Soil Characteristics and Management in an Urban Park in Hong Kong

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ABSTRACT / The limited acreage of Hong Kong's urban parks receives a huge number of visitors, imposing a heavy strain on the soil base. Most parks show widespread trampling-induced soil degradation, such as bare patches and compaction. These symptoms erode the quality of amenity vegetation and recreational experience. Soil in the most popular park was studied through detailed field and laboratory analysis of six pits denoting different levels of user impacts. Soil profiles show unnatural stratification and poor structure of decomposed granite fill materials used in reclaiming the land from the sea. Marked compaction in surface layers is induced by foot-traffic pressure, with aggregate breakdown and formation of platy structure. Compaction in subsoil layers is inherited from construction damage that persists 40 years after park opening. The predominantly coarse texture has been packed to high bulk densities exceeding the 1.75 Mg/m^3 threshold. With diminished porosity, transmission of air and water, storage of plant-available moisture, and root growth suffer. Chemically, the samples have an unnatural alkaline pH; inadequate organic matter, nitrogen, phosphorus, exchangeable cations; and limited cation exchange capacity. The results can help park-soil management, including the need to evaluate soil in planned park sites, salvage high-grade soil parcels, prevent construction damage, ameliorate structure by mechanical operations and suitable amendments, and replace site soil of very poor quality. Edaphic problems can be forestalled or solved by treating soil as an integral component of park planning and management based on scientific principles and methods.

Urban parks provide an essential service to inhabitants living in an overwhelmingly artificial environment (Welch 1991). They are indispensable for a livable city, and visiting them has become a social institution. Notwithstanding their multiple objectives (Muller-Perband 1979), various functions of formal green spaces depend on the quantity and quality of amenity vegetation (Zipperer and Zipperer 1992). Park attractiveness is often gauged by the caliber of natural ingredients, relying on a combination of physical and cultural factors in a management regime (Joardar 1989). Whereas much attention is given to vegetation selection and care, the same unfortunately cannot be said for soil. It is too often taken for granted and seldom analyzed vis-à-vis its ability to support plant growth (Gray 1972, Watson and Neely 1994).

During urban development, most natural soil would have been damaged and modified (Blume 1989, Craul 1992). Grade changes and engineering requirements are the major negative impacts. The original soil is often buried, truncated, removed, compacted, and contaminated. Foreign soil of inferior quality frequently finds its way into city areas, including those designated as green space. It is not uncommon to have urban parks established on impoverished substrate, inheriting various physical, chemical, and biological maladies inimical to plants (Dutton and Bradshaw 1982). Soil specifications in landscaping contracts tend to focus narrowly on topsoil provision, with little regard for subsoil (Bradshaw 1983), which can hardly ameliorate the poor initial state. The surficial veneer, by covering poor-quality existing soil, can induce a false sense of satisfaction. Park construction can frequently cause additional soil disturbance (Lichter and Lindsey 1994). By the time the parkland is ready to receive plants and users, the soil may have been badly damaged.

Hong Kong lacks easily developable land; land has to be obtained at great effort and cost by leveling hillslopes and reclaiming from the sea. The high-density and high-rise mode of city growth (Lo 1992) is a necessity, resulting in a pervasively congested and stressful city. With most people living in multistoried apartments, the need for public amenity space is serious, yet past policy and the pattern of urban sprawl have left few gaps in its tight fabric (Jim 1987a, 1989a). Urban parks are limited in area and are heavily patronized.

No systematic study of the natural aspects of urban parks has been attempted in Hong Kong. The few studies conducted elsewhere (e.g., Warner and Hanna 1982, Weber and others 1984) are confined to temperate cities. With inherently poor qualities compounded

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by heavy user impacts, local park soil in a humid tropical climate faces many problems related to composition and properties. Some difficulties are inherited, others are induced continually by visitors or unsuitable management. The substrate's ability to maintain a good vegetation cover has been overtaxed, thus degrading the quality of the recreational experience. Proper understanding of soil will help in upgrading services. A comprehensive evaluation of soil attributes was attempted in a popular venue by both field and laboratory methods to assess park soil as a medium to support amenity vegetation and to receive user impacts. The results are expected to establish the general conditions of park soil, particularly highlighting the inadequacies, to develop appropriate techniques for amelioration and management, and to provide guidance for proper soil specification for future projects.

Study Area and Methods

The eight heavily patronized urban parks in the city core of Hong Kong, with a combined area of 109.7 ha, serve a population of 4.04 million (total territorial population is 6.5 million). Victoria Park, in existence for 40 years and situated in the densely packed Causeway Bay District, was chosen for the present study (Figure 1). As the second urban park established in Hong Kong in 1957, it occupies 17 ha of land acquired entirely by reclaiming a shallow bay (Bristow 1984). Decomposed granite obtained from cutting into hillslopes was the principal source of fill material. About two thirds of the park has artificial surfaces or structures for soccer, basketball, tennis, roller skating, and swimming (Figure 1). The remaining area is covered by vegetation, mainly turf areas with trees and other ornamental plants. Park identity lies in the ‘‘soft’’ portion, which has no practical restrictions on user numbers, with crowding on most weekends and holidays. It is a popular venue for nearby residents and visitors to the commercial and entertainment district, receiving recently over two million users per year, with a tendency for visitors to congregate in the cooler months from October to February. The carrying capacity of the soft areas to receive trampling has been exceeded, as evidenced by widespread degradation of turf, bare soil, and erosion. To keep good quality grass surfaces, management has cordoned off a large ‘‘lawn’’ (Figure 1), which is open only at weekends. Some vegetated areas are permanently fenced off, further limiting the soft ground with unrestricted access. This measure has concentrated trampling damage to the open sites, leading to accelerated degradation and difficulty of recovery (Jim 1989b).

An initial site evaluation in Victoria Park stratified it into four grades of visitor impacts on soils, namely good (site P), moderate (Q), poor (R), and very poor (S, T, and U). The classification was based on field evidence of trampling damage, such as loss of grass vigor and cover, loss of organic litter, erosion of mineral–organic A-horizon materials, compaction, and extent of bare patches. A map was produced indicating the pattern of soil quality (Figure 1). For each of the good, moderate, and poor classes, one representative location was identified where a soil pit about 1 m deep was dug. For the very poor class, more attention was given by finding three representative locations where open pits were dug. The positions of the six soil pits (P–U) are marked in Figure 1.

