EVERY TREE OWNER

What every tree owner needs to know to have happy trees.

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A Free Gift From

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TREE HEALTH

CONSULTING SERVICES

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Definition & Manifesto

This is for you, Calgary: a free download, a brief summary of my tree experience and knowledge. The core of what you need to know is simple, and if you practice these few lessons, you WILL have happy trees. You will also save a fortune on your tree care budget—yes, the one you won't need much anymore. So, thank you very much for all the support and work through the years. Happy trees.

What follows is a major rewrite of the tree biology section I wrote for my first book, *Your Trees: What They Want You to Know*. I always felt I should have gone a bit deeper in the book and that the biology section was a bit weak, or at least needed some help. Here it is. Now, with this work, my published work on tree biology is current and gives people a much clearer idea about the inner workings of their trees. If you want to go really deep, see the essays in two other sections in the articles section of the website, the Botany Talks, and Care and Feeding.

Apart from tree biology, how they really work, there is another huge aspect of their lives that concerns us. This is the hands-on part when we select a tree, plant it, prune it, water it, or even, sadly, need to remove it. All of this was dealt with in detail in my first book. Also, there is lots of additional material on my website, in the articles menu choice called Tree Care, where all of those subjects were dealt with to my satisfaction then, and I stand by it.

Arborists should be women and men who love trees.

Like many things in our lives, much of the tree service industry has now become a rather corporate affair. Unfortunately, as this happens, caring, real knowledge, and common sense are lost, and the almighty buck becomes the focus. Injecting a birch with a little bit of chemical for an insect they don't have takes just a few minutes and costs $400 for each small tree. This true story, relayed to me from an acreage just outside the west side of the city, is becoming more frequent. Perhaps you have your own? Those types of high-cost, no-result practices are not mine, and I have spent my entire working career trying to bring some clarity and science to the trees and their owners, in my own small way. Arborists should be women and men who love trees. If your draw to money is that strong, then lean towards finance.

What follows is based on the best modern botany texts, my decades of hands-on tree work, and my inherent love and respect for trees as other living beings who also find their native home right here on Earth with us.

Ancient beings who have been all around the world, except the driest places, for many millions of years.

What is a tree? One of the wonders of the world, some would say. Ancient beings who have been all around the world, except the driest places, for many millions of years. Trees that we would recognize as conifers, evergreens, have been here for 325 million years. Their younger cousins, trees that flower in the spring and lose their leaves in the fall, have been on Earth for 125 million years. The grasses and their grasslands, major competition for trees, didn't show up until 55 million years ago. Big numbers, deep time. Trees are survivors and are here to stay, some of their most difficult and stressful new homes are cities. Cities aren't nature but a hybrid of human culture and sometimes heavily modified nature. Thin, low-quality, poor soils are just one of the urban trees' problems.

A tree is a plant, usually with a single woody stem over 10 feet tall, many exceptions occur, but most people agree on this simple definition. The tree's body consists of three main organs: roots, stem, and leaves; flowers are a fourth. The organs are all made of complex aggregations of trillions of microscopic cells that form into tissue groups, just like your own body. For example, we think of leaves as just leaves, but from the upper surface on through to the lower surface, we would pass by some 8 or 9 different cell types. Depending on the specific leaf, we start with leaf hairs, then pavement cells of the epidermis, which are covered with a waxy cuticle layer. Then, inside the actual leaf, vertical rows of palisade cells full of chlorophyll for photosynthesis. Farther inside the interior, we would pass the "veins and arteries" (the xylem and phloem transport tissues) of the plumbing system, which runs through the veins of all leaves. Midway, we find the spongy mesophyll, where sun-catching green cells are close to the inner leaf spaces which lead to the outside air. This is essential because CO_2 gas in the air has to be in contact with the inner green cells for the process of photosynthesis, which makes all the sugars the tree burns to run all its life processes. On the lower surface of the leaf, we would again find the epidermis as we found it on the upper surface. The lower leaf surface is where most of the gates are that allow air into the leaf, called the stomata. These gates are very sensitive to the amount of water in the tree and if water levels are low,

Trees are survivors and are here to stay, some of their most difficult and stressful new homes are cities.

they close so that the wet inner tissue does not lose too much water. Yes, you can starve your tree by under-watering. When the stomata close, sensing low water levels, photosynthesis stops, energy production stops, and the tree waits for a cooler time of day or year to begin work again. Sorry for all this detail (botany); I will try to avoid that as we continue. I just wanted to give one example of some complexity; this was a very rough overview of what actually is in and goes on inside a living leaf.

What Trees Require

What does a tree need to live? Amazingly, very little, all free and abundant in the natural world: sunlight, air, water, and minerals from the soil. That's it. Sometimes water and the minerals are not so abundant; we can help with those. Green plants are autotrophs—they are self-feeding. Given the materials mentioned above, they make all the sugar and chemicals they need to perform all their natural functions. Growth, both taller and wider, stronger, and they store a lot of energy in living tissue for the winter and other challenges. They are strong in an immune system sense and able to defend themselves very well from the hungry host of insects, fungi, and bacteria that accompany them through life.

Trees live a clean life, produce almost no waste, and have no kidneys. During the chemical process of photosynthesis, which occurs in cells that are green from the pigment chlorophyll, they release oxygen and water vapor as byproducts, while capturing and keeping the carbon from the split CO_2 molecule to form simple sugars. These sugars are the basic building blocks and energy providers the trees use to manufacture every protein, every enzyme, indeed every cell and necessary molecule in their whole body. They ask for little from us, mostly for water, and ask to be left alone, to a greater extent, so that they can be as strong as possible and live a full life.

> *Any tree that gets the water it wants will be healthy, full, with little dead wood, and strong enough to defend itself.*

I will repeat this many times because it is the most important core idea about having healthy trees: "Any tree that gets the water IT wants will be healthy, full, with little dead wood, and strong enough to defend itself." This is the one simple great truth. Water as required and watch your trees flourish. No one talks about water because they can't sell it to you; they prefer weak, failing trees that are then over-fertilized, over-injected, over-pruned. Yes, it sure gets expensive to get tree care done. Throw all those heavily marketed ideas away, water your trees, and relax. And as to pruning, this is completely overdone. We live in a world that seems to value "a look" over health.

A tree is a balanced system. No leaves are designed to be extra, superfluous; they don't grow just for some arborist to cut them off. All are needed, required, no waste. Let's keep the natural allotment of leaves, make a lot of sugar, and have as strong a tree as possible.

Trees ask for little yet give so much: shade, soil stabilization around the world, community, living space for many other life forms. Then, of course, there are all the useful products from trees, uncountable: wood, fruit, rubber, rope, chemicals, drugs. Cruise through an economic botany text for a sample of the riches. Or just look around your home or kitchen for the many products from trees we take for granted every day. We do have a lot to be grateful for. Then there is the pleasure of forests, being inside a tree community. Trees can give us the strength to carry on, to see our problems in perspective. The forest experience can lower blood pressure, clear the mind, let us see the light. You just gotta love trees.

Soils & Grasslands

Soils and water. This is the most important thing anyone could ever say about tree care, it's about soils and their relationship to water.

From the above paragraph, any tree that… well, you know. Water availability controls all aspects of a tree's life and health. Ignore everything else, let it all go, but give a tree water and it smiles, then grins and belly laughs—thank you, thank you, thank you! For millions of years, no one pruned, fertilized, or injected; the rain fell, or it didn't, and trees thrived or didn't. But now we live in cities, in suburbia designed, formed, changed, and modified; the land, the soil profile in our city is like nothing in nature, and that's bad.

Let's step back a few years, before the city was here; it's not that long ago. 1875 brings the mounties, 1883 brings the railway, and the 1930s and 40s bring heavy diesel equipment, bulldozers, scrapers, etc. Let's say it is a summer morning in 1875, I stand on North Hill looking south and survey the landscape for many miles around. I am in a grassland, rough fescue, a few miles south of me I can see a green ribbon showing plainly where the river is, there are no other trees in sight. Like a picture of a historical home in Mount Royal I have seen, taken in 1911, it is a bit south, where 26th Avenue and 14th Street would end up being. Nothing in sight but the new home, no city, it's in the valley, no neighbours, lots of grass and no trees, again not one. Calgary sits in an ancient grassland, the only trees, four salient natives—Rocky Mountain Douglas fir, white spruce, balsam poplar, and trembling aspen—are all hiding in the river valley, the bravest, the trembling aspen, grows on some hillsides, that's it. A grassland, the NW corner of the great North American plains, and beneath that grass is some of the most fertile soil in the world. The breadbasket. This is the farmland that drew Easterners and immigrants from around the world to open up a new land to a farming life.

