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Woody Plant Physiology

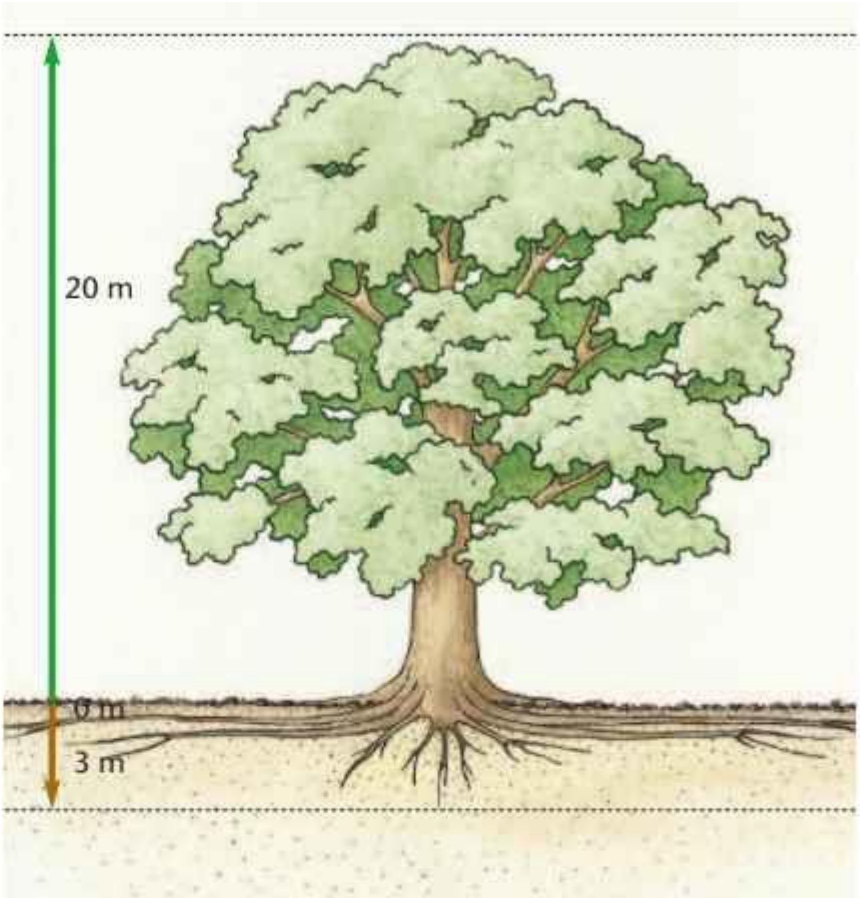
Unit Code: A/602/3922

UNIT GUIDE 2023-24

LO 5 Understand the woody plant root system

5.1. Identify the functions of tree roots

It is a general misconception that a tree root system grows deep into the ground and only grows to the edge of the crown (drip line). In fact, ordinarily a tree root system will extend well beyond the trees crown spread with most roots being found within the top 600 mm of soil. The images below help demonstrate this.



In addition to storing carbohydrates and absorbing water and nutrients from the soil, tree roots also create a structural framework that supports the crown and trunk of the tree. This system's nature is often misinterpreted, most likely due to its underground location. The idea that the root system is a "reflection" of the trunk and branches is a frequent one. A tree's root system is rather shallow, with long, relatively short lateral roots that extend out near the soil's surface predominating as opposed to a taproot that penetrates deeply. Trees rarely have roots deeper than two metres, yet on rare occasions, tiny roots (a few mm in diameter) might reach five metres or more.

The primary functions of tree roots are:

1. Anchorage:

Roots take part in fixation of the plant and supporting the aerial shoot system.

2. Absorption of Water:

Roots absorb water from soil.

3. Absorption of Minerals:

Roots absorb mineral salts from soil.

4. Prevention of Soil Erosion:

Roots hold the soil particles firmly to prevent soil erosion.

5. Transport:

They take part in transport of absorbed water and minerals to shoot system. Similarly, root has channels for the flow of organic food from aerial parts.

Mycorrhizae are a symbiotic interaction between plant roots and fungi. Their primary purpose is to utilise more soil than roots alone can, enhancing the host plant's ability to absorb water and nutrients. Various mycorrhizae species exist, based on the fungus's taxonomy and that of the host plant. The distribution of these forms within ecosystems is affected by a variety of factors, including soil, climate, and the position of host plants. The ability of mycorrhizae to improve nutrition and water intake, support defence against root infections, and allow root feeding might alter the host plant's performance. Mycorrhizae can modify the composition of plant communities, increase competition, and foster synergism among species by sharing resources in a way that varies from species to species. Both invertebrate and vertebrate species rely on mycorrhizal fungi and their fruiting structures as major food sources. In forestry, agriculture, and restoration, mycorrhizae are utilised to increase yield and reduce some of the pollutants that come with planting on disturbed sites. Because mycorrhizal fungi may store radionuclides and heavy metals, they could be used in the cleanup and regeneration of damaged habitats. The changes that pollution, climate change, and habitat loss are causing to our ecosystem necessitate increased efforts in fungal conservation. The relative abundance of mycorrhizal fungi has shifted to saprotrophs because of these modifications.

