil temperatures which reduce the frequency of complete freeze-thaw cycles thus further preventing the formation of soil structure, the occurrence of various physical activities that take place over a range of moisture conditions destroying plant coverage, leaving the soil surface bare and unprotected while eliminating the binding effect of the plants' roots on the soil particles and, finally, differences in the wetting and drying cycles of the soils.

Bulk density (BD) is the measure to determine the degree of compaction and indicates how closely the soil particles are packed together. Urban soils that have been thoroughly cultivated such as those of allotments and flower beds have BD within the range of 1.0-1.6 g cm^{-3} (Marcotullio et al., 2008). The "ideal" soil for plant growth ranges from 1.45 g cm^{-3} for clays to 1.85 g cm^{-3} for loamy sands (Brady & Weil, 2008). Papamichos (1985) states that in natural soils BD values range between 2.0 g cm^{-3} in the very compacted, sandy clay soils with low organic matter content, and 0.7 g cm^{-3} at topsoils under forestry vegetation. Short et al. (1986) measured BD of 1.25-1.85 g cm^{-3} on the surface horizon and 1.4-2.3 g cm^{-3} at 0.3m depth for open parkland in the Mall of Washington, DC. Craul (1985) found values of 1.52-1.96 g cm^{-3} for subsoils in Central Park, New York City, while Jim (1998b) measured values of 1.6-1.8 g cm^{-3} in parks of Hong-Kong. Simmons & Pope (1987) also reported that root growth was limited when BD increased from 1.40 g cm^{-3} at 1.55 g cm^{-3}. In any case, a direct consequence of these adverse conditions is also the reduced growth of the above ground part of the plants.

Apart from BD, another index of soil compaction which depends on soil strength is the mechanical impedance experienced by roots growing through soil, i.e. penetration resistance (PR). In other words, PR is the resistance of soil's solid phase to its deformation (Bengough & Mullins, 1990). The ability of plant roots to penetrate soil is restricted as soil strength increases (Mason et al., 1988; Hamza & Anderson, 2005) and ceases entirely at 2.5 MPa (Taylor, 1971; Hamza & Anderson, 2005). According to Hakansson et al., (1988), the PR threshold for the root's growth ranges between 2 and 5 MPa, while Bengough & Mullins (1990) state that root elongation stops when PR values range between 0.8 and 5 MPa. Also, according to Raper et al., (1994) PR values greater than 2 MPa are often considered to be root restricting.

Park soils face many problems related to properties and use. This research aimed at studying selected soil physical properties, such as texture, structure, porosity and color, and soil compaction through BD and PR, along with other soil characteristics, in three urban parks in the Municipality of Thessaloniki city. The results can help in gaining knowledge and understanding of the soil status and the effects of human impact after decades of use and maintenance activities. Thus, the final goal is to promote the necessary soil physical conditions for the protection of the so valuable to urban environment parks through the application of the proper management practices.

2. STUDY AREA, MATERIALS AND METHODS

This research was conducted in parks that are located within the administrative boundaries of the Municipality of Thessaloniki. The urban area of Thessaloniki is developed along the northeastern coast of Thermaikos gulf, northern Aegean Sea, and the climate is of Mediterranean type. The area belongs to the vegetation zone of *Quercetalia pubescentis* and especially in the *ostryo-carpinion* subzone and in the *coccifero-carpinetum* growth space (Athanasiadis, 1985). Taking into account the census of 2011 according to which Thessaloniki City (only the central municipality) has 325000 residents and the whole urban fabric has 1.1 million residents, the ratio of green spaces (m^2) per inhabitant is about 2.6 (Matziris, 2011). This ratio ranks Thessaloniki among the European cities with the lowest percentage of green space per inhabitant.

Three forested parks were selected which are of particular importance for the city and its residents: the "Y.M.C.A" park of 60000 m^2 total area, located at the center of the city, the park “Pasha’s Gardens" of 30000 m^2 total area located to the north of the urban fabric and the “Nea Helvetia” park of 40000 m^2 total area, located to the south-east part of the city (Fig. 1). These parks are the largest in size in the Municipality of Thessaloniki after the green spaces of the city’s waterfront that have been totally reconstructed during the last years. According to Matziris (2011) “Y.M.C.A” and “Nea Helvetia” parks are classified as metropolitan parks, their present form has been created about twenty to fifty years ago, they are characterized as mature, i.e. the vegetation is aged and there is need for renovation and redefining of their functional role. On the other hand, “Pasha’s Gardens” is classified as an historical park (parks that surround archaeological sites or highlight historical monuments) and it is next to the byzantine walls of the city. Despite their different characterization, all three of the parks function more or less like neighborhood parks. Their area is divided in a grassy part with small (if any) flower beds and shrubs, a tree covered part that has no other infrastructure, children’s playgrounds, a small open theatre (Y.M.C.A and Nea Helvetia park) and usually a snack bar. There are no defined pathways (except Y.M.C.A park) or special activity areas and the whole grounds are open to everybody.

Eight (8) soil pits were dug up to 100 cm depth and each profile was described and divided into layers according to texture, structure, color and material composition. According to Jim (1998b) banded morphology cannot be characterized as horizons as that has inferences on soil genesis not very applicable to the artificial soils. Therefore the term “layers” is used. The depth of 100 cm was considered adequate for the study of the soil characteristics that affect vegetation as it usually exceeds root depth. For each layer, a composite soil sample was taken from the walls of the pit. A total of thirty two (32) soil samples were taken to the laboratory for analysis (Table 1).

Figure 1. Thessaloniki city and the three studied parks, Pasha’s Gardens, Y.M.C.A and Nea Helvetia (from left to right). The red markers indicate the soil profiles and the yellow ones the sampling sites. (*GoogleEarth*).

Additionally, sixty four (64) disturbed soil samples, one per 20 cm depth, were taken from seventeen (17) sampling sites. The sampling sites were selected in order to ensure full coverage of the spatial distribution of the studied properties.

