A DESCRIPTION OF URBAN SOILS AND THEIR DESIRED CHARACTERISTICS[1]

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Abstract. Human activity in urbanization creates urban soils that have characteristics unlike those of their natural counterparts. Compaction, restriction of water movement and of aeration, presence of anthropeic materials, limited or confined rooting space and interrupted nutrient cycling are major problems, among several others, commonly encountered when planting and maintaining urban vegetation. These are explained to aid in their recognition in the field. Desired urban soil characteristics are given and possible solutions are briefly discussed.

Most people involved with planting vegetation in the urban environment soon discover that the soil material excavated by shovel or backhoe does not have the appearance or properties very similar to that found in the surrounding country, or what they might have learned from a textbook on the fundamentals of soil science. Further, the soil material presents them with problems of plant survival and growth (2). The purpose of this paper is to describe these dissimilarities and their implications for management, and finally, discuss the desired characteristics for urban soils. This should aid in the recognition of problems presented by urban soils and suggest possible solutions of a practical nature, though a detailed discussion of the latter is beyond the scope of this paper.

Definition of urban soil. Urban soils are created in the process of urbanization and therefore cannot be separated from the geographic bounds of the process. Highly distrubed land and the associated soil material, such as strip-mine spoil banks, do occur outside of urbanized areas and they have some similar characteristics to those found in urban areas, but they are not considered here.

Human activity, by modification of the natural soilscape, is the predominant active agent. This is in contrast to the natural agents of wind, water, ice, gravity and heat that are the active agents in the placement of parent material within which the resultant soil-forming processes occur in the natural environment. Urbanization also contributes unique amendments and contaminants to the urban soil which create special problems.

Bockheim (3) gives an appropriate and useful definition of urban soil: *A soil material having a non-agricultural, manmade surface layer more than 50 cm thick, that has been produced by mixing, filling, or by contamination of land surface in urban and suburban areas.* The inference is that the soil has been at least partially disturbed in some portion of the profile or perhaps the entire profile may consist of fill, and that human activity is the primary agent of the disturbance. The mixing, filling and contamination creates a soil material that is unlike its natural counterpart in appearance and properties. Mixing of soil material occurs when the soil is scraped away, stockpiled and respread, or it may be transported to another location and spread as topsoil. Exposure of subsoil by cutting down truncates the profile which is not unlike the eroded soil profile found in nature. Filling refers to the process of dumping and spreading soil material over an existing surface to raise it to a higher level, to backfill ditches and foundation walls or to construct berms. Contamination arises from the deposition, mixing, and filling of materials in the soil not found, or at concentrations greater than those found, in natural soils. The materials may be anthropeic solids such as glass, wood metal, asphalt, masonry, and plastic. Atmospheric-deposited material is included. Gases from landfill or pipeline leaks must be considered as contaminants as well.

Characteristics of urban soil. Several general characteristics of urban soils emerge. These are:

1. Great vertical and spatial variability
2. Modified soil structure leading to compaction
3. Presence of a surface crust on bare soil,

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usually water-repellent
4. Modified soil reaction, usually elevated
5. Restricted aeration and water drainage
6. Interrupted nutrient cycling and modified soil organism activity
7. Presence of anthropeic materials and other contaminants
8. Modified soil temperature regimes

Vertical and spatial variability. Properties in most natural profiles gradually grade from one horizon to the next lower one, while some may exhibit abrupt changes. Urban soil profiles show abrupt changes from one layer to another depending upon the constructional history of the soil. If topsoil is scraped away and later backfilled, two distinct layers result, particularly if the topsoil is from elsewhere. The abrupt change is commonly referred to as a lithologic discontinuity (Figure 1) and an interface is created. (The importance of the interface will be discussed later.) This condition is common following home construction. Craul and Klein (6) observed this layer to range from 6 to 35 cm in streetside soils. The material lying below the first dicontinuity may be of the original soil profile. Each layer may drastically differ in texture, structure, organic matter content, pH and bulk density together with their related properties of aeration, drainage, water-holding capacity and fertility. One layer may be hospitable to plant root growth and survival (not always the upper layer), while the other may not. If the site has a constructional history of fill, there may be several discontinuities present, each with an interface (Figure 1). Therefore, great vertical variability exists which could present multiple problems for plant root growth.