https://www.youtube.com/watch?v=oVK9TCXZz6I
Suzanne Simard on tree roots and their relationships with each other

5.2. Identify a minimum of four factors affecting root distribution

The location where the roots extend downward from the tips of the branches is not where they are limited to spreading. Results from excavations have shown that roots can extend much beyond the branch spread, frequently up to the height of the tree and sometimes up to three times that height (especially in compacted or infertile soils). Deep roots typically grow near the soil's surface. Physical barriers such as building foundations, kerbs, and rocks can prevent root extension. When roots encounter such impediments, they frequently redirect them and, once beyond the barrier, resume growth in the original direction.

Soil compaction

When soil density rises, root development drastically decreases; optimal growth is reached at 1.2 g/cm3 or less. Growth essentially stops at a bulk density of roughly 1.6 g/cm3 in heavy clay soils and at roughly 1.7 g/cm3 in lighter sandy soils. Compaction can occur naturally in some places (due to glaciation, for example) or be artificially created (due to repeated vehicle traffic over the soil surface, for example). It is frequently challenging to grow trees in areas with compacted soils because the roots are unable to adequately pierce the soil. In the comparatively less dense surface soil, trees growing in these types of soils form a very shallow root system with a higher number of lateral roots. In the comparatively less dense surface soil, trees growing in these types of soils form a very shallow root system with a higher number of lateral roots. When roots meet a compact subsurface horizon, they often flex or branch out widely, continuing laterally above the compaction plane. These roots may continue growing downward if they come to a path through the compact layer, such as by following a crack or a decomposing root canal. A two-tiered root system may form if the soil beneath the blockage is suitable for root growth. When established trees are suddenly compacted, as happens when machinery moves about building sites, they typically undergo root death and crown dieback because of the tree's slow response to the abrupt changes in soil conditions.

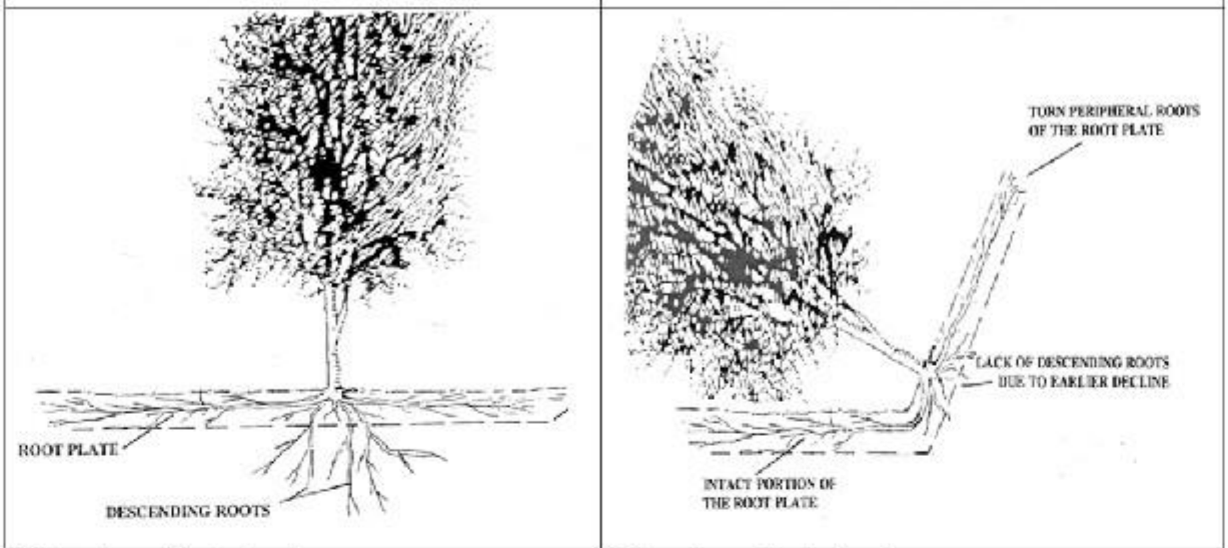
Soil aeration

Roots require oxygen to be present in the soil right around them to survive. The structure and texture of the soil determine how much oxygen reaches the roots. In loose or coarse-textured soils, ambient oxygen diffuses easily into the soil, while carbon dioxide, a byproduct of respiration, can diffuse away due to the relatively large air gaps between the soil particles. Since gaseous diffusion occurs 10,000 times faster in air than in water, this process is impeded in fine-textured (clayey), wet, and compacted soils because the pore spaces are limited and may also be filled with water. Insufficient soil aeration, especially from prolonged periods of waterlogging, can lead to a large portion of the existing root system dying and decomposing, as well as prevent the growth of new roots. Trees in these types of settings usually develop very shallow root systems, resembling plates, and are limited to the top, more aerobic soil. Dormant tree roots are more resilient to periods of insufficient aeration than those of actively growing trees because they have a lower respiration rate and require less oxygen.