In each soil profile, morphology and selected physical properties - specifically soil texture and structure, color, BD and porosity - were studied in the field and the laboratory according to standard methods of soil analysis.

The disturbed soil samples were air dried, passed through a 2-mm sieve and assayed for their physicochemical characteristics. Particle size distribution was determined by the pipette method (Gee & Bauder, 1986), organic matter was determined by the Walkley-Black wet combustion method (Nelson & Sommers, 1982) and soil color was determined using the Munsell soil color chart.

The undisturbed soil samples were used for BD and porosity determination. BD was determined as the mass of dry soil per unit bulk volume, the soil being dried at 105°C (Blake & Hartge, 1986) and total porosity (n) was calculated by means of the relation:

$$n = 1 - (BD/D_s)$$

where D_s= soil particle density (~ 2.65 Mg m^{-3}).

All analyses were run in duplicate.

Soil compaction was measured with a portable penetrometer (Eijkelkamp Penetrograph) which shows the actual PR encountered by the roots of plants during their growth in the soil (Randrup & Lichter, 2001). The conical edge of the penetrometer had an angle of 60° and a base of 1cm². This kind of penetrograph is capable of recording resistance up to 5000 kN m^{-2} (= 5 MPa) and 0.80 m soil depth. PR values were recorded on special charts. Measurements were taken adjacent to the eight soil pits, under similar soil water content conditions.

3. RESULTS AND DISCUSSION

3.1. Soil Profiles and Morphology

The morphology of all the soil profiles is characterized by a lack of natural soil horizons; in their place clearly distinct soil strata appear, which were determined on the field and defined as soil layers (Table 1, Fig. 2a,b). At the four soil profiles in the park of Nea Helvetia, three layers were distinctive in the 1st and 2nd profile, while four layers were found in the 3rd and 4th profiles. In the two soil profiles dug in the park of Y.M.C.A, seven layers were found in the 1st profile and four layers in the 2nd. In the park of Pasha's Garden, the 1st profile has four distinct layers and the 2nd profile three.

Most of the soil profiles exhibit homogeneity in terms of the number of soil layers (3 or 4) up to 100 cm depth. The only exception is the 1st soil profile in the park of Y.M.C.A which has seven soil layers. The heterogeneity shown in this profile could be attributed to the fact that at this site there is an artificially elevated surface for its formation large amounts of human transported materials were used.

The boundaries of most soil layers are characterized as "abrupt" (15), there are enough "clear" (10) and less "gradual" (7) (Table 1). The contrast between the layers in terms of their texture and boundaries suggests that these soils were artificially created and have not been given enough time for the pedogenic factors to take effect. The soil material used in the construction (or reconstruction) of parks originates from various sites and from different depths around the urban fabric of Thessaloniki such as road and building excavations and agricultural soils. This fact combined with the random spreading of the soil material during the various earthworks, created the soil layers. Urban parks with a similar history of fillings and soil disturbance, show remarkable discontinuity in the soil profiles (Norra et al., 2008; Pickett & Cadenasso, 2008).

Absence of soil fauna was found in almost all soil horizons. The only fauna's (earthworms) activity was observed in the topsoil of profile 1 in the park of Nea Helvetia, where the presence of organic matter was satisfactory (4.47%). Persistence of layers with abrupt and clear boundaries is an indication of limited soil fauna' s activity which has the ability to mix soil from different depths and to eliminate the abrupt soil horizons' boundaries formed from earthworks during the construction of a park. This harsh soil environment has not been conducive to the normal growth of soil fauna, allowing the initial state of synthetic stratification to be retained (Jim, 1998a,b).

According to Scharenbroch et al., (2005) time is one of the most important factors of soil evolution in urban soils, as the negative effects of the initial disturbance decline and the physical, chemical and biological soil properties are ameliorated.

The same researchers who studied urban soils in Moscow and Washington state that older soils exhibit development processes as compared to younger soils. Other studies (Short et al., 1986; Harris, 1991; Jim, 1998b) also report that a degree of soil evolution and development of the soil profile occurred several decades after the artificial filling with soil material. Soil color provides a visual indication of the soil material's composition, such as organic matter and Fe and Mn compounds (Table 1).

Table 1. Soil profiles characteristics at eight sampling pits.

Park	Soil profile	Soil layers depth (cm)	Soil layers boundaries resolution - topography	Color (dry soil)	Debris from human activities	Vegetation
Nea Helvetia	1	0-3 3-16 16-67	abrupt smooth abrupt smooth abrupt wavy	10YR 5/6 10YR 6/6 10YR 6/4	transferred soil*	turf, coniferous trees
	2	0-2 2-12 12-77	abrupt smooth clear wavy clear wavy	7.5YR 5/3 10YR 7/6 2.5YR 8/4	transferred soil	coniferous trees
	3	0-2 2-19 19-37 37-82	abrupt smooth abrupt wavy gradual wavy gradual wavy	7.5YR 4/3 5YR 4/4 7.5YR 6/6 7.5YR 5/6	transferred soil	turf, coniferous trees, shrubs
	4	0-2 2-7 7-33 33-75	abrupt wavy clear wavy gradual wavy gradual wavy	7.5YR 4/4 7.5YR 6/4 10YR 7/4 10YR 8/3	transferred soil	coniferous trees
Y.M.C.A	1	0-2 2-9 9-30 30-37 37-40 40-54 54-85	abrupt smooth clear smooth clear wavy clear wavy abrupt smooth clear smooth clear wavy	10YR 5/4 10YR 7/4 7.5YR 6/4 10YR 5/6 7.5YR 4/4 7.5YR 6/6 10YR 6/3	gravels, bricks (>10%)	turf, coniferous and broad-leaved trees, shrubs
	2	0-3 3-11 11-40 40-85	abrupt smooth abrupt wavy gradual wavy gradual wavy	10YR 6/3 7.5YR 5/4 7.5YR 5/6 10YR 7/6	transferred soil	turf, coniferous and broad-leaved trees, shrubs
Pasha's Gardens	1	0-2 2-12 12-30 30-77	abrupt smooth clear smooth gradual wavy abrupt smooth	10YR 4/6 7.5YR 5/6 7.5YR 6/6 10YR 6/3	gravels, bricks (>10%)	turf, coniferous trees, shrubs
	2	0-3 3-44 44-78	abrupt smooth clear smooth abrupt smooth	7.5YR 4/4 7.5YR 5/6 10YR 6/3	gravels, bricks (>10%)	turf, coniferous trees, shrubs

