TREE STRUCTURE AND FUNCTION

Bruce W. Hagen

BASIC TREE PARTS:

- **leaves** - produce 'food' and create the transpirational stream.
- **flowers/fruit** - the reproductive organs of plants.
- **buds** - growing points for shoots, leaves or flowers, systhesis of growth regulators.
- **dormant buds** - those produced at the end of the previous season which expand during the current year.
- **meristematic points** - groups of cells (points), just under the bark that are capable of growing when stimulated, e.g. topping, exposure to light, depleted energy reserves.
- **epicormic sprouts** - leafy stems that grow on four-year or older branches or trunks, which typically are free of new growth. They are a symptom or stress and decline.
- **branches** - woody framework that supports leaves, transports water and nutrients, and stores (carbohydrates).
- **trunk** - support, transport, storage, contains bulk of wood
- **root flare** - enlarged base of tree where roots originate. Stress is greatest at this point.
- **buttress roots** - large support roots at base of tree.
- **woody roots**- support, transport, storage.
- **non-woody** - absorption (water and mineral elements), synthesis of growth
- regulators, and nitrogen bases compounds.
- **mycorrhizal roots** - a beneficial fungal/root association that enhances water and nutrient uptake.

WOOD ANATOMY:

- **bark** - dead, protective layer ('skin') that ensheathes the entire tree, protecting against temperature extremes, desiccation, insects, disease and physical wounding.
- **cork cambium** - actively growing (meristematic) layer, which produces the outer, dead bark.
- **phloem** - the living, inner bark that transports sugars, starch, fats, enzymes, growth regulators from the leaves through phloem in the leaf veins to the branches, trunk and roots through the leaf vein phloem and trunk to the roots.
- **cambium** - an actively dividing (meristematic) layer of cells, producing wood (xylem) to the inside and the phloem to the outside.
- **xylem** – is the wood which can be divided into sap and heartwood (some tree lack heartwood)
- **sapwood** – conducts water and dissolved minerals from the roots to the leaves through conducting elements (vessels and tracheids). These connect directly to the xylem in the leave veins. Sapwood contains *living* cells (**parenchyma**) that store energy and defend against pathogens. Most of the wood consists of fibers, which function in support. Vessels tracheids and fibers are dead
- **heartwood** - does not transport water and minerals, and contains no living cells. As new wood is added each year, the inner most rings (increments) of sapwood gradually die, becoming heartwood. Chemicals accumulate, changing its color, making it more resistant to decay. In addition, the moisture and nutrient levels decrease, creating a harsh environment for pathogens.
- **parenchyma** - living cells that store the trees energy reserves. They also resist pathogens. Parenchyma is arranged radially (in and out) and axially (up and down) in the stem. The radial parenchyma connects directly to the phloem. In this

manner, materials can move from the site of production (leaves) to their storage site in the living cells of the sapwood.

- **annual rings** (increments) are formed by variation in growth rate:
  - **earlywood/springwood** - large vessels *(pathogens can easily invade and move rapidly within)*
  - **latewood/summerwood** - small vessels, thick cell walls *(greater resistance to pathogens).*

GROWTH - The cambium generally grows in a downward fashion, e.g., growth in diameter begins in the branches proceeding to the trunk and roots. Growth in height and spread occurs at the tip of each shoot. These growing points are called buds or *meristems*. They are areas of rapid cell division and elongation. Flowers, leaves, axillary buds and conductive tissue of the shoot are formed here. The shoots are formed here. The terminal bud **(leader) of each shoot dominates, to varying degree, those below it by growth regulating chemicals (auxins).**

Each year, shoots grow from buds and end by producing new buds for the next season's growth. The growth of new buds is dependent upon energy (starch) and nitrogen stored in the buds the previous season. Buds can form shoots with leaves and flowers, leaves or flowers. They are either:

- **dormant** - one year old (formed the previous season).
- **adventitious** - can form anywhere usually from callus tissue.
- **latent** - these are not true buds; rather they are *meristematic points* that produce **epicormic** sprouts along the trunk, older branches and below pruning cuts.

Annual shoot elongation is a measure of tree vigor. There are two basic types of shoot growth:

- **fixed** - bud contains a pre-formed shoot, which expands over a short period of time. Once expanded, there is little further growth, ex. deciduous trees and some conifers, e.g., most pines, fir and spruce.
- **free** - some shoots not pre-formed longer period of growth). Growth will continue as long as environmental conditions are favorable, ex. redwood, juniper, and broadleaf evergreens.