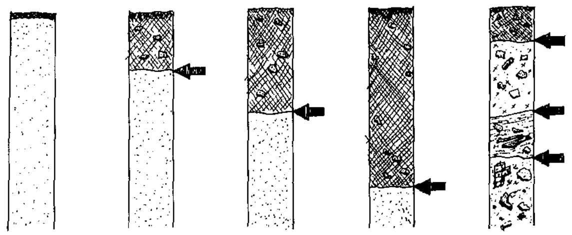
Spatial variability may be just as complex as vertical variability. Superimposed upon the variability in natural soilscapes are the variation in agricultural or forest land-use prior to the urban constructional features of buildings, roads, mass transportation and utility networks. In a historical perspective, several cycles of change and evolution could exist, depending upon the history and geographic location of the site under considertion. The influence of human activity is simple or complex but contributes to spatial variability in both cases. Therefore, it is not uncommon to find a drastic contrast in profiles from one tree planting pit to another on the same street within the same block. The variability is illustrated in Figure 2 (8), and necessitates detailed soil sampling and the production of small-scale maps.

Structure modification and compaction. The development of soil structure is one of the end-products of the natural soil-forming process. Aggregation of sand, silt and clay particles increases the soil bulk volume (decreases bulk density) and tends to create large pore spaces between the particles and between aggregates. This has favorable effects on aeration, water permeability and root penetation. One of the most important functions of wise agricultural land husbandry is the maintenance of this good structure or tilth.

The natural process of structure formation and the operations to maintain it are lacking in urban soils. In fact, most conditions present in the urban situation tend to destroy structure and increase bulk density, compacting the soil (6, 13). These conditions include:

1. Most urban soils have been disturbed or displaced, at least partially destroying structure and reducing pore space, especially macropores.
2. Low organic matter content which disfavors aggregation. The aggregating effects of soil organism activity are also reduced.
3. Low frequency of structure-enhancing wet-dry or freeze-thaw cycles.
4. Urban soils are subjected to surface traffic or other forces over a range of moisture condi-

DEGREE OF PROFILE DISTURBANCE



surface only 6cm | topsoil only 30cm | into subsoil 55cm | effective rooting depth 90cm | entire profile >90cm

potential lithologic discontinuity

Figure 1. Vertical soil profile variability showing locations of potential lithologic discontinuities or interfaces.

tions that contribute to compaction.

5. Vegetation is subject to damage and reduction of cover, leaving the soil bare and susceptible to crust formation, compaction and erosion.

All of these deterimentally influence other soil properties such as water infiltration and permeability, water-holding capacity, aeration status and root penetrability, especially of the upper soil layers where roots are concentrated. Poor vigor and decline in the general well-being of trees and shrubs follow from poor root development and the lack of water and oxygen. Mortality is the usual result under the stressful conditions of the urban environment.

Soil compaction and loss of pore space arises from forces exerted on the soil surface compressing and crushing the aggregates into smaller sizes (14). Foot and vehicular traffic exert the forces. Soil with high silt or very fine sand components coupled with low organic matter content tends to naturally compact under certain moisture conditions, and with the additional contribution of vibrational forces acting on the soil as the result of heavy traffic on the adjacent roadway (6). The phenomenon is one reason for the compaction of the lower soil layers beyond the influence of surface compressive forces. Urban soils may have bulk densities that occur within the range of natural soils, but most often they are at or exceed the higher limit of the bulk density range. Patterson (13) found average values ranging from 1.74 to 2.18 mg/m^3 in four profiles of the Washington, D.C. Mall. Root penetration is highly restricted at values exceeding 1.70 mg/m^3. Craul and Klein (6) found a range of 1.54 to 1.90 mg/m^3 with most centering on 1.82 mg/m^3. Values from New York Central Park (unpublished data) range from less than 1.00 to 1.34 mg/m^3 for undisturbed surface soil and 1.52 to 1.96 mg/m^3 for subsoils. Roots may penetrate these compacted subsoils by following cracks or pipelines, or in channels created by rotted anthropeic materials or old root channels.

It should be obvious that careful planning and incorporation of design features and maintenance to prevent or minimize the effects of compaction are necessary to provide a rooting medium that enhances the survival and growth of trees and shrubs under stressful conditions (13).