***** transferred soil (comes from excavation sites and construction material residues constitute more than 10% by volume) was brought in during the initial construction or reconstruction of the park from other areas to level the surface

The existing organic matter is a result of accumulation and, to a lesser degree, decomposition. Periodic removal of organic debris (leaves, branches, grass cuttings etc.) as well as the high soil compaction levels reduce the possibility of enriching the soil with organic matter (Craul, 1999).

Regarding the classification of soils in the studied parks and in accordance with the WRB system described in the FAO World Soil Resources Reports 106 (IUSS Working group WRB, 2014), these can be classified as *Technic Anthrosols*, as they have been modified through human activities, such as addition of mineral or organic material etc., and they have ≥ 10% (by volume, weighted average) debris and construction materials in the upper 100 cm from the soil surface.

3.2. Soil texture and structure

The results of soil texture and structure analysis are presented in Tables 2 and 3. The soil samples belong to the loamy textural class, namely sandy loam (SL), loam (L), silty loam (SiL), sandy clay loam (SCL), silty clay loam (SiCL) and clay loam (CL). The variability that occurs in the texture of soils, both among soil profiles and different layers within a given profile is an indication that there is a variation of soil material used in the construction of green spaces. The differences in texture and the discontinuities along the soil profiles of urban soils are due to the fact that these soils came from fill materials of different sites and characteristics (Stein, 1978; Patterson et al., 1980). The display of horizontal and vertical variation which is one of the characteristics of urban soils, is also present in the studied parks. It is well known that the existence of soil horizons with different texture or structure along the soil profile slows down water infiltration (Hillel, 1980; Panayiotopoulos, 2009) therefore this phenomenon is likely occur at the studied parks.

Regarding the soil structure in the eight soil pits, most of the soil layers (20) had subangular structure, 5 angular, 4 granular and 3 platy structures. In the rest (17) sampling sites, 33 layers had subangular structure, 16 angular, 11 granular and 4 platy structures (Tables 2, 3). In the soil profile samples taken from the sites where intense use and trampling from visitors is taking place, i.e. green areas around playgrounds or pedestrian crossing areas, platy type in surface layers is the prevailing type of soil structure. This was observed in all the studied parks (1st soil profile and 2nd sampling site in the park of Nea Helvetia, 1st soil profile and 7th sampling site in the park of Y.M.C.A, 1st sampling site in the park of Pasha' s Gardens) (Tables 2, 3).

The vertical forces exerted by the visitors on the soil resulted in a counteraction of the soil material converting the original structure to a new type more resistant to the external forces (Harris, 1991). This is accomplished by the repositioning of the soil units and pores perpendicular to the direction of the applied forces. Platy structure in topsoils is referred by Short et al., (1986), Jim (1998b) in studies concerning soil conditions in parks of Washington and Hong-Kong, in which the main type of soil structure is angular. Surface soils in New York Central Park exhibit mainly granular structure and only in a few areas platy structure occurs (Warner & Hanna, 1982). Platy structure was also found in the 1st soil profile and the 2nd sampling site of the Y.M.C.A park at 9-37 cm and 41-60 cm depths, respectively.

Table 2. Soil texture, structure, bulk density and porosity in soil profiles.

Park	**Soil profile**	**Depth of soil layers (cm)**	**Texture**			**Classifica-tion***	**Structure**			**BD (g cm^{-3})**	**n (%)**
			Sand (%)	**Silt (%)**	**Clay (%)**		**Grade**	**Type**	**Class**		
Nea Helvetia	1	0-3	55.61	31.41	12.98	SL	moderate	granular	fine	1.53	42.26
		3-16	55.21	30.63	14.16	SL	moderate	platy	fine	1.51	43.02
		16-67	48.83	24.73	26.44	SCL	moderate	subangular	fine	1.38	47.92
	2	0-2	53.47	35.12	11.41	SL	weak	subangular	very fine	1.54	41.89
		2-12	54.92	32.85	12.23	SL	moderate	subangular	medium	1.49	43.77
		12-77	36.31	43.11	20.58	L	moderate	angular	medium	1.35	49.06
	3	0-2	54.69	27.79	17.52	SL	moderate	subangular	fine	1.48	44.15
		2-19	62.04	20.86	17.10	SL	strong	angular	fine	1.33	49.81
		19-37	43.30	30.16	26.54	L	strong	subangular	medium	1.36	48.68
		37-82	48.56	28.90	22.54	L	moderate	subangular	coarse	1.38	47.92
	4	0-2	56.77	34.24	8.99	SL	weak	granular	fine	1.59	40.00
		2-7	59.87	29.46	10.67	SL	weak	subangular	medium	1.52	42.64
		7-33	52.79	34.59	12.62	L	moderate	angular	medium	1.41	46.79
		33-75	52.51	32.98	14.51	L	moderate	subangular	medium	1.43	46.04
Y.M.C.A	1	0-2	51.44	32.81	15.75	L	moderate	subangular	very fine	1.56	41.13
		2-9	54.20	29.25	16.55	SL	moderate	subangular	medium	1.52	42.64
		9-30	41.04	47.24	11.72	L	moderate	platy	coarse	1.71	35.47
		30-37	37.09	51.20	11.71	SiL	moderate	platy	coarse	1.74	34.34
		37-40	50.64	36.95	12.43	L	weak	granular	medium	1.42	46.42
		40-54	51.25	38.30	10.45	SL	weak	subangular	very fine	1.34	49.43
		54-85	62.63	23.96	13.41	SL	weak	subangular	medium	1.38	47.92
	2	0-3	61.03	21.07	17.90	SL	moderate	subangular	fine	1.62	38.87
		3-11	52.71	27.87	19.42	SL	strong	angular	medium	1.57	40.75
		11-40	37.42	38.11	24.47	L	moderate	angular	medium	1.49	43.77
		40-85	58.65	26.87	14.48	SL	moderate	subangular	fine	1.36	48.68
Pasha's Gardens	1	0-2	43.36	33.62	23.02	L	weak	granular	very fine	1.53	42.26
		2-12	40.38	35.01	24.61	L	moderate	subangular	coarse	1.40	47.17
		12-30	42.52	36.95	20.53	L	moderate	subangular	medium	1.38	47.92
		30-77	70.58	18.91	10.51	SL	weak	subangular	very fine	1.28	51.70
	2	0-3	48.69	30.00	21.31	L	moderate	subangular	very fine	1.51	43.02
		3-44	56.59	26.90	16.51	SL	moderate	subangular	fine	1.42	46.42
		44-78	76.80	12.77	10.43	LS	weak	subangular	very fine	1.26	52.45