In each soil pit, profile morphology and selected physical properties were studied in the field following standard soil survey methods (Hodgson 1974). Each profile was divided into horizontal layers according to color, texture, structure, and material composition. For every layer, two sets of soil samples were taken for laboratory analysis. Composite disturbed samples, each about 3 kg, were dug from four walls of the pits to take into account soil-property variables. Undisturbed samples, four from each layer, were collected by driving a stainless steel cylinder (15-cm long × 10 cm diameter) gently into the profile wall with a rubber-headed mallet. The methods of physical and chemical analyses are summarized in Table 1.

Soil Profile Characteristics

All six soil profiles have a pronounced banded morphology (Figure 2). They have not been demarcated into pedological horizons, which has inferences on soil genesis (Soil Conservation Service 1975) not very applicable to the largely artificial soils. Instead, the distinctive strata identified in the field are labeled layers. Four layers can be identified in site P, and five each for (sites Q–U) (Table 2). Some layer boundaries are abrupt, whereas other are gradual and diffuse. With only 40 years of changes beginning as decomposed granite fill materials, pedogenesis under humid-tropical conditions (Buol and others 1997) could not possibly have produced the pronounced layers. Sharp composition and property differences between layers suggest an artificial rather than natural origin. The haphazard filling process with batch differences in materials could have induced layering. Other urban parks with a similar history of filling and drastic soil disturbance also have soils with evident discontinuities in the profile (Weber and others 1984, Short and others 1986). Humid-tropical natural soil is strongly influenced by pedoturba-

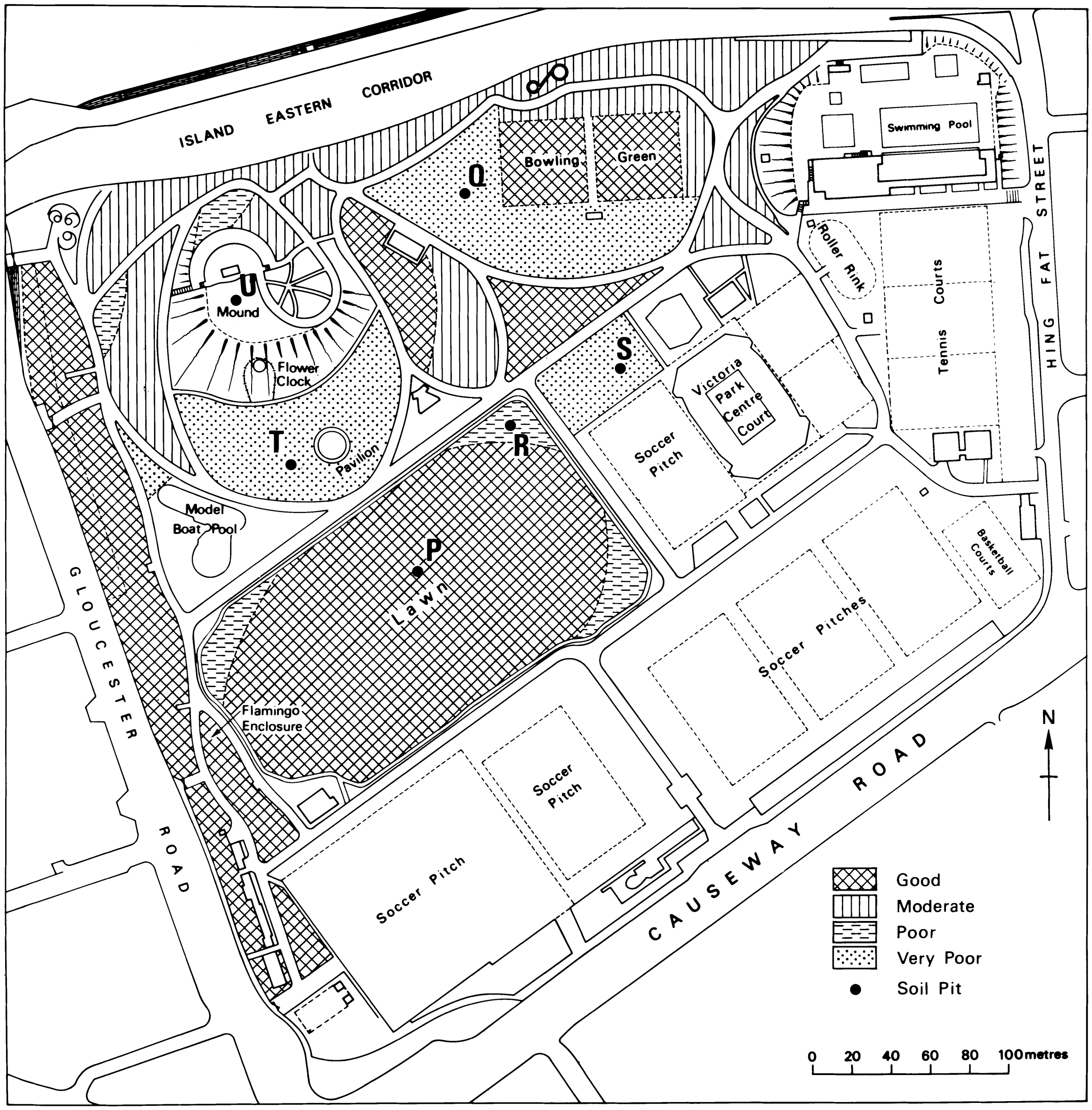
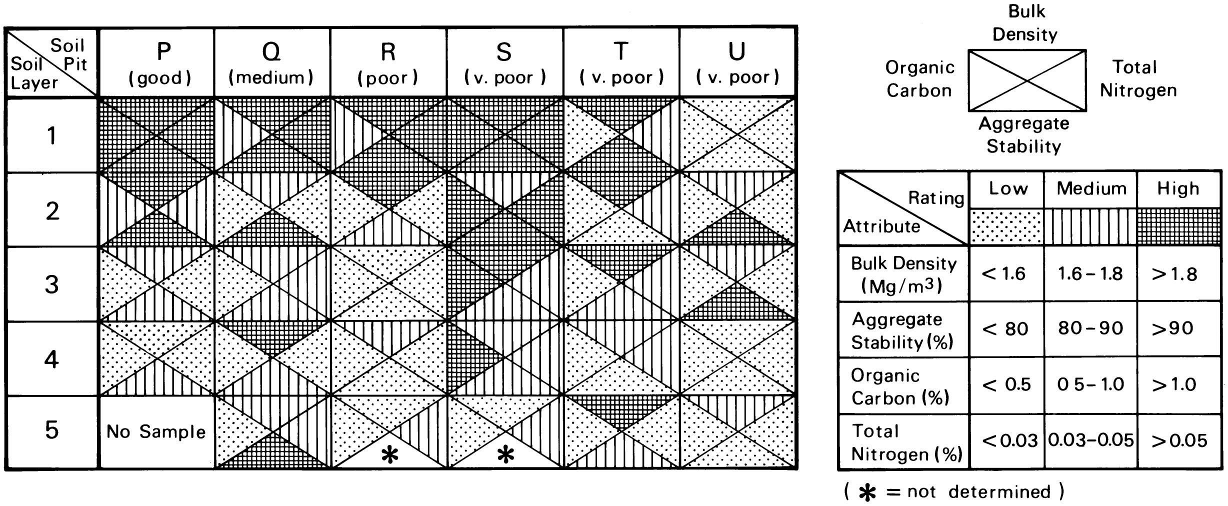