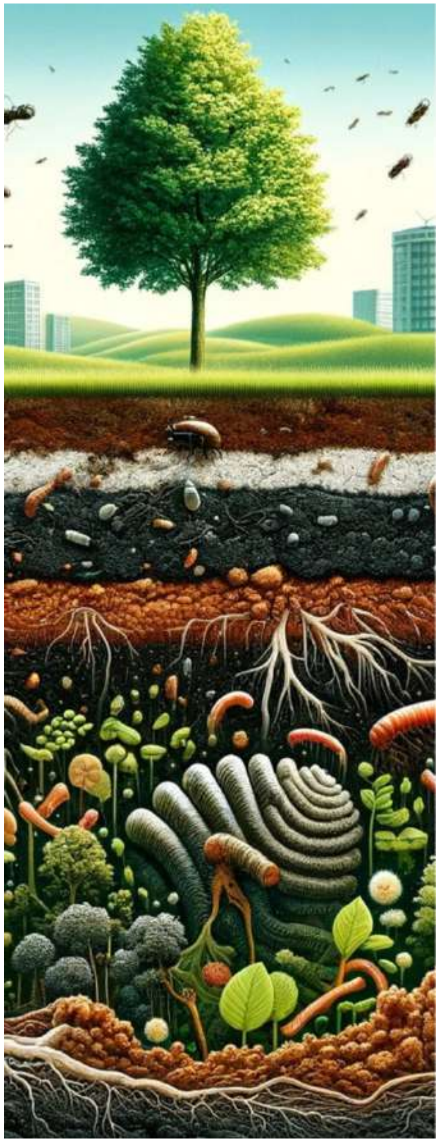
Let's talk about that native soil, what it was, how much there was, and what it was made of. We need one more step back in time, to the end of the last ice age, approximately 20,000 years ago. By 16,000 most of the ice had melted, retreated north as another major climate change swept northward. Before that, earlier as the ice sheet advanced south, it operated like the greatest dredge and scrape operation imaginable, almost all life, down to bedrock, is scraped away by the mighty forward blade of the ice sheet, nothing but scraps of soil and some bacteria, microscopic in size, survive beneath. It is with the change and retreat of the ice 16,000 years ago that our story of Calgary soils can begin.

This is the farmland that drew Easterners and immigrants from around the world.

Recycling, Elements and Fertilizer

Before digging in, I want to define and describe soil. Soil, the nursery bed of life, is made of only two things: tiny pieces of rocks of various sizes and types of organic material—dead plant material, or humus. In the wild it usually also contains bones from animals and other organic molecules. It also contains a city of tiny microscopic life, bacteria by their billions, fungi digesting plant material, and lots of invertebrate animals—insects, beetles, centipedes, worms and many others. Soil is not just dirt; it is alive, a thriving community. Plants grow in their season, then die back and drop to earth where they are welcomed each year into the process. As they live and grow, they extract essential elements from the soil. Later, after decomposition in the soil, most is returned. The years and millennia circle around. A complete, let's say *nearly* closed system that is self-perpetuating.

Calgary is situated in the black soil zone in Alberta. Black soil is richer than brown soils, with more life and nutrients. The average natural soil thickness in our area is about 15 inches; below that is the clay



layer. That is about an inch added every thousand years since the ice sheet retracted. This soil depth and type is *only* found in undisturbed soils that have never been dug, farmed or changed in any way. It is extremely valuable, for it will grow food. Most plants need a variety of essential elements, a slightly different recipe for each species from the soil to maintain health. There are approximately 20 elements considered essential for plant life. This would closely mimic your own nutrient needs. We call them vitamins; most of the world,

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when thinking of plants, call them fertilizer. But really, they are vitamins to plants also. Just as in your own diet, vitamins are not food, but the essential elements you need to live. So it is the same for plants—fertilizer is *not* plant food. The marketing genius who came up with “weed and feed” really hit home, but it's a lie. Fertilizers contain no energy. Plant food is always only one thing, and they make all they need. Yup, sugar. Nitrogen is the element used the most by plants and performs a multitude of functions in the plant's physiology. In higher doses, it can create a situation inside the plant that pushes growth. This is not always a good thing. Great for grass and having the best lawn on the block, but needs mowing twice a week. It can also push trees to grow beyond their natural measures, which can form weak stems. All plants, trees included, have hormones, growth regulators that take care of the job nicely. Over-fertilizing can also contribute to poor plant water relations. Fertilizers act like salts, and can hold or bond with lots of water molecules that otherwise would be free to be extracted by a searching, hard-working root system.

As mentioned above, marketing and sales of fertilizers are so out of hand that most people have been led to believe that they aren't doing a good job if they don't fertilize every year, at least once for the trees and several times for the lawn. This is all part of a general North American thinking that keeps you active as a consumer, always spending. I myself have never fertilized a tree. I *have* fertilized some house plants that had lived long enough to start depleting the nutrient reserves in their pots. The slight colour change of the leaves, a yellowing, told me so. This is called chlorosis. I guess I should repot and change some soil. Colour change is something to look for in your trees. Look around your neighbourhood, know what the normal colour of your species of tree should be. If it is yellowy, and getting more so each year, then *yes*, that tree needs some nutrient it is not getting. In most cases, our trees are planted in the lawn, surrounded by grass. When you fertilize the lawn you, fertilize the trees too; there is nothing that can stop the fertilizer from also interacting with the roots of your tree, sometimes on the surface or just below the turf.

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Chemicals & Suburban Soils

OK, that's about enough about fertilizer for now, I think. Fertilizers are a tool; when you need the tool to do the job, then use it. Somewhere in all this is the idea that we need to be good stewards of our own land and community. The heavy use of fertilizers in North America in agriculture and urban environments has contributed greatly to the salinization of groundwater, streams, and rivers, and also vast tracts of farmland. Due to heavy irrigation practices coupled with the regular use of fertilizers, vast tracts of California farmland now sit sterile, too salty to grow crops—we are not far behind.

The same stewardship applies to the free use of other chemicals, fungicides, herbicides, and insecticides; we all need to be responsible for the overuse of these chemicals in what is becoming a more and more toxic world. It is better to dig or hoe weeds than spray, it is better to know that most insects are relatively harmless, and not to spray. There are always exceptions, but remember, “Any tree that gets the water it wants will be healthy, strong, have little deadwood, and will be able to defend itself”—defend itself from insects and diseases. You notice how healthy people stay healthy; it's the same with trees, all the trees need is the right amount of water.

So, we had approximately 15 inches of soil in the Calgary area, built up through thousands of years of annual plant growth and decay with the constant addition of sand, grit, dust, and tiny fragments of rocks, steadily brought by the wind. Our native soils are a bit sandy; this prairie soil is called loess. Underlying the topsoil or loam layer is the clay layer. Plants love the topsoil but are reluctant to grow much into the clay. Compared to loam, clay has very little nutrient and, as important, the soil particles that make clay soils are so small that the inner spaces between particles have very little room for air in the soil. These spaces between soil particles are called pores and are very important for the storage and movement of water and air in soils, two things plants have to have.

> *We all need to be responsible for the overuse of these chemicals in what is becoming a more and more toxic world.*