- *TREE SHAPE* is related to inhibition of growth of lower, lateral buds by the apical or top most bud (leader) of a tree or branch. **Apical dominance** refers to the inhibition by the leader of only those lateral buds produced on current growth. These buds are released the following year. Thereafter, the leader is unable to control their growth. Because they often grow more vigorously than the leader, they usually overtop it. Trees with type of growth are said to be *DECURRENT* - round-headed, no dominant central leader, typical of most hardwoods.
  Apical control, on the other hand, refers to the condition where the leader is able to influence (suppress) the growth of laterals for most of the life of the tree. Trees with this type of growth are said to *EXCURRENT* - pyramidal, dominant central leader with lateral branches increasing in length from the top downward:

Excurrent growth form can result from:

- **weak apical dominance** and **strong apical control** - (ex. liquid ambar, pin oak, etc.), or
- **strong apical dominance** and **strong apical control.**(ex. pines, Douglas–fir)

Decurrent growth form result from:

- **strong apical dominance** and **weak apical control** (oaks, elm, maples etc.) or
- **weak apical domimance** and **weak apical control** (willows).

GROWTH REGULATORS:

- **auxins** - produced in **shoots**, initiates cell division, cell elongation, protein synthesis, stimulates root growth in high concentration.

- **giberrelin** - controls flowering and internodal expansion.
- **cytokinins** - produced in **roots**, these compounds release lateral buds and stimulate shoot growth in high concentration.
- **abscisic acid** - slows or stops growth, initiates senescence, aging, and dormancy. Inhibits lateral and latent buds in combination with auxin.
- **ethylene** - involved with the elimination of excess auxin.

Growth regulators are basically chemical signals allowing the tree to respond appropriately to environmental stimuli. They interact with one another to maintain a balance between root and shoot growth (auxin and cytokinin), and control the timing and sequence of growth. Their concentration and ratios are important. Environmental change or physical damage can disrupt the balance of growth regulators resulting in predictable tree responses.

Trees, in order to grow and function properly, need oxygen, carbon dioxide, water, mineral elements, and sun light, all in proper concentration.

WATER is necessary for tree growth because it is a:

- solvent for minerals, gases, sugars, etc.
- medium for transport
- constituent of protoplasm
- building block for photosynthesis
- fluid to maintain leaf turgor
- coolant

MINERALS are necessary for growth because they are:

- constituents of plant tissue, enzymes, growth regulators, etc.
- catalysts
- osmotic regulators
- constituents of the buffering system
- regulators of membrane permeability

OXYGEN is needed by all living cells for respiration, an energy releasing process. Respiration is a constant process converting carbohydrate into energy.

PHYSIOLOGICAL PROCESSES:

- **photosynthesis** - production of sugars (food energy).
- **respiration** - the breakdown of sugars to provide energy for growth.
- **absorption** of water and minerals
- **transport** - the movement of carbohydrates, growth regulators, elements, etc., within conducting system.
- **transpiration** is the movement of water from the roots out through the leaves.
- **nitrogen and fat metabolism** - protein, DNA, suberin, etc.
- **assimilation** - conversion of food into new protoplasm and new cells (growth).
- **storage** - reserve foods (carbohydrates, fats, lipids, etc.).

PHOTOSYNTHESIS converts light energy to chemical energy that can be stored and used later as needed:

$$6CO_2 + 12H_2O \xrightarrow[\text{light + chlorophyll}]{} C_6H_{12}O_6 \text{ (sugar)} + 6O_2$$

Glucose is a source of energy and the starting point for all other compounds, e.g., proteins, fats, etc. Glucose is converted to starch (carbohydrate) whenever high levels are present and stored in parenchyma cells in branches, trunk and roots. Starch is converted back to sugar when the concentration is low or it is cold. Energy can also be stored in the form of lipids (fats, oils etc.).

RESPIRATION releases the energy stored in carbohydrate, fat and other storage products to provide energy for:

- water and mineral absorption
- growth
- transport of materials across membranes.
- reproduction - flowers and fruit

- protection and defense

$C_6H_{12}O_6 + 6O_2 \dashrightarrow 6Co_2 + 6H_2o$ + ENERGY

When overall respiration exceeds overall photosynthesis the tree will decline. If there is no change, the tree will die.
Beneficial fungi associated with tree roots (mycorrhizae) use up a large portion of a tree's carbohydrate reserves to help absorb certain minerals.

WATER AND MINERAL ABSORBTION - water, and minerals dissolved in soil water are absorbed at the root surface or by mycorrhizae and moved into the conducting elements of the roots. The exact nature of absorption is not known. Mineral elements are the basic building blocks for new growth and cellular function. Thirteen are required for normal growth. Energy for absorption is provided by respiration. Thus oxygen is required for normal root function. Oxygen is a critical resource because it is often limited in the soil.

TRANSPIRATION - water is pulled up through the roots and conducting elements of the xylem as a result of capillary action and evaporation from the leaves. As water molecules escape, they pull more water molecules up (cohesion). Before leaves form, roots can "pump" water by increasing their osmotic potential causing an inflow of water. The opening and closing of minute opening (stomata) in the leaves can control water loss. Cells (guard cells) surrounding the stomates control their opening and closing. Stomates generally open in light and close in dark. Light, temperature, humidity and wind influence the rate of transpiration. Certain anatomical features, e.g., number of stomata, presence of hairs, thickness of cuticle (waxy layer), etc. affect transpiration.