***** SL = sandy loam, SCL = sandy clay loam, L = loam, SiL = silty loam, LS = loamy sand

Table 3. Soil texture, structure and organic matter in sampling sites.

Park	Sampling sites	Depth (cm)	Texture			Classification*	Structure			O.M. (%)
			Sand (%)	Silt (%)	Clay (%)		Grade	Type	Class	
Nea Helvetia	1	0-20	43.04	27.75	29.21	CL	strong	angular	coarse	0.83
		21-40	39.09	27.89	33.02	CL	strong	angular	coarse	0.25
		41-60	39.80	28.51	31.69	CL	strong	angular	medium	0.88
		61-80	48.08	22.31	29.61	SCL	moderate	subangular	medium	0.87
		80-100	51.39	24.68	23.93	SCL	moderate	granular	medium	1.36
	2	0-20	39.51	30.61	29.88	CL	strong	platy	medium	0.99
		21-40	38.04	26.29	35.67	CL	strong	subangular	medium	0.54
		41-60	39.58	26.50	33.92	CL	moderate	angular	fine	0.93
		61-80	41.22	26.68	32.10	CL	moderate	angular	fine	1.27
		80-100	39.53	26.30	34.17	CL	moderate	angular	fine	1.30
	3	0-20	44.85	31.05	24.10	L	strong	subangular	medium	1.69
		21-40	34.38	36.19	29.43	CL	strong	subangular	medium	0.25
		41-60	41.32	34.83	23.85	L	moderate	subangular	fine	1.18
		61-80	51.34	26.76	21.90	SCL	moderate	subangular	fine	1.41
		80-100	35.99	28.85	35.16	CL	moderate	subangular	medium	0.84
	4	0-20	54.94	26.29	18.77	SL	weak	angular	medium	0.55
		21-40	74.71	16.24	9.05	SL	weak	angular	medium	0.74
		41-60	76.97	14.29	8.74	SL	weak	granular	coarse	1.03
	5	0-20	48.00	27.84	24.16	SCL	moderate	subangular	medium	3.30
		21-40	52.34	28.66	19.00	SL	moderate	subangular	medium	1.15
		41-60	58.92	24.31	16.77	SL	moderate	subangular	medium	0.62
		61-80	58.78	22.16	19.06	SL	moderate	granular	fine	0.36
	6	0-20	39.85	31.70	28.45	CL	moderate	subangular	fine	2.68
		21-40	39.41	29.16	31.43	CL	moderate	subangular	fine	1.37
		41-60	35.79	30.44	33.77	CL	weak	subangular	coarse	0.71
		61-80	37.95	36.45	25.60	L	weak	granular	coarse	0.61
		80-100	52.28	26.24	21.48	SCL	weak	granular	medium	0.45
Y.M.C.A.	1	0-20	25.04	41.81	33.15	CL	strong	subangular	medium	1.72
		21-40	33.93	37.17	28.90	CL	moderate	subangular	medium	1.56
		41-60	27.70	37.54	34.76	CL	moderate	subangular	medium	1.08
		61-80	28.30	38.14	33.56	CL	weak	granular	coarse	2.32
	2	0-20	26.23	36.22	37.55	CL	strong	subangular	coarse	2.06
		21-40	28.64	36.88	34.48	CL	strong	subangular	medium	0.69
		41-60	21.03	45.15	33.82	CL	strong	platy	medium	2.68
		61-80	23.71	41.79	34.50	CL	moderate	subangular	medium	2.56
	3	0-20	28.10	39.76	32.14	CL	weak	subangular	coarse	2.20
		21-40	24.96	42.28	32.76	CL	moderate	subangular	medium	3.11
		41-60	53.74	30.91	15.35	SL	moderate	subangular	fine	2.05
	4	0-20	44.35	24.20	31.45	SCL	moderate	angular	fine	1.15
		21-40	40.75	33.26	25.99	L	weak	granular	medium	2.43
		41-60	51.09	29.16	19.75	L	weak	granular	medium	2.59
	5	0-20	39.65	32.72	27.63	L	strong	angular	coarse	1.64
		21-40	42.20	32.61	25.19	L	moderate	granular	medium	0.93
		41-60	58.85	24.25	16.90	SL	moderate	granular	medium	0.50
	6	0-20	45.30	33.20	21.50	L	moderate	angular	coarse	1.80
		21-40	56.77	24.29	18.94	SL	moderate	angular	medium	0.58
		41-60	40.26	34.59	25.15	L	moderate	angular	fine	0.84
	7	0-20	35.03	38.36	26.61	L	strong	platy	coarse	0.46
		21-40	34.95	37.53	27.52	L	strong	subangular	coarse	2.10
		41-60	35.42	30.87	33.71	CL	strong	subangular	medium	1.99

Table 3 (continued). Soil texture, structure and organic matter in sampling sites.