Fertility
Fertile soils yield more robust, well-branched root systems that may reach deeper into the ground, while infertile soils create lengthy, poorly-branched surface roots. Although roots cannot actively grow in the direction of a source of nutrients, they will multiply when they encounter places that are particularly high in phosphate and nitrogen. This usually refers to the top, organically rich soil layers in undisturbed soils.

Water / Moisture
Poor gas exchange in wet soils causes the soil to lose oxygen, which creates anaerobic conditions and eventually causes root death. Trees with permanently high-water tables tend to have very shallow root systems that are widely dispersed. Certain plants that experience droughts also develop shallow root systems to maximise rainfall penetration close to the soil's surface. Roots may be able to make use of a deeper subterranean water supply if the soil conditions are right for root penetration and respiration at that depth.
The proportionate amount of water that a soil can hold depends on its mineral and organic content. Long-term drying will not significantly alter the structure of free-draining sands and gravels, but soils with a high clay concentration are known for their propensity to shrink and fracture. A vacuum is produced when water is drawn out of the spaces between soil particles by roots or a dropping water table. Certain clay soils may shrink as a result; however, this is typically linked to an increase in the amount of air between the particles.

Wind
Roots that contribute to the anchorage are the resistance of leeward roots to bending (25%) and the resistance of tap roots and descending roots to uprooting (75%). Therefore, the windward roots, which is pulled upwards during toppling, is the most important component in resisting windthrow. When they do get pulled up, the descending roots, if present, often follow intact. If there are no descending roots in the exposed windward side, it is often an indication that they have not been present, which may be important in diagnosing the causes of failure. Failure usually occurs closer to the trunk in wet soils.