TRANSPORT involves the movement of materials in solution within the tree's conducting system (xylem and phloem) from the source to the site where they are stored or used. There are two basic directions of transport, radial and longitudinal. Longitudinal (**axial**) movement is mostly downward in the phloem, and mostly upward in the xylem. **Radial** transport is mostly outward in the spring and inward later. Energy is required to transport materials in solution. It involves the movement from one living cell to another through membranes.

PHENOLOGY is the timing of natural events in plants. Trees have 5 major phenological periods:

1. onset of growth - root elongation
2. formation of leaves, shoot expansion
3. cambial growth - xylem and phloem
4. energy storage, increased root growth
5. dormancy

1 3 4 5

energy 2

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time →

1. Elongation of non-woody roots, and absorption of water and minerals.
2. Leaf-flush from buds formed the previous season. Stored energy is used to expand buds and eaves.
3. Leaves expanded and functional. Wood and inner bark forming, fruit may form in this period or in 2.
4. Excess energy being stored in new wood.
5. Leaf shed, non-woody root replacement slowing with cold weather.

CRITICAL TIMING - because carbohydrate reserves are at their lowest just after leaf flush, it is advisable to avoid injuring a tree or stimulating growth, e. g., pruning, transplanting, root pruning or fertilizing, at this time.

ROOTS

Tree roots provide anchorage and support, absorb water and mineral elements, and store energy reserves. Tree roots are often ignored or poorly understood because they are largely hidden from view. The roots of trees often extend outward two to three times the radius of the dripline. Roots branch and rebranch many times forming and extensive network of absorptive tissue with an immense surface area. Although the type of root system a tree develops is largely an inherent characteristic, factors such as soil texture, structure, depth, fertility, available moisture, etc. greatly influence depth, spread and degree of branching. Most tree roots grow within the upper meter of the soil, however in clay soil or poorly drained soils tree roots may be confined to the upper 12 inches or near the surface. In sandy soils it is not uncommon to find roots at ten feet or even deeper.

The root systems of trees consist of a framework of relatively large, perennial and woody roots, and many smaller, short-lived and non-woody roots. Tree roots are similar in structure to stems after developing secondary growth. Large roots are woody and surrounded by phloem and outer bark. The cambium between the bark and wood is responsible for diameter growth.

Tree roots form a symbiotic relationship with certain beneficial soil fungi. These fungi, which enhance root function, have allowed trees to survive in habitats that would otherwise be too harsh. Roots colonized by these specialized fungi are termed 'mycorrhizal'. They contain both tree and fungus tissues. Both organisms benefit from this arrangement. While the fungus aids in the absorption of water and essential mineral elements, it derives nourishment from the roots.

Water and minerals dissolved in soil water, are absorbed by the roots or mycorrhizae and transported into the conducting cells of the roots. Energy required for growth and the absorption of minerals is obtained by oxidizing sugars in the process of respiration. Thus, root growth and function depend on the oxygen contained in the soil. All living cells in a tree require oxygen for respiration, but it is more critical for roots since oxygen is often limited in the soil

Nitrogen and the mineral elements are absorbed by roots as ions (charged molecules or atoms) dissolved in the soil water. Evidence suggests that certain proteins may carry ions across the membrane and /or that specific root membrane sites attract and bind ions. The concentration of ions within roots is likely to regulate ion absorption and may be at least partially under hormonal control.

A high concentration of ions in the soil solution may cause plant injury, dehydration, stomatal closure and reduced photosynthesis.

Practically all movement of nitrogen and minerals from roots to shoots occurs in the xylem carried **by** mass flow in the transpirational stream. There is also considerable lateral movement of minerals between xylem and phloem and recirculation in the phloem plays an important role in mineral nutrition.

Soils:

Soil—single most critical environmental determining growth, health and longevity
Most problems in urban areas are soil-related
Soil provide water, minerals, anchorage and support
Soil is an ecosystem

Important characteristics:

Depth – rock or impenetrable layers
Volume for roots to exploit.
Texture: relative proportion of sand, silt and clay:

- water-holding capacity (availability)
- nutrient-holding capacity (fertility)
- penetration
- drainage (percolation)
- aeration

Structure: how particles are arranged into clumps

- aeration
- drainage
- ease of root penetration

Other considerations:

Organic matter content:

- source of nutrient
- energy source for soil organisms
- nutrient-holding capacity
- helps maintain structure
- improves biological activity

Soil pH: relative acidity or alkalinity

- determines mineral availability

Biological activity

Salinity, toxicities

Urban soils: associated problems

- mixed layers
- low in organic matter
- difficult to wet – run off, poor water-retention
- poor drainage, low oxygen
- resist root penetration
- toxins
- paving over roots
- restricted volume

Introduction

Soil: A discussion

Soil is much more than a substrate of rocks, sand, silt and clay that anchors roots and provides water and minerals to trees. In fact, soil is an ecosystem, teeming with life – insects and other, arthrodods, worms, fungi, bacteria, and other microbes all living together in a delicate balance. A thimble full of soil can contain tens of millions of living microbes, each with some function in the soil's ecology.