Surface crusting. A bare urban soil exhibits a pronounced tendency to form a crust on or within several centimeters of the surface. The phenomenon is caused by several factors. The most obvious one is foot and wheel traffic destroying vegetative cover and compacting the surface soil. The binding effect of roots is absent as is the surface protection provided by organic litter. The kinetic force of raindrop splash disintegrates aggregates and washes very fine particles downward, filling small pores (7). A horizontal orientation of particles occurs, creating one and sometimes two distinct microlayers within the surface two centimeters (16). Water infiltration and gaseous diffusion are reduced. A contributing factor to the crust effect is the hydrophobic nature of many urban soils. Some have sandy texture and are water-repellent by nature (4) and this is more pronounced than in fine-textured soils. Surface deposition of ammonia is an additional cause together with the metabolic byproducts of soil organisms particularly the

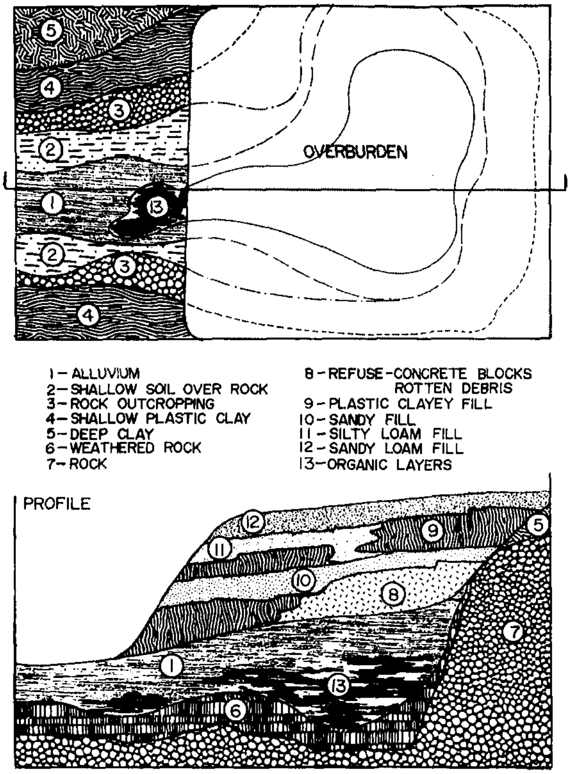


Figure 2. Spatial variability illustrated by a hypothetical fill site. Adapted from Kays (8).

Basidiomycetes (17). Organic matter coatings on the mineral particles (especially sand grains) are important hydrophobic features (17). Sulfur and soluble salts have also been suggested as causes in arid soils (4). Wander (22) indicates that calcium and magnesium soaps may be water-repellent substances in Florida soils. In any case, evaporation and infiltration are greatly reduced even if the water-repellent layer occurs below the soil surface, acting like a least-permeable horizon. The effects of water-repellency on moisture flow is greatest at the dry end of the moisture content range. Though not well-documented, it is thought that the atmospheric deposition of petroleum-base aerosols and particulates on the soil surface in the urban environment may be a cause of water-repellency. These seem to react with the soil to form hydrophobic compounds. The crust is rewetted with extreme difficulty after being dried. This indicates the formation of difficulty reversible hydrophobic compounds. The effect persists until rainfall eventually 'washes' the soil, changing the contact angle of the water-solid interface in the unsaturated pores. In light of the vertical variability of urban soils, including organic matter content (13), their water-repellency should be anticipated.

Modified soil reaction. Urban soils tend to have soil reaction (pH) values higher than their natural counterparts (3,5,6). Streetside soils of Syracuse, New York had a pH range of 6.6 to 9.0 with an average of about 8.0. Urban soils of Philadelphia, Pennsylvania ranged from 3.7 to 9.0 with a mean of 7.6. In Berlin, a pH of 8 was observed at streetside and less than 4 within a forest a short distance from the street.

Bockheim (3) suggests three reasons for the elevated pH values. First, the application of calcium or sodium chloride as road and sidewalk de-icing compounds in northern latitudes. A second one is by irrigation of vegetation with calcium-enriched water. Thirdly, soil pH is elevated by the release of calcium from the weathering of building rubble comprised of masonry, cement, plaster, etc. (5), and the surface weathering of buildings and sidewalks under the acidic (and sometimes alkaline) atmosphere of the urban environment.