Figure 1. Map of the study area, Victoria Park in Hong Kong, showing the stratification of the green areas according to the levels of trampling impacts and the locations of the six soil pits.

tion processes, effected mainly by soil organisms (Hole 1961), which mix materials at different depths and in time obliterate inherited stratification. Persistence of layers in the park indicates that such biological mixing has not been active even in the topsoil where organism activities are usually more energetic. The harsh soil environment has not been conducive to the normal growth of soil fauna, allowing the initial state of synthetic stratification to be retained. Other studies also reported limited profile development after some decades of site filling (e.g., Short and others 1986).

Soil colors provide a visual hint of material composition and related processes. The original fill material has little organic matter, and current contents are the net results of accumulation and decomposition. The topsoil, equivalent to the O and A horizons in natural soil, should have a blackish or brownish color, reflecting organic enrichment. Sites P and S have limited organic accumulation; other sites have less. The subsoil layers have mainly brown to orange colors typical of the raw parent material (decomposed granite). Higher levels of trampling tend to reduce the chance for organic accumulation (Table 2).

Overall, four decades of soil formation has done



Attribute \ Rating	Low	Medium	High
	▒	▥	▦
Bulk Density (Mg/m^3)	< 1.6	1.6 - 1.8	> 1.8
Aggregate Stability (%)	< 80	80 - 90	>90
Organic Carbon (%)	< 0.5	0 5 - 1.0	> 1.0
Total Nitrogen (%)	<0.03	0.03-0.05	>0.05

(* = not determined)

Figure 2. A synpotic chart comparing the four levels of visitor trampling impacts with reference to four selected soil properties.

little to alter the profile morphology of the fill material. Vegetation growth has a limited effect on organic matter accumulation in the topsoil, which still deviates much from the norm of local natural soils. The poor initial state of the parent material, compounded by continual trampling and associated erosion, have overwhelming and arresting impacts on soil development. The soil–vegetation management regime of the park has to be substantially modified in order for pedogenetic improvement to occur.

Soil Texture and Structure

Stone content (Table 3) is exceptionally high for some samples, exceeding 50% in some cases, and mainly concentrated in subsoils. This suggests that topsoils are a different material than subsoils, probably a topsoil mix prescribed in a landscaping contract. Proliferation of stones in subsoils may reduce moisture-holding capacity, nutrient supply, and root growth. Stone contents in the few urban park studies conducted elsewhere generally also increase with depth, and vary from 4.6% to 13.5% in the Mall in Washington, DC, USA (Short and others 1986) to higher levels, reaching as much as 95% in the subsoil in New York's Central Park (Warner and Hanna 1982). Samples R5 and S5, at the bottom of soil pits, contain many seashell fragments, indicating their origin as sandy beach or littoral marine sediments buried by fill materials during reclamation. Some mixing between in situ sediments and granitic fill occurs near pit bottoms.

The samples are predominantly course textured (Table 3) at all depths, with sand particles exceeding 70% by weight in all but one sample. They belong to the coarsest textural classes, namely sandy loam, loamy sand, and sand (US Department of Agriculture scheme). Other research findings in urban green space also using fill materials did not report such an extremely coarse texture (Short and others 1986). Except at site U, with the lowest silt and clay contents, trampling intensity has a limited effect on the preferential removal of fine materials from topsoil. The much skewed particle-size distribution, typical of local decomposed granite used as fill material, is an inherited feature. Simple packing of coarse materials provides sufficient large pores, allowing an open matrix for excellent drainage and aeration, as long as the soil surface is not sealed by crusting or compaction (Jim 1987b,c). Despite a heavy local rainfall regime, (>2000 mm/yr and concentrated in summer months), water can quickly infiltrate into the soil. Where the soil is not compacted, occasional waterlogging or saturation do not last long after rain. Small variations in texture, both between soil pits and between layers within a given pit, indicate limited batch differences in the texture of the fill materials. A perched water table due to a sharp textural difference between layers (Baver and others 1972, Hill and Parlange 1972) is unlikely to occur.

The shortage of fine particles limits the formation of a strong soil structure due to the lack of aggregating agents and bridging materials between coarse grains (Dalrymple and Jim 1984). This is aggravated by the lack of organic matter. Topsoil structure for the good and moderate sites (P and Q) is moderately angular blocky (Table 3). Despite the low impact level, these sites fail to develop the granular or crumb structures normally developed in natural and agricultural topsoil. The lack of aggregating agents, particularly humic substances, rather than structural degradation due to trampling, accounts for subdued structure formation.

Table 1. Field and laboratory methods adopted for soil analysis

Soil attribute	Method
Physical attribute	
Profile description	soil survey method (Hodgson 1974)
Colour	Munsell standard soil colour chart (Kawai 1970)
Texture (particle size distribution)	hydrometer (Gee and Bauder 1986)
Consistence	soil survey method (Hodgson 1974)
Structure	soil survey method (Hodgson 1974)
Bulk density	clod method, Saran resin coating (Brasher et al., 1966)
Aggregate stability	wet sieving (Kemper and Rosenau 1986)
Aggregate slaking	technique of Emerson (1967)
Chemical attribute	
pH in water	glass electrode 1:2.5 w/w soil–water (McLean 1982)
Loss on ignition	800°C for 2 h in muffle furnance (Kalra and Maynard 1991)
Organic carbon	Walkley-Black wet combustion (Nelson and Sommers 1982)
Organic matter	calculation, organic carbon ×2.0 (van Reeuwijk 1986)
Total nitrogen	Kjeldahl (Bremner and Mulvaney 1982)
Extractable phosphorus	Bray & Kurtz I (Kalra and Maynard 1991)
Cation exchange capacity (CEC)	ammonium acetate saturation (van Reeuwijk 1986)
Exchangeable bases (Na, K, Ca, Mg)	atomic absorption spectrophotometry (van Reeuwijk 1986)
Conductivity (soluble salts)	saturation extract, conductivity meter (Rhoades 1982)
Chloride	saturation extract, specific ion probe (Adriano and Doner 1982)
Total heavy metals (Cu, Zn, Pb, Cd, Ni)	mixed acid digestion in microwave oven (Kalra and Maynard 1991)