The ecology of a soil varies by geographic region and with the plant community growing there. For instance, the mix of plants, soil types, animals and microbes including pathogens in grassland are not the same as those in a hardwood forest... The soil beneath an oak forest in Minnesota is distinctly different than the soil within a eucalyptus grove in California. .

The characteristics of the soil in which a tree's root grow are perhaps the single most important environmental factor influencing tree health. By knowing more about soil texture, structure, pH, and water- and mineral holding capacity, the arborist will be better equipped to manage trees in an urban environment.

Physical Properties of Soil
Native soils are the result of thousands of years of biological, chemical, and physical weathering and erosion of **parent material**, or underlying bedrock. Soils are usually dominated by the geology of the soil parent material. By volume, ideal soils are composed of about 45 percent mineral materials (sand, silt, and clay), 5 percent organic matter and living organisms. The remaining 50 percent is pore space. pore space, and over time soils develop layers, called **horizons**, due to rainfall, (erosion, soil movement, natural deposition, sedimentation) ?, heating and cooling, chemical reactions, and biological activities. The description and classification of these soil layers are part of a **soil profile**.

The soil profile normally consists of five major horizons (O, A, E, B, and C), although soil scientists classify a number of sub layers and transitional layers. Sometimes these layers can be distinguished by differences in color, which can indicate variations in drainage, organic-matter content, and other characteristic changes. The top of the profile, in an unaltered soil, is a thin layer of decomposing organic material called the **organic layer**.

The next layer down is the A horizon. The A horizon contains most of the absorbing roots of trees. This horizon is normally rich in organic matter. The E horizon is an area of mineral weathering. The B horizon, intermediate in depth, is composed of fine-textured materials from the A horizon and soil particles from the lower parent material. The A and B horizons can be modified enough by the environment to be considered "topsoil." In urban situations, it is not unusual for much of the topsoil to have been stripped away during development. .

The C horizon, or subsoil, is the lowest layer just above the bedrock, and it is composed of the rocky parent material. Mineral elements, decayed organic material, and other residues move down into the mineral soil. Soil is continually forming through the physical, chemical, and biological weathering of the parent material and the organic layer.

The organic layer, on the soil surface, contains materials such as leaves, twigs, spent flowers, fallen fruit, bark, and dead organisms that compose the *litter* layer. The litter layer is very active biologically and is slowly decomposed by this activity. **Organic matter** consists of dead plant and animal material in various stages of decomposition. Organic matter shrinks and swells with varying moisture content and helps to form pore space within the soil. Some organic matter helps to stick soil particles together to form larger aggregates, which improves soil structure. In addition, organic matter improves water- and nutrient holding capacity and provides mineral nutrients upon decay. In fact, much of a soil nutrient content is held in the organic material fraction.

Tree roots proliferate where soil conditions are most favorable. Roots require adequate oxygen and water, essential mineral elements, stored largely in the soil's organic material, and of course, space among soil particles and aggregates, s and, and. Thus, absorbing roots are typically found in the upper 6 to 10 inches of soil, and tree roots seldom grow deeper than 3 to 4 feet unless growing in fractured rock or in deep, well structures soils.

Soil texture refers to the relative fineness or coarseness of soil mineral particles, specifically the proportions of sand, silt, and clay. Sand particles are relatively large, resulting in coarser-textured soils. Soils having a high percentage of clay, the smallest soil particles, are fine textured. Silt particles are intermediate in size. Textural classes of soil are determined by the percentage of the three particle types, as shown in the soil textural triangle). Loam is a mix of particle sizes often considered ideal because of the favorable characteristics for plant growth. . Soil texture affects a soil's ability to hold water and to provide oxygen to the roots. Texture also influences mineral holding capacity. For example, soils high in clay content have a high CEC, as the clay particles attract cations, e.g., Ca, Mg, K, etc., By comparison, sandy soils, lacking clay and organic matter, are typically nutrient poor. Thus, texture plays a role in determining which species of trees will do well in a particular soil. .

Bulk density is the weight of dried soil per unit of undisturbed soil volume. Bulk density is a measure of a soil's porosity, or airspace between the particles or soil aggregates. High bulk densities indicate a low percentage of total pore space. Large gaps between soil particles and aggregates are known as **macropores**. Macropores are normally filled with air. Small gaps between soil particles and aggregates are called **micropores**. They tend to be filled with water. Macropores dominate coarse soils (sand), yet fine soils tend to have more overall pore space, or lower bulk densities. Water movement through the soil, and root growth occur predominantly within the macropores.