Park	Sampling Sites	Depth of soil layers (cm)	Texture			Classifica-tion*	Structure			O.M. (%)
			Sand (%)	Silt (%)	Clay (%)		Grade	Type	Class	
	8	0-20	44.16	32.35	23.49	L	moderate	subangular	medium	1.64
		21-40	42.90	35.19	21.91	L	moderate	subangular	medium	2.71
		41-60	34.37	37.51	28.12	L	moderate	granular	medium	2.48
Pasha's Gardens	1	0-20	42.59	33.14	24.27	L	strong	platy	fine	1.72
		21-40	43.12	30.78	26.10	L	moderate	angular	fine	1.27
		41-60	49.78	26.06	24.16	SCL	weak	subangular	medium	1.49
	2	0-20	16.95	45.66	37.39	SiCL	moderate	subangular	medium	2.60
		21-40	52.59	27.13	20.28	SCL	weak	subangular	medium	2.08
		41-60	54.45	27.26	18.29	SL	weak	subangular	coarse	2.31
	3	0-20	35.31	32.63	32.06	CL	strong	angular	medium	0.97
		21-40	23.04	40.81	36.15	CL	moderate	angular	medium	0.98
		41-60	51.64	30.58	17.78	L	weak	subangular	medium	0.94
		61-80	38.81	30.88	30.31	CL	weak	subangular	medium	1.42
		81-100	42.33	25.90	31.77	SCL	weak	subangular	medium	3.66

***** CL = clay loam, SCL = sandy clay loam, L = loam, SL = sandy loam, SiCL = silty clay loam

The presence of platy structure at these depths, combined with the soil compaction, could be attributed to the machinery used during the earthworks for a past small reformation of the park. Thus, at 9-37 cm depth, BD has rather high values (1.71-1.74 g cm^{-3}) (Table 2). Similar findings were reported by Norra et al., (2008) in urban soils, stating that because of intense human activities there was loss of any granular structure and presence of blocky structure up to 2 m depth. This type of soil structure was interrupted at 58 to 62 cm depth by the presence of a strong platy structure that was possibly the limits of the natural soil covered by soil material from other areas. In any case, platy structure does not appear frequently, unless there are internal natural pressures because of freezing and thawing (Brady & Weil, 2008).

In soil layers with high sand and low clay levels, as in the 4th sampling site of Nea Helvetia park (Table 2), the reduced presence of fine soil grains limits the formation of strong structure because of lack of coagulation factors, such as clay particles (Hillel, 1980; Foth, 1984; Papamichos, 1985; Panayiotopoulos, 2009). The dominance of sand particles does not contribute to the formation of stable structure; it reduces the moisture available to plants and enhances drainage and soil aeration (Kays, 1982). At the 21-60 cm depth of the above mentioned profile with high levels of sand, weak structure is dominant. Thus, weak grade and destruction of soil aggregates often appear in soils during various types of handling and use. Destruction of aggregation in these soils could happen at various soil water content regimes. On the other hand, soils with high clay content are more resistant to aggregation destruction under low water content levels, but they become prone to destruction under high water content levels (above the threshold of plasticity). Therefore, in order to minimize the negative effects caused by the use of machinery during construction of green spaces, their use should be limited to when the soil is relatively dry (Ramsay, 1986; Rimmer, 1991). This is of particular importance during the construction or reconstruction of green spaces, when removal or filling with significant amounts of soil material is taking place.

It is clear that the soil structure is destroyed during the various earthworks excavations as well as the formation of embankments. One important unanswered question is how much time is needed for the structure to be restored. Apart from several field observations, there is no adequate information about this subject (King, 1988). Laboratory studies and field observations are necessary to determine the factors that influence the restoration of the soil structure, such as the effects of clay, soil texture or drying and wetting cycles (Rimmer, 1991).

In urban soils all the above mentioned situations are exacerbated by the absence of organic matter and the lack of sufficient soil micro fauna (Beyer et al., 1995). The absence of these aggregation factors is considered to be responsible for the reduced presence of a strong degree of aggregation more than the degradation of soil structure due to compaction.

Organic matter content in the soils of the study area are low with an average 1.46% and standard deviation 0.82, a phenomenon not uncommon in soils parks (Craul, 1992; Jim, 1998b; Marcotullio et al., 2008). The highest content (3.66%) is observed at 81-100 cm depth in the profile of the 3rd sampling site of Pasha's Gardens park, while the lowest one (0.25%) is observed in the profile of the 3rd sampling site of Nea Helvetia park at 21-40 cm depth. The highest mean value is displayed in the park of Pasha's Gardens and Y.M.C.A (1.77% and 1.76%, respectively) and the lowest in the park of Nea Helvetia (1.04%) (Table 2). The high organic matter content observed at 81-100 cm depth in the profile of the 3rd sampling site of Pasha's Gardens park is due to a past top layer that was buried during a previous reconstruction of this park. Similarly, the increased organic matter content found in deep layers in the soils of the Mall, Washington D.C., is due to a buried A horizon (Short et al., 1986). High organic matter levels in deep layers in relation to topsoils are referred by Jim (1998b) in his study about urban parks in Hong Kong, and Lorenz & Kandeler (2005) in their research in the city of Stuttgart, Germany.

In general, soil structure does not directly affect plant growth, which is influenced by soil physical properties such as soil bulk density, mechanical strength, aeration and soil temperature, and soil - water relationships; they in turn depend on the soil structure and texture (Craul, 1992, 1999; Panayiotopoulos, 2009). Soils with satisfactory and desirable texture and structure, allow water retention and movement, the renewal of soil air and the unrestricted growth of the root system of plants. Thus, the existence of satisfactory structure and texture is considered to be one of the major factors of soil productivity. In the study areas, it is ascertained that the structure of both the topsoil and subsoil remains rather immature, keeping the original characteristics of the fill materials even many decades after their use in the park's formation, construction or renewal.

3.3. Soil compaction

Soil factors such as low organic matter content, destruction of aggregation (structure), and textural classes high in silt and fine to very fine sand, contribute to compaction (Craul, 1985).