The heavily used sites (R, S and T) develop a strong platy structure in topsoils. In natural soil, the platy structure is rarely formed except under the internal physical stresses of freezing and thawing (Brady and Weil 1996). A platy structure is developed only in a small number of topsoil samples in the Mall in Washington, DC, which has a mainly angular blocky structure in the A horizons (Short and others 1986); topsoils in Central Park in New York (Warner and Hanna 1982) are dominated by a granular structure with only a few places developing a platy arrangement. The vertical force of visitor trampling has disintegrated the original structure and remolded materials to match the new stress regime (Chauvel 1983, Harris 1971), with particles and pores rearranged to lie perpendicular to impact direction. In the poor site R, this surficial platy stratum is limited to 5 cm thick; in the very poor sites S and T, intensive trampling has organized particles down to 10 and 12 cm, respectively. In poor and very poor sites R–T, with trampling damage of the protective cushion of turf and organic litter, the platy arrangement could have been assisted and accentuated by rainsplash impacts. The heavily trampled site U has extremely coarse-textured topsoil, resulting in a single-grain structure that interferes with platy reorganization. It remains loose with no compaction.

The subsoil structure is mainly weak angular blocky. Formation of a high-level prismatic structure, common in local natural subsoil, is hampered by the coarse texture and lack of aggregating medium. Three samples (R4, S2, and S3) have unnatural massive structures, probably an inherited feature formed by heavy-machinery compaction and earth stockpiling during construction of the park. The feeble structure-forming process has failed to rejuvenate the damaged layers. The single-grain sites are tied to the sandy texture.

Overall, both topsoil and subsoil structure remain rather raw after 40 years and still retain many of the inherited features of the original fill material. Visitor trampling has a significant influence on artificial platy structure development, which is limited to the topsoil. In general, the high trampling intensity increases the depth of structural damage, resulting in poorer topsoil for plant growth and more restricted air and water movement into subsoil. The propensity to structural breakdown and platy reorganization of particles is affected by texture, but only excessively coarse soil can resist the rearrangement induced by trampling.

Aggregate Stability and Compaction

Aggregate stability in water is high, above 70%, for most samples (Table 4, Figure 2). Topsoils, with more organic matter inducing resistance to mechanical disintegration, have better aggregate stability than subsoils. For platy samples (R1, S1, and T1), compaction induces aggregate breakdown followed by closer particle packing, which increases shear strength by interparticle physical friction and physicochemical attractive forces (Chancellor 1971, Sands and others 1979). Thus compaction could trigger a negative feedback, with compacted soil becoming more resistant to further structural degradation. The generally robust aggregates, even in subsoils and despite low organic content, can be imparted by iron oxides in the weathered granite, a common cause of physical stability in humid-tropical soil (Quirk 1978, Lal 1987). Even in heavily trampled samples (sites S and T), aggregate stability has not been

Table 2. Site, profile, and color characteristics of soils at six sampling pits

Sample	Site condition	Depth (cm)	Horizon boundary	Moist color		Dry color	
				Munsell	Description	Munsell	Description
P1	good	0–5	diffuse	10YR 3/2	brownish black	10YR 5/4	dull yellowish brown
P2	good	5–30	diffuse	7.5YR 4/4	brown	7.5YR 6/3	dull brown
P3	good	30–76	gradual	7.5YR 5/8	bright brown	7.5YR 7/6	orange
P4	good	76–95	n.a.	2.5Y 4/2	dark grayish yellow	2.5Y 7/2	grayish yellow
Q1	medium	0–6	gradual	7.5YR 5/6	bright brown	7.5YR 7/6	orange
Q2	medium	6–32	gradual	7.5YR 4/6	brown	7.5YR 6/4	dull orange
Q3	medium	32–52	clear	5YR 4/4	dull reddish brown	5YR 6/4	dull orange
Q4	medium	52–70	gradual	5YR 4/4	dull reddish brown	7.5YR 6/4	dull orange
Q5	medium	70–82	n.a.	7.5YR 5/6	bright brown	7.5YR 6/6	orange
R1	poor	0–5	abrupt	2.5Y 4/2	dark grayish yellow	10YR 5/2	grayish yellow brown
R2	poor	5–33	clear	5YR 5/6	bright reddish brown	5YR 6/4	dull orange
R3	poor	33–59	gradual	10YR 4/3	dull yellowish brown	10YR 6/3	dull yellow orange
R4	poor	59–81	clear	7.5YR 5/6	bright brown	7.5YR 7/4	dull orange
R5	poor	81–98	n.a.	2.5Y 5/2	dark grayish yellow	2.5YR 6/2	greyish yellow brown
S1	very poor	0–12	clear	10YR 3/2	brownish black	10YR 5/3	dull yellowish brown
S2	very poor	12–25	clear	7.5YR 4/6	brown	7.5YR 5/3	dull brown
S3	very poor	25–42	gradual	10YR 4/4	brown	10YR 5/3	dull yellowish brown
S4	very poor	42–62	clear	10YR 3/1	brownish black	10YR 5/2	grayish yellow brown
S5	very poor	62–98	n.a.	2.5Y 4/2	dark grayish yellow	2.5Y 6/1	yellowish gray
T1	very poor	0–10	gradual	2.5YR 5/6	bright brown	2.5YR 7/4	pale reddish orange
T2	very poor	10–41	diffuse	7.5YR 5/6	bright brown	10YR 6/6	bright yellowish orange
T3	very poor	41–54	clear	5YR 5/6	bright reddish brown	7.5YR 6/4	dull orange
T4	very poor	54–66	clear	7.5YR 4/4	brown	7.5YR 7/4	dull orange
T5	very poor	66–98	n.a.	7.5YR 4/6	brown	7.5YR 6/4	dull orange
U1	very poor	0–4	abrupt	7.5YR 5/4	dull brown	7.5YR 7/4	dull orange
U2	very poor	4–18	gradual	10YR 5/6	yellowish brown	10YR 7/6	bright yellowish brown
U3	very poor	18–50	clear	5YR 6/6	orange	5YR 7/4	dull orange
U4	very poor	50–61	gradual	10YR 5/4	dull yellowish brown	10YR 7/4	dull yellow orange
U5	very poor	61–73	n.a.	10YR 5/4	dull yellowish brown	10YR 6/3	dull yellow orange

weakened. Samples with more organic matter (P1) and subjected to more trampling pressure (R1, S1, and T1) are resistant to disintegration due to air explosion (Emerson 1967, Bolt and Koenigs 1972) when aggregates are wetted suddenly. Aggregate strength is augmented by compaction. Aggregates fail mainly in brittle-deformation mode, reflecting the lack of clay particles and humus that are needed to generate plastic behavior. Maximum stickiness and plasticity support the dominating influence of particle size on physical properties, furnishing good handling properties in relation to operations such as tillage, scarifying, and mixing of amendments. In general, aggregate stability tends to be preserved despite trampling pressure, implying that the affected soil manages to resist further structural breakdown.