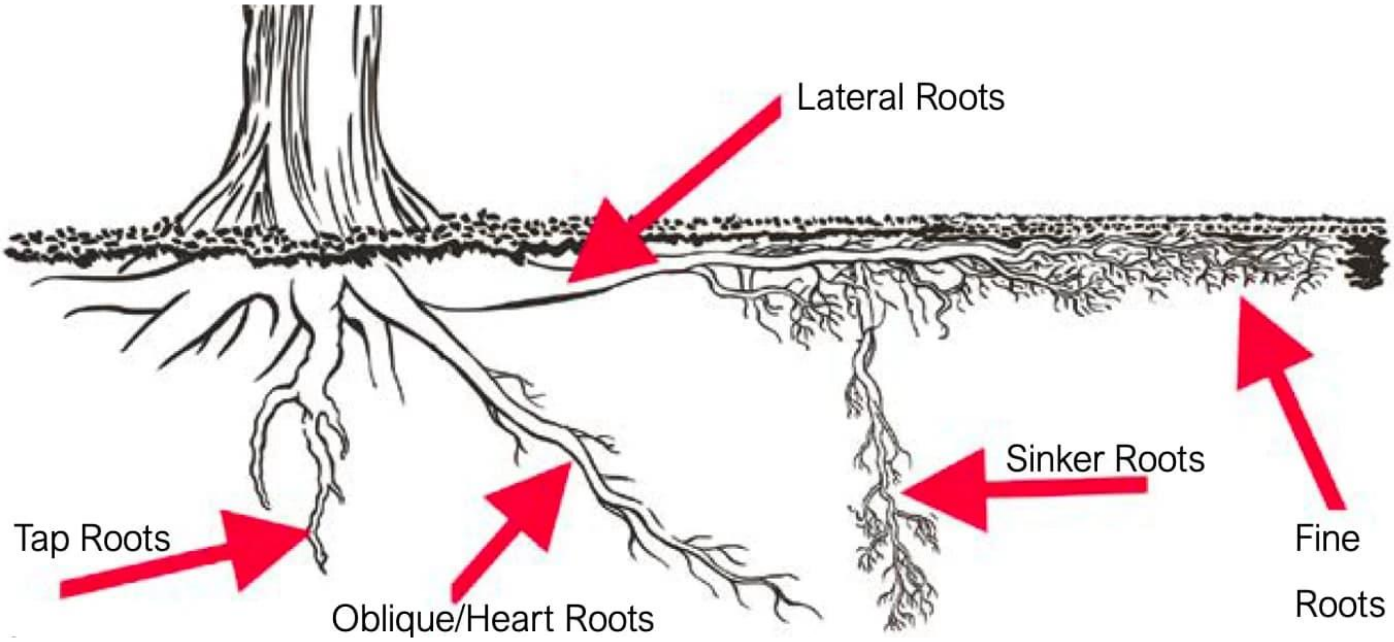


STABLE TREE	WINDTHROWN TREE
Direction of wind ←	Direction of wind ←
Wide and solid root plate	Wide and solid root plate
Descending roots intact	Loss or absence of descending roots
Windward roots intact	Windward roots pulled from soil, breaking in tension and snapping in sheer
Leeward roots intact	Leeward roots buckled and hinged in compression close to trunk
Healthy canopy by Visual Tree Assessment	Healthy canopy by Visual Tree Assessment

Windthrow due to the failure of windward roots and the buckling of leeward roots.

5.3. Describe how trees are anchored in the ground

Form of Roots
There are five basic types of roots and their function:

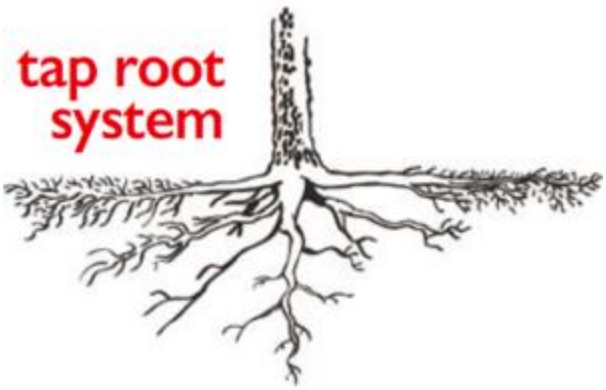


Tap roots: Every tree is built on these absorbing and anchoring roots. Eventually, new roots begin to outgrow the taproot. Deep soils lack the nutrients and oxygen needed for roots to survive, which is why most taproots eventually stop growing as deep as they can.

When the soil conditions are right, a germinating seed starts off with a single root called a taproot, or radicle, which grows vertically downward. The first two or three years are when elongation happens the fastest, but as trees get older and the soil gets deeper, it slows down. Laterals, or side roots that develop horizontally, first appear early on, and quickly take on a major role in providing structural support. After that, the taproot's development slows down, and only a tiny percentage of trees have a sizable taproot by the time they reach maturity.

Stability: Tap root systems are very stable, but extremely rare in mature trees.

Common Species: Some oaks and pines, hickory, sweet gum, tupelo, walnut.



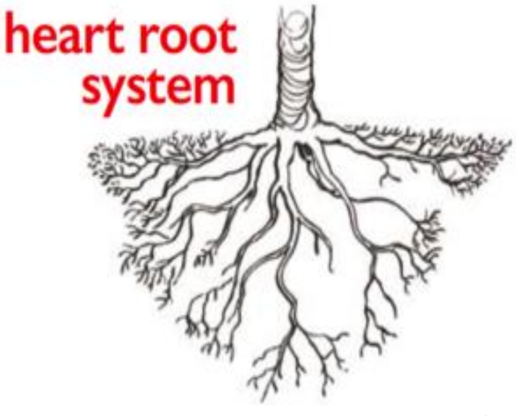
Lateral roots: Just beneath the soil's surface, lateral roots spread outward. They anchor the tree and take up a lot of water and nutrients.

Finally, lateral roots close to the soil's surface, which become thicker over several years, generate the huge woody roots that make up a mature tree's framework root system. These roots, which can reach a diameter of 30 cm or more, are usually seen four to eleven times close to the stem. Their diameter generally reduces to 2 to 5 cm at a

distance of 2-3 metres, at which point they have mostly lost their physical stiffness and strength. They tapered swiftly after that. This is where they typically break due to root plate failure, such as during a storm.
From the upper side of the laterals, roots branch forth and multiply widely in the well-aerated surface soil, forming fans or mats of hundreds of fine, non-woody, 'absorbing' or 'feeder' roots (<2 mm diameter). They develop horizontally in wooded areas between two- to three-year-old fallen leaves. Each root fan might occupy a thin, horizontal layer of 300 cm2 or more. Root fans infiltrate and keep together the litter over a substantial region. These roots are associated with considerably finer mycorrhizae that resemble threads.

Stability: Lateral root systems obtain their stability from tree weight and root spread. These root systems do not necessarily have a lot of root mass, but because the roots are so widespread, the tree can be supported without investing so much in roots. About 80% of tree species and most urban trees have lateral root systems. Common Species: Ash, birch, cottonwood, hackberry, maple.