As a soil weathers, as organisms reproduce and die, and as organic materials are consumed and excreted, the basic soil particles become grouped or clumped together. These secondary groups or clumps are known as soil aggregates and provide **soil structure**. Roots growing through the soil break it into aggregates, thus increasing its porosity and ability to take in water. Freezing and thawing, and burrowing insects and other animals contribute to changes in soil structure over time. These processes increase the ratio of macropores to micropores, improving soil aeration and root growth.

The size and shape of soil aggregates, or particle clusters, are important in water and air uptake by tree roots. Soil structure modifies the influence of texture on pore space and drainage. For example, a well-developed granular structure facilitates aeration and water movement. Poor soil structure can have adverse effects on water **infiltration** and **percolation** and soil compaction. Soil organism, particularly fungi, aid in soil aggregation, which improves water infiltration rates, tilth, and aeration necessary for good root growth

Soil aggregates, and accompanying pore spaces, are easily disrupted by physical compaction of the soil. When soil minerals are compacted by vehicles, foot traffic, or other causes, pore space is greatly reduced, especially macropores that tend to be oxygen filled. Soils that have a broad range of particle sizes and those that are wet can be severely compacted. When a soil is severely compacted, the soil particles at the surface often align parallel to the surface, much like shingles on a roof, inhibiting water percolation. Compacted soil resists root penetration, reduces water infiltration and availability, and limits the movement of oxygen and carbon dioxide in the root zone–The net effect is restricted root growth and function.

Chemical Properties of Soil

Soil **pH** is a measure of the acidity or alkalinity of soil. The pH scale ranges from 0 to 14. A pH of 7 is considered neutral. Soils with a pH less than 7 are acidic, and those with a pH greater than 7 are alkaline. Because pH is a logarithmic function, a pH of 6 is ten times more acidic than a pH of 7, and a pH of 5 is 100 times more acidic than a pH of 7. Although variable for different tree species, a pH in the range of 6.0 to 6.5 is generally favorable for most plants.

Soil pH has many effects on the ecology and chemistry of the soil. Soil pH may affect which species will grow and which soil organisms are present. One important effect of pH on tree growth is the availability of minerals. At certain pH levels essential elements form chemical compounds that are insoluble in water and thus unavailable to plants because roots can only take up minerals dissolved in water. For example, in highly acidic soils with a pH of 5.5 or below, phosphorus may be deficient while other elements may become toxic.

In alkaline soils, iron and manganese may be unavailable because the chemical form of these elements changes, and they become insoluble, solid particles. **Micronutrients** such as iron and manganese may then be deficient, showing up as **chlorosis** – discolored or yellow foliage. The availability of calcium, magnesium, and potassium, however, may increase with higher pH.

It is difficult to alter soil pH to achieve a more desirable growing medium. Sulfur may be added to lower the pH, and lime may be added to raise the pH. However, altering the pH is usually not practical for arborists because the volume of soil in the tree root area is so great. In addition, many soils have a high **buffering capacity**, or resistance to change in pH, especially soils high in clay or organic matter.

Minerals required for tree growth (essential elements) dissolve in water, making them available for absorption by tree roots. In solution, these elements are charged particles called **ions**. Negatively charged ions are called **anions**; positively charged particles are called **cations**. The **cation-exchange capacity (CEC)** is a measure of the soil capacity to attract, retain, and exchange positively charged cations. (ex. Ca^{++}, Mg^{++}, K^+, NH_4^+, etc.

Organic matter and clay normally carry a net negative charge. This negative charge attracts and holds cations, giving soils high in clay and organic matter a high cation-exchange capacity. This makes them more fertile than coarse-textured soils. The attraction between cations and soil particles minimizes the tendency of minerals to **leach**, or wash through the soil.

Soil salinity is a measure of the quantity of mineral ions dissolved in soil solution (water). Although mineral ions in the soil water are essential to plants, excess quantities can be harmful. Certain types of soils have a tendency to accumulate soil salts to excessive quantities and must be monitored and managed closely. The recommended treatment for excessive salts in the soil is to flush them through the soil solution with low salinity water.

Biological Properties of Soil

Soil is an ecosystem containing billions of organisms. Although some soil organisms may damage roots, many are beneficial, and others have no direct effect on tree roots. Organisms such as insects and earthworms, which inhabit the soil and litter layer, increase aeration and accelerate decay. Other organism feed on roots. **Nematodes**, microscopic roundworms, can parasitize tree roots, and some transmit disease. Other nematodes feed on pathogenic, disease-causing organisms. Other organisms found in the soil ecosystem include bacteria and fungi. Most of these are an essential part of the balance of life, helping to decompose organic matter or aid in nutrient uptake. A few cause diseases in plants.

The **rhizosphere** is the zone of intense biological activity surrounding actively elongating roots. As roots extend through the soil, the root caps and external layers are sloughed off and materials (sugars) from the roots are released into the soil. This source of carbohydrate can be used by microorganisms as a food source... The rhizosphere is an altered environment within the soil where many living organisms flourish.