Compaction is expressed as the soil's BD. Measured values of BD in the eight soil profiles are presented in Table 2. In general, BD values decrease with depth and the maximum values are observed on the top 2 or 3 cm, except profile 1 of the Y.M.C.A park where the maximum values are observed at 9-37 cm depth as it was previously explained. The higher values observed on the top centimeters of the soil are caused by anthropogenic factors, mainly pedestrians and periodic use of maintenance machinery.

PR is also a measure of soil compaction. In the studied parks PR values range from 0.6 MPa (minimum) to 4.9 MPa (maximum), while mean values range from 1.9 to 3.6 MPa (Table 4). PR changes with depth are presented in Fig. 3, 4a,b and 5.

The lowest mean PR values appear in the 3rd soil profile of Nea Helvetia Park where there is no trampling from the visitors. At this part of the park, plants display very good growth conditions. On the other hand very close to playgrounds or areas with intense use and trampling from visitors, the mean PR values are greater than 3 MPa as is the case in the 1st and 4th soil profiles of the same park. Changes of PR with depth at these profiles show recorded PR values of 3.5 MPa even at 5 cm depth. In these areas there is obviously reduced root growth and a negative effect on the growth and vitality of trees and shrubs.

If soil PR values exceed a critical value, then the roots' elongation and growth is retarded and as a result they exploit a smaller volume of soil and therefore smaller quantities of water, oxygen and nutrients are available to them. The PR critical values are not constant for all plants, but depend on the type of plant and its growth stage, ranging from less than 1 to greater than 4 MPa (Mullins, 1991).

Table 4. Penetration resistance (PR) at studied parks

Park	Soil profile	Minimum PR (MPa)	Maximum PR (MPa)	Mean PR (MPa)
Pasha's Gardens	1	1.00	4.40	2.50
	2	1.00	4.00	2.20
Nea Helvetia	1	1.00	4.90	3.30
	2	1.00	4.40	2.50
	3	0.60	4.45	1.90
	4	1.00	4.70	3.60
Y.M.C.A	1	0.80	4.60	2.80
	2	0.90	4.50	2.00

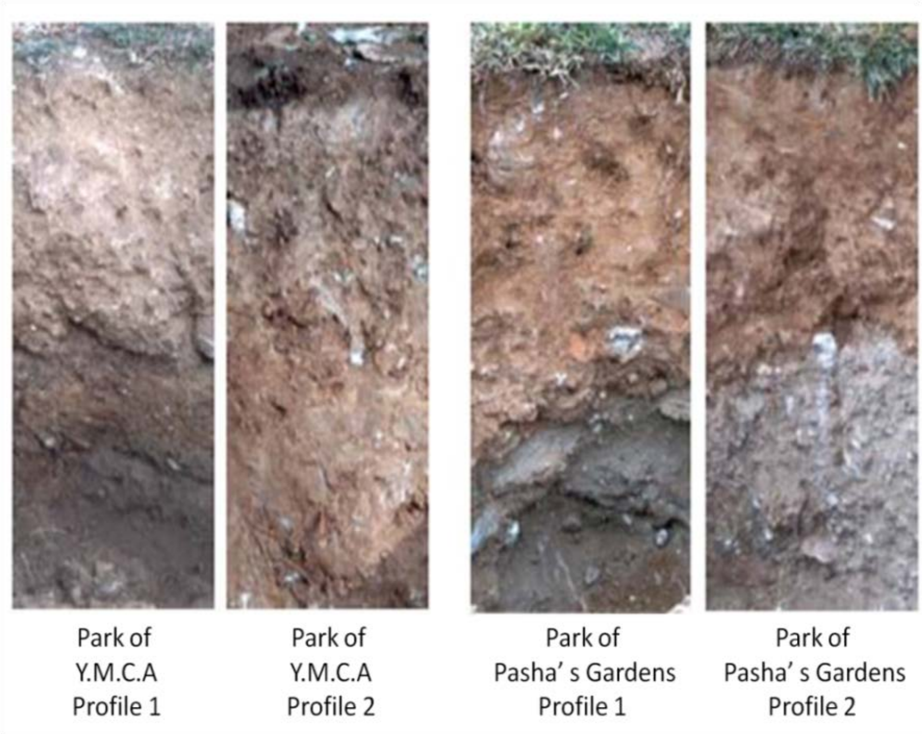

Figure 2a. Soil profiles in the studied parks.