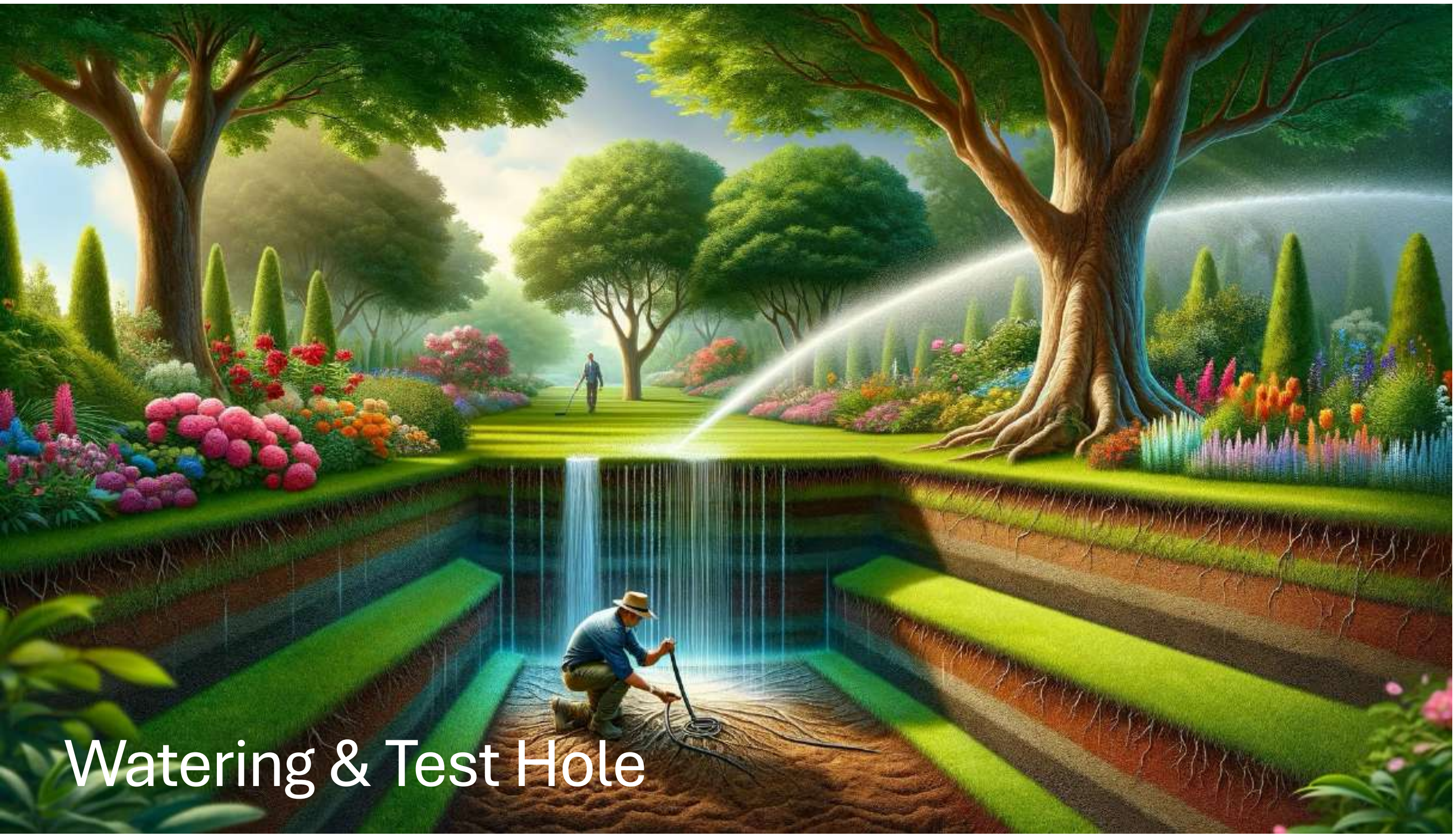
Roots are respiring organs; all life are respiring organisms, like yourself or a tree, or almost any other living thing. We burn sugar with oxygen, in the mitochondria in our cells, receive energy from it and produce CO_2 as a waste product—respiration is the flip side of photosynthesis. So it is with your tree roots; they receive sugars from the green parts of the tree through complicated plumbing structures, the phloem, sugar, energy they need to grow and perform their essential functions of water and nutrient extraction from the soil. They avoid a solid layer of clay like the plague.

Now to the crucial aspect of growing trees in the city: all that wonderful soil I have described, the work of 15,000 years of prairie life, has all been removed from the city. The soil in your suburban lot is typically thin and poor, meaning we have a thin layer of mixed topsoil that is usually blended with lots of clay. Underlying this "loam" is a layer of solid clay, the native subsoil. Most Calgary urban soils are very sticky when wet—this is the first proof of their high clay content. Good loam, even when quite wet, is still somewhat crumbly.

The soil is poor enough and thin enough that during a hot spell, it only retains a useful amount of water for the trees for something like a period of two weeks. Water it, or receive a heavy rain, let two weeks of high 20-degree days go by, and the soil will again be dry.

Where did all our beautiful soil go? All the topsoil is removed from the land during the construction of a new neighbourhood. Many times this has to happen, due to the hilly terrain of many outlying Calgary neighbourhoods, to create a neighbourhood that works (minimum flooding); the new neighbourhood needs to be sculpted. Formed so that it drains well and no one gets a basement full of water during heavy rainstorms. Another reason for the removal of the loam is to sell it back to whoever needs it, almost always cut, or mixed with a good percentage of clay and other materials. Developers always use a thin layer of these poor soil mixtures, many times in a layer thin enough to create an inherent drought situation for the trees planted into it. In other words, the soil is poor enough and thin enough that during a hot spell, it only retains a useful amount of water for the trees for something like a period of two weeks. Water it, or receive a heavy rain, let two weeks of high 20-degree days go by, and the soil will again be dry. This is so important, so very important for you to know—as bad as things are, with "proper" watering you can still have healthy trees.

With the construction and development of new neighbourhoods, crucial topsoil is often removed, leaving behind thin, clay-rich layers ill-suited for healthy tree growth. However, with adequate and proper watering techniques, it's still possible to nurture and maintain healthy trees in urban environments.



Watering & Test Hole

I apologize for all the gloom. For many people, this can be serious, and unhealthy trees are widespread. But, with a little work and know-how, learning about the watering program your trees need, all will be well. Before we can come up with a solution, we need to properly understand the problem. What you need to do is spend some time digging test holes in your lawn—they repair easily—and see exactly what you have on your property. Once we know the soil depth and its consistency, we will know how to address it. This will require a little work, but once done, it never needs to be repeated, and you will KNOW, and be able to act appropriately to keep your trees healthy.

A good way to start would be to water a section of your lawn that has trees in it. I like a big sprinkler, something that really delivers some volume, simulating a good rain. Let it get wet, water for two hours. Now let's give it a day to settle. Pick two or three random sites in the lawn, stay away from the trunks of the trees and, better yet, not underneath the upper canopy of the tree, by doing this there will be minimal root disruption. Use a full-size spade, make three or four cuts into the soil forming a circle, we want to remove a large plug of soil. Either use the shovel to lift out the whole plug or pull it out with the grass, try to keep it in one piece. Set it aside and clean out the loose soil that has fallen back into the hole. Now we get to see a mini soil profile.

Once we know the soil depth and its consistency, we will know how to address it.

Look at the fresh wall of the hole you dug. In most Calgary lawns, a blackish, somewhat sticky mix of loam and clay will be what you see. If you are really curious, you will keep digging until you see a color change; below the black layer, you will find the clay layer. It can be a tan color or even greyish. When you find the clay layer, you know exactly how deep your loam layer is.

What we are really looking for is how wet the soil is at the bottom of the hole. Perhaps prior to watering, the soil under the turf was so dry that the water you added didn't soak all the way down to the bottom of your hole. That would tell us you should have watered for a longer period. What we are trying to do here is get all the loam soil wet, as this is the soil full of your tree's roots. They will grow all the way down to the clay layer, at which point they are reluctant to go deeper. They also grow all the way up to the surface. One way to encourage deeper roots is to deep water, as I am describing, where the water is, is where the roots will be. We want to water long enough to get all the topsoil good and wet, to the point where it can't hold any more water. This is called field capacity. Beyond this point, water will run off or flow away, wasting water. The topsoil is your water reservoir; if you fill it up, you then give your trees the maximum amount of water that you can, lasting the longest time, sometimes weeks. Surface watering for short periods easily evaporates away. When the water is deeper in the soil, it is naturally conserved and will last as long as possible by being deeper. Place the soil plugs back in their holes, give them a stomp, and you're good. Turf responds well to this; when you cut their rhizome-like roots, they tend to form new growing nodes at the cuts.

Let a week go by, time, heat, sunshine, and constantly drinking trees will all do their thing; don't add additional water. Remove your plugs and inspect; how are we doing? Not bad, the surface is dryer, but not bad, the bottom of the holes are still moist, still holding water, this is good, as expected, we've learned something, replace the plugs. Let another week go by, again don't add any additional water, recheck your holes. At some point, the soil will not clump well in your hand, and you will know it's drying out. Maybe three weeks later, it is time for another long soak, which will again fill up your soil reservoir, and your trees will have the steady supply of water they love and will begin to become vigorous and trouble-free. The hole digging and repeated clump removals and inspections, only needed once, have given you an infallible tool to learn how to gauge water use on your property. From mid-May to the end of September, keep the trees well-watered. Take note of the rare heavy rainfalls, adjust your schedule accordingly. I keep a water log, which includes how much rain my garden receives. 2023's log begins like this: May 15, drought continues, dry winter, low snowpack, soil is somewhat dry. First watering of a group of large spruce for 4 hours with sprinkler. June 7, 1.5 inches of rain. This last note is important; use some straight-sided container as a rain gauge, so you really know what you did or didn't get. A good rain readjusts your watering schedule, you could gain a week or two when the rain gift is doing your watering work for you.