Mycorrhizae, literally meaning "fungus roots," are roots colonized by special, fungi. Most plants are associated with such fungi... Mycorrhizal fungi live in a **symbiotic** relationship with the roots. This means that the fungi and roots both benefit from the relationship. The roots provide a place for the fungi to live, and provide food (sugars), and in return the fungi aid in water and mineral uptake. .

Nutrient cycling is especially important in natural plant systems. As a plant grows, roots absorb essential mineral elements from the soil solution and produce new woody material and leaves. As seasons pass, plants or plant parts die and are returned to the soil surface where they are broken down and eventually decomposed by soil organisms and the weathering processes. Decomposition releases the nutrients that were bound in the organic material back into the soil where they become available, once again, to plant roots.

Soil Moisture and Plant Growth

Soil and water exist in a dynamic equilibrium that makes it almost impossible to discuss one without discussing the other. The physical, chemical, and biological properties of soil are all somewhat dependent on soil moisture. Arborists must understand this relationship to manage the health of trees.

The amount and size of soil pores and the total surface area of the particles determine the amount of water that a soil can hold. Clay soils have more total pore space and particle surface area than sandy soils. Thus, clay soils have a higher **water-holding capacity** than sandy soils. Water that drains from the larger macropores under the force of gravity is called **gravitational water**. A soil is said to be at **field capacity** when gravitational water has drained away. Water that remains is held by the soil particles.

Once a soil is at field capacity, water can be absorbed by plant roots or it may be lost to evaporation... Roots can draw water from the soil as long as they can overcome the forces of adhesion, which hold water on the surface of the soil particles. Tree leaves may wilt during periods of high water demand during the day but usually recover at night when transpiration decreases and the roots can replenish the water (equalize the water deficit?). Eventually, depending on the water-holding capacity of the soil, a point will be reached at which a tree cannot pull any more water from the soil. This point is called the **permanent wilting point**. A plant will not recover from wilting unless water is added to the soil. Trees existing in soil at the permanent wilting point, when no usable water is available from the soil, usually decline, dieback or die.

Trees need both air and water, and there is a delicate balance of water and gases (mostly oxygen, nitrogen, and carbon dioxide) in the soil pores. Tree roots require oxygen for root respiration, which releases the energy needed to absorb water and minerals. Carbon dioxide is given off by the roots as respiration takes place. Gas exchange between the soil and the atmosphere generally occurs by diffusion through the soil surface. Oxygen levels tend to be higher near the surface. If there is insufficient gas exchange, such as in saturated or compacted soils, carbon dioxide levels may build up to toxic levels and there may be an oxygen deficit as well. This can reduce root function and growth, and if it occurs for prolonged periods, can lead to root death.

Layers of varying soil texture are common in urban soils and can be a problem in planting situations. The texture of the soil plays a major role in the **infiltration rate** of water. If a layer of coarse soil (sand) is placed on top of a fine-textured soil (clay), water will accumulate in the upper layer as it slowly infiltrates into the lower layer. Inversely, if the coarse layer is below the fine layer, the water will not drain into the lower layer until the upper layer is completely saturated.

If a tree is planted in clay soil and the backfill is amended with a more coarse soil, the planting hole may act as a bowl and retain the water (the “teacup effect”). If the water is held for a long time, the roots drown. Placing gravel in the bottom of planting holes, pits, or containers does not improve drainage as commonly thought, because the water remains in the finer-textured soil until saturation is reached.

Urban Soils

While natural conditions create most undisturbed soils, human activity is the principal influence on urban soil, often degrading the soil’s natural characteristics that favor tree growth. . Urban soils often do not have an organic layer. The soil may be compacted or crusted and may have a disrupted soil profile, altered drainage, elevated pH, or subsurface barriers as a result of building foundations, roads, or underground utilities. All of these factors may impact root growth and tree health, eventually leading to decline.

Turf, bare ground, or hard cape replaces the organic layer in many urban soils. Hard cape may impair aeration and water infiltration. Organic-matter reduction decreases biological activity, hampers soil structure development, and interrupts nutrient cycling. Urban soils may lack important microorganisms such as mycorrhizae. Furthermore, the absence of the insulating forest organic layer and vegetation can contribute to greater fluctuations in temperature extremes.

Compaction is one of the biggest problems in urban soils. Compaction is often caused by construction, foot or vehicular traffic, engineered soils to support roads or buildings, or other factors. Compaction reduces total pore space and the proportion of macropores to micropores. Loams, silt loams, and other soils with a variety of particle sizes may be particularly vulnerable to compaction because small particles are pressed into large pore spaces between coarse particles.