Bulk density is a sensitive indicator of compaction. A range of 1.1–1.4 Mg/m^3 is expected of natural soil in the humid tropics (Landon 1991). For urban soils, an upper threshold of 1.55 Mg/m^3 for fine- to medium-textured materials and 1.75 Mg/m^3 for coarse ones have been proposed (Craul and Patterson 1989). Short and others (1986) reported 1.25–1.85 with a mean of 1.61 Mg/m^3 for the Mall in Washington, DC. Values in the study area, (1.14–2.16 Mg/m^3, Table 4), are similar to other urban habitats (Jim 1993). Extremely coarse-textured samples (P4, R3, R5, S5, U1, U4, and U5) fall below 1.4 Mg/m^3. A coarse matrix supports many interstitial pores despite compaction (Bodman and Constantin 1965), hence it can sustain a lower density. Sandy samples maintain high total porosity (around 50%) with large pore diameter (Byrd and Cassel 1980) to facilitate aeration and drainage, but plant-available moisture is limited due to rapid gravitational emptying of large pores. Most remaining samples are compacted, with three exceeding 2.0 Mg/m^3 and total porosity only around 20% (v/v). Such tight materials restrict air and water transmission, water storage, and root growth.

Bulk densities tend to be higher in topsoils, and generally decrease with depth (Figure 2). Higher trampling intensity (sites S and T) induces higher topsoil bulk densities, except at site U with an excessively sandy texture that disrupts dense particle packing. Trampling has compacted the surface layer that was added initially as a

Table 3. Particle-size distribution, texture, and structure of soils at six sampling pits

Sample	Depth (cm)	Stone >2 mm (%)	USDA (%)			ISSS (%)		Textural class USDA	Structure		
			Sand	Silt	Clay	Sand	Silt		Type	Size	Grade
P1	0–5	7.23	72.24	17.33	10.43	80.39	9.18	loamy sand	angular blocky	medium	moderate
P2	5–30	35.40	80.35	11.30	8.35	84.42	7.23	loamy sand	angular blocky	medium	very weak
P3	30–76	53.19	79.68	11.93	8.39	84.46	7.15	loamy sand	angular blocky	medium	very weak
P4	76–95	65.51	88.54	8.55	2.91	91.58	5.51	sand	single-grain	n.a.	n.a.
Q1	0–6	13.64	72.55	11.27	16.18	77.62	6.20	sandy loam	angular blocky	medium	moderate
Q2	6–32	26.92	79.60	11.27	9.13	83.70	7.17	loamy sand	angular blocky	fine	very weak
Q3	32–52	32.74	83.61	10.34	6.05	87.74	6.21	loamy sand	angular blocky	fine	very weak
Q4	52–70	63.47	79.53	14.36	6.11	86.10	7.79	loamy sand	angular blocky	fine	very weak
Q5	70–82	20.29	70.33	9.23	20.44	73.85	5.71	sandy clay loam	angular blocky	fine	moderate
R1	0–5	5.85	75.62	11.96	12.42	79.66	7.92	loamy sand	platy	coarse	very strong
R2	5–33	31.99	82.55	11.07	6.38	85.62	8.00	loamy sand	angular blocky	medium	strong
R3	33–59	39.56	86.54	11.21	2.25	91.64	6.11	sand	single grain[a]	n.a.	n.a.
R4	59–81	51.45	69.01	22.52	8.47	75.53	16.00	sandy loam	massive	n.a.	n.a.
R5	81–98	32.28	96.19	2.56	1.25	97.81	0.94	sand	single grain[a]	n.a.	n.a.
S1	0–12	6.51	75.50	13.12	11.38	81.59	7.03	loamy sand	platy	medium	very strong
S2	12–25	37.10	76.47	10.24	13.29	80.94	5.77	loamy sand	massive	n.a.	n.a.
S3	25–42	56.84	77.94	13.98	8.08	84.01	7.91	loamy sand	massive	n.a.	n.a.
S4	42–62	71.36	84.64	9.24	6.12	88.12	5.76	loamy sand	angular blocky	medium	weak
S5	62–98	34.21	94.84	3.16	2.00	95.24	2.76	sand	single grain[a]	n.a.	n.a.
T1	0–10	14.32	69.82	12.50	17.68	72.66	9.66	sandy loam	platy	medium	very strong
T2	10–41	36.25	81.87	8.93	9.20	85.34	5.46	loamy sand	angular blocky	fine	weak
T3	41–54	36.60	74.55	11.12	14.33	80.69	4.98	loamy sand	angular blocky	fine	very weak
T4	54–66	38.17	77.72	14.48	7.80	83.22	8.98	loamy sand	angular blocky	fine	weak
T5	66–98	28.51	79.63	9.73	10.64	82.70	6.66	sandy loam	massive	n.a.	n.a.
U1	0–4	31.86	86.66	10.18	3.16	91.36	5.48	sand	single-grain	n.a.	n.a.
U2	4–18	16.24	76.43	11.26	12.31	79.90	7.79	loamy sand	angular blocky	medium	weak
U3	18–50	15.73	68.29	13.61	18.10	71.35	10.55	sandy loam	angular blocky	medium	weak
U4	50–61	27.39	89.05	8.72	2.23	92.75	5.02	sand	single-grain	n.a.	n.a.
U5	61–73	27.16	88.16	10.69	1.15	92.68	6.17	sand	single-grain	n.a.	n.a.