Heart roots, often referred to as oblique roots, grow diagonally and serve the same purpose as lateral roots.
Stability: Heart root systems obtain their stability from root ball weight and soil resistance. The tree is held up by the weight of its root ball counteracting the weight of its aboveground parts and the strength of the soil around it. Heart root systems are prone to failure in wet soils. Once the soil is wet, wind and gravity can make the tree rotate in the ground, much like a ball-and-socket joint.
Common Species: Honey locust, red oak, sycamore. More common in Mediterranean and arid climates.



Sinker roots: Sinker roots extend several feet below the surface of the lateral roots. There, lateral roots not only give the tree more stability but also benefit from any water and nutrients found deeper in the soil.
"Sinkers roots" are roots that branch from the bottom side of the laterals and are often found a few metres from the stem. Typically, 1-2 cm in diameter, they develop downward and, unlike oblique laterals or taproots, split into fine, non-woody roots at their extremities.
Fine roots: All the previously mentioned root forms have the potential to develop fine roots, which are the direct absorbers of nutrients and water. In addition, they harbour mycorrhizae, fungi that form partnerships to enhance the capacity of roots to absorb nutrients.

The mechanical characteristics of the soil and roots, as well as the size and structure of the root system, all affect the anchorage's strength. For trees with shallow roots, four anchorage components have been discovered (Figure 2.8). **First**, the weight of the roots and the soil they adhere to helps keep down the root/soil plate and withstands the forces that would otherwise cause the tree stem to topple over due to wind. **Second**, while uprooting, the soil beneath and around the plate's edges must be broken, which adds to the resistance. The tensile strength of the roots around the windward edge of the plate generates a **third** component. The **fourth** is the soil's and roots' resistance to bending in the hinge area on the tree's lee side.

When the wind-induced overturning moment in the root anchorage surpasses different resistive forces, it is known as windthrow (Figure 2.5).

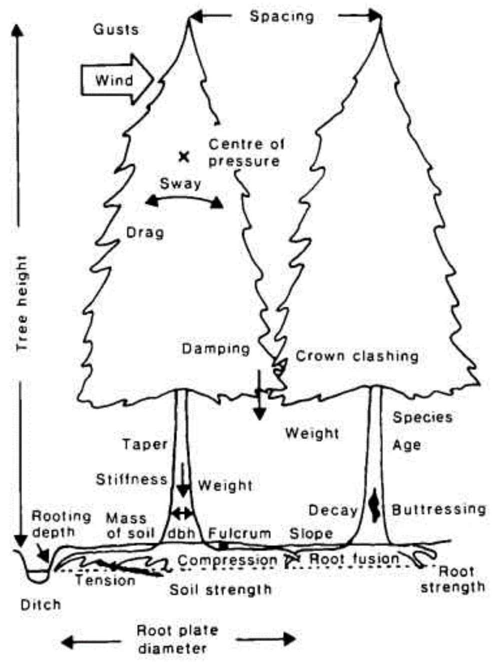


Figure 2.5 Mechanical factors influencing the stability of a single tree.

There are two parts to the actual overturning moment. The wind's lateral force, or drag, on the tree crown comes first. The applied turning moment is determined by multiplying the force at the wind's centre of pressure, which is assumed to be in the crown, by the height above the ground (Figure 2.6). The wind bends the tree, creating the second turning moment. The shifted weight of the stem and crown is the cause. This second overturning moment is determined by multiplying the weight by the horizontal distance between the bent tree's centre of gravity and its fulcrum, or hinge. It can be significant: the turning moment due to the weight can account for up to 30% of the total uprooting turning moment by the time the wind has driven a 20-metre-tall spruce tree to the point where it uproots.

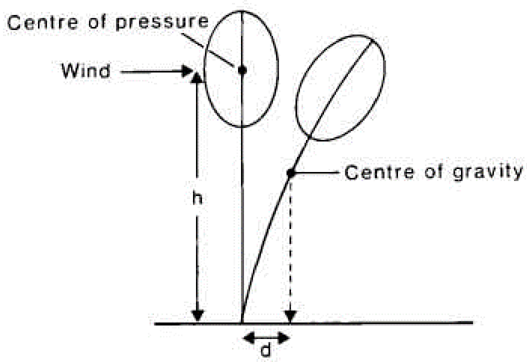


Figure 2.6 The overturning moments acting on a single tree. The wind acts at a centre of pressure in the crown at a height (h) above the ground. The applied turning moment at the stem base is a product of drag x height. Once the tree has been bent, the weight at the centre of gravity, acting over the lever arm (d), provides an additional turning moment at the stem base.

The size and structure of the root system, as well as the mechanical characteristics of the soil and roots, all affect how strong the anchorage is. For trees with shallow roots, four anchorage components have been discovered (Figure 2.8).