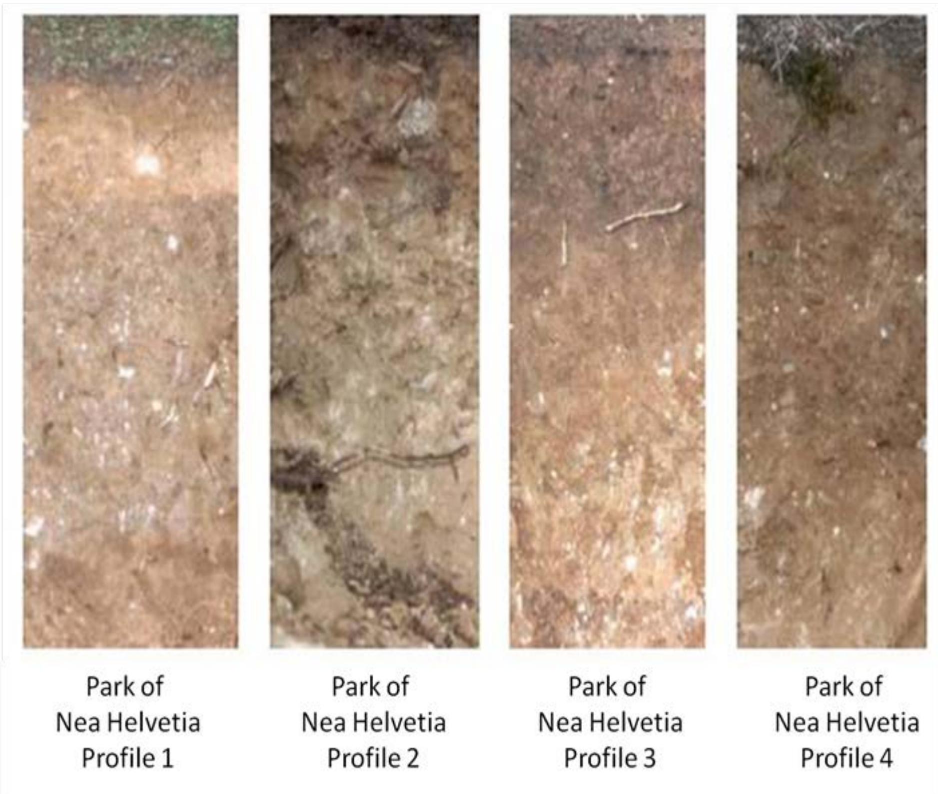

Figure 2b. Soil profiles in the studied parks.

The relationships between root growth and PR are largely unknown for many tree species. In more recent studies concerning the growth of trees in urban environments, Trowbridge & Bassuk (2004) state that measuring PR in urban soils, values between 0 and 200 psi (1.38 MPa) show that the roots display normal elongation and growth, between 200 psi (1.38 MPa) and 300 psi (2.07 MPa) root growth is retarded, while at values greater than 300 psi root growth is interrupted and stops.

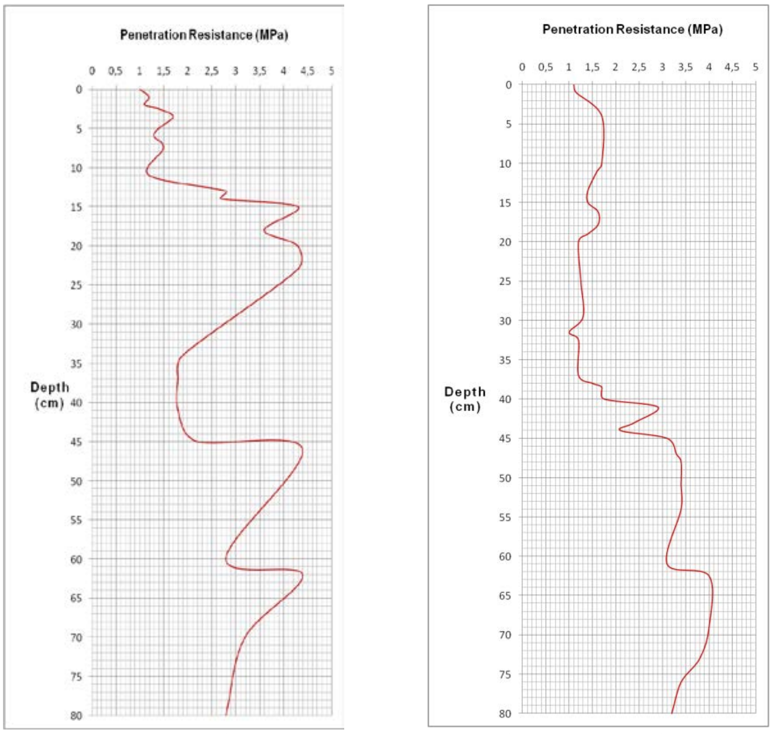

Figure 3. Change of PR with depth in soil profiles 1 and 2 of Pasha's Gardens park.

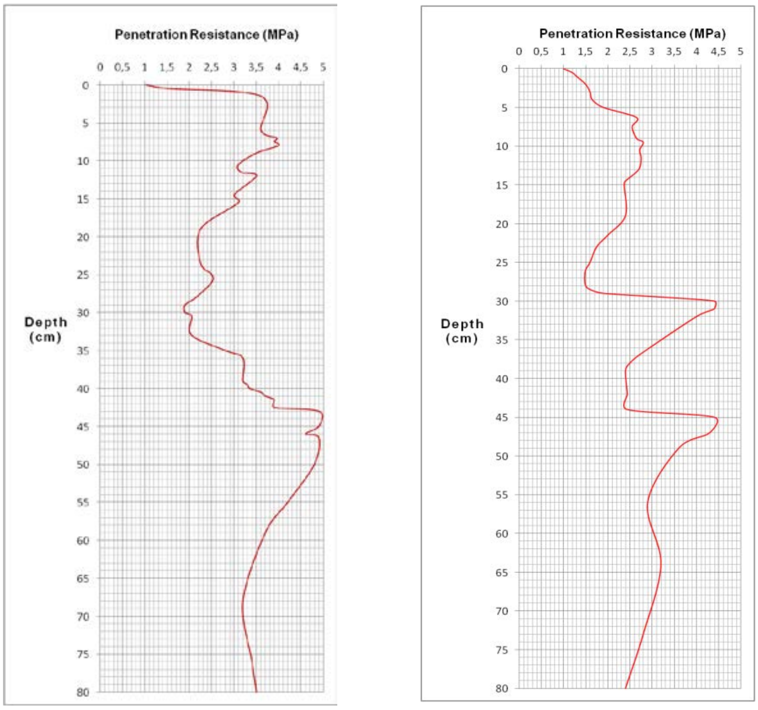

Figure 4a. Change of PR with depth in soil profiles 1 and 2 of Nea Helvetia park.

In all the soil profiles compacted soil layers with high PR values are observed below the 35 cm depth, even at 70-80 cm depth. These high PR values could be attributed to compaction caused by heavy machinery used during the construction or reconstruction of the parks and the spreading of soil material. Randrup (1997) in his study in built-up areas, found compacted soil layers in clayey soils up to 80 cm depth, while Craul (1992) states that compacted subsoil layers were created during reconstruction works in Sheepmeadow of Central Park, New York. Compaction created by the use of heavy machinery could remain for a long time if soil loosening with the proper mechanical means is not taken into account.