[a] With abundant broken seashells.

porous topsoil. Where the original topsoil has been partly removed by erosion in poor and very poor sites (R, S, and T), surface compaction has developed on exposed subsoil. Even in good and moderate sites (P and Q), surface bulk densities attain 1.83 and 1.86 Mg/m^3, respectively. For poor and very poor sites (R, S, and T), the platy topsoils have been packed to around 2.0 Mg/m^3. With inhibiting porosity on the surface, air and water movements into and out of the soil are retarded. Elevated bulk densities are commonly found in subsoils, dampening air and water percolation and physically as well as physiologically restricting root development. Subsurface compaction is a result of from construction activities (Alberty and others 1984) when the park was built 40 years ago and is associated with heavy machinery and earth stockpiling (Abdul-Kareem and McRae 1984). Subsequent pedogenetic processes failed to loosen the soil. Measures have to be adopted to minimize harmful influences of construction. Damage to soils should be ameliorated before plants are installed.

Soil Nutrient Status

Most samples have an atypical alkaline reaction for humid-tropical soil (Table 5), with pH exceeding 8.0 in some cases. Local hill soil developed on granitic material has a pH in the 4–5 acidic range. Unnatural soil alkalinity, however, is common in urban soil (Craul and Klein 1980). The fill materials have been contaminated with building wastes, leaving an enduring chemical legacy, with release of calcareous solutions facilitated by abundant and acidic rainwater. Some 27% of the samples from the Mall in Washington, DC, containing fill materials contaminated with building rubble, have alkaline reactions (Short and others 1986). The more natural fill materials used in Central Park in New York have acidic pH (Warner and Hanna 1982). The alkaline reaction acts as a check on the solubility and availability of manganese and iron in soil (Messenger 1986), with nutrient-balance implications for the humid-tropical horticultural species planted in the park. This chemical anomaly probably contributes to the common occur-

Table 4. Consistence and aggregate stability of soils at six sampling pits

Sample	Depth (cm)	Aggregate			Failure mode	Maximum stickiness	Maximum plasticity	Bulk density (Mg/m^3)	Total porosity (%) v/v
		Stability (%)	Slaking	Strength					
P1	0–5	95.76	none	firm	deformable	slightly sticky	slightly plastic	1.83	30.94
P2	5–30	91.86	complete	firm	semi-deformable	non-sticky	moderately plastic	1.82	31.32
P3	30–76	84.42	complete	firm	semi-deformable	non-sticky	moderately plastic	1.71	35.47
P4	76–95	80.00	loose	loose	n.a.	non-sticky	nonplastic	1.27	52.08
Q1	0–6	95.56	complete	weak	deformable	moderately sticky	moderately plastic	1.86	29.81
Q2	6–32	92.45	some	weak	brittle	moderately sticky	very plastic	1.79	32.45
Q3	32–52	86.49	complete	weak	brittle	non-sticky	nonplastic	1.77	33.21
Q4	52–70	84.27	complete	weak	brittle	non-sticky	nonplastic	1.87	29.43
Q5	70–82	91.57	complete	weak	semi-deformable	slightly sticky	very plastic	1.79	32.45
R1	0–5	91.18	none	strong	brittle	non-sticky	nonplastic	1.92	27.55
R2	5–33	83.87	none	strong	brittle	non-sticky	nonplastic	1.90	28.30
R3	33–59	51.92	none	loose	n.a.	non-sticky	nonplastic	1.38	47.92
R4	59–81	73.72	complete	strong	brittle	slightly sticky	nonplastic	1.77	33.21
R5	81–98	n.a.	n.a.	loose	(shell fragments)	non-sticky	nonplastic	1.33	49.81
S1	0–12	93.53	none	rigid	brittle	slightly sticky	moderately plastic	2.07	21.89
S2	12–25	92.74	complete	strong	brittle	slightly sticky	nonplastic	1.78	32.83
S3	25–42	84.42	complete	weak	brittle	non-sticky	nonplastic	2.03	23.40
S4	42–62	82.93	loose	weak	brittle	non-sticky	nonplastic	1.68	36.60
S5	62–98	n.a.	n.a.	loose	(shell fragments)	non-sticky	nonplastic	1.35	49.06
T1	0–10	93.79	none	strong	brittle	slightly sticky	very plastic	2.16	18.49
T2	10–41	79.79	none	firm	semi-deformable	non-sticky	nonplastic	1.88	29.06
T3	41–54	90.00	complete	rigid	brittle	non-sticky	nonplastic	1.82	31.32
T4	54–66	79.31	complete	strong	brittle	slightly sticky	moderately plastic	1.70	35.85
T5	66–98	82.80	complete	firm	brittle	non-sticky	nonplastic	1.83	30.94
U1	0–4	78.26	loose	loose	n.a.	non-sticky	nonplastic	1.17	55.85
U2	4–18	92.62	complete	weak	brittle	slightly sticky	moderately plastic	1.72	35.09
U3	18–50	96.02	complete	weak	semi-deformable	moderately sticky	very plastic	1.74	34.34
U4	50–61	71.43	loose	loose	n.a.	non-sticky	nonplastic	1.14	56.98
U5	61–73	77.27	complete	loose	n.a.	non-sticky	nonplastic	1.28	51.70

rence of suboptimal plant performance. As alkaline dissolution will remain a persistent phenomenon, the choice of tolerant species may provide a solution. Soil amendments and partial soil replacement can also be tested. The use of soil materials contaminated with building rubble should be avoided in park construction and landscaping sites.

Organic matter contents are low even by the norm of humid-tropical soil (Landon 1991), a phenomenon not uncommon in urban soil (Craul and Patterson 1989), with only three samples (P1, S1, and S3) exceeding 30 g/kg and 24 samples falling below 10 g/kg. The unusual concentration in subsoil S3 implies a buried topsoil or a fill material with an above-average amount of organic substance. The paucity of organic matter in the fill material and the meager accumulation of organic litter after planting explain the low contents. Loss of organic constituents can be accelerated by trampling and erosion. In contrast, the soils of the Mall in Washington, DC, have accumulated more organic matter, ranging from 3.5 to 46.9 g/kg (Short and others 1986); much higher contents, occasionally exceeding 100 g/kg, are attained in the topsoils of Central Park in New York (Warner and Hanna 1982). Measures need be taken to enhance organic matter accumulation that may improve the structure and reinforce resistance to compaction and erosion.

The loss on ignition for many samples do not match the organic concentration due to combustion loss of calcareous seashells. The presence of the prereclamation marine sediments well mixed with fill materials in the subsoil is thus quite common. The alkaline reaction in the subsoil can come partly from carbonate release from shells (Kooistra 1978).