There are both advantages and disadvantages to elevated pH. Near-neutral soil reaction (pH 7) favors many processes beneficial to a wide array of plants and enhances soil fertility, but creates a soil management problem for the acid-loving plants. Also an overabundance of calcium or sodium (or even chloride) creates an inbalance with other nutrient ions and may prevent their uptake by roots.

Restricted aeration and water drainage. Compaction of the urban soil decreases total pore space and reduces the proportion of large pores. It is within these pores that saturated water flow occurs and most of the gaseous diffusion of oxygen and carbon dioxide after the soil has been drained by gravity. If these macropores are present only in small proportion, or lacking, as in compacted soil, the soils drain slowly and the water retained in the small pores acts as barrier to diffusion of oxygen and other gases. Since water flow and gaseous diffusion is controlled by the least permeable (most compacted) horizon, even a compacted subsoil horizon may affect water movement and aeration of the entire profile. The nearer the least permeable horizon to the surface, the greater the negative influence on plant growth and vigor (10). A compacted surface horizon is extremely detrimental, if not an impossible rooting medium.

Covering the soil surface with impervious material like asphalt or concrete cuts off water infiltration and gaseous diffusion. These processes are therefore confined to the uncovered surface. Lateral movement of water and gaseous diffusion is limited, the more so in compacted soils. Therefore, a tree placed in a pit surrounded by concrete or asphalt and underlain by compacted soil is supplied with very little natural precipitation in summer, followed by too much water in the dormant season and too little oxygen throughout year, setting up the extremes in stressful conditions for plants, which few can tolerate (11).

Confinement of water movement and gaseous diffusion by curbing, pipe traces, foundation walls, subway and parking garage ceilings must also be considered as being restrictive. Here again, planning, design and maintenance operations can overcome many of the difficulties by furnishing sufficient rooting volume.

Interrupted nutrient cycling and modified soil organism activity. The urban soil generally lacks the organic matter cycling and its nutrient contribution that typifies the soil of the natural ecosystem. Beneficial organic nutrient-containing (especialy nitrogen, sulfur and phosphorus) leaves, litter, and animal remains are removed as wastes, or are produced in small quantities due to stressful conditions. Also, some urban soils do not rest on parent material or bedrock and do not receive the continuing benefit of nutrients released from inorganic mineral weathering. The weathering of building rubble may be beneficial to nutrient cycling, but ion inbalance must be considered as a potential problem. Restricted vertical and lateral water movement inhibits the movement of solutes from an enriched to an impoverished area.

Organic matter is a major source of energy for most soil-inhabiting organisms. If lacking, the soil organism population is limited and the activity is reduced below natural soils levels. In fact, some components of the organism population may be absent. Because of limited moisture and aeration it is reasonable to expect the nitrifying and nitrogen-fixing bacteria to be limited in urban soils. Without the organic horizons present, as in forest or agricultural soils, many soil invertebrates are lacking, especially earthworms, further contributing to the reduced degree of aggregation and the rate of nutrient cycling. The anaerobic conditions created by high moisture levels and reduced aeration favors fermentation bacteria producing methane, ethane, hydrogen sulfide, nitrous oxide, fatty acids, alcohols and esters — all detrimental or toxic to most plants favored in urban design.

Presence of anthropeic materials and contaminants. During urbanization and its renewal the landscape is reshaped, filled or cut. This modification of the topography creates made land. Large portions of many large cities are built on made land (18). Made land is typified by containing a high percentage of anthropeic materials (solid waste) as masonry, wood and paper, glass, plastic, metal, asphalt and organic garbage. These materials become incidentally mixed in the soil profile and affect the physical, chemical and biological properties of the soil. The rooting volume is diluted, mechanical impedence to root penetration is created, and water-holding capacity may be reduced. The decomposition byproducts, especially some of the gases, of some waste materials may be detrimental or toxic to plants and animals. Chemical byproducts may potentially interfere with the nutrient cycling and uptake. Likewise, as plants suffer, soil inhabiting organisms also suffer, affecting their population levels and degree of activity. Corrosion of buried metal installations is increased by the large concentration of acids formed in landfill leachate and other anthropeic material decomposition.