Trees and soils are so ecologically interdependent that it is hard to imagine separating them from one another. Yet the processes involved with urban development disrupt this ecological balance, creating growing conditions that may range from unfavorable to antagonistic. It has been said that the vast majority of tree decline situations can be attributed to an initial soil stress. Trees are living systems driven by energy. They must obtain sufficient oxygen, water, essential elements, and other components from the soil to meet their energy requirements. Understanding soil is vital to arboriculture because soil is, quite literally, the foundation within which a tree grows.

Organic matter in the soil improves nutrient- and water-holding capacity, soil structure, aeration, mineral content and biological activity. Organic matter favors the development of beneficial fungi and bacteria that compete with and parasitize certain pathogenic fungi. Root diseases are more likely to develop in soils containing low levels organic matter.

Soil aeration is determined by both soil texture and structure. In general, compacted and finer soils, due to a higher proportion of small pore spaces, tend to drain poorly and hold less oxygen than coarser, sandy soils or well-structured soils. Water retained in the small pores displaces oxygen and inhibits gaseous diffusion. Soil structure, however, can greatly increase the proportion of large pore spaces.

Soil structure describes the arrangement of soil particles in a soil. Soil particles aggregate naturally to form larger particles, improving porosity (aeration, permeability, drainage, root penetration and water-holding capacity). Soil aggregates, which greatly increase porosity, are readily destroyed by activities that compact the soil. Thus, compacted soils inhibit gaseous exchange, permeability, drainage and root penetration.

Excerpted from a ISA publication: Tree and Soil Relations

Back to basics: Root structure and function

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The performance of urban trees is closely linked to the health and structural integrity of their root system and the soil in which they grow. Roots have multiple roles that are essential to tree growth: absorption and transport of water and minerals, storage of energy reserves, synthesis of organic materials (hormones, amino acids, and other organic compounds), and anchorage and support of lower trunk and tree crown. Because tree roots are largely hidden from view, they are often ignored or poorly understood.

Root systems vary widely in distribution depth, and spread: some are shallow, while others are relatively deep. Some extend far beyond the crown, while others are concentrated primarily within the drip line. They vary in root type and number: some root systems consist of a large number of lateral roots, while others have a combination of tap, oblique, sinker and lateral roots. These variations develop in response to differing soil conditions and to some extent from inherent differences within and among species.

Root growth, morphology, depth and extent are greatly influenced by the surrounding soil. Aside from serving as a substrate for anchorage, soils provide essential resources for roots, including water, minerals, and oxygen. In soils where these resources are limited, root function and development can be severely impaired.

Disturbances to the soil around existing trees (root zone) as a result of grade changes, removal of topsoil and organic material, excavation and trenching, soil compaction, paving, landscaping and irrigation can adversely affect root systems. These changes can have direct or indirect impacts on root function and development, ranging from slight to severe.

In urban areas, most tree roots tend to be fairly shallow—within the upper 2 to 3 feet of the soil, and a large portion of the root system is contained within the dripline, although roots often radiate well beyond. Thus, excavation for a building site, foundation, retaining wall, etc., within the dripline can easily sever major roots. Although research conducted on trees growing in temperate (mild) climates demonstrates that root growth is largely restricted to the upper meter of the soil. It's important to recognize that in the more arid regions of the West, roots of the native tree species typically grow much deeper, depending on soil conditions. Tree roots in heavy clay, poorly drained and frequently irrigated landscapes are usually confined to the upper 12 inches of the soil or even closer to the surface.

Root distribution is an important issue for tree stability. The roots of naturally generated trees typically grow radially outward and largely parallel to the surface. In some cases, additional roots grow downward to lend additional anchorage. This provides for stability as trees grow. Trees propagated in containers, however, often develop serious defects that greatly affect stability and longevity. Unless treated during propagation or at the time of planting, the resulting trees often are less stable than those with well-formed root systems. They may also grow poorly. Treatment is relatively simple—prune away the outer ½ to one inch of the 'root ball', outer edge and bottom to eliminate matted, kinked, circling and roots directed downward or upward by the sides or bottom of the container. The roots developing from the cut portions will grow radially outward as they should. (See Guidelines Specifications for Nursery Tree Quality, pages ?)

Root size, structure (morphology), depth, spread and distribution, are influenced by soil conditions and difficult to predict from an aboveground inspection. Pneumatic tools (devises using air pressure to displace soil particles) can be used to locate roots to avoid unnecessary injury during construction.
Soil texture—the relative proportion of sand, silt and clay particles, largely determines its capacity to hold water and air. Soil structure—the arrangement of the soil particles into clumps (aggregates), increases a

soil's porosity, providing for the movement, and availability of both air and water. Other factors that influence rooting depth include soil fertility, available moisture and depth to impenetrable layers such as rock, hardpan, claypan, high water table, etc.