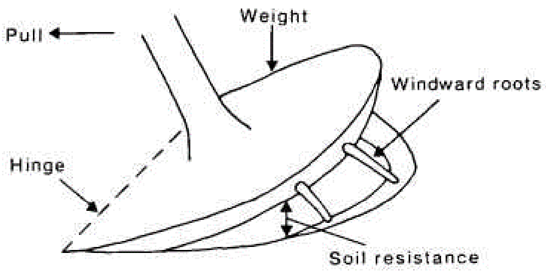


Figure 2.8 The four components of the anchorage of a shallowly rooted tree which resist the horizontal force acting on the stem: the weight of the root/soil plate; resistance of the soil to (mainly) tensile failure; resistance of the roots placed under tension on the windward side of the tree; resistance to bending at the hinge.

The physical characteristics of the soil and roots determine the resistance they provide. Tensed roots have a strength three to five orders of magnitude greater than that of soil. Nonetheless, soil strength is crucial because the amount of fractured soil in the zone where the root/soil plate separates from the surrounding soil is three orders of magnitude larger than the cross-sectional area of the roots. Soils stretch less than 2% under tension, yet roots stretch 10–20% of their length before failing. Therefore, when force is applied to the root system, the soil is broken before the roots are broken. This clarifies why the soil is so important in the initial phases of uprooting. The tree becomes free to rock after the soil fails, and the anchorage may gradually deteriorate due to root loosening.

<u>5.4. Identify two causes of a loss of anchorage</u>

The most frequent reasons why trees become unstable include problems with the soil and roots' ability to anchor the tree, problems with the tree's roots or stem base, and weather-related factors like strong winds.
Trees frequently become unstable because of damage to their roots. This may occur because of direct injury to the roots from excavation, or it may be due to fungal activity producing root rot, which in turn inhibits the roots' capacity to anchor inside the soil. It may reach the point where the tree's weight becomes too much and it lifts at the root plate if there are fewer roots supporting the tree because they have been broken off or if the roots are rotting or dying because of fungal activity.

Root Defects
What a foundation is to a house, roots are to a tree. They keep a tree safe and upright. It can be disastrous for people and trees alike when roots fail. Because of this, it is critical to ensure that tree roots are healthy and strong. Root failure can be divided into two categories. One happens when the root system can no longer be held in place by the soil. This kind of soil failure can result from severe winds paired with wet soil. It is more common in trees with very shallow roots, although little can be done to diagnose it. Compacted soils, shallow soils, or excessive irrigation over a tree's life can all contribute to shallow roots.
When roots are broken off, rotted, or suffer other harm, it leads to the second kind of root failure. These kinds of flaws are easier to spot and avoid. To determine whether there has been root failure, look for indications such as huge roots that have deteriorated, perished, fractured, or are unable to grow normally.

A few technical terms are the first thing to grasp in tree mechanics. I will start by going over some of these fundamental phrases and then try to explain how the meanings behind them relate to the trees in our local Northwest environment.

Engineering terms
Force = Mass X acceleration

Stress = Force per unit area
Strain = Extension per unit area
Strength = The maximum stress that can be tolerated without permanent deformation of the material.
Bending moment = Force X length of the lever arm

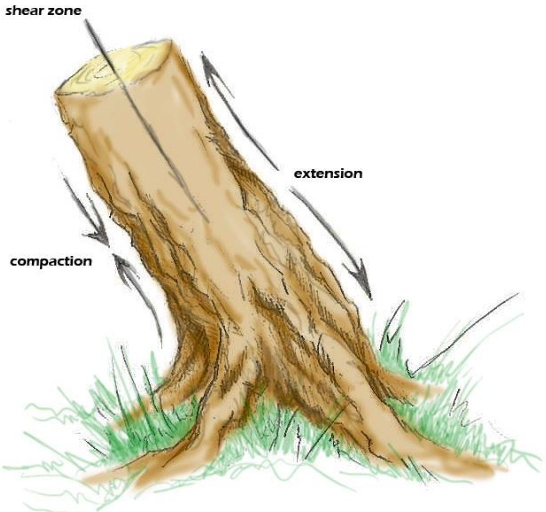
Force

Throughout their existence, trees encounter two basic types of force: gravity, which is regular and predictable. Gravity constantly presses down on limbs and tilts trees, compacting the wood into straight trunks. The fact that this force is constant allows the tree to readily adjust to it by adding more wood where stress (compaction) and strain (extension) are highest.

Less dependable elements like wind, ice, and snow are things that trees can adjust to if they continue to exist year after year. The biggest danger to any healthy tree can come from unanticipated sources. A powerful windstorm coming from the incorrect direction or a tree growing in the centre of a stand of trees after all neighbouring trees have been cut down could do this. In this instance, the tree is standing by itself and has never been subjected to wind pressure. It has no need to extend its root plate or add more woody material to sustain itself as it grows to get stronger.