Concentration of heavy metals through atmospheric deposition and decomposition byproducts in the soil are additional sources of contaminants. The closer to the street, the higher the heavy metal concentration in the soil (18). Spirn cites four urban situations where high lead content is likely to occur: close to city streets; areas where lead paint has washed from wooden structures; vacant lots formerly occupied by wooden structures; and garden soil amended with sewage sludge containing lead. The greatest danger is the absorption of the dust, as on a playground, or the uptake by vegetable plants, thus entering the food chain. Direct effects on plants themselves are not well-understood.

Herbicide and pesticide residues are also contaminants in urban soils, either remaining from former agricultural operations or as residues from direct application to urban vegetation. Some of these represent the toxic decomposition byproducts of other chemicals. Time and dilution help to alleviate the danger, but some persist in toxic concentration to plants and animals for many years. Again, having the past history of the site is important for soil contaminant evaluation. Detailed soil analyses are recommended if the history is unknown. Many conifers have died as the result of herbicide residues of former cornfields and lawn shade trees have been killed as the result of the application of incompatible turf herbicides.

Modified temperature regimes. It is a well-known fact that urban areas create a heat island compared to the surrounding countryside (12), and that heat loading is determined by the surrounding environment for a given urban site. From work at Storrs, Connecticut (19), an open grass area with distant buildings was coolest (−1200 cals/min) at mid-day while the warmest was an asphalt parking lot (+1400 cals/min) surrounded by a closed border of trees. A curb-side location with trees and buildings on both sides of the street was intermediate (+350 cals/min). A nearby oak forest had a heat loading of −75 cals/min. Therefore, in most cases, on the basis of many air temperature observations, the heat loading on the rural soil is less than that of the urban soil. The amount of heat adsorbed and reradiated by building and street surfaces is greater than vegetation, raising both daytime and nighttime air temperatures. The same authors found that heat loading increased linearly as the percentage of synthetic material (buildings) in the sky view increased, with the onset of positive heat loading at about 41 percent. Vittum (20) measured surface temperatures in the urban setting in Syracuse, New York. At 6 pm on a sunny June day, a grassy area had the coolest temperature of 30 degrees C except for a honeylocust canopy which was 27 degrees C. The relationship was consistent throughout the 24-hour period, with the grass surface temperature being 19 degrees C at 6 am. Even though the grassy area is the coolest in the urban setting, it is warmer than the floor of a natural forest. A continuous vegetative canopy is absent and the soil is generally lacking the insulating property of an organic layer on the surface, causing the amount of radiation reaching the soil to be great. In many cases the soil is surrounded by large capacity heat-absorbing and reradiating surfaces, increasing the heat flux to the cooler soil. Evaporation of water from the soil surface eventually dries it and more radiation is used to raise the soil temperature, increasing the daytime maximum and imposing greater stress upon the plants. Nighttime minimum soil temperatures tend to be high because of the high air temperatures from the heat retention of structures. Plant metabolism rates potentially remain high (11). Unfortunately, few actual soil temperature data are available for urban soils. Inferences must be made from air or surface temperature measurements and heat budget evaluation at the mesoscale level, or from the observation of plant response.

Soil temperature is important since it controls the growth environment of roots and soil organisms, and inorganic chemical processes. A warmer temperature increases rates of reaction and biological processes. The rate of organic matter decomposition is increased, provided the necessary organisms are present, and the overall soil-weathering process may be intensified. The latter may have beneficial effect from the release of nutrients for absorption by roots. Root growth is extended well into the fall and early winter. This may prevent hardening off of the plants in northern latitudes before first damaging frost.

Organic mulching or other shading protection of the soil surface will do much to lower daytime maximum temperatures and prevent the drying out of the soil, benefiting fine root growth and development (23).

Desired characteristics in urban soil. Urban soil characteristics, as described, present plant survival and growth problems to the urban forester, arborist, horticulturist and landscape architect. The question then arises as to what the desired characteristics should be for soils used in planting and management of urban vegetation and how they are achieved. Only inferences to the latter will be provided here.