> *Turf is a major competitor with trees for water and nutrient resources. You might like some flowers instead.*

A few more ideas about soils and watering, and we can move on to how the tree works, the mechanics of growth, and fluid movement in your tree. If you are lucky enough to buy a new home without the finished landscaping in place, this is the best, easiest time to modify your soil zone. Once grass and trees have been planted, adding and amending soil is impossible. Measure your property and determine how many square yards of soil you need. I would add a foot of quality loam, not the cheapest stuff; it's good to go see it. The addition of a foot of good soil on top of the nominal layer from the developer will give you a nutrient-rich, major water-holding capacity garden that will seriously flourish and bloom. Many people in the city are now removing their turf or sections of it; now they can garden! Turf is a major competitor with trees for water and nutrient resources. You might like some flowers instead. In nature, in the whole closed systems I earlier described, nothing is ever taken away or cleaned up. The essential elements that were extracted from the soil remain in place, slowly returning to the soil to be used again. The clean front lawn, always with its clippings, leaves, and branches removed, creates a situation that needs fertilizers more than one where some of the "debris" is allowed to remain. Pick a style that works for you and deal with it appropriately.

Watering & Sprinkler Placement

Just a couple more watering ideas. The water of life couldn't be more true; according to trees, it is everything and all. Controls all aspects of growth and defense, is stored when it can be, used in every live cell, every second, 365 days a year. All plants, especially trees, live a life of internal hydrostatic pressure, or turgor. Water a dry limp house plant for a quick refresher course in this. Good water pressure in newly formed growing cells allows them to stretch and grow as much as possible.

Water is used internally to move all substances made by the tree, from sugar for food to secondary metabolites, phenols and terpenes used as antibacterial, antifungal agents. The hungry roots, always needing their allotment of sugars (real tree food) from the leaves, depend on that sugar moving in a steady, watery stream from above via tissue called phloem. Yes, it's all water for trees. Start to dry it out and watch the new growth shrink to nothing—a loss of leaf mass, deadwood, then dead patches on the trunk, followed by an invasion by its enemies, insects, bacteria, and fungi, always looking for easy prey.

The presence of water in leaves strongly affects the rate of photosynthesis activity. Dry trees close the lower leaf pores, the stomata, when sensing low internal water pressure. This conserves water for the whole system, but shuts down sugar production, causing starving due to low water levels. The live outer sections, not the core of the trunk, can contain a large number of living cells used for energy and water storage. These cells are called axial and radial parenchyma, braided in amongst the vessel elements that move water upwards to the leaves. Tree trunks that contain lots of water are stronger, more flexible, and deal with powerful west winds much better than their dry cousins.

> *Tree trunks that contain lots of water are stronger, more flexible, and deal with powerful west winds much better than their dry cousins.*

Another word about conservation when watering—that is, targeting where your water resources are best used. Sprinkler placement is very important. In most cases, water uphill, above the trunk. Once in the soil, the water will be carried downhill through capillary/gravity action. You do not need to water your whole property, nor do you need to water a 360-degree circle all around the trunk. Trees are very happy to receive any water in their root zone, and watering heavily in a 1/4 pie slice of your full 360 gets the job done. There are trees for which this doesn't work—it's called sectorization, and does not apply much here in Calgary. I have several large spruce on my property that I have kept healthy now for about 10 years, including during the last bad drought years. Because of physical constraints, they receive their water in approximately 1/4 of the full 360 circle that is their root zone. They look good, are happy, have good annual growth, are thick and full, and have

The water goes deep, safe from heat and evaporation. More frequent, shorter-duration surface waterings would lose a lot more to evaporation.

no insect or disease presence. It's working. They receive about 4-5 hours of water once a month, which soaks the soil zone, filling their reservoir, and allows the trees to extract the water they need for a period of weeks. The water goes deep, safe from heat and evaporation. More frequent, shorter-duration surface waterings would lose a lot more to evaporation. More importantly, the water won't soak in where a lot of roots are.

Another major consideration is that the plants that make up your garden have very different water requirements and schedules. The spruce tree watering in my garden that I just described is a good example. At the other end of the scale is a patience plant in a pot in the sun on your deck. This plant needs watering nearly every day. Generally, turf, perennials, smaller shrubs are happy with about an inch a week. Plant size and especially root mass, to a great extent, determine water needs and timing. My spruce watering is dealing with a plant with a massive root system that explores a large volume of soil. The larger the root system, the greater the volume of soil it

Many times people get enough water to most of the garden; it's the trees that suffer.

occupies, and, once soaked, the longer it takes for that volume to dry out. When I soak a portion of my spruce's root zone, I give it enough water for a period of weeks. This thinking would be wasteful and unnecessary with the turf, which is usually happy with an inch a week, being a more surface rooted plant. Many times people get enough water to most of the garden; it's the trees that suffer. Using the soil sampling method described above and watering infrequently, deeply as needed is, in most gardens, the missing component. So do what you are doing; just add a separate set of ideas about your trees to maintain a state of trouble free health.

Irrigation

Irrigation. This is a large and tricky subject; sometimes it works, many times the trees suffer. I have seen a lot of irrigated-only gardens with unhappy trees.

If your garden and turf seem OK but the trees are suffering—the first sign is little annual growth—then keep doing what you're doing. But either reprogram for an occasional deeper watering or water the trees once a month or every three weeks by hand, especially during periods of prolonged drought.

Irrigation systems are the children of golf courses, where turf reigns supreme. Lots of regular brief waterings during the week will always keep the surface plants and the turf happy. But frequent, short duration watering has its own problems. Evaporation and lack of deep penetration being the two most important. As described in detail above, trees need a steady available source of water; wet, damp, moist soil to stay strong and trouble-free. Turf is a major competitor with trees for available water; being surface rooted, it will get the lion's share of frequent but shallow waterings.

Like anything else important in life, test it, test your irrigation system. It should also be occasionally maintained; anything this important needs to be in tip-top shape. Have your tech inspect and do test runs on each zone to see that they are as they should be. Or test the system yourself by measuring your weekly output: place small, straight sided-containers—a yogurt container will work—randomly in the watering zone. Either after each cycle or at the end of the week, check your water levels. A minimum of an inch a week is a good start. During really hot weather your test will lose accuracy due to evaporation, so you might be better checking after each watering cycle.

Another important aspect of irrigation watering is dry spots—dry areas no longer receiving the water they once did. This is caused by plant material that has grown much larger than when it was initially planted and now creates "rain shadows" areas behind the taller plants that are blocked from receiving the water they need. Either prune and/or add "towers" to the irrigation heads.

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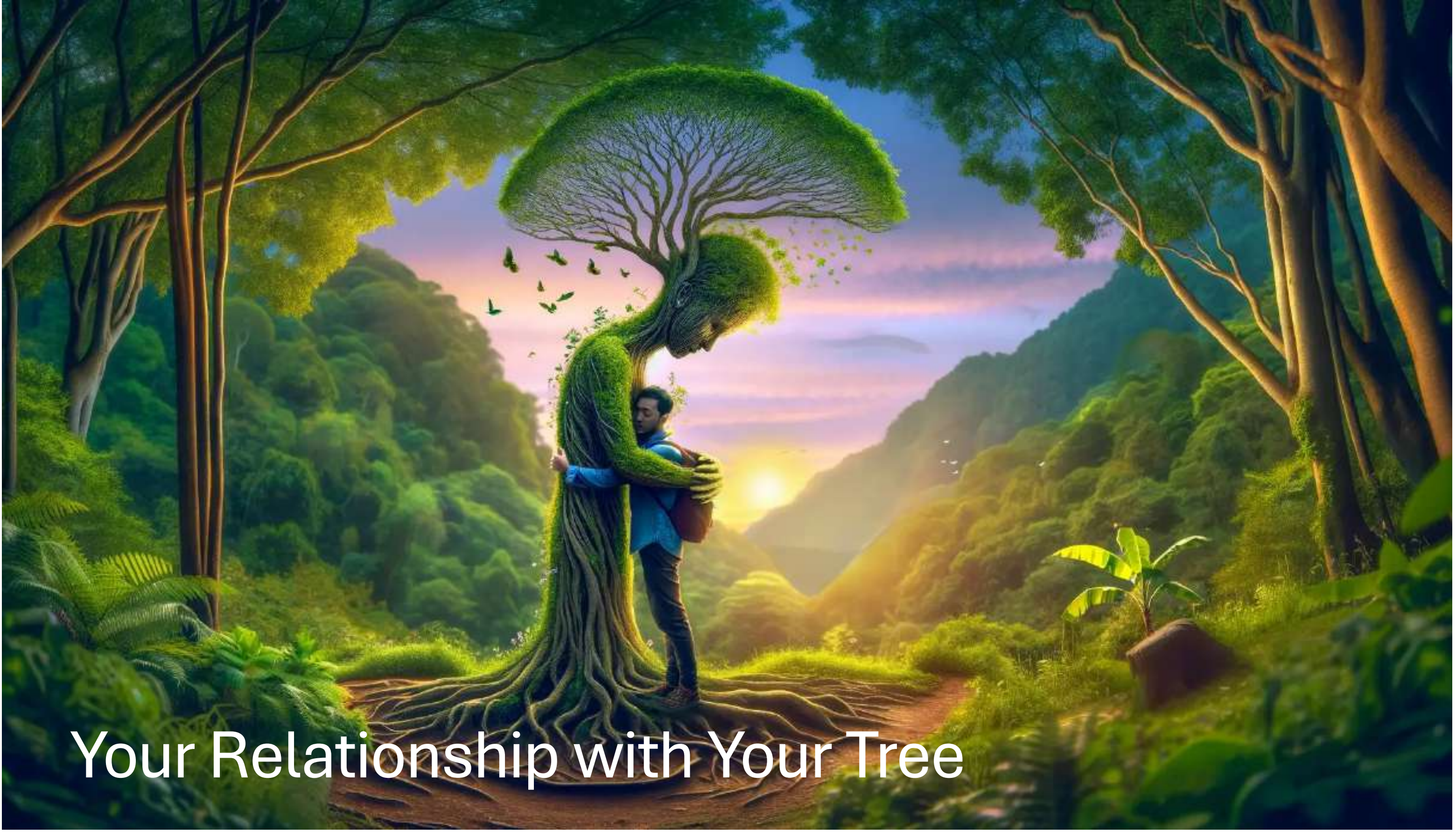
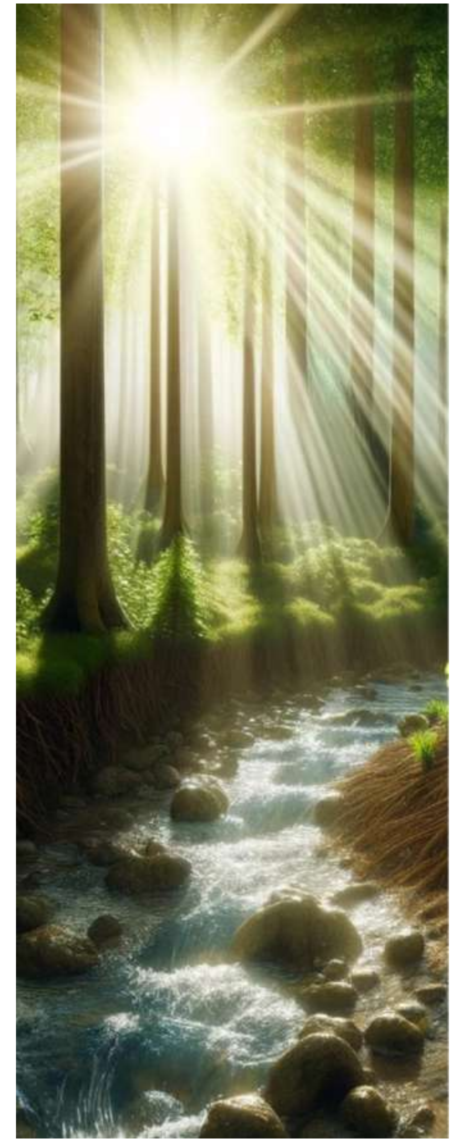


Your Relationship with Your Tree

Thank you for your patience! That was a long discussion about soils and watering and if you made it to here, I can guarantee you will have stronger, healthier, happier trees that will require very little other maintenance. Insect spraying, overfertilizing, overpruning and trunk injection all quickly fall away in the presence of a strong healthy tree. One that, although it finds itself in a less-than-ideal urban setting is doing about as well as it can. Your tree had something all others are strongly jealous of: you! Someone who knows, cares, and loves it as it loves you. Lucky tree, lucky human.

> *Your tree had something all others are strongly jealous of: you! Someone who knows, cares, and loves it.*

Once you do all this digging, sampling, measuring and corrective changes and practices, you will be different, no longer a marginal or surface participant on your property. You have made major steps to becoming a good steward of your land; you have bonded with it. It will never be the same. This is a huge part of what I call being at home. Now, on to some very cool stuff trees have done for time nearly immeasurable: how they grow, how their major fluid systems work, a few essential chemical processes they mastered early on, really a brief overview of the major systems of a healthy tree body.



Evolution, Photosynthesis, Respiration

In this section I want to share some of the wonder, truly the magnificence, that is the blend of complexity and practicality of the workings and the presence of a tree's body. No less a miracle than your own, it's a little scary how perfectly-designed natural systems are and how well they work, usually without any dysfunction. Even one single cell, one of trillions in a tree or human body, is a long way off in complexity and intricacy from what we can currently imagine humanity being able to duplicate. I want to discuss growth, form and function.

> *I want to share some of the wonder, truly the magnificence, that is the blend of complexity and practicality of the workings and the presence of a tree's body.*

We've got tissue, and we can tell them apart by looking at the tree's anatomy. Then there's function, which we get into through physiology. So, we're talking about the parts—the form, the anatomy—and what they do, which is all about function and physiology.

One of the most amazing things about plants as we know them today, and in their 425-million-year history here on earth, is how little they were given to work with. What was the early world like that they evolved into? Really not so different from our own. Atmospheric oxygen levels were lower, but the basic physics and materials were pretty much the same. So let's start with something that looks like a small leaf lying on the surface of the mud and think about what it might take to become, through a long set of steps, something like an oak tree. Here's the early playing field: They had lots of sunshine, there was lots of water—although sometimes too salty or in the wrong places. They had abundant carbon available as gas in the atmosphere in the form of CO_2 and, just as importantly, they had gravity. Anyone who walks up hills knows this; lifting any mass to a greater height requires some tricks. It's work.

Everything changes, and plants were very different back then. The most important step that led to

where we are today was the evolution of a set of internal, self supporting pipes that could move fluids inside the plant. These pipes needed to be strong so that the plant's own weight and the constant draw of gravity were offset by the stem's strength. Lying in the wet mud, you can absorb most of what you need right from the surface with no need for either structural support or internal piping. But the life force in early plants was strong. All living things on earth want to be successful, prosper, and somehow, through endlessly creative methods, ensure that their offspring have a fighting chance. So up they went, into more sunshine, and high enough for wide seed dispersal.

Much work had already been done, in the deep early history of Earth, to give early plants a head start. It is rare on Earth that complex systems just show up or that every life form would have to start from scratch. Nature always borrows systems that have proven their worth through time, and reuses or slightly modifies them to get a new working model. So, in the early harsh environment, plants already had photosynthesis, developed billions of years earlier by a bacteria called cyanobacteria. They formed our early atmosphere. So now we have a way to get energy. All living things need energy, and the early green single-celled lifeforms that had the pigment chlorophyll in them could make sugar from sunshine; a pretty good trick, in fact the best trick on earth. Without it, everything we know either wouldn't be here or would be very different. Plants have always supplied the food basis that all other life forms depend on. No plants, no life as we know it.

All living things need energy, and the early green single-celled lifeforms that had the pigment chlorophyll in them could make sugar from sunshine; a pretty good trick, in fact the best trick on earth.

So we have energy and sugar; how to use them? That major innovation is called respiration, burning sugar with oxygen. It happens in almost every living cell of almost all living things. I have to say almost, because life on earth is so creative and diverse that there are always exceptions—sometimes just a few, but they are there. Vive la créativité!

With photosynthesis and respiration on board, all early plants needed was a support system to hold themselves up against gravity and into the light. The answer came in the form of cell wall reinforcements. Makes perfect sense; the right answer is many times as easy as possible with the minimum of complexity: Don't waste energy! If something is going to change, it's going to happen inside the cell first. So if cells walls were really strong and, in their numbers uncounted, could stack and lie together to form a tissue that was flexible yet strong, and could move a lot of fluids, you could be very successful. We all call this miracle tissue wood; living functioning wood.