The shortage of organic matter in urban soil curtails the supply of available nitrogen and phosphorus (Pulford 1991). The total nitrogen of all samples falls below the 20 g/kg minimum threshold regarded as low grade for tropical soil, with U samples notably deprived. Moreover, mineralization of nitrogen from organic matter in urban soil can be suppressed by pollutants (Carleton and McDonnell 1988). Shortage of this essential nutrient element suppresses plant growth unless nitrogen-fixing species are used. The carbon–nitrogen ratios for some samples exceed 10, which in tropical soil may incur nitrogen immobilization problems and aggra-

Table 5. Nutrient status and cation exchange characteristics of soils at six sampling pits

Sample	Depth (cm)	pH	Loss on ignition (g/kg)	Organic carbon (g/kg)	Organic matter (g/kg)	Total nitrogen (g/kg)	Carbon/nitrogen ratio	Extractable phosphorus (mg/kg)	Cation exchange capacity (cmol/kg)	Exchange sodium (cmol/kg)	Exchange potassium (cmol/kg)	Exchange calcium (cmol/kg)	Exchange magnesium (cmol/kg)	Base saturation (%)
P1	0–5	6.50	72.40	19.40	38.80	1.50	12.93	12.30	9.31	0.08	0.22	1.10	0.48	20.19
P2	5–30	7.43	59.70	7.60	15.30	0.50	15.20	2.77	8.81	0.08	0.19	1.69	0.20	24.52
P3	30–76	8.20	64.90	1.40	2.90	0.20	7.00	1.35	10.27	0.10	0.21	1.79	0.14	21.81
P4	76–95	8.62	89.30	3.40	6.80	0.20	17.00	2.00	9.69	0.15	0.34	2.20	0.37	31.58
Q1	0–6	5.66	68.90	5.70	11.40	0.60	9.50	1.84	8.10	0.12	0.30	0.47	0.33	15.06
Q2	6–32	7.50	75.40	3.80	7.60	0.20	19.00	0.34	10.45	0.49	0.14	1.02	0.35	19.14
Q3	32–52	7.98	73.30	1.60	3.30	0.30	5.33	1.35	9.36	0.44	0.12	1.49	0.18	23.82
Q4	52–70	8.16	77.50	3.60	7.10	0.20	18.00	1.29	11.01	0.29	0.25	3.51	0.24	38.96
Q5	70–82	7.96	80.80	2.30	4.50	0.30	7.67	0.00	14.28	0.20	0.21	3.53	0.16	28.71
R1	0–5	7.68	68.30	8.50	17.10	0.80	10.63	5.41	6.32	0.14	0.14	1.74	0.53	40.35
R2	5–33	7.61	80.90	2.20	4.50	0.20	11.00	1.23	9.34	0.17	0.13	1.04	0.30	17.56
R3	33–59	7.51	46.00	0.80	1.70	0.20	4.00	0.11	8.00	0.08	0.10	0.57	0.16	11.38
R4	59–81	7.76	57.40	1.50	3.10	0.07	21.43	1.48	9.77	0.16	0.06	1.34	0.34	19.45
R5	81–98	8.45	164.40	1.60	3.10	0.30	5.33	0.00	3.66	0.18	0.04	2.44	0.34	81.97
S1	0–12	6.42	75.70	18.90	37.80	1.60	11.81	10.34	9.45	0.08	0.26	0.83	0.40	16.61
S2	12–25	7.07	70.90	11.00	22.00	0.60	18.33	3.42	8.71	0.06	0.26	0.93	0.27	17.45
S3	25–42	8.15	67.90	18.60	37.20	0.30	62.00	1.38	7.21	0.08	0.19	3.75	0.17	58.11
S4	42–62	8.14	99.50	12.60	25.20	0.40	31.50	2.76	6.84	0.15	0.23	2.15	0.30	41.37
S5	62–98	8.64	185.10	2.40	14.80	0.30	8.00	0.00	4.04	0.19	0.09	2.54	0.42	80.20
T1	0–10	4.65	72.40	2.30	4.70	0.30	7.67	0.15	8.66	0.06	0.07	0.08	0.11	3.70
T2	10–41	7.35	67.90	2.40	4.80	0.40	6.00	0.95	8.99	0.19	0.11	0.74	0.20	13.79
T3	41–54	7.83	60.10	1.50	3.10	0.30	5.00	0.04	10.74	0.20	0.10	0.80	0.11	11.27
T4	54–66	8.33	63.30	2.50	5.10	0.30	8.33	0.75	8.61	0.15	0.12	2.88	0.13	38.10
T5	66–98	8.23	73.60	1.90	3.80	0.10	19.00	4.13	11.61	0.13	0.17	2.80	0.14	27.91
U1	0–4	6.32	59.70	1.50	2.90	0.07	21.43	0.26	8.95	0.05	0.41	0.41	0.31	13.18
U2	4–18	6.31	72.40	3.20	6.40	0.10	32.00	0.99	10.27	0.11	0.37	0.54	0.20	11.88
U3	18–50	4.34	80.90	2.10	4.20	0.10	21.00	4.12	12.11	0.31	0.15	0.33	0.19	8.09
U4	50–61	4.00	60.00	1.00	1.90	0.07	14.29	0.34	8.63	0.59	0.13	0.25	0.24	14.02
U5	61–73	3.93	48.30	0.90	1.80	0.09	10.00	0.29	7.95	0.60	0.12	0.38	0.31	17.74

vate deficiency. The supply of available phosphorus, also closely tied to organic matter and its mineralization, is similarly constrained. Most samples drop below the 5.0 mg/kg limit designated as low grade. The possibility of fixation by the high contents of iron oxides may further limit phosphorus availability. The shortage of both N and P, an important limiting factor to plant growth, has to be rectified by suitable amendments and organic matter maintenance measures.

The cation exchange capacity (CEC) results are rated as low (<15 cmol/kg) for most samples. Similarly low values have been reported in the Mall in Washington, DC (Short and others 1986), whereas in Central Park, New York, has registered higher values, up to 31.3 cmol/kg mainly due to higher organic matter content. Scanty colloidal materials, both organic and inorganic, do not furnish the necessary negatively charged sites. Moreover, the 1:1 kaolinitic clays in the tropical weathered granitic materials have limited exchange capability (Mohr and others 1997). Most samples have low (<20%) base saturation. The suppressed release of nutrient cations into the soil solution may trigger deficiency problems. Of the four cations, exchangeable calcium is better endowed, likely coming from the dissolution of calcareous cement, mortar (Short and others 1986), and comminuted seashells. Despite the marine origin of some subsoil materials, exchangeable sodium is rated as low (<0.5 cmol/kg). Soluble salts inherited from the sediments have been thoroughly leached out of the profile by heavy rainfall. The conductivity tests on saturation extracts, all dipping below the low-rating threshold of 2.0 dS/cm, provide supporting evidence that the inherited salinity has been purged.