In agriculture the crops grown and the field management to maintain fertility, tilth, and to control erosion are based upon the soil characteristics of each field, with each field usually bounded by changes in soil or landscape condition. The same principle must be applied to urban soils except that the urban manager or designer can generally control or modify the characteristics of the soil material to suit the needs of the intended use of the area. Thus, different soil characteristics are required for turf areas or playfields from that of an open meadow receiving low intensity use. Soil for streetside tree planting will need different characteristics than those for tree planting in an open "green" or a yard with grass. Certain shrubs will require different soil characteristics from trees or turf. Even with the need for diversity of characteristics, there are several that can be applied generally to urban soils and will be helpful to all who are active in the urban environment.

Resistance to compaction. Soil factors that contribute to compaction are low organic matter content, destruction of aggregation (structure), and textural classes high in silt and fine to very fine sand. Under most practical conditions, loss of aggregation cannot be avoided and adding sufficient amounts of organic matter in a well-mixed material is not feasible unless large supplies of compost are available. It must be remembered that soils high in organic matter will compact if moisture conditions are toward the wet limit and if surface compressive forces are applied. The major reason moderate amounts of organic matter helps to ameliorate compaction is from its enhancement of aggregation, which takes time and soil organism activity together with physical and chemical processes. Thus, it is a long-term treatment and eventually produces the desired results if given the opportunity. Top-dressing of turf areas with compost is one solution.

Coarse sandy loam or loamy sand, with some organic matter (3-5 percent) to improve water relations, appear to be textural classes most resistant to compaction, especially if they are not hydraulically placed. Heavy, or clayey, soils may compact and have undesirable water and aeration relations unless well-aggregated, which are exceptions. Several disadvantages of the coarse soils include: susceptibility to scuffing and tearing of turf if the roots are not well-knitted; low water-holding capacity requiring frequent irrigation; low cation exchange capacity requiring frequent fertilization; and the danger of creating an interface between the coarse layer and adjacent finer-textured material that restricts water movement and may present an aeration problem. Even thin layers of diverse texture can create these problems. Care must be exercised in constructing the texture profile.

Amending the soil with porous, yet durable, materials ameliorates compaction. Patterson (13) suggests the addition of sintered fly ash or expanded slate as two possible solutions. These materials create a pore-size distribution that is favorable for water storage, movement and aeration status. Certainly, the bulk density should be maintained below a value of 1.60 mg/m^3. The addition of peat moss alone as a source of organic matter and to reduce compaction potential is not satisfactory in most cases because of the lack of uniform distribution in the soil and the expense.

Adequate aeration and drainage. In order for the urban soil to provide optimum conditions for rooting it must have a 'balanced' pore-size distribution. That is, there must be a minimum proportion of large pores to allow drainage of surplus water during the dormant season and immediately after heavy rains. These pores, when empty of water, then provide the diffusion pathway for oxygen movement into the soil from the atmosphere, and carbon dioxide formed in the soil, to move outward to the atmosphere. The macropore space (gravity-drained pores) should be about 20-25 percent of the soil volume (1). The medium and small pores, retaining water against the force of gravity, serve as the water storage for root absorption and must be present without being in extreme proportions—neither too much nor too little. Coarse-textured soil, as described above, provides a favorable but not ideal pore-size distribution. Disturbed fine-textured (silty clay loam and the clays) soil, or a compacted one, has mostly small pores. It will be waterlogged when wet and have a poor diffusion rate when dry.

Beside the consideration of the drainage and aeration charactersitics of the planting soil, provision must be made for drainage of the soil profile within the tree pit or planting bed. If proper drainage cannot be provided by the design or by modification of the planting area, use of even the most optimum soil material will not overcome the problem. Vegetation adapted to poor aeration should be used, or perhaps the planting should not be made in the first place.

Sufficient soil waterholding capacity and permeability. A soil, through its properties of texture, structure, total pore space and pore-size distribution, provides water that is available to plant roots for absorption. The total amount of available water retained by the soil is termed its water-holding capacity. This capacity is greatest for well-structured, medium-textured (loam and silt loam) soils and some exceptional fine-textured soils. Coarse-textured soils (very coarse loamy sand to coarse sandy loam) have very little water-holding capacity; however, they drain rapidly and do not readily compact. Therefore, it requires a greater volume of sandy soil compared to a fine-textured soil to store an equal volume of available water. The water-holding capacity should be at least 12 percent optimum at about 20 to 25 percent. A loam texture provides the latter and the minimum is provided by a loose sandy loam. To provide for these volume values, the total pore space should range from no less than 35 to 50 percent or more of the soil volume. This infers a bulk density range of less than 1.33 to no greater than 1.70 mg/m^3.

The amount of available water present in the soil at any given time is primarily dependent upon the moisture content in addition to the above properties. And, the total amount of water held in the soil is obviously dependent upon the combined influence of the properties of each horizon.

The water-supplying rate, or hydraulic conductivity, of the soil is important for meeting the diurnal needs of the plant. The soil must be able to supply water to the plant at the rate sufficient to satisfy its evapotranspirational requirements; otherwise,the plant wilts. Medium- and fine-textured soils (well-aggregated) have adequate hydraulic conductivity over a range of moisture contents because they have a wide array of pore sizes, which are well-interconnected and transmit water at an adequate rate. Sandy soil has adequate hydraulic conductivity only when near field capacity; as it dries, the conductivity is drastically reduced, and movement of water from the soil volume unoccupied by roots is extremely slow or non-existent because the sand has such a small proportion of medium and small pores that would be involved in moisture flow in the drier available range.

Abrupt changes of texture within the profile also has profound effect on moisture flow due to the presence of an interface between the two horizons. Flow from the coarse layer into the fine layer is controlled by the slower hydraulic conductivity of the fine layer; hence the coarse layer may easily become saturated if water is applied at a rate exceeding the fine layer conductivity. Conversely, flow from the fine layer into the coarse layer does not occur until the fine layer is saturated. The latter case arises many times when a fine-textured backfill lies against the coarse-textured nursery soil tree ball (Figure 3). When a fine layer lies above and below a coarse layer, the coarse layer is in effect isolated and may be saturated or very dry. Diversity in textures of the soil materials can create serious flow problems in the tree pit (the teacup effect) or planting bed and should be avoided. Gradual transition or near uniform texture is desirable. A possible solution to the problem in tree pits is to simply use the same material excavated from the pit or material that matches the soil surrounding the pit, providing other actions are taken to enhance root extension such as enlarging the pit. Bare-root planting is an additional alternative that helps overcome the interface and teacup problems.

Adequate rooting volume and configuration. Our present knowledge of the amount of rooting volume in a given soil material required to supply the plant, particularly an individual tree, with sufficient moisture from one precipitation or irrigation event to the next is very limited. It is a complex problem because it depends upon the water requirement of the plant species (genetically controlled), the water-holding capacity and hydraulic conductivity of the soil (determined by its texture, structure, total pore space and pore-size distribution as discussed above), and the stress demand of the environment in which the plant is located (determined primarily by the heat budget of the site).

Vrecenak and Herrington (21) have constructed a table based on model calculations giving the estimated water loss for trees of various crown diameters and leaf area indicies (LAI), assuming a water loss of 60 g/m^2 leaf area/hr and well-watered conditions. The example provided shows that a tree with a LAI of 4 and a crown radius of 10 meters would lose 75398 g/hr, or about 250 gallons of water in a 12-hour day. They then assume that the roots extend to the crown radius and are in the upper 0.5 meter of soil and calculate that the available rooting volume is 157.08 cubic meters. This would provide approximately 2 cubic meters of rooting volume for each

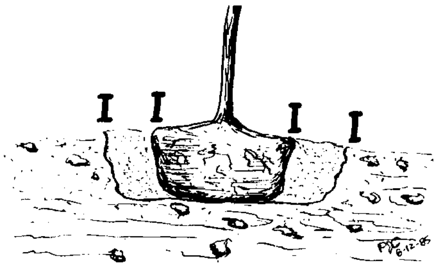


Figure 3. The tree pit and ball showing location of interfaces (I). Contrasts in texture will create water movement and rooting problems.

square meter of crown projection. Kopinga (9) gives a figure of 1.75 cubic meters of sandy loam as being adequate. If the soil is of loam texture and has a bulk density of 1.33 mg/m^3, and thus is 50 percent pore space half filled with water, the available supply would last for 23 days. There are two problems with these assumptions. The first is that the urban soil is seldom a loam with 50 percent pore space, as the bulk density tends to be greater than 1.33 mg/m^3, causing pore space to be less than 50 percent; and secondly, in the confined rooting space of the urban tree, the roots seldom extend fully to the crown projection. The suggested situation is that the roots are confined to a small space and the soil provides less available water than the model permits (15). In open areas where the roots are relatively unrestrained, the model is probably appropriate. The model does show that a 4-foot x 4-foot x 4-foot root volume is not adequate for large trees. Kopinga cites other work in the Netherlands that suggest 70 cubic meters is the optimum volume for elm and that the species grows very poorly in less than 10 cubic meters. As the authors (9,21) suggest, much more work needs to be done in this field.