Primary Growth

The only way early plants could become more competitive was to get bigger, taller, and move up into the unimpeded sunshine where photosynthesis could be as efficient as possible. More photosynthesis, more sugar, more energy, better life. Two amazing molecules facilitated the whole journey: cellulose and lignin, the cell wall reinforcers. These molecules, along with the development of more efficient root systems, allowed plants to leave the steady guaranteed water supply of seashore, creekside, and lakeside, and they would begin their incredible journeys to the farthest ends of the earth—from high in the mountains, north and south to the edges of the polar ice caps and everywhere in between. The planet is 70% blue—the oceans—and nearly 30% green, except, of course for the world's deserts. Today nearly 400,000 species of all types of plants are known, with, no doubt, more discoveries to come. It seems plants like it here.

> *The only way early plants could become more competitive was to get bigger, taller, and move up into the unimpeded sunshine where photosynthesis could be as efficient as possible.*

Early plants were small by today's standards; the first early plants were basically flat upon the land. Then, as some evolutionary developments began, other types appeared, many larger than their early relatives. Those early relatives are still with us; they are called bryophytes, mosses, hornworts and liverworts. These early plants do not have the vascular plumbing, or the root systems, of most other larger plants, which are called the tracheophytes. The root words of these two terms are moss plant for the bryophytes and trachea plant for the tracheophytes. Spending some time on the forest floor with these ancient beings is like time travel to deep in the past, well before the large trees that now surround them developed. This attests to their survival skills; you have to have your chops down pretty good to survive unchanged for over 400 million years.

Most smaller plants (not trees and shrubs) exhibit one growth method called primary growth—primary being first, or shoot growth. Woody plants also have primary growth, but additionally exhibit secondary growth, which allows the stem to increase in width and strength. Both primary and secondary growth occur in zones called meristems, which are tissue zones that exhibit cells that are called initials, and their derivatives, mother cells and daughter cells. Meristems have the ability to produce new cells, new growth, either annually or overextended periods of time. The meristems for primary growth, the lengthening of shoot and root tips, only function during one growing season. The next year, the new bud that formed at the shoot tip will take up the task for the next year. The root tip functions in a similar way. The shoot apical meristem is called the SAM; the root apical meristem is called the RAM. The meristems responsible for secondary growth are called the vascular cambium and the cork cambium. The vascular cambium (VC) grows nearly the entire growth and bulk of the trunk, whereas the cork cambium (CC) grows the outer bark layer. The CC is produced annually. The VC lasts as long as the tree, sometimes thousands of years.

Let's think about shoot growth (primary growth) for a minute. At the overwintering shoot tip is the terminal bud. It was the last bud on the shoot formed in the previous year's growth. During the previous year as the shoot continued to grow, it kept expanding from the tip, pushing the SAM outward, the latest newly-forming cells just behind it. As it does so, it also generates the nodes or buds that later form into side shoots. These have three patterns along the new stem, either singly (alternate), in pairs (opposite) or in groups (whorls). Look closely and you can prove this for yourself.

It is the first thing I look at when approaching a new tree - How are you growing? How are you doing? Do they treat you well here?

Let's imagine a point during the first growth flush that is usually ongoing sometime in June. Take a hold of the new shoot; you can follow it back towards the trunk to its bud scar. The bud scar is a tiny ring of tissue all around the shoot in the bark that marks the transition to this year's growth from last year's growth. It is the site where the last overwintering terminal bud was, the bud that became this shoot. When that bud started growing (broke) it began to grow the shoot we are looking at. As you inspect this year's shoot you will see that the oldest newly formed side buds are closest to the bud scar. The farther you move out to the tip, the smaller and less developed the side buds are. If there is a newest, last formed bud at or close to the tip, it will be the smallest, least formed, most immature of all the buds along the stem. This is because it is the youngest bud on the shoot, meaning it was formed last, meaning that the shoot constantly expands from the SAM right at its tip. The new shoot tissue forms behind it. Cool, eh? Bud scar identification is a tool you need to learn. It is the first thing I look at when approaching a new tree—how are you growing? How are you doing? Do they treat you well here? I stand way back to look up to the tops of spruce trees where I can see the latest shoot extensions, to gauge the growth rate and overall health of the tree.

Secondary Growth

First, the VC. To me the VC is the heart of the tree. The complexity, longevity and near perfect production of trillions of cells just boggles my mind. Want to find the VC? Well it's too small for you to see, but it's right between the outer bark and the last woody growth ring of the stem, branch or trunk. Earlier in the year when it's working overtime and laying down a lot of new cells, by peeling the outer bark off a branch you will find a slippery wet area. This is the VC at work. When we think about it, it's intuitive; the space between the bark and the wood underneath it is a natural seam. It just makes sense—wood to the inside, new bark to the outside.

How does the VC accomplish this? The VC is either a single layer of cells or several cell layers thick. Think of a piece of paper wrapped around the trunk, but inside beneath the bark. It is a two-sided (bifacial) tissue that, during the growing season, steadily produces new cells from both sides. The inside, the wood side, is called the xylem. A two-by-four is a piece of xylem. To the outside, the bark side, it produces the phloem, the major sugar conduction pipe of the whole tree and, farther out, the bark. In between there is the other trunk meristem, the cork cambium (CC), which is produced annually from meristemically active cells that have their origin back at the VC. These are phloem ray cells (ray parenchyma) that run out like spokes through the cambium, through the phloem, and outwards. They run across, perpendicular to the long axis of the trunk, radially.

Let's talk about the inside, the xylem side, first. Both sides of the cambium are similar but generate different tissues. There are two kinds of mother cells or initials; one produces the cells that are vertical, that run up and down with the long axis of the trunk, and the other kind produces the cells that run horizontally, the rays. The proper name of the vertical cell initials is the fusiform initials; the other, horizontal cell initials, are called the ray initials. Living (and dead) wood is three-dimensional. It's these two types of initials that weave the woody tissue, cell layer by cell layer uncounted—through the growth rings, through the years.

The fusiform initials of the xylem produce the vessels, the cells that will line up in long vertical rows, like spaghetti in a bundle, that are used solely to move water from the roots upward to the leaves. Water is also siphoned off from the vessels for other tissue that needs it. Xylem ray cells absorb needed water and pass it out through the VC to the phloem side rays where it replenishes water constantly needed by the phloem. All these interwoven, closely-packed cells have tiny holes in their ends and their sides that allow water movement in as many directions as needed.

To the outside (the phloem side) of the VC, slightly different cells are produced, still following the vertical and horizontal patterns. Fusiform initials of the phloem side produce the phloem cells proper, their companion cells that assist them, and phloem fibers that help support the greater phloem structure. The ray initials of the phloem side of the VC produce the phloem rays and, farther outward it's these ray cells that are transformed into the CC. The phloem runs from inside the leaves into the branches, the trunk, and deep into the roots. Its placement just to the outside of the VC ensures its safety deep inside the outer bark. It also assures it a steady supply of needed water from the rays that supply water from the high flow volumes just to the inside of the VC in the vessel elements. Conversely, the placement of the VC right beside the phloem couldn't be better. The VC needs a huge amount of energy for its work, and being right beside the greatest concentration of sugar in the entire of the tree body (the phloem) is no coincidence.

As the trunk expands underneath the bark, the bark tissue is pulled, stretched in two directions; it expands outwards and it also expands across.

There is another cell layer to the outside of the phloem tissues: the cortex, in young stems especially; it helps by supplying another layer of photosynthetically active cells. Give a young branch a light scratch with your fingernail. Doing so, you pass through the epidermis, the outer bark, the CC, and then into the thin cortex layer. You will know it when you see it by its intense green color. Outside of the cortex is the CC. This thin layer of meristematic cells produces the outer bark, the phellem; another name for the CC is the phellogen—gen as in generate. Phellem is cork, the waterproof, insect-proof, fireproof (when thick) outer layer of the tree, its bark, and it's loaded with a wax called suberin. There is a different bark pattern for every species of tree. Know the bark, know the tree. There are as many ways to form the outer bark as there are types of trees. The bark stays in place on the outside; underneath it seismic changes occur every year in the expansion of the xylem tissue. Xylem expansion accounts for over 90% of trunk growth and size increase. What is the nice smooth skin of the young epidermis to do as the subsequent yearly rings are added underneath? Many are stretched and pulled, and pile up on each other until a deep corky layer is seen, as in pine trees. Some, due to their more elastic-like skin, stay smooth through hundreds of years, like beech trees. As the trunk expands underneath the bark, the bark tissue is pulled, stretched in two directions; it expands outwards and it also expands across. Each tree has its own specific way of doing this, and we see a great variety in bark textures as a result.

Roots

We have spoken of roots a fair amount in the earlier soils/watering sections. Here I want to touch on growth and some of their processes.

Roots are, by far, the most important, and yet the least understood, of all plant organs. We can't see them, and it takes a lot of work to learn anything, so they remain the great mystery. Roots do more to control overall tree health than the other parts; without a happy root system constantly drawing water and nutrients from the soil, the upper visible parts, trunk, branches, leaves do not flourish. Their wellbeing is all tied to what the root system can do. The tree "thinks" roots first. This begins at seed germination. Once given the go, a little engine starts to rev up inside the seed. Starch, stored for long periods, is now converted to sugars, readily-available energy for growth. The seed cap ruptures from internal expansion, the seed cracks open, and who sticks their head out first to have a look around? You got it, the first little root, the radical. Before anything else can happen, we need water, nutrients, and anchorage, all readily available in the surrounding soil. Roots first. Once the radical gets settled, then the tiny little stem, with its baby leaves on the end, can unfurl and start its journey upwards to the light.

Root growth is a bit different from the primary and secondary growth we have discussed in the context of the above-ground organ, the stem. Roots have a much denser and more difficult medium to grow into: soil, full of sharp edged rocks and immobile rocks that have to be grown around. They have learned how to overcome these obstacles.

Roots are, by far, the most important, and yet the least understood, of all plant organs.

Let's talk about primary root growth. Similar to the SAM, the RAM root apical meristem has its own way of growing. Let's start with what is called the root cap. Because of the harsh soil medium, growing root tips evolved some protection: the root cap. This glove-like covering for the root tip produces and is covered with a natural soil lubricant called mucilage. This greatly eases the root tip's journey. Under the cap is the heart of the RAM, an area that behaves very much like SAM; it is a meristematic cell generating tissue.

Different from the above-ground meristems, the roots only grow more roots—that's it. As the growing root cap pushes ahead, behind it are the youngest new cell zones. The first zone is called the zone of division. Back a bit farther is the zone of elongation, where cells and the new section of root are achieving their for now finished size. Farther back still and older is the zone of maturation and it is only in this zone, where the new root is stable and immobile, that we see tiny side roots, root hairs popping out through the outer covering of the root, the epidermis. This is really genius. If the tiny—honestly smaller than a baby's hair—new root hairs were to emerge while the growing root is still moving in the soil, they would be sheared off by sharp soil particles as they were pushed by them. During all of the growing season this process continues. Indeed, sometimes root hairs only live for a week. Their constant new growth is essential for the ongoing life of the tree. Even before buds break, the water required must be available, supplied by who else but the first flush of non woody root hairs. These root hairs in their millions do all the water and nutrient absorption for the whole tree. A small root, even the size of a pin, is at least a year old, and its main function is as conduit for the water/mineral stream absorbed by the root hairs. That stream is on its way into the root xylem tissues with its vessels, and on its way up to the thirsty leaves.

This has dealt with primary growth and some function; we should discuss secondary root growth also.

Roots also experience secondary growth, an increase in diameter, and get rougher and develop cork on their outside surface.

Roots also experience secondary growth, an increase in diameter, and get rougher and develop cork on their outside surface. This is quite different from the secondary growth in the trunk. The secondary growth of roots is a reduced affair

compared to the trunk just above. Once the first year's primary growth is finished, a number of inner tissues go through some interesting changes as they mature into their finished pattern. In both primary stems and roots, the vascular tissues (xylem, phloem), used for liquid transport, are initially formed in bundles of both tissues together. These circular bundles are located toward the outer edge of the new stem/root. They reside in the cortex in stems and the ground tissue of the root. They are found just inside the epidermis. As the transition to the mature pattern begins, the vascular bundles split, the xylem is drawn inwards, the VC begins to develop from the bundle sheaths, and the phloem tissues move to the outside of the VC. This is the mature pattern we find in both shoots and roots that have finished their first year's growth. Next year they are ready for secondary growth.

Leaves

Leaves are the one organ that produce energy—sugar for respiration. Some energy, small amounts, comes from other tissues containing chlorophyll, like cortex in young stems, but the leaves, by far, supply the bulk of energy for a tree's life. And it is a tough life. In Calgary, most trees produce energy for about six months, yet they are alive and functioning for every second of every day, all year. The tree, like you, has a basic economy; you have so much income balanced against all the expenses. Laid off, lost your job, seized the engine on your car? Expenses always go on. The economic model of the tree is an example of practical sound economic practices. When you only work for six months but pay out for twelve, you have to be very careful. Lots of saving—this is exactly what every tree, given a chance, will do. Work like crazy during the growing season, hunker down, get through winter, wait, hope for spring. The lesson here is that trees only produce sugars when they have enough water on board, and there are no extra leaves. We have all for so long been bombarded with the rhetoric of tree service sales departments that now most people, if asked, think that pruning trees is good for them. That somehow just having the crew on site is going to make everything all right. There are some real good health aspects to pruning, disease removal, deadwooding, and practical considerations like house, sidewalk, and street clearances. But a brief tour through some real tree science yields this conclusion: There are no superfluous leaves on trees. Any tree that produces suckers (replaces missing leaves) after pruning was overpruned.

Delicate as leaves seem, they are tough little engines. By fall, like exhausted marathon runners, they long for the end. Chewed by insects, invaded by fungus, cut by hail, and torn by the wind, they persist, working till they can work no more. By practical considerations, a leaf is a small efficient container that holds a lot of chlorophyll that will produce as much sugar as their simple, delicate design will allow. Perfectly engineered, with a wide flat surface to catch all the

In Calgary, most trees produce energy for about six months, yet they are alive and functioning for every second of every day, all year.

sunlight they can, they are amazing. I briefly described a journey through a leaf's structure way back in the first essay, so don't want to repeat too much here.

Upon attaining full size, the leaf can really get to work, for growth is an expensive process, a necessary yearly expense.

The process of photosynthesis and its electron transfer chain is one of the most complicated chemical reactions we know, with something like 35 different chemical and energy transfer steps involved. I love the science that untangled that but, as an arborist, I really don't need it; it's enough to know how essential a full, well-watered leaf mass is. Briefly, the leaves' year starts like this. The first set of tiny juvenile leaves is contained in the bud that formed last growing season. Trees are the masters of preparedness and, when spring finally arrives, they have everything in place to take full advantage of the summer sun.

One aspect of the growth of the SAM is called the leaf primordia, which is again meristematic cells producing new leaf tissue as the young growing leaf expands. Shortly after all is in place, an array of different tissues interlaced with veins for water supply and sugar collection begins to form. The veins taper down beyond the ability of our eyes to see them. But know that they reach into every group of cells and are never more than three to four cells apart.

Upon attaining full size, the leaf can really get to work, for growth is an expensive process, a necessary yearly expense. The arrangement of the leaves throughout the tree is interesting. There are two main types of leaves on most trees: sun leaves and shade leaves. On most trees the upper canopy is so full that it shades different parts of itself during the sun's movement across the sky. Shade leaves are usually larger, with thinner cuticles and fewer pavement cells, allowing easier entry of the sun's photons. Many times they also have a higher percentage of chlorophyll contained in the chloroplasts and more chloroplasts than shade leaves.

As summer winds down and the approach of winter is sensed through shorter days and colder nights, the tree begins to shut down the busy activity of the leaves, which will not survive the cold. This process is called senescence. Resource extraction from the leaf, a loss of chlorophyll, reveals other pigments, and the final removal of the leaf from the twig, abscission, will all occur in its time. Valuable molecules of

As summer winds down and the approach of winter is sensed through shorter days and colder nights, the tree begins to shut down the busy activity of the leaves, which will not survive the cold. This process is called senescence.

proteins, amino acids, and mineral ions all need to be recovered, and are drawn out of the leaf before it fails. The two main other pigments usually not seen when the leaf is green are anthocyanins and carotenoids, which give us the rich yellows, oranges, and reds of fall leaves.

The season rolls on, the leaves keep working, producing lots of sugar that is stored in many tissues as starch. Roots, trunk, and branches all store starch in living parenchyma cells. Converted back to sugar, it is then ready to be used for fuel to get through the winter. Winter is a tough time for trees. When you see a tree wake up and turn green in the spring, know that all you see passed through winter unharmed. It doesn't take much frost to kill living cells. Protected inside, most cells don't freeze and are in good shape for spring. The cell's regular metabolic life doesn't stop for winter; every second, every living cell needs water, sugar, and oxygen. All this cost is covered by stored energy, starch.

Life Processes 1 – The Ascent of Water

A tree's body is every bit as intricate as your own: many types of cells, formed into many tissues, energy produced in one zone, water and nutrients extracted in another. How to orchestrate all this activity of trillions of cells that have constant needs? How to make enough energy to survive the winter and keep everybody happy? Life, a highly ordered set of procedures, has all this figured out for all of us, from single-celled bacteria on up in size to redwoods and whales. Quite the planet you got there!

How to make enough energy to survive the winter and keep everybody happy?

From the tree's perspective there are two main operations: first how to get the water and minerals out of the ground and up into the most remote leaves where they are needed and, secondly, how to get the abundant sugars produced by the leaves all the way back down to the farthest root tip, where they are needed. Two different processes, two different tissues. The first, groundwater and minerals moving up, is called the ascent of sap, or the cohesion/tension (CT theory) model of the ascent of sap. It is accomplished by the tissue called xylem. The second, the distribution of sugar to all hungry plant parts, is called the pressure flow hypothesis, and uses a tissue called the phloem. Traffic in both ways is busy, so each system has its separate series of lanes (pipes).

First, the ascent of sap. I mentioned earlier when speaking of plant evolution that early plants seemed to have been given little to work with. This couldn't be more true when it comes to the major problem of how to lift a lot of water

We needed powerful cell walls that could stand up to high pressure, hold up the trunk, and yet the cells had to be hollow and, there-fore dead, to allow water movement. They needed to be in a range of internal sizes that worked with the inherent natural properties of water.

a long way up. The long time of evolution, many failed experiments, back to the blackboard again must have been the struggle of early plants as they attempted to rise above the mud. The solution was twofold; first, we needed powerful cell walls that could stand up to high pressure, hold up the trunk, and yet the cells had to be hollow and, therefore dead, to allow water movement. They needed to be in a range of internal sizes that worked with the inherent natural properties of water. The first problem, cell wall strength was solved by the creation of two miracle molecules: cellulose and lignin. When the two are combined in interior cell wall fortifications, the strength issue is solved. The second problem, dealing with the natural properties of water, may have taken some time. To say water is the miracle molecule of our home planet is the biggest understatement possible, simply water is life, and learning how to use it is some of the mystery.

> *So the warm wind blows, drying out the leaf, the leaf asks for water from the twig, the twig asks the branch, the branch asks the trunk, and the trunk asks the roots. The roots ask the water present in the soil.*

A triangular shaped molecule with two hydrogen atoms and a single oxygen molecule, H2O has some amazing properties, considering its simplicity. Water molecules love each other, love to stay together. Apart from being very "sticky" with each other (tension), they also adhere to surfaces with great strength (cohesion). It is these two seemingly simple properties that early plants utilized to get water up to their tops. So if you had pipes small enough to take advantage of these properties and could find a way to move the water up, you would have conquered gravity, with no expenditure of resources, apart from the building of the structure. The final puzzle piece is the evaporation of water from the leaves, again dealing with the natural properties of water. A warm, hot wind has an amazing pull (convection), and literally sucks water vapor away from the surface and open stomata of the leaves. So great is this ability to literally suck water away that the leaves together act as the "mouth" sucking at the end of a great, long, but very thin straw.

So the warm wind blows, drying out the leaf, the leaf asks for water from the twig, the twig asks the branch, the branch asks the trunk, and the trunk asks the roots. The roots ask the water present in the soil. In your garden, that won't be a problem, because you love your trees and water them. We feed what we love. In dry conditions, the water's bond to the soil particles is stronger than the root's ability to try to draw the water away and the root gets nothing or very little. In extreme drought, water can be drawn from the roots into the much drier soil. On its long journey to the upper crown, the water is asked to do many things and go many places. Living radial parenchyma, arranged horizontally in the trunk, lie wrapped up with the vertically aligned dead vessel elements. Water, if needed, easily passes from vessels to rays, through tiny holes in the cell's walls, and is then moved laterally where needed. This is how the phloem gets all the water it needs.

Life Processes 2 – The Distribution of Sugar

In the trunk, the rays deliver water to the phloem tissue; they extract it from the vessels (where else?), move it to the outside edge of the VC where the phloem tissues are, and deliver it to the phloem sieve tube cells and their companion cells. In the leaves it's a little different, with the xylem and phloem tissues lying side-by-side in a bundle in the leaf veins—not so much of a reach for the water.

Hungry tissue needing sugar is a sink. Sinks vary; wherever energy is currently needed is a sink.

That explains the phloem's water source, but there is more to it. We need to return to the chloroplasts, innumerable in the leaves. As sugars are produced in the chloroplasts, they are exported into the phloem sieve tube elements in the vasculature of the tiniest leaf veins. As sugar concentrations rise, an imbalance occurs, creating an osmotic pull of water, mostly from the companion cell, to rush into the sieve tube element, a phloem cell. The pressure flow hypothesis states that sugars are loaded into the phloem tubes at the sources, causing a high-concentration sugar solution to build up. This draws water in, water transported by the rays from the xylem to the companion cells. The increased pressure pushes the sugar solution in that sieve tube element (STE) through its pores and into the next STE. The entire phloem element becomes pressurized and flows. At the sink end, the sugars are unloaded. The sugars are unloaded from the STE and water moves out of the phloem cells into adjacent tissue, restoring normal pressure. The sugars have been delivered to where they are needed.

Locations change through the season. First thing in the spring is non-woody root growth - that's a sink.

Sinks are the recipients of phloem sugars. Chloroplasts in leaves are sources; they produce sugars. Hungry tissue needing sugar is a sink. Sinks vary; wherever energy is currently needed is a sink. Locations change through the season. First thing in the spring is non-woody root growth—that's a sink. Cambial startup and first growth are early sinks, shortly followed by bud break and juvenile leaf growth, which are also sinks. Leaves still growing, costing more than they produce, are a sink. The phloem is not a strict leaf-to-root downward journey; at times it works this way, but phloem action can move in both directions and there is always a lot of radial movement of sugars from the phloem to wherever sinks are working. It is no coincidence that the phloem is right beside the VC—the VC is one of the hungriest, hardest-working tissues of the whole tree complex.

The phloem is responsible for the movement of sugars produced in leaves to wherever there is a demand for energy or sink. Phloem cells are alive and usually only live for one growing season, sometimes for just days or weeks. New phloem cells are constantly being generated by the VC. Phloem sap is so valuable that when STE are broken or fed upon (by aphids) there is a backup response that plugs the holes. This is accomplished by P-proteins, phloem proteins, which are filamentous and attach to the hole and plug it.

Conclusion

I hope you enjoyed our incredible journey inside the tree. There are many more, deeper ones to take. When I was a kid, there was a TV show where a group of people lived in a spaceship/submarine—not sure which—and traveled inside the human body. The ship was very small... that's about all I remember. I hope our journey has been similar as far as getting inside a tree. We haven't been everywhere or seen everything, but it's a good start.

I don't think that we can really relate to trees until we have a basic understanding of their bodies, like we do of our own. For many people, their experience is surface only, not knowing what's inside. This could be said for most tree workers and arborists—years ago including myself. I remember clearly my knowledge quit at the outer edge of the bark, with no idea of what was inside. My experience then was only visual, just the look. We chop away at the surface, not really knowing how what we do affects the inner life of the tree. If you love trees, you will be curious; when you start to answer your questions then you are moving along well.

There is another major part to tree knowledge and tree work, and that is the hands-on practices from planting to removal. I have dealt extensively with selection, planting, pruning, insects, diseases and other problems in my first book, Your Trees: What They Want You to Know. That book makes a good companion to this current writing. Much of the information it contains is on my website in different forms. The Articles section is getting plump and will shortly contain about 190 of my essays about trees. Please enjoy! I do this for you and your trees.

Biography

Kevin Lee has been an arborist in Calgary since the 80s.

He is the owner of KRL Tree Service at krltreeservice.com, and the author of "Your Trees. What They Want You to Know" published by Lee Valley tools. His early teacher was Dr Alex Shigo.

Kevin's love of trees and his study in Botany, has produced nearly 190 essays, free to the public in the articles section of his website. Lately he added, 17 more called "What every tree owner needs to know to have happy trees" a free downloadable book.

He now works as a consulting arborist, helping people in Calgary with their tree problems.

Kevin and his wife are avid gardeners and live with about 200 happy trees.

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