Leverage

Compared to trees that have grown inside a stand or forest, trees that have grown outdoors will get shorter. They behave this way because they are more exposed to open breezes and do not have to compete for sunlight. The lever arm increases with tree height. It takes less force to move an object the longer the lever arm, just as our predecessors learned.



The bending moment is a concept that extends beyond a tree's height when it comes to the force that descends to the root plate. The length of a branch that transfers that force to the trunk is also considered. Both situations include two structural movements in the tree: extension or strain on the branch or trunk's bending side, and compaction or stress on the inside of the leaning trunk, or the bottom of the trunk.
The underside of a leaning trunk or its branches are rich in lignin, which gives trees their compression strength. On the upper side, where cellulose is more prevalent, lignin is less prevalent. Tensile strength is the result of cellulose. The weakest point under these two opposing forces is the area that lies between these two sides and is referred to as the shear zone. This neutral area is where fissures will start to appear, progressively weakening the tree or even bringing it to collapse.

Torsion

Torsion, or "twisting," is a third force that trees must contend with. Trees in the wind do not just travel in a straight line back and forth; instead, they will move back, then left or right, twisting to release wind from their crown and then reverting to their original position in the centre. They frequently twist more on one side than the other, producing wood that is adaptable and tightens as it twists in that direction, much like a rope. Torsion cracks or failures happen when an unforeseen wind comes and twists the structure in the opposite direction.

The tree root system will encounter two opposing forces when subjected to force. To prevent the tree from collapsing, one side of the root plate will function as guy wires and the other as support beams. When the tree's root system does break down, it will be because the soil can no longer sustain the tree. This is typically caused by moist soil, which lubricates the root system, or when illness or above-ground human activity has physically harmed the roots.

Cut Roots

The weight of a tree is transferred to its enormous structural roots, known as the root plate, via the tree's trunk. This protects the tree from forces that are horizontal (wind) and vertical (gravity). Consider a drink glass resting on a dinner plate to gain a better understanding of the load-bearing structure of trees (Figure 3). In this comparison, the base serves as the structural root plate that offers stability, while the stem of the glass represents the trunk. The purpose of the dinner plate, or the remaining tree roots, is to take in water and minerals.

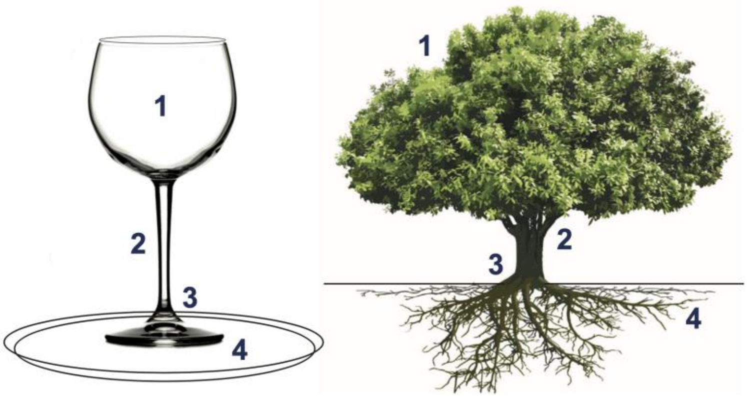


Figure 3. A tree is like a wine glass sitting on a dinner plate. The top of the glass represents (1) leaves and branches, (2) tree stem, and (3) the structural root plate. A dinner plate (4) represents the feeder root system.

Removing a section of the base of a drink glass is analogous to cutting roots inside the root plate, which reduces the stability of the glass and the tree. The stability of the tree will be impacted by removing roots inside the root plate, but the health of the tree will be affected by removing any roots inside the essential root zone (Figure 4). Removing roots also creates a conduit for illness and rot to worsen tree roots.