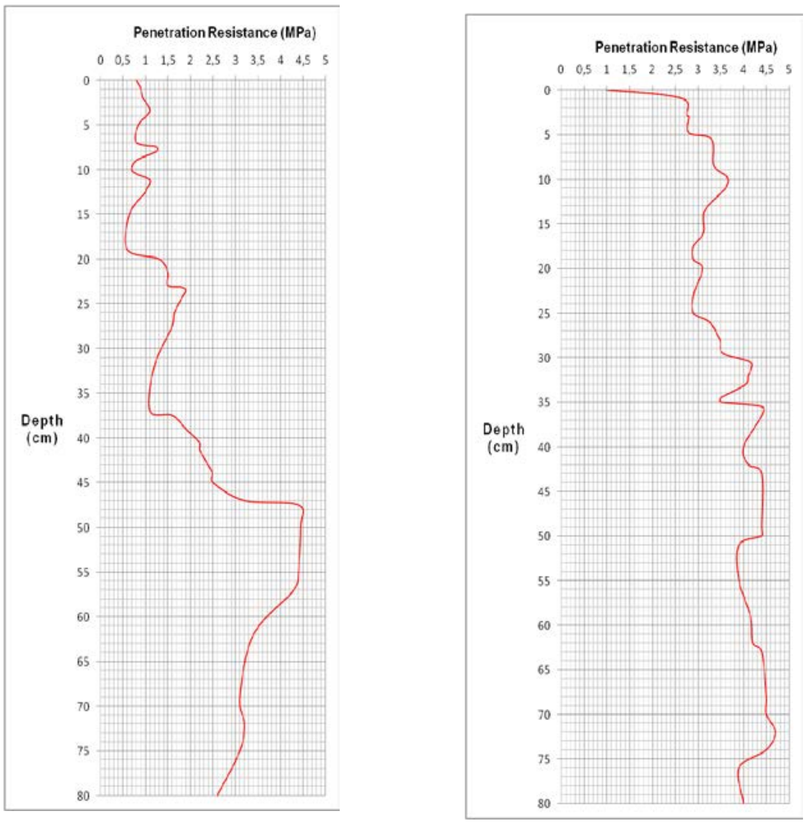

Figure 4b. Change of PR with depth in soil profiles 3 and 4 of Nea Helvetia park.

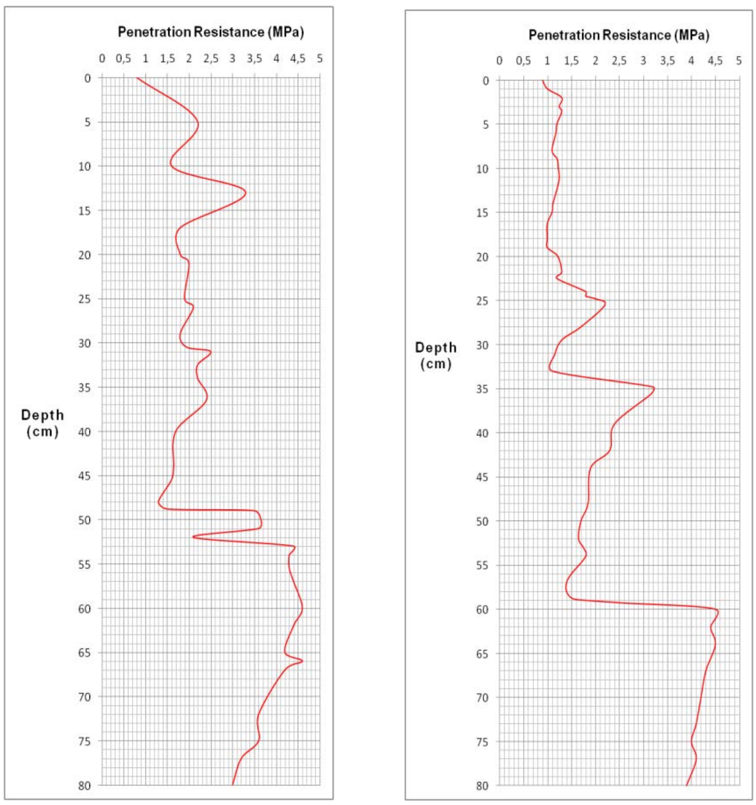

Figure 5. Change of PR with depth in soil profiles 1 and 2 of Y.M.C.A. park.

Therefore, both during the planning and the earthworks for the construction or reconstruction of an urban green space, all the necessary soil measurements should be taken into account so that soil compaction is not a limiting factor to the normal growth of plants.

4. CONCLUSIONS

Thessaloniki is a European Mediterranean city with a very small ratio of green spaces (m^2) per inhabitant (2.6) and therefore green spaces are of great importance for the urban environment and the city's residents. Their importance lies also on the fact that because of the limited green spaces, human impacts are increased. Urban soils constitute a significant part of this environment and their protection and amelioration must be included in management practices.

All the soil characteristics studied in this research lead to the conclusion that the property that plays a significant role in the urban soils of the three parks in Thessaloniki city is soil compaction, which is a probable factor in reduced plant growth. The question that needs to be answered is how is it possible to prevent the formation of compacted soils during construction or reconstruction of the parks or how these already formed soils can be ameliorated. This procedure is extremely difficult as it is almost impossible to bring a compacted soil back to its previous status, especially if compaction takes place in greater depths.

Some suggestions offered for the better management of these soils are first conducting a full evaluation of the soil conditions during the designing phase for the construction or the reconstruction of a park - including field observations as well as measurements and analysis of soil samples - followed by the determination of the specific sites of land filling and the planning of the earthworks in such a way as to minimize the use of heavy machinery that burden the soil. Land-use zones must be created, such as playgrounds, picnic sites, venue sites etc. in order to minimize compaction. Finally, improvement of the soil conditions (aeration, soil moisture etc) is necessary in order to encourage the growth of soil microfauna combined with regulation of the organic matter decomposition cycle by increasing the time the organic residues remain on the surface of the soil or by the use of compost.

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