Configuration of the rooting volume is as important as the amount. A deep, narrow configuration is not useful because the lower portion of the volume may not be occupied by roots because of poor aeration. Infiltration of water and diffusion of gases are confined to a small surface area. Unless the soil is very permeable, problems arise. A shallow, broad configuration is susceptible to high evaporation demand and dries quickly, requiring more frequent watering. The shallow pan utilized for bonzai trees, requiring careful daily watering, is a miniature example of the problem presented by this configuration. It must be concluded that there must be an optimum configuration for each application, but research has not yet discovered what the required array may be. Certainly the ratios of height, width and depth of the optimum greenhouse pot may give us a faint clue.

Appropriate soil reaction and fertility status. These two properties are probably the easiest of the list to adjust to the requirements of urban plants.

Soil reaction can be raised by liming, or as in the case of many urban soils, the soil reaction can be lowered by the addition of acid-forming substances. These include: organic matter, iron or copper sulfate, sulfur, and various inorganic acids. The latter are not always effective and are expensive. The best remedy is to provide soil material that appropriately has the desired soil reaction. Maintenance of the appropriate soil reaction is then easier. It should be remembered that different kinds of vegetation will require different soil reaction for optimum growth; therefore, different soil materials or management recommendations may be required for various portions of the planting design. Groundcover or perennials requiring a high pH should not be planted under trees or shrubs that have a low pH requirement; the incompatibility should be obvious.

Soil fertility status is related to the cation exchange capacity, a measure of nutrient storage, and is determined by texture and organic matter content as well as soil reaction. Most urban soils are not inherently infertile, but they usually exhibit in insufficiency of one or two nutrients, especially nitrogen. These nutrients are amended to the soil as fertilizer in granular form applied on the surface or mixed in during installation, or added in irrigation water. Differential nutrient requirements of various plant types can be easily accommodated much in the same manner as soil reaction. Regular controlled fertilization, with surface application being totally satisfactory, is a valuable aspect of any vegetation program. Over-fertilization should be guarded against because of the danger of the vegetation outgrowing its designed space or taking on unpleasant morphological features, or causing "salting out" in the limited soil volume.

Surface protection. Surface protection is important from the standpoint of preservation of the vegetation and its root system, prevention of surface soil compaction and erosion and the formation of a hydrophobic crust. Grating, mulching, groundcover, fencing and construction of other barriers are possible alternatives. Paving of heavily used but fragile areas to control and guide traffic has been practiced extensively in the National Parks with some degree of success.

Furnished in the design (if one exists) are the rooting volume, drainage of the site, surface protection, and irrigation and fertilization. The latter are really subsequent management and operation responsibilities. The configuration of the design provides the dimensions (height, width, length ratios), the shape (round, rectangular, cone, etc.) and also determines the kind and number of interfaces present by the choice of planting and backfill method and the kind of stock.

Summary

Urban soils have characteristics that are distinct from their natural counterparts. These characteristics include: great vertical and spatial variability; modified soil structure leading to compaction; presence of a surface crust on bare soil that tends to be water-repellent; modified soil reaction, usually elevated; restricted aeration and water drainage; interrupted nutrient cycling and modified soil organism activity; presence of anthropeic materials and other contaminants; and modified soil temperature regimes. The interaction of these characteristics presents problems to those active in the management of vegetation of the urban environment. Thus, attempts must be made to obtain a soil that is resistant to compaction and provides sufficient water supply at an appropriate rate, while at the same time having adequate aeration for normal root respiration. Further, the design or plan should provide sufficient volume of the soil in a configuration that enhances survival and aids the ease and low cost of maintenance. The design should also provide surface protection in highly-used areas. Additional work must be done to define the appropriate soil for each application. However, in the final analysis, the good judgement and common sense of the person "on the ground" together with simple guidelines presented here will solve many of the problems encountered with urban soils.

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