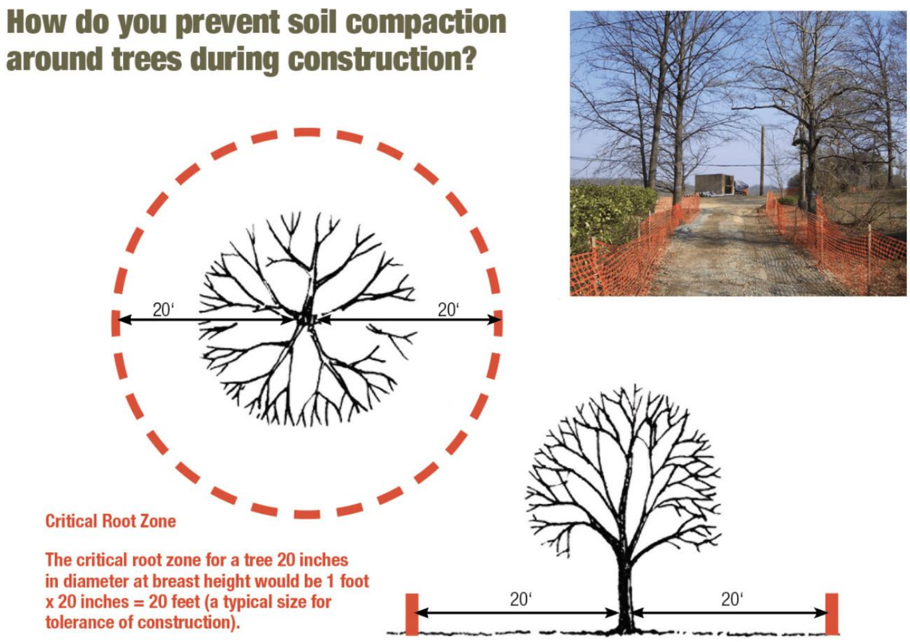


Figure 4. The critical root zone is derived by measuring the trunk diameter at breast height (DBH), which is measured with a diameter tape at 4.5 feet from the ground, and multiplied against a multiplier. The multiplier ranges from 0.5 to 1.5 feet for every inch in DBH. To determine the correct multiplier, consider the tree's tolerance to root severance. A common multiplier for many trees is 1 foot.

Root Decay

Over time, root decay can cause a tree to collapse completely by weakening the roots. Decomposition pathogens come in a variety of forms, and it is critical to recognise them, as some are more aggressive than others. Root decay symptoms include the following:

Conks or mushrooms? Both new and old are reliable markers. Carpenter ants.

Ants consume decaying wood, not living wood. Seeping cuts. There will be a yeasty, sour scent. Bark is missing and loose. To check for rot, do not be scared to pry back loose bark. Vacuums or openings Examine the area beneath the tree, searching for any gaps.

Trunk Defects

Trees rely on their trunks to support their weight and their roots to anchor them to the earth. Wind and gravity are the two fundamental forces that affect trees. The canopy moves in response to wind, and the trunk serves as a lever to transfer the force into the roots. A robust trunk that can withstand the weight and strain of these bending forces is just as vital as having a healthy root system (Figure 9). Tree failure can result from any fault on the trunk, especially those that are midway between the roots and crown. We shall talk about faults to pay special attention to in the next section.

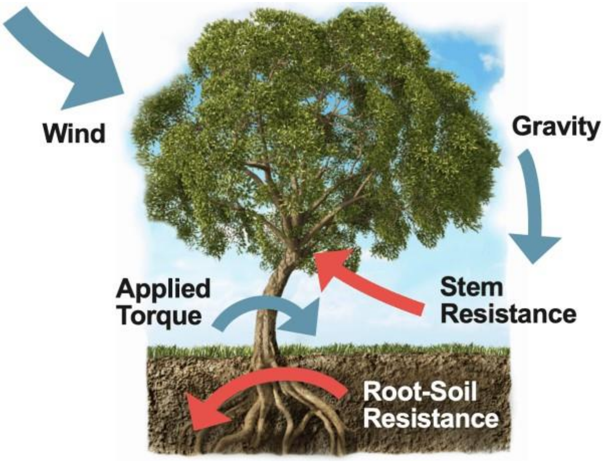


Figure 9: Torque is exerted halfway between the crown and the roots due to the combined effects of gravity and wind on tree crowns. When comparing trees with larger lower crowns and torque pressures applied closer to the ground to those with longer, spindly trunks, the latter are more likely to break because of their smaller trunk diameters.

When taking wind impacts into account, there are notable variations between trees grown in forests and those planted in open spaces. Larger canopies that reach closer to the ground (with more sunlight) are developed by open-grown trees. The trunks of these same trees get thicker and taper, or alter in trunk diameter, from base to top. Trees grown in forests, on the other hand, have canopies considerably higher in the tree and long, straight trunks with little taper (lower branches are shadowed out).

Trees bend midway between the ground and their lowest branches when the wind blows (Figure 9). Large, low-canopy trees will force the bending location to be a stronger, lower section of the trunk with a larger diameter. There are little worries if forest trees are still surrounded by other trees since the other trees act as a wind buffer. However, issues occur when forests become thinner due to development, historical storms, or tree removal. Wind can break these tall, often spindly trees more easily, frequently breaking midway between the ground and the canopy. Look at the following:

Trees in the forest, recently exposed, with tall canopies (Figure 10). Trees with over-raised canopies because of pruning (Figure 11) Large pruning cuts on the trunk that are at least 1/3 of the diameter of the tree produce weak spots by producing pockets of rot.

Figure 10. Recently exposed oak, has a small canopy and long thin trunk.

Figure 11. Take note of the most current trimmings. The canopy of this tree has been lifted too high.

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