Roots branch and rebranch many times, forming an extensive network of fine roots—absorptive tissue with an immense surface area. Much of a tree's root system responsible for the uptake of water and minerals is concentrated within about 18 inches of the soil's surface, however, roots can and do grow much deeper. This helps explain how trees obtain water once soil moisture in the upper layers is depleted. When tree roots are restricted by unfavorable soil conditions, such as shallow, impenetrable soils, poorly aerated soils, raised planters, etc., tree health suffers. Trees with extensive and well-distributed root systems are more likely to tolerate adverse environmental conditions or development impacts than those with roots systems compromised by unfavorable soil conditions or inappropriate management practices.

Root systems of mature trees consist of the large, lateral roots at the trunk base that radiate outward. Within a few feet of the trunk, these roots quickly decrease in size and grow mostly in the upper foot or two of the soil, largely parallel to the soil surface. Depending on species and soil conditions, some roots near the trunk base grow vertically or diagonally downward. Such roots are often called 'oblique' or 'heart' roots. The lateral roots of many species produce a number of downward growing roots within several feet of trunk. They are called 'sinker' roots and are thought to be important in providing anchorage. Taproots produced by some tree species, such as oaks, seldom persist for very long. They are usually overgrown by lateral and heart roots.

The root system is a framework of relatively large, perennial and woody roots and many smaller, short-lived and non-woody roots. Woody roots are similar in structure to the branches and stems. Large roots are woody and surrounded by phloem and outer bark. The cambium between the bark and wood is responsible for diameter growth. The phloem or inner portion of the bark conducts sugars, hormones and other substances produced by the leaves to the other parts of the tree and to the roots. Pores (conducting elements) in the wood of the roots and stem conduct water, minerals, hormones and other substances upward from the soil to the leaves. Lateral roots unlike branches develop from a tissue layer inside the root (the epidermis) rather than from buds.

The fine, absorbing roots of trees form symbiotic relationships with specialized fungi (mycorrhizae) naturally occurring in the soil. These fungi, which enhance root function, allow trees to survive in habitats that would otherwise be too harsh. Roots colonized by these fungi are termed 'mycorrhizal.' They contain both tree and fungus tissues. Both organisms benefit from this arrangement. While the fungus aids in the absorption of water and certain essential mineral elements, it derives nourishment (sugar) from the roots.

Water and minerals dissolved in soil water, are absorbed by the roots and mycorrhizae and transported into the conducting cells of the roots. Energy required for growth and the absorption of minerals is obtained by releasing the energy bound in sugars in the process of *respiration*. Thus, root growth and function depend on the oxygen contained in the soil and sugar produced by the leaves during the process known as *photosynthesis*. All living cells in a tree require oxygen for respiration, but it is more critical for roots since oxygen is often limited in the soil due to poor soil aeration as a result of excess irrigation, poor drainage, soil compaction, or pavement over the root zone of trees.

Nitrogen and the other minerals that trees need are absorbed by roots as ions (charged molecules or atoms) dissolved in the soil water. Evidence suggests that certain proteins may carry ions across the membrane and /or that specific root membrane sites attract and bind ions. The concentration of ions within roots is likely to regulate ion absorption and may be at least partially under hormonal control.

A high concentration of ions (salts) in the soil solution due to excess fertilization use of saline or reclaimed water may cause plant injury, root dehydration, stomatal closure and reduced photosynthesis, all of which can cause poor growth, pest susceptibility, dieback decline and even death, depending on salt concentration.

Practically all movement of nitrogen and minerals from roots to the growing shoot above occurs in the xylem carried in the transpirational stream. There is also considerable lateral movement of minerals between xylem and phloem, and recirculation in the phloem plays an important role in mineral nutrition.

Significant root loss is a serious problem for trees because it limits the uptake of water and minerals. The level of impact of root loss will depend on the size, number of roots cut, proximity to the trunk and the percentage of the root system lost. The larger the roots, the greater the number of roots cut, and the closer the cuts are to the trunk—the more serious the damage. Other factors include age and health of the tree and soil moisture.

Root can be severed by soil excavation or utility trenching within the root zone of a tree, or when pruned for various reasons, such as during sidewalk repair. The closer the disturbance is to the tree, the more serious the damage. Others factors such as reduced soil aeration due to compaction, flooding, pavement or fill-soil placed over the root zone can affect root function and result in root death or increased susceptibility to root disease. The cutting of large roots close to the trunk also opens the trunk base to decay and potential failure. Root cutting within 5 times the diameter of the tree measured at 4.5 feet above the ground should be avoided. When this is not possible, the minimum distance that tree roots can be cut without destabilizing the tree is 3 times trunk diameter. Cutting roots any closer than this can predispose the tree to failure or lead to root decay. Roots larger than 2 inches in diameter should always be cut cleanly and squarely using sharp hand tools. If more than one third of the large lateral at the stem base are cut, the tree should be considered a risk.

Tree roots and the soil in which they grow, must be protected as much as possible during construction or root pruning to avoid unnecessary injury and to minimize the impact on tree health and stability. Tree roots and a favorable soil environment are critical for normal growth structural stability safety and long term survival.