Overall, the lack of organic matter and a poor inherited fill material do not furnish a good medium for plant growth. The limitations are due to inherently low nutrient as well as poor capability to hold nutrients in readily available forms even if they are added subsequently. The alkaline environment further upsets the nutrient balance. The heavy leaching regime, despite a reduction by structural damage and compaction, does not help to retain nutrients in the profile. Poor structure also limits root growth and hence the ability of plants to extract fertility from the soil. The lack of fine materials, both mineral and organic, has to be rectified in a sustainable manner in order that the park soil can be upgraded to a reasonable quality as a medium for plant growth.

Management Implications and Conclusions

As a city gravely short of developable land, Hong Kong uses this valuable resource at a high intensity, resulting in an extremely tight urban matrix. The limited acreage of urban parks receives millions of visitors per year to satisfy the growing demand. In the planning, construction, and maintenance of parks, much attention is paid to hard structures and surfaces as well as amenity vegetation. The subterranean aspect, unfortunately, is too often taken for granted, as though all soil materials will always satisfactorily fulfill their role as a growing medium. Yet this realm plays a key interface role between a park and its users. This study has identified some fundamental edaphic problems in a heavily used urban park accumulated over its 40 years of existence. The unusually high ratio between visitors and accessible green area is a recipe for unavoidable degradation. The management response of excluding foot traffic in a sizable portion of the turf area accelerates and exacerbates soil damage where use is allowed. To be able to step on a living carpet of grasses below tree canopies is earnestly desired, yet it could only be satisfied in a highly restrictive and degraded environment.

The composition of the fill materials used in the park offers a substandard precursor for subsequent soil formation. The fill is inherently deficient in physical organization and nutrient capital and is susceptible to further impairment. The excessive stone content and coarse texture are fundamental attributes that can hardly be modified by natural soil-forming processes. Moisture-holding capacity, especially the plant-available fraction, can only be limited. Many edaphic problems, notably poor structure and compaction especially in the subsoils, have been inherited from construction impacts. The meager native fertility in the fill material is worsened by its inherently low capability to hold nutrients in readily available forms. Sluggish organic-matter accumulation, in particular, perpetuates the problem of nitrogen and phosphorus deficiency. The unnatural alkaline reaction further limits nutrient release and uptake by roots. The heavy compaction in both topsoils and subsoils and the high stone occurrence are unfavorable to root growth, thus confining the ability of plants to extract nutrients and water from the soil. Four decades of soil development, under a humid-tropical soil-genesis regime that should be conducive to relatively fast changes, have done little to ameliorate the inherent physical and chemical limitations. This persistence indicates the lasting arresting effects of the inferior parent material and the inability of the soil–vegetation management approach to bring improvements. Trampling has caused further restrictions in topsoils, leading to reduced organic matter content, formation of unnatural platy structure, an increase in bulk density and a concomitant reduction in porosity, and a loss of organic litter and topsoil through erosion. The magnitude of soil degradation in general is commensurate with the intensity of trampling pressure.

The affected soil is inimical to the infiltration and transmission of both air and water and is unfavorable to the growth of microbes and roots. Bare patches are dusty when dry, and puddled when wet. The effective rooting volume of the soil, for both surface and subsoil layers, is drastically curtailed. Whereas some limitations result from soil chemistry (mainly inadequate nutrient supply), the more prominent ones are related to physical properties (particularly compaction). Routine soil management, however, tends to focus on ameliorating the chemical shortcomings while neglecting the more grave physical ones. Vegetation development, both groundcover and woody, therefore suffers chronically. The degraded soil becomes a substandard medium for both plants and recreation, imposing an apparently insurmountable obstacle to upgrading the quality of the park. In effect, the park soil has been trapped in a vicious circle which begs a bold departure from deeply ingrained and often inappropriate practices. Park management thus far has not been able to provide lasting solutions. The range of problems is large, encompassing both surface and subsurface, inherited and user-caused, physical and chemical, and compositional and behavioral. The less acute sites can be ameliorated by suitable mechanical operations and amendments with a view to rebuilding structure, strengthening aggregate stability and resistance to trampling pressure, and augmenting fertility. The idea is to furnish a soil with the right combination of organic and mineral constituents in an open-fabric arrangement that can sustain itself without the need for laborious and continual inputs. Soil in the extremely bad locations could better be completely replaced (Watson and others 1996) with a suitable soil mix.

For the future, it is necessary to adopt rigorous preventive measures during the construction phase to forestall the all too common problem of compaction (Lichter and Lindsey 1994). The need to incorporate a detailed soil study in site surveys cannot be too strongly emphasized (Marsh 1991). Similar to the preservation of trees of high amenity value, enclaves with good soil should be kept for vegetation rather than building or hard-surfaced uses. Land parcels destined for vegetation can be clearly demarcated to exclude potentially harmful activities. If the site soil is already compacted, subsoiling or deep plowing should be applied to correct the limitation (Day and Bassuk 1994). If new fill materials are to be added, proper specification should be stipulated to ensure that only good-quality soil of an adequate depth without undesirable composition and properties should be supplied. For locations designated for heavy foot traffic, it may be necessary to adopt an innovative soil mix with a coarse matrix that can support trampling pressure and with sufficient fine materials and porosity to take care of root requirements (Grabosky and Bassuk 1995). In the storage, stockpiling, and handling of such materials, care should be taken not to introduce unwanted changes. The soil management measures can be suitably combined with a choice of more trampling-resistant grasses and other ground-cover species, and a strategy to influence visitor movement and access to spread out and reduce overall impacts on green areas.

Just as the multiple problems associated with urban soil are due to inappropriate human manipulation, its improvement and management require appropriate human manipulation. For too long attention on park soil has been marginalized and subjugated among the many management tasks, and this negligence is common during site formation and construction, as well as after the opening of the venues. Urban parks in Hong Kong, as it is the case for other expanding cities, will have to meet increasing patronage and rising expectations for quantity and quality. As more parks will be built in the near future, and they will occupy mainly newly formed land reclaimed from the sea in Hong Kong, it is essential that similar soil problems not arise. The neglected resource should be treated as an integral component of a rational park management regime, to be based firmly on objective scientific concepts and methods.

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