Illinois Trees

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healthy trees, happy homes
ILLINOIS ARBORIST ASSOCIATION (IAA)

Remote Sensing

by Lindsay Darling

Arboriculture has long been a field that relies on hands-on measurements. Arborists are adept at using a DBH tape, estimating canopy height and volume, and keying out tree species. However, these on-the-ground measurements are time consuming and costly when scaled up to municipal or forest patch scales. In the past decade, remote sensing of forests and trees has grown by leaps and bounds. In this article, I will outline some of the past remote sensing efforts, describe how these technologies have improved, the future directions that they may take, and give some practical applications for how they can be used by arborists.

Aerial imagery (both from airplanes and satellites) can be used to estimate canopy cover. The National Land Cover Database (NLCD) is one of the most well-known examples of remotely sensed land cover. It uses satellite imagery to classify a variety of land cover types, including several types of forests (Yang et al. 2018). It is updated every five years and has a 30m resolution. This dataset is curated for the entire United States. However, the course resolution makes it unsuitable for most urban forest applications as it tends to underestimate canopy cover in areas with patchy trees (like streets and parks) (Fig. 1). Higher resolution imagery can overcome this limitation, but it often fails to

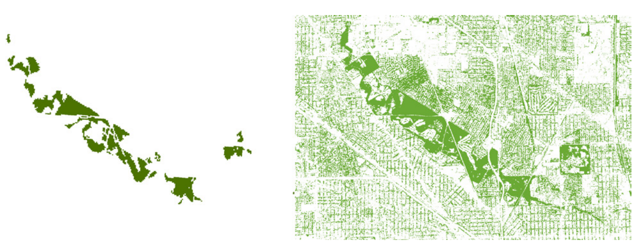

Figure 1: Comparison of NLCD (left) and UTC (right) tree canopy maps. Both of these images show trees along the North Branch of the Chicago Region. While the NLCD picks up the large forest preserves, it misses the adjoining residential trees.

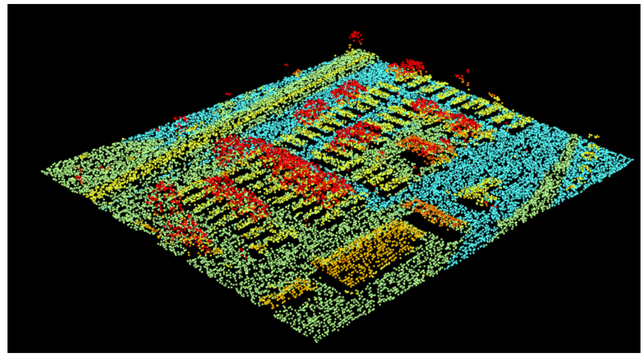

Figure 2: A LiDAR point cloud of a neighborhood in Kendall County, IL. The colors correspond to elevation, with warmer colors showing higher elevations. Note the diffuse, red trees above the yellow and orange buildings.

detect trees that are in shadows. This can be especially problematic in dense urban areas, where tall building can cast shadows for blocks. Fortunately, LiDAR can detect trees in shadows. LiDAR is similar to radar, but it uses lasers instead of radio waves. LiDAR can create extremely accurate visualizations of elevation, infrastructure, and vegetation (Fig. 2).

LiDAR is commonly flown by counties, and these data are freely available at the Illinois Geospatial Clearinghouse. LiDAR data can be used to identify the height and extent of tree canopy using free software like QGIS and R or paid software like ESRI's ArcMap. However, working with LiDAR data requires a bit of GIS savvy. Some municipalities or tree care companies may have staff on hand that could do this work, but in some places that analysis has already been done. The USDA Forest Service in partnership with the University of Vermont have created urban tree canopy (UTC) layers for many areas, including the seven county Chicago region (Univeristy of Vermont 2016). These layers are commonly used to create canopy goals and to identify current canopy and areas

(continued on page 4

Table of Contents

Don't forget to sign-up for the upcoming IAA Certification Workshops

Illinois Arborist Association

Mission Statement

"Foster interest, establish standards, exchange professional ideas and pursue scientific research in Arboriculture"

President's Message

Hello IAA members!

I would like to start the year by welcoming all of our new Illinois Arborist Association Members. Last year was taxing on everyone, but we have been able to adapt and provide our members with web-based education and conferences of the highest quality. Not just allowing you to earn CEU's, but allowing for networking and professional growth essential in ensuring our local industry thrives. This has been thanks to the tireless efforts of our staff, board members, and volunteers. Thank you all for your extraordinary efforts and innovations to keep this organization's mission on track.

Our mission is to "Foster interest, establish standards, exchange professional ideas and pursue scientific research in Arboriculture." This is only possible through the continuing contributions of volunteers from our Association and the greater Arborist and Tree industry community. I invite all of you to volunteer for one of our events or conferences in whatever capacity you are comfortable participating. It takes a full crew to keep this ship sailing! Lastly, I would like to thank all of you for entrusting me to lead this organization. The Illinois Arborist Association has been here for me my whole career and I want to help ensure it is here to support the next generation of Arborist's development. We will continue to adapt with the changing environment continuing to find safe innovative ways to keep our members engaged, educated, and always growing!

Illinois Arborist Association President,

Sincerely,
Beau Nagan

Remote Sensing (cont.)

where additional plantings are possible (Locke et al. 2010, Scott et al. 2020).

The UTC layers only identify the extent of tree canopy and give no data about the individual trees. However, LiDAR can be used to model individual trees including their canopy height and area (Alonzo et al. 2014) (Fig. 3). This sort of analysis requires a more advanced knowledge of GIS, and is generally done using the software eCognition, but to a lesser extent can be done in the aforementioned GIS platforms. These layers can be used as a component of tree inventories. Surveyors can start with the LiDAR derived tree locations and height, and add other attributes like DBH, health, and species in the field. This lessens the need for GIS units and range finders in the field, and LiDAR sourced tree heights are generally more accurate than ground-based assessments. Further these layers can be used to estimate stored carbon and other ecosystem service benefits.

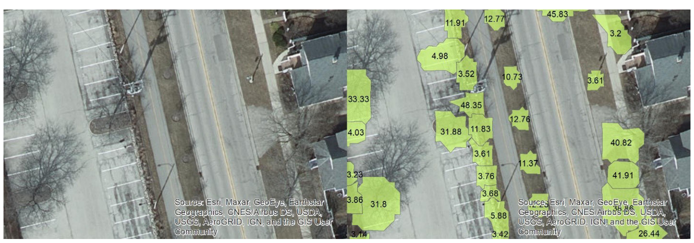

Figure 3: A satellite image shows the location of a few trees in Lake County, IL (left). On the right, LiDAR was used to identify individual tree crowns. From here, the maximum height can be calculated (displayed over each tree), as well as canopy diameter and the variation in height. Note that in the image tree shadows are present far beyond the canopy, but the LiDAR only detects the actual tree canopy.

The technology to collect and analyze remotely sensed data is advancing. The resolution of LiDAR and aerial imagery is increasing (Ullrich and Pfennigbauer 2016), both are less expensive to collect, and the tools to analyze them continues to grow. This has opened new opportunities for working with these data. Researchers have been able to identify tree species in northern, evergreen dominated forests and in cities with limited tree diversity like Los Angeles (Liu et al. 2017). In these areas, there are fewer species, and those species tend to be very different from each other morphologically; palm trees look very different from cedars. There has been less success in they hyper-diverse midwestern urban forests, but it is likely that advances will be made in the coming decade to make the remote sensing of tree species possible. Higher-resolution LiDAR is also able to penetrate the tree canopy and measure sub-canopy species. This will further LiDAR's ability to understand canopy metrics, measure above ground carbon, and even map shrub level dynamics (Chance et al. 2016, Martinez et al. 2020). This could be a powerful tool for land managers to identify the extent of invasive, shrubby species and to track the outcomes of landscape-scale efforts. Going forward, I expect arborists to integrate these remote-sensing techniques into their wheelhouse. While on-the-ground assessments will always be necessary, these techniques can speed up and expand those efforts.

Citations:

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Time to Revise 20th Century Tree Ordinances for 21st Century Needs

by Mike Brunk

Tree Ordinances and tree program policies are vital to developing a viable and long-lived community forest. Illinois has wisely utilized the Arbor Day Foundation's Tree City USA program for 4+ decades to attract communities towards proper tree ordinance development. More and more I look at tree ordinances as a starting point for urban forest survival. Therefore, I advocate, that we all pursue known communities to contact me to become a Tree City USA community. I have basic tree ordinance templates I can share.

After reviewing close to 200 community tree ordinances and encompassed tree policies, I have come to realize that our 20th century regulations and guidelines are needing revisions to meet 21st century needs. Tree ordinances, the community's way to regulate how trees grow, are cared for, protected and preserved are the structure from which our urban and community forests will develop or maybe better said "survive". Today's world is much different than the decades of past, and change is advancing in many ways that were not known or considered in 1995. Let's face it, many municipal arborists are working from tree ordinances and in some cases tree management policies that were developed in the 80's and 90's.

There are communities that maintain a pretty good cycle of tree ordinance revisions, every 5 years or so, to keep up with changing needs. And there are communities that only have nuisance tree ordinances dealing with nuisance trees and no tree care, protection or preservation codes or policies. Generally, I see community tree ordinances fall under two ordinance categories - municipal codes which cover the general health, safety and welfare of its citizens and zoning ordinances which guide new development within the community. Both areas are critical to a community forest's 21st century care, preservation, protection, and ongoing growth. Our goal is to guide green and gray infrastructure maintenance and development as a symbiotic relationship.

We, the world, our communities, are experiencing rapid change in our environment. We are experiencing genus specific tree diseases and pests; invasive plant species (many of which communities allow to be planted) that are destroying native ecosystems at alarming rates; new political movements that are advancing the need to protect and preserve more green space; changing climate zones, and more occurrences of extreme weather; technology advancements with infrastructure repair/development that continue to improve tree protection and tree establishment. Many of these changes have been around for a decade or more, some are newer, and more changes are around the corner.

No one size fits all when it comes to community ordinances or policies and every community has its own needs and priorities. Communities' therefore, exercise some form of Adaptive Management to fine tune regulations towards their community priorities. This process should be ongoing with tree ordinances and or policies being the agile receptors. In fact, ordinances are generally setup with the expectation to be revised, no matter how simple or advanced they may be. Communities (municipal leaders, planners, arborists) just need to engage in the process. Tree ordinance/policy revision work will be time well invested and our community forests success and future vitality are dependent on these community regulations. The first step

(continued on page 6)

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is to review our community tree ordinances to know the community's base regulating structure. This is our starting point.

I will be maintaining a focus on community tree ordinance and policy development as a part of Illinois DNR's urban and community forestry program. I hope with a combined effort of many that we can create and regularly disseminate a list of tree ordinance and policy items for communities to consider. This is something I will work to develop. I have already seeded the idea of studying 21st century tree ordinance needs with the Trees and Green Infrastructure Work Group under direction of The Morton Arboretum and the Illinois Forestry Development Council's Urban Forestry Committee. I hope to get others involved as well in creating some ordinance language and putting together a simple listing of tree ordinance ideas to consider. So stayed tuned and be prepared to compare this information with your existing tree ordinance language. I am hopeful many of you will see some useful revision ideas and act to get them incorporated into your community tree ordinance/s.

Below is a short list of items to review and share that is a start to this conversation. Listing of tree ordinance/policy items that are presently required for all Illinois USFS Urban and Community Forestry related grant recipients. *Prior to grant reimbursement, a tree protection/preservation ordinance shall be approved by the organization's authority and shall meet the following requirements:*

1. Statement of purpose for the tree protection/preservation ordinance.
2. Clear definitions of terms.
3. Clear statement of the value and service of the urban forest as infrastructure.
4. Clear scope of protection, preservation, management, removals, care and pruning, selection, and planting requirements.
5. Clear specifications standards referencing the most current American National Safety Institute, National Association of Arborists, International Society of Arboriculture, National Association of Nurserymen and/or other nationally recognized organizations for the following:
   a. tree production (nursery source production standards)
   b. tree planting
   c. tree care
   d. tree pruning including frequency
   e. species restrictions, e.g. under utilities, use of invasive species
   f. tree removal

6. Skill requirements or certifications for individuals/organizations managing trees for the community.
7. Tree protection from construction impacts, and fee and penalty requirements.
8. Replacement requirements, fees, and penalties for trees damaged or killed.
9. A list of invasive or prohibited species, or a reference to a list in a tree management plan/policy.
10. Clear prohibition of tree topping, including fees and penalties.
11. Tree permit requirements, penalties, enforcement, variance and civil remedies.
12. Identified individual and/or group responsible for making decisions about trees.
13. Formation and qualifications, responsibilities, and terms for a Tree Board or other advisory group responsible for trees.
14. A preferred species list or reference to list in a tree management plan/policy
15. Restricted or illegal species list, e.g. invasive species list or reference to list in a tree management plan/policy.

(continued on page 7)

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16. Insurance requirement policies.

It is recommended but not required that the tree protection/preservation ordinance include:

1. Tree risk assessment protocol and frequency.
2. Education, outreach, and/or assistance to private property owners on tree planting, management and assessment.
3. Incentives or regulations for trees located on private property.

<u>These are additional categories/ideas to think about for inclusion into community regulations and or guidelines:</u>

- Focus on genus (not species) diversity limits of 10% or less (to protect from species specific disease and pests)
- Establishment / recognition of citizen-based tree advocacy groups, boards or committees (super good idea for gaining added citizen-based support and bridging lost program knowledge after staff retirements)
  - Volunteer based programs
  - Preserving undisturbed soil profiles in new developments (once soil profiles are damaged, they are very hard to repair)
- Preparing root zone areas for / proper topsoil depths and volumes for urban plantings
- Reference to follow most current utility tree trimming best management practices
- Public tree assessment guidelines
- New subdivision tree related requirements
  - Min # of trees along street frontage for each street side of lot
  - Natural landscape and tree plantings stormwater management
  - Min parkway widths / min planted median widths
  - Utility and tree location parameters
  - Topsoil preservation and topsoil placement / volumes for medians, parking lot islands
  - Visibility intersection triangle tree, plantings, obstruction setbacks
- Commercial and industry tree buffer requirements
- Parking lot tree planting requirements
- Heritage/special tree protection
- Citizen and Corporate cost share tree planting program
- Native forest, woodland, prairie other ecosystem habitat protection
- Ordinance regulations that set tree preservation/protection parameters for utility franchise agreements
- Canopy cover goals
  - % Native tree species goals
- Development Incentives for tree preservation and new tree planting
  - Impervious area construction/regulation to incentivize tree planting
    - Reduction in retention basin size
    - Parking lot greenspace percentage requirements for impervious surface areas
  - Greenbelt development (connecting the community via non-vehicular / greenspace ways)
    - Incentivize connection of parks or other greenspace areas
    - Bike and pedestrian trails
    - Incentives to seek opportunities with property demolitions and revitalization projects to create greenbelt links
    - Establish partnership opportunities, private sector, intergovernmental, nonprofit
      - Share community boundaries as greenspace connections
  - Commercial, Industry, Residential development/regulation
- Establish public education as a component of program purpose
- Send me more ideas at michael.brunk@illinois.gov

UPCOMING
CERTIFIED ARBORIST
WORKSHOPS/EXAMS

When you become an ISA Certified Arborist®, you are recognized by your peers and the public as a tree care professional who has attained a generally accepted level of knowledge in areas such as tree biology, diagnosis, maintenance practices, safety, and other subject and practice areas within the tree care profession as identified through periodic job task analyses.

Prerequisites for this certification:
- Minimum of three (3) years in the field or two (2) years with a two (2) or four (4) year degree in a related field

IAA offers workshops to help prepare you for the exam. Classes are taught from the Arborist Certification Study Guide and the ANSI Z-133 Safety Standards.

Certified Arborist Workshop Exam – In-Person
Exam – March 27   **EXAM DEADLINE:** March 11, 2021
Location: Dex's Tree Service, 4272 Blackburn Rd., Edwardsville, IL 62025

Click here to learn more or to register for an upcoming Certified Arborist Workshop.

UPCOMING
MUNICIPAL SPECIALIST
WORKSHOPS

When you become an ISA Certified Arborist Municipal Specialist®, you are recognized by your peers and the public as a tree care professional who has attained a specialty in municipal arboriculture with a generally accepted level of knowledge in other areas within the tree care profession, such as tree biology, diagnosis, maintenance practices, safety, as identified through periodic job task analyses. Hiring an ISA Certified Arborist Municipal Specialist® provides tree owners and government decision makers the opportunity to become better informed about proper tree care and their selection of services based on the expertise represented by your credential.

Prerequisites for this certification:
- You must be an ISA Certified Arborist
- Have a minimum of three additional years of documented and verifiable work experience in a position managing the establishment and maintenance of urban trees.

Municipal Specialist Workshops via Zoom
Tuesday's, March 9 – March 30 from 6:00pm – 8:30pm. **EXAM DEADLINE:** March 17, 2021
Exam – Tuesday, April 6 check-in 5:30pm at the Village of Lombard, 255 E. Wilson Ave., Lombard, IL

Click here to learn more or to register for the upcoming Municipal Specialist Workshop.

CEUs are available for Certified Arborists
Single session participation is also available and 2.5 CEUs can be earned for each class. Fees are $25 per session depending upon space availability. Registration in advance is required.

~~2020~~ 2021!!! A Thank You to Our Essential Utility Workers

by Geoff Watson

The turn of the new year is time to reflect and plan for the coming year. Thank you all for doing what you do and navigating the many hurdles in order to do so safely and effectively. As Utility Arborists, our jobs already have much risk to mitigate and 2020 certainly added more.

Swiss Cheese
This Swiss Cheese Model of Accident Causation was ever apparent this year. Not only did we need defenses in place to mitigate all the risks normally associated with our jobs, we needed additional defenses to deal with COVID, Stress, Depression, Heat, Crime, and Mother Nature. Without these defenses and an adequate support system, the worst is waiting to happen. If you are not familiar with the model, it's worth a few minutes of research.

~~2020~~: COVID
This past year is certain to be a year we will remember for a long time. As essential energy workers, there was no pause, no lockdown, instead a scramble to find ways to continue keeping ourselves and the public safe while much of the world came to a screeching halt. Thank you, it was not easy.

It is also worth mentioning here all the mental stressors, the impact COVID, and the effect everything else had on us, our co-workers, our families, and our communities at large. Our support systems had to change, many hugs became virtual, and we had to work harder to keep in touch and keep spirits up. Your presence in communities was a welcome sight of normalcy for many, especially during the 'lockdown'. Thank you for your stewardship.

~~2020~~: Heat, Hospitals, and Workers from Home
This summer was HOT!!! We experienced more than 2X as many days over 90 degrees than average. You made sure the public received the energy service reliability they needed. This year, reliability was even more important for so many hospitals and for many more working from home. You did this in the heat, as protests erupted around job sites, and as crime increased. Thank you - from me, from my grandma, and from many healthcare workers who depended on you whether they knew it or not.

~~2020~~: Derecho, Hurricanes, & Wildfires
One of the critical functions of a utility worker is responding and restoring power when mother nature tries her best, and she sure did. You weathered the largest derecho straight line wind event on record, and restored power in record time! Team members put their lives on hold and worked 16 hour shifts for weeks. This was also a record year for hurricanes and wildfires. Undoubtedly, you all know at least one person who picked up and left Illinois to help others in their storm response. Thank you and your families for your sacrifices during those times.

2021!!!
But enough of 2020, what does 2021 have in store? First, we have a new President!!! No, not the one you're thinking of... The Illinois Arborist Association has a new President, Beau Nagan. That's exciting not just because he is a great leader, arborist, and champion tree climber, but he was also a Utility Arborist and has experience serving the communities of Illinois.

What else can we look forward to in 2021?

- In-person conferences? Maybe, but don't hold your breath.
- More and more online learning modules? Absolutely, and we need your help to build them.
- Finding new ways to keep your mask from fogging up your safety glasses? Unfortunately.
- A vaccine? Yes. Energy workers are being considered in Phase 1b & 1c in Illinois.
- More storm work? Probably.
- More technology helping us be more connected and more efficient than ever? Yes
- The need to continue performing our job in the safest and most effective way possible? Always.

In closing, I encourage everyone to have a conversation with their peers, their leadership, and their customers and ask, "What are we going to learn from our experiences and leverage those learnings to improve our safety, our culture, our training, our preparedness, our teams, our communication, and our community?" Change is not only the new norm, but change should be welcome. For if we don't change, the world will change around us and leave us behind.

Lastly, the Illinois Arborist Association Annual Conference will happen at the end of the year in some form as it always does. How will you be a part of it? We need new ideas, new faces, and new presenters. Please consider and submit your ideas for a presentation to the IAA, it's not as scary as you think!!! Let's change the world together, starting right here in Illinois.

Digital Guide for Plant Appraisal, 10th Edition, Revised

By Council of Tree and Landscape Appraisers

TEMPORARILY DISCOUNTED UNTIL FEBRUARY 28, 2021!
Regular Non-Member Price: $90/ Regular Member Price: $75 ***Digital Purchase***

*__NOT AVAILABLE FOR DOWNLOAD__

The *Digital Guide for Plant Appraisal, 10th Edition, Revised*, identical to the print version, is now available online. This text offers the most informative and comprehensive alignment of current knowledge of the approaches, processes, and methods of plant valuation.

This edition represents a systematic evolution of plant appraisal that integrates new research into a deeper understanding of the strengths and weaknesses of the available methods. Included in this edition are detailed discussions of newly streamlined core concepts and terminology, a review of the organization and context of appraisal reports, and an updated emphasis on appraiser awareness of the environmental and ecological benefits plants provide. Also new to this edition are appendices and a glossary. (Revised October 2020, digital, 170 pp)

For the convenience of users of the Guide, ISA has also made all the forms in the Guide available as fillable PDFs, which are located below in Related Files.

The *Digital Guide for Plant Appraisal, 10th Edition, Revised* corresponds with the third printing of the 10th Edition. The only changes since the *Second Printing are to two forms: Repair Method: Direct Cost Technique and Functional Replacement Method: Trunk Formula Technique. In all other respects, the 10th Edition, Revised is identical to the 10th Edition, Second Printing. If you already own the Second Printing, we recommend you simply download the two updated forms below. Details of the changes to these forms are outlined in the Corrigenda, also available below.*

Also available in ***Print.***

“Illinois Trees” Newsletter

presented by the
Illinois Arborist Association
www.illinoisarborist.org

Illinois Trees is the quarterly newsletter distributed exclusively to members of the Illinois Arborist Association – one of the International Society of Arboriculture’s (ISA) largest single state chapters. According to preliminary results from the 2002 IAA Membership Survey, total *Illinois Trees* readership *per issue* exceeds 2,000 professionals.

Readership includes: Arborists, Urban Foresters, Tree Care Companies and Commercial Arborists, Park Managers, Community Foresters, Utility Foresters, Educators, Grounds Maintenance Personnel, Municipal, County and State Urban Forestry Personnel, Recreation Site Managers or Owners, Nursery and Landscape Professionals, Educators, and Natural Resource Managers.

QUESTIONS & TO RESERVE AD SPACE – Email April Toney at april@illinoisarborist.org to reserve your ad space. Email message must include company name, ad size, invoice contact and billing address.

Abiotic Stresses & Their Effect on Woody Plants

by Fredric Miller, PhD

Introduction: Dramatic changes in weather patterns are beginning to negatively affect the physiology and overall health of woody plants. Abiotic stresses, like drought, flooding, and temperature stress, are considered major factors affecting plant health. The science of plant physiology is directly related to a plant's ability to grow, fight off secondary pests and diseases, and acclimate to changing climatic conditions. If plants are not able to adjust and/or acclimate then they begin to decline and may eventually die. In many cases, these physiological changes or alterations may not always be obvious to the naked eye and may begin appear many years after the initial stress or stressors have occurred. Unlike a medical doctor, we are unable to interview our plants, so understanding the impact abiotic facts have on their health is an important step in advocating for them. With a better understanding of these concepts, hopefully we can anticipate, recognize, and mitigate plants problems in the early stages, which will allow us take remedial actions before problems become too serious.

In Part I of this article, I will elaborate on an earlier presentation I gave at the 2020 IAA Virtual Conference and discuss the effects of drought, flooding, and temperature on soil properties and how soils affect woody plant physiology with an emphasis on pest and pathogen resistance. Where possible, I will provide practical management tactics to help mitigate the impact of abiotic facts on woody plants. To do all this, I will provide a review of soils and how they interact with plant physiology, especially under stress.

In a subsequent article (Part II), I will discuss how stress facilitates infection by pathogens and colonization by arthropod pests.

Importance of water for living organisms. Water is essential for all life, including plants. For example, leaves consist of 55 to 85% water along with other succulent plant parts. Non-living woody tissues may consist of 30-60% water. The hydrodynamic system, within the plant, is not static, and includes the absorption of soil water by plant roots via osmosis, its translocation throughout the plant via vessels (angiosperms) or tracheids (gymnosperms), and loss to the environment by transpiration (Brady and Weil, 2010)..

Soil Water Potential (SWP or "Energy"). The hydrodynamic system is partially possible due to the inherent energy in water (**water potential**) and two very important properties of water: **adhesion** and **cohesion**. Water potential is another way of describing the energy of water, just like you have heard people say "they have a lot of potential" meaning they have the ability to do perform work. Because of water's ability "to do work", soil water always moves from areas of high energy (potential) to areas of low energy by a passive (no energy) process called osmosis (Figure 1).

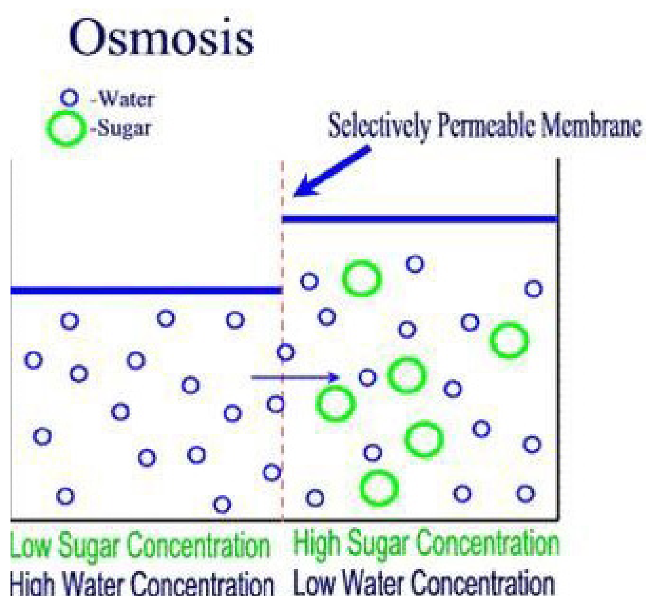

Figure 1: Osmosis

For example, water will move from areas of moist soil to dry soil and enter plant roots. The movement in the soil and the plant is due to differences in SWP and this difference

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will determine the direction and rate of water movement (Note: the more negative the SWP value, the less energy) (Figure 2).

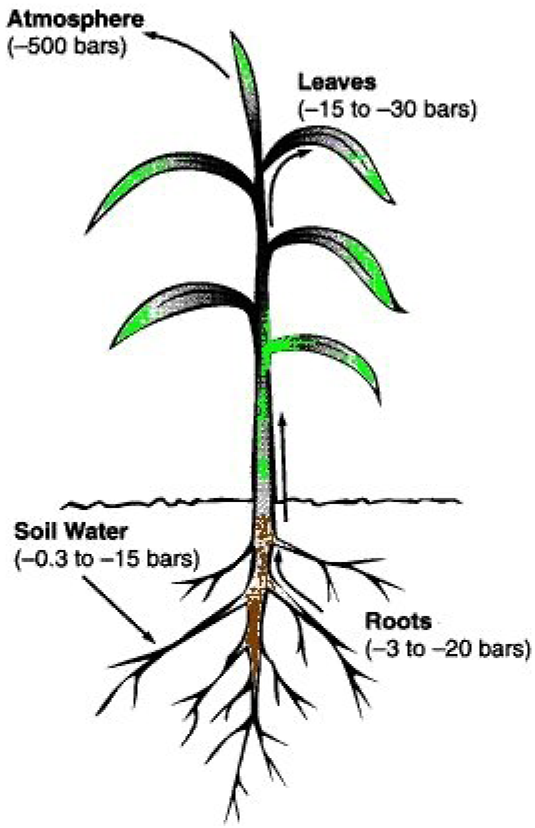

Figure 2: Soil Water Potential (SWP) and Water Movement from the Soil Up Through the Plant
Note: The more negative the value or farther from zero, the less energy of the water.

The reverse is also true. During droughts or the application of fertilizer, when the soil is dry, water will move out of the root (higher SWP) to the adjoining soil (lower SWP) resulting in root desiccation, drying, and death. SWP also plays a role in transpiration. As water moves into the leaves, the direction and rate of water loss from the plant will be a function of the difference in water potential between the water inside the leaf's interior and the surrounding atmosphere. A 50 foot tall silver maple (Acer saccharinum) growing in full sun can transpire 59 gallons of water per hour and a large oak (Quercus sp.) tree can lose 40,000 gallons of water per year. Transpiration will be at its maximum efficiency on warm to hot sunny days with low relative humidity (RH), a light breeze, and adequate available soil water. As soon as the plant exhausts the available soil moisture, problems begin. This is why prolonged dry spells (i.e. 2020 summer), and the droughts of 1988 and 2012 are very damaging to plants. In contrast, during when there is abundance of soil moisture (i.e. springs of 2018-2020), the leaf cells will approach an isotonic ("balance") condition on a day that is cloudy with very high RH (i.e. raining or fog) because the water potential in the atmosphere is similar to water potential within the leaves (Brady and Weil, 2010).

Osmosis and its importance in water movement. There are three types of osmotic solutions, **isotonic** , **hypertonic**, and **hypotonic** (Figure 3).

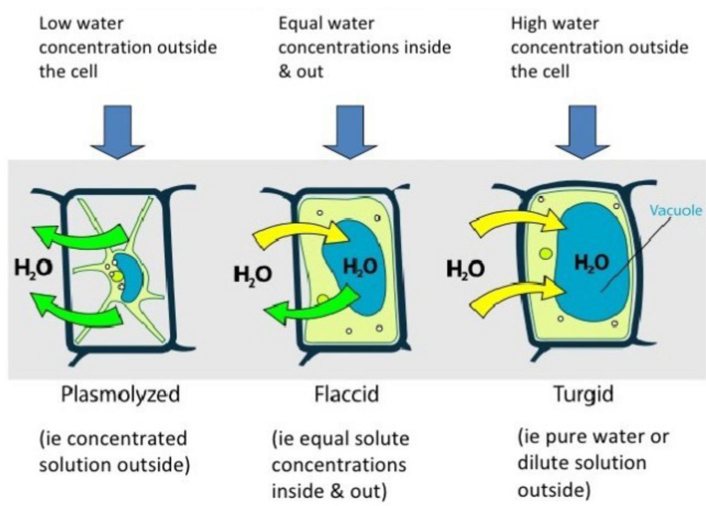

Figure 3: Types of Osmosis in Plant Cells

In an isotonic ("iso" means equal) solution, there is a balance of concentrations on both sides of the semi-permeable root membrane (water gets through, but not other things). In other words, the concentration of water molecules on the root side of the membrane is equal to the concentration of water molecules on the soil side of the root membrane. A **hypertonic** solution occurs when there are fewer water molecules

(continued on page 14)

are outside of the cell than inside. Adding a fertilizer, which are mainly salts, to dry soil will desiccate and even kill fine roots because there is less water in the soil relative to the root. A **hypotonic** solution is just the opposite, and occurs when there are fewer water molecules inside the root relative to the adjoining soil, and water will tend to move into the root. Here the plant may be “flooded” with too much water. Plants, like all living organisms, are constantly trying to balance water relations by osmotic regulation, not too much and not too little, but just right. Balance is the key! (Brady and Weil, 2010)

Not only is osmosis important to the plant in the uptake of water from the soil, but it also plays an important function within the plant. Osmosis affects the transport of nutrients from the soil into the roots and throughout the plant. **Remember, plant nutrients must in solution (“liquid) in order to be taken up by plants.** Osmosis also helps in the release of metabolic waste products from the cells and the plant. At the cellular level, osmosis helps stabilize the balance between intercellular (between cells) water and and helps maintain cell **turgidity (deplasmolysis)** which allows for leaves to be fully expanded and for herbaceous plants to stand upright. In transpiration, osmosis helps plants maintain their water content despite constant water loss. Plants only store about 5% of the water they take up from the soil with the rest being used for metabolic functions (i.e. photosynthesis) or lost via transpiration. At the intracellular (within cells) level, osmosis helps control cell to cell diffusion of water, and during drought it can help protect the plant against loss of plant turgidity **(plasmolysis)** resulting in leaf droop, wilting, scorch, or more serious drought injury. In well-watered plants or plants with access to adequate soil moisture, the **guard cells**, which surround the **stomatal openings** in leaves, are filled with water, swell up, and open to allow for the entry of carbon dioxide (CO_2) from the atmosphere, and the escape of water vapor due to transpiration, and the escape of oxygen (O_2) as a byproduct of photosynthesis (Brady and Weil, 2010).

Water is a unique molecule. Water (H_2O) is **polar**, or has **polarity**, and demonstrates properties of adhesion and cohesion (Figures 4 and 5).

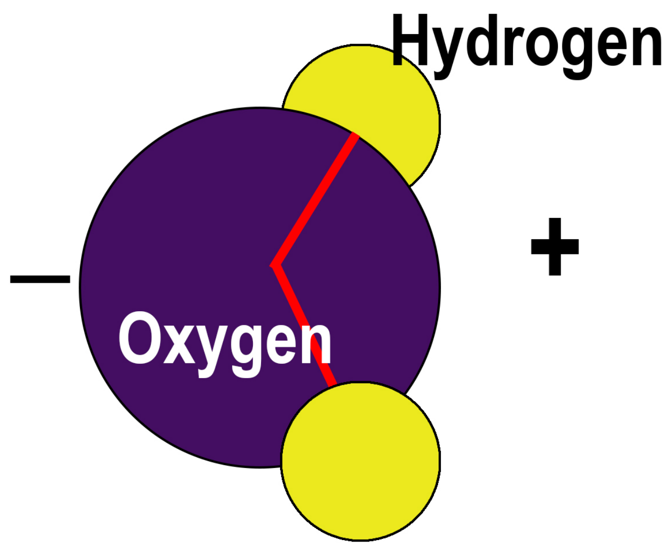

Figure 4: The Water Molecule

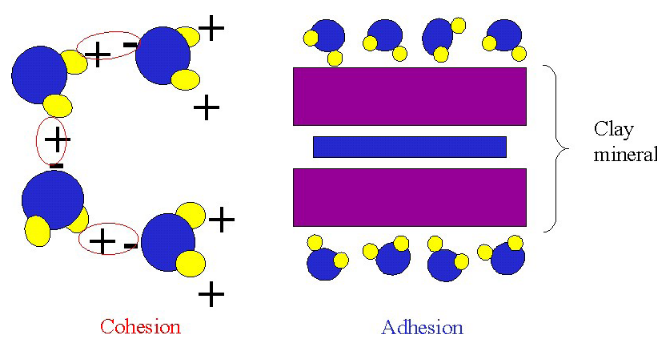

Figure 5: Cohesion and Adhesion of Water

Polarity means that the H_2O molecule has a positive (+) hydrogen (H) end and a negative (-) oxygen (O) end. As a result, water molecules are able to adhere to the negatively charged surfaces of clay particles and organic matter **(colloids)**. This is why clay soils are slow to drain and stay saturated for extended periods of time. Silt will retain water (a good thing) but not as tightly as clay. Sandy soils, which do not have a surface charge, do not hold water at all, drain

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very quickly, and can be droughty. In this way, soil texture (proportion of sand, silt, clay) is important (Figure 6).

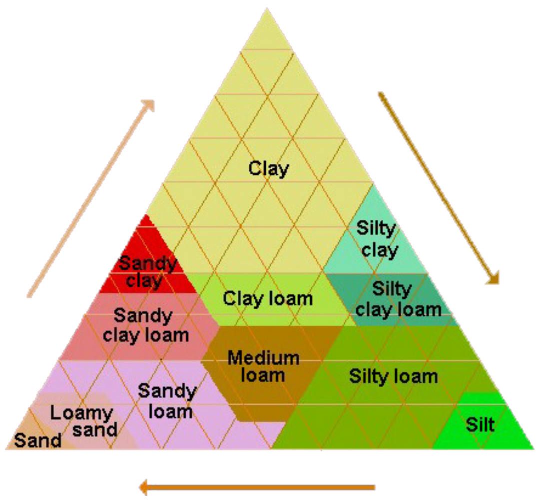

Figure 6: Soil Texture Triangle

The ideal should have equal proportions of sand, silt, and clay **(i.e. loam)** in order to maximize the benefits (water retention, drainage, fertility) and minimize the negatives (water retention, quick drying) of each of the soil mineral components. The other colloid, organic matter (OM) is very beneficial and helps hold water in the soil making it available for plants, and is an important in water storage particularly for sandy or very well-drained soils (Brady and Weil, 2010).

Additionally, adhesion allows water molecules to "adhere" to soil particles and move up the soil profile against the forces of gravity through a process known as **capillarity** or **capillary action** (Figure 7).

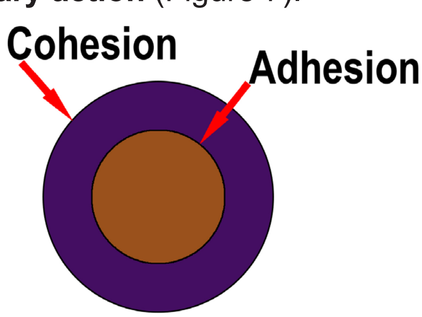

Figure 7: Adhesion & Cohesion of Water to a Soil Particle

Think about a wick in a kerosene lamp. The fuel (kerosene) moves up the wick, burns off to produce heat and light, and then more kerosene moves up the wick to replace it. The same thing happens in soils. As the upper layers of the soil profile dry out, water moves up via capillary action to replace the lost water (Figures 8A and 8B). This upward movement of water will occur as long as there is adequate soil moisture in the lower soil profiles or if there is not a compacted or impervious layer restricting upward water movement.

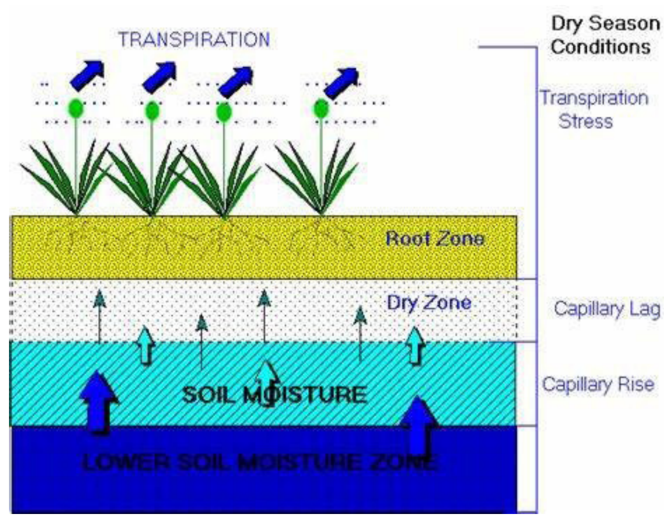

Figure *8A: Water Movement in Soil of Capillarity

Figure 8B shows that capillary water will move up at a faster rate in a course textured soil (sand), but not rise as high in the tube, compared to a fine-textured (clay) soil where the

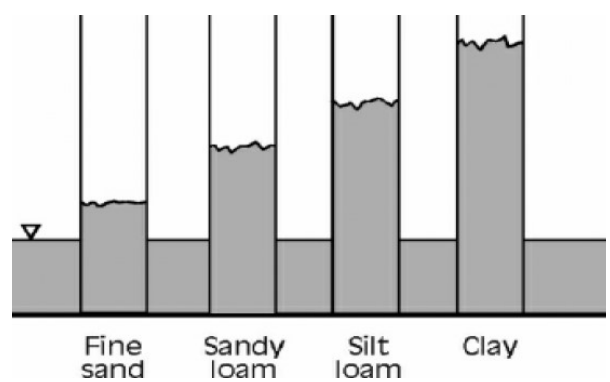

Figure *8B: Capillary Action of Water as a Function of Soil Texture *(Note: Capillary water will rise higer in fine-textured clay soil compared to a course-textured sand soil)*

(continued on page 16)

soil rises more slowly, but will reach a higher level in the tube. Soil water will also move horizontally and commonly occurs in urban soils when the very thin layer (2-3 inches) of top soil becomes saturated forcing water to move laterally because the compacted layers below do not allow downward movement of water. This can lead to saturated soils and flooding in low lying areas (Brady and Weil, 2010).

The third unique property of water, cohesion, means that water molecules are attracted to each other because the negative end (oxygen) is "attracted" to the positive end (hydrogen) of an adjoining molecule or, as the old saying goes "opposite charges attract". This allows water to form water columns (chains) main up of individual water molecules, and facilitates the translocation of water from the roots, up through the xylem, and out through the leaves via transpiration (Figures 9A and 9B) (Brady and Weil, 2010).

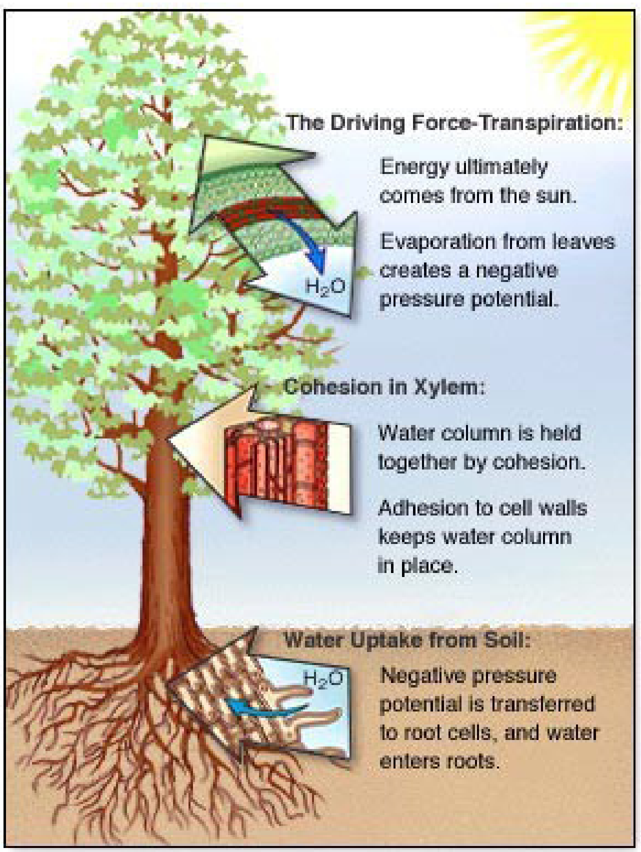

Figure 9A: Transpiration in Trees

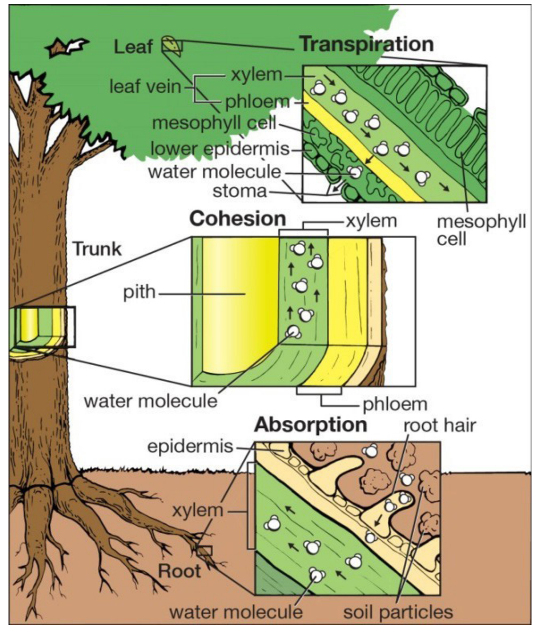

Figure 9B: Transpiration in Trees

The rhizosphere, root respiration and photosynthesis. The rhizosphere is the area where the soil is in immediate proximity (1-2 mm.) to the roots and where much of the physical, chemical, and biological soil processes take place. Root respiration is an essential physiological function all plants have to perform in order to be healthy. **Respiration is complementary to photosynthesis meaning you cannot have one without the other.** Simply put, respiration is a metabolic process by which plants (and all living organisms) convert "food" into energy (Figure 10).

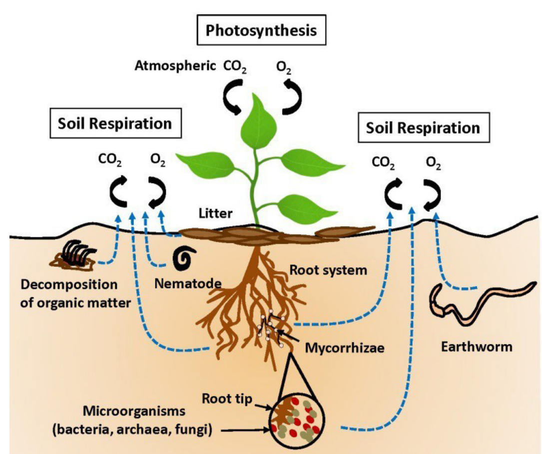

Figure 10: Soil Respiration and Photosynthesis

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Abiotic Stresses & Their Effect on Woody Plants

In photosynthesis, plants make their "food" by combining water and carbon dioxide, in the presence of sunlight, into sugars and carbohydrates with oxygen as a byproduct (Figure 11).

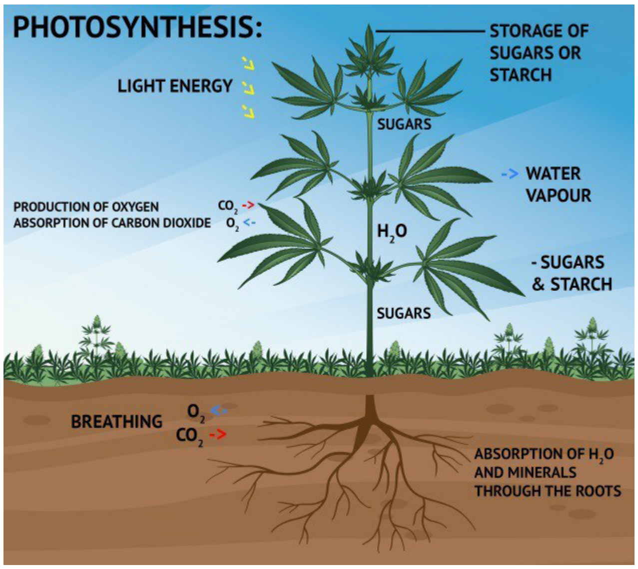

Figure 11: Photosynthesis

As the "food" is chemically broken down during respiration, energy is released and is utilized by the plant for growth, reproduction, maintenance, defense against abiotic and biotic factors, production of allelochemicals, and wound healing. If the plant cannot make "food", then there is no fuel for respiration and the plant cannot function properly. For plant health care (PHC) practitioners, it is very important to remember that **respiration has to occur in the presence of oxygen or an aerobic environment.** If soils are waterlogged, there is no room for soil air and plant roots enter into an **anaerobic condition (oxygen depleted)**, which results in root rot and death. This is why soil water and root relations are so important (Brady and Weil, 2010; Watson, et al., 2014a and references therein).

Roots, flooding, and tree health. For roots to function optimally there needs to be an equal exchange of oxygen diffusing into the soil and carbon dioxide diffusing out of the soil (Figure 12).

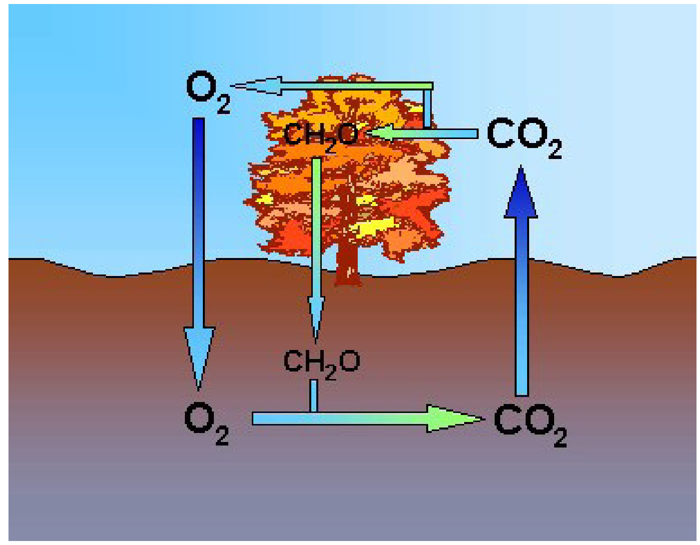

Figure 12: Oxygen & Carbon Dioxide Gas Exchange in the Soil

Most tree species require about 10-12% soil oxygen and once carbon dioxide levels approach 0.6%, root damage may occur (Watson et al., 2014). If soils are properly drained with good aeration, oxygen and carbon dioxide levels may be approach atmospheric levels near the soil surface, but will rapidly decrease in the first 30 cm (12 in.) of the soil profile (Yelenosky, 1963). Weather can greatly affect oxygen levels in the soil. In previous springs (2018-2020), record breaking rainfall, flooding, and saturated soils can lead to fine root death. In general, roots are usually more sensitive to flooding than shoots, but death of shoots may occur later. Areas with high water tables (within 50 cm (20 in.) of the surface) may also inhibit root growth (Callebaut et al., 1982).

The effects of saturated soils and flooding will vary, but in general, it contributes to inhibition of gas exchange (buildup of **ethylene**, methane, carbon dioxide), reduction in photosynthesis and respiration due to hypoxia (reduced oxygen), and energy imbalances. Insoluble ethylene (plant hormone associated

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with fruit ripening and root rot) and other chemicals (i.e. methane, hydrogen sulfide) can build up in the soil giving off a "rotten-egg or sewer" odor and causing a reduction in root growth, root rot, decay, and even death. It can also build up in cell membranes affecting gene expression for shoot elongation, leaf hyponasty, and adventious root formation (Lamers, et al., 2020; Watson et al., 2014a and references therein).

Flooding and saturated soils can also impact the above ground portions of the plant by affecting respiration, photosynthesis, gas exchange, cellular osmotic regulation, and invasion by water-borne pathogens. Some species, such as willow (Salix spp.), alder (Alnus spp.), and birch (Betulus spp.) can withstand chronic flooding due the presence of oxygen-transporting root tissue called aerenchyma. In these plants, up to 60% of the root volume may be dedicated to oxygen storage for diffusion from the shoot (Drew, 1997; Armstrong and Drew, 2002) (Figure 13).

Figure 13: Flood Adapted Tree Species

Additonally, flood-adapted bottomland species, such as silver maple (i.e. Acer saccharinum), green ash (Fraxinus pennsylvanica), eastern cottonwood (Populus deltoides), sycamore (Platanus occidentalis), bald-cypress (Taxodium distchum), and hackberry (Celtis occidentalis) did not show serious effects from the prolonged 1993 Mississippi and Illinois River floods (Miller, F. unpublished data). However, other plants may be more sensitive to saturated soils and flooding (White, 1973, Bell and Johnson, 1974; Whitlow and Harris, 1979) and may die within just a few days or hours or may persevere for months (Watson, et al., 2014). Whitlow and Harris, 1979) found that red maple (Acer rubrum), sugarberry (Celtis laevigata), deciduous holly (Ilex decidua), sweetgum (Liquidambar styraeflua), shingle oak (Quercus imbricaria), pin oak (Q. palustris), bur oak (Q. macrocarpa), and honeylocust (Gleditsia triacanthos) are relatively tolerant or able to survive deep flooding for one growing season. However, trees, such as bitternut hickory (Carya cordiformis), shellbark hickory (C. laciniosa), shagbark hickory (C. ovata), and mockernut hickory (C. tomentosa), redbud, (Cercis canadensis), flowering dogwood (Cornus florida), Kentucky coffeetree (Gymnocladrus dioicus), black walnut (Juglans nigra), red mulberry (Morus rubra), shortleaf (Pinus echinata) and loblolly pines (P. taeda), Colorado blue spruce (Picea pungens), plum (Prunus americana), black cherry (P. serotina), sugar maple (Acer saccharum), and many of the oaks including white (Q. alba), red (Q. rubra), shumard (Q. shumardii), and black oak (Q. velutina) are very sensitive to saturated soils, and intolerant of flooding; unable to survive more than a few days of flooding during the growing season (Whitlow and Harris, 1979). Long-term field studies, by the author, following the 1993 Mississippi and Illinois flood events, revealed additional, unreported flood intolerant species of Amur maple (Acer ginnala), cucumbertree magnolia (Magnolia acuminata), Ohio buckeye (Aesculus glabra), Turkish filbert or hazel (Corylus colurna), pear (Pyrus spp.), eastern white pine (P. strobus), Scots pine (P. sylvestris), eastern red cedar (Juniperus virginiana), Catalpa (Catalpa spp.), Russian-olive (Elaeagnus angustifolia), 'Greenspire'

(continued on page 19)

and 'Little Leaf' linden (Tilia cordata), American linden (T. americana), and Zelkova (Zelkova spp.) had 100% mortality within just days or weeks of flooding (Miller F. unpublished data). The season of the year the flooding occurs is also an important factor in post-flooding recovery. Saturated soils in spring and early summer are more harmful than during the dormant season due to the high oxygen demand from plants in spring (Heinicke, 1932). The temperatures of the water will also determine how much available oxygen it can hold; cold or cooler water can hold more oxygen than warmer water and can help mitigate anaerobic conditions. This is why soil drainage and chronic flooding is such an important consideration when designing and selecting landscape plants, and for trees growing in existing landscape and parkways.

Soil moisture, field capacity, and drought. In recent years, the springs of 2018, 2019, 2020) have been very wet followed by hot dry summers, even extending into fall and early winter (i.e. 2020). Just like flooding, too much of a good thing can be detrimental to plants, and in this case, it is soil air. A similar problem occurred during the 1988 and 2012 droughts resulting in dry soils and very little available water. When soil conditions reach this point, the plant has to start making some really tough choices. Initially, the plant will attempt to conserve water by closing stomates and reducing photosynthetic activity. On hot, dry days, the leaves with large surface areas (i.e. catalpa, maple, sycamore) may droop or appear wilted by late afternoon or early evening because the tree cannot keep up with water loss due to transpiration. Overnight, the tree will attempt to replenish the lost water. Additionally, trees with dense canopies will begin to shed excess foliage to try to balance water relations.
As available soil water becomes less and less, a water deficit will begin leading to a ripple effect impacting both photosynthesis and plant growth. Photosynthesis is usually more sensitive to drought stress than growth (Figure 14).

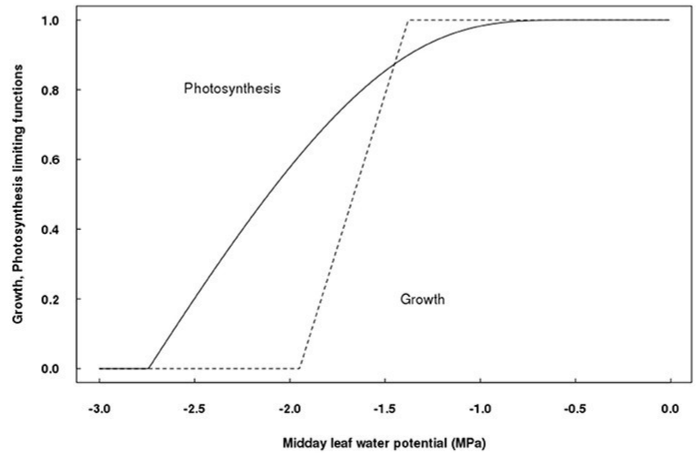

Figure 14: Effect of Water Stress on Photosynthesis & Plant Growth *(Note: The more negative the leaf water potential (farther from zero), the less water inside the leaf)*

A reduction in plant growth is the most common effect of lack of water due to a reduction in cell division, and enlargement of, and differentiation in the meristematic tissues (Barlow et al., 1980). As much as a 90% of the annual variation of xylem increment in arid forest trees and up to 80% in humid regions may be attributed to water deficits (Zahner, 1968).

Leaf characteristics may also be impacted, including leaf size, thickness, waxiness, and trichome density and size during and after droughts (Mattson and Hack, 1987 and references therein). Under severe water deficits and drought stress, chlorophyll production and nutrient uptake is inhibited, which reduces growth and results in leaf yellow or chlorosis (Figure 15).

Figure 15: Chlorosis in Red Maple

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Abiotic Stresses & Their Effect on Woody Plants

Plant temperature increases due to a reduction in transpirational cooling and leaf and whole plant temperature differentials between well-watered plants and water-stressed plants is commonly 2-4C and up to 10-15C (Drake, 1976; Bucks et al., 1984). As water stress becomes more severe, major changes occur in plant metabolism, namely plant physiology and metabolic reactions. For example, water vapor loss from the leaves is regulated by stomatal behavior to help reduce transpiration, restore turgor and growth, and protect leaf organelles sensitive to desiccation (Mansfield and Davies, 1981). Stomatal closure reduces photosynthesis by inhibiting CO2 conductance, and CO2 assimilation. Since the degree of photosynthetic ability of a plant is a function of its total leaf area and photosynthesis in the leaves, the plant's ability to recover from a drought is a function of water deficit duration, degree of leaf shedding, and injury to the stomata, chloroplasts, and roots (Kramer and Kozlowski, 1979). Respiration also suffers under severe moisture deficits and inhibits photosynthesis. Due to the reduction in respiration, more of the carbon budget ("food" produced photosynthesis) is used for maintenance instead of growth resulting in a varied response in carbohydrate reserves (Figures 16 and 17).

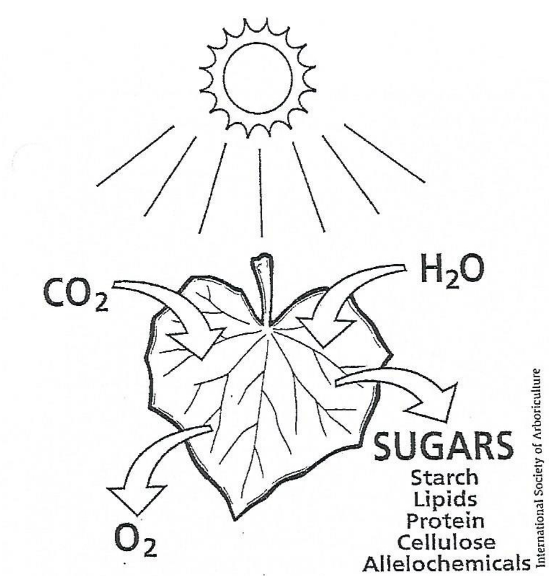

Figure 16: Energy Budget in Plants

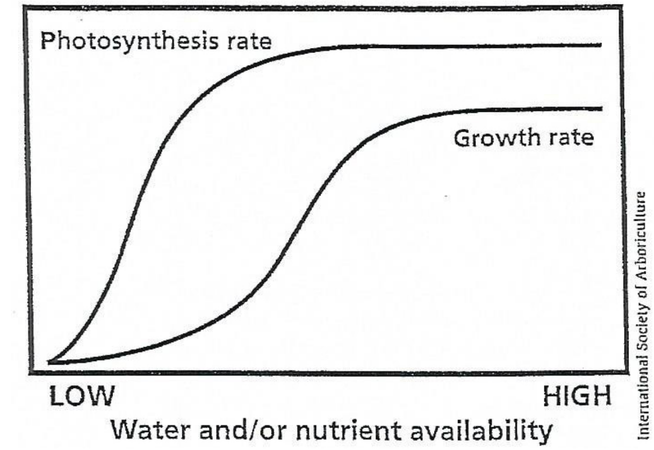

Figure 17: Relationship between Photosynthesis & Growth and Water Stress

For example, changes in the carbohydrate content (i.e. sucrose and sugar) decreases in the root bark of sugar maple (A. saccharum), the stem phloem in yellow poplar (Liriodendron tulipfera) and the roots root bark of northern red oak (Quercus rubra) and black oak (Q. velutina),respectively (Roberts, 1963; Parker, 1979; Wargo, 1984),. In contrast, sugars (i.e. glucose, fructose, sucrose) and starch levels increased in the root sapwood of sugar maple, stem phloem of yellow poplar, and leaves of Austrian pine (Pinus sylvestris) (Otto, 1970). Sugar and starch levels varied (increased or decreased) in the leaves bark and wood of common apple (Malus pumila) and inner bark of loblolly pine (P. taeda), and leaves and bark of kermes oak (Q. coccifera (Magness et al., 1932; Hodges and Lorio, 1969; Parker (1979). These reserves are what the plant will use for wound healing and for growth the following year.

If dry conditions continue, then the plant will begin "cannibalizing" itself and begin using intercellular (between cells) water, and then eventually intracellular (within cells) water. Along with this loss of cellular water, turgor pressure will decrease and the leaves will begin to wilt and eventually dry out and die. Leaf scorch, and dieback and death of small twigs and branches usually follows. In severe and/or prolonged drought (i.e. 1988 and 2012), tree death may occur for young newly

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transplanted trees with reduced root systems and trees that are already compromised. In order to defend against intercellular and intracellular water loss, the plant will attempt to make osmotic adjustments (lower their osmotic potential) by accumulating solutes such as carbohydrates, sugar alcohols, amino acids, organic acids, and inorganic ions. By lowering their osmotic potential (less energy relative to pure water energy), the plant can reduce water loss from the surrounding dry soil environment, but also may be able to take up water from the drying soil (Cram, 1976; Morgan, 1984; Wyn Jones, 1984). Unfortunately, osmotic adjustment is not as well-understood in woody plants and shrubs as in herbaceous plants (Tyree and Jarvis, 1982).

Drought is considered a major pre-disposing factor that weakens the tree and allows for secondary pathogens and insects to invade the tree. This has been very well documented with conifers and bark beetle infestations in the western United States and has led to heavy tree mortality from outbreaks of mountain pine (Dendroctonus ponderosae) and western pine bark beetle (D. brevicomis). Contributing factors have been a decade of prolonged drought or below normal rainfall, and milder winter temperatures, which results in a drop in tree resin pressure and higher overwintering bark beetle survival. Once tree resin pressure drops below a critical threshold, the tree is no longer able to “pitch” the beetles out and the bark beetles can gain a foothold (Lorio and Hodges,1968; Hodges and Lorio, 1975).

Soil temperature and tree stress. Soil temperature also plays a major role in a plants’ ability to develop, grow, and to respond to extreme short-term temperature fluctuations (i.e. 2019 polar vortex). Temperature affects many aspects of plant life including root and shoot growth, seed yield, flowering, changes in the physical properties of molecules, and a variety of metabolic processes (Lamers, et al., 2020). These plant processes are important in helping the plant repair wounds, cold damage from frost cracks, and assist in cold hardiness. Soil temperature data taken from the University of Missouri agriculture experiment station, during the 2012 drought, revealed 90F+ soil temperatures in the top 1 to 3 inches of the soil profile. These temperatures can be very detrimental to plant roots and important microbes causing desiccation and death affecting the tree’s ability to take up moisture and affecting microbial-driven metabolic functions such as nitrogen fixation. Just like saturated soils and flooding, drought can be just as detrimental to root systems and require major expenditures of energy (“food”) to repair lost root system infrastructure. Depending on the extent of the damage and duration of the harsh conditions, it may take months or years for trees to recover.

It is not just summer temperatures, but cold temperatures can also affect plant health. In temperate climates, trees enter a dormant phase by hardening off and preparing for winter. This hardening off process protects plants from cold winter temperatures. However, we appear to be experiencing much milder falls and winters with an occasional “Arctic outbreak” of just a few days or weeks of severe cold temperatures. For trees that have not totally hardened off, this can cause considerable damage to plant cells and tissues; both roots and above-ground portions of the plant can be impacted. This was quite evident following the “1991 Arctic outbreak”, where a mild fall, with lots of precipitation, was followed by a severe cold spell in late October with January temperatures at Halloween. Plant roots were sitting in water which water froze into ice, and the following spring, many trees and shrubs flowered, leafed out, and promptly died. Their root systems had been killed or severely damaged the previous fall, and they had just enough energy left to flower and leaf

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out (F. Miller personal observations).

Physiological Drought. Drought is not just a growing season issue. A similar condition can occur during the winter months called **physiological drought**. This condition is most common on broad-leaved evergreens (i.e. boxwood, rhodendron, azalea, holly) and conifers, particularly pines. Both broad-leaved evergreens and conifers will transpire (lose water) during the winter. Like in summer droughts, the plants cannot access water. Winters with very deep frost and very little snow cover contribute to this problem; the soil water is frozen and is not available for uptake. On those "relatively warm" days or spring thaws, the trees will transpire, but cannot replace lost water. Trees growing along roadways or near driveways exposed to road salt spray or where de-icing salts have been used will also suffer. Physiological drought will usually occur on the same side as prevailing winter winds (northwest and west) and/or downwind of salt spray. All plants will suffer from the effects of de-icing salts due to its effect on soil structure and drying of roots with symptoms showing in the spring and early summer.

Watering, field capacity and the permanent wilting point. Previously we discussed soil water deficits (drought) and excess soil moisture (saturated soils and flooding). We cannot control the weather or the amount of rainfall that we receive, but we can work at creating soil conditions that will help mitigate extremes in soil moisture. This leads to the concept of **gravitational water (GW), field capacity (FC)** and the **permanent wilting point (PWP)** (Figure 18).

As soon as a soil becomes saturated, gravity begins to pull excess water down through the soil profile, creating what is called **gravitational water**. As soil water moves down through the soil profile due to gravity over time (i.e. hours, days, weeks,

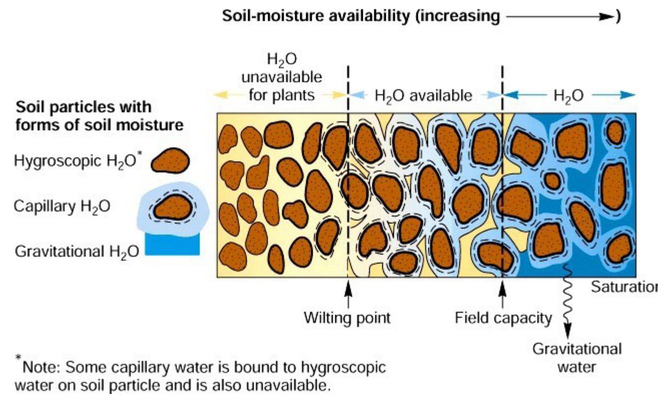

Figure 18: Soil Water Saturation, Gravitational Water (GV), Field Capacity (FC), and Permanent Wilting Point (PWP)

months), the soil water component will reach equilibrium and gravity is no long able to remove water. **This is known as field capacity (FC) and represents the maximum amount of available water for plants.** At FC, most of the available water to plant roots is held in micro-pores, while air, soil organisms, and plant roots are found in the macro-pores. "The driving concepts behind watering decisions are field capacity (FC) and the permanent wilting point (PWP)". As the plant removes soil water from the micro-pores via transpiration, the film of water around the soil particles gets thinner and thinner and the water molecules are held more tightly due to adhesion. Think of peeling an onion or head of lettuce. The outer layers are fairly easy to remove, but as you get closer to the center of the core of the onion/lettuce, it gets much harder. Once the water film on a given soil particle gets "thin" enough, the plant is no longer able to extract water from the soil. If soil water lost to transpiration is not replaced by irrigation or rainfall, a soil water deficit begins, and the plant begins to approach its **permanent wilting point (PWP)**. Depending on the length of the soil water deficit, some plants may recover when soil water is replenished. If extreme conditions last too long, then the plant will not recover and begin the downward spiral of dieback, decline, and even death (Brady and Weil, 2010). This was observed very clearly back in the late 1980's and early

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1990's during and following the 1988 drought with white-barked birch and the bronze birch borer, pines and bark beetles.

Soil compaction and bulk density. Two other physical soil properties that impact the roots and ultimate health of plants are soil compaction and bulk density. Soil compaction can result from adding excess fill on top of root zones, planting trees too deep or settling after planting, construction activity around trees, human foot traffic, rainfall on bare soil, or other causes. (Brady and Weil, 2010; The Morton Arboretum, 2008).

Soil compaction affects trees by interfering with water infiltration and storage, aeration, root growth into adjoining soil, and soil porosity (pore space). **Soil porosity** is important for storage of water and air, habitat for soil organisms, and root growth. Compaction decreases soil porosity. **Bulk density (BD)** is a common measure of soil porosity and is related to soil structure (arrangement of soil particles) and texture (proportion of sand, silt, clay) (Brady and Weil, 2010). For example, on sandy and sandy-loam soils, a BD >1.6g/cm3 will begin to inhibit root growth while a BD >1.4gm/cm3 on a clay soil will inhibit root growth (Table 1).

TEXTURE	IDEAL BD (gm/cm3)	MAY EFFECT ROOT GROWTH	RESTRICTS ROOT GROWTH
Sands and loamy sands	<1.60	1.69	>1.80
Sandy loam, loams	<1.40	1.63	>1.80
Sandy clay loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.40	1.55	>1.65
Sandy clays, silty clays	<1.10	1.49	>1.58
Clays	<1.10	1.39	1.47

Table 1: Bulk Density (BD) as a Function of Soil Texture

Most urban soils may have BDs as high as 1.6 g/cm3 up to 2.6g/cm3. Fine textured soils (i.e. clay) are slower to recover than course textured soils (i.e. sand) (Brady and Weil, 2010). Soil compaction can occur very early in the construction process with 50% of the increase in soil BD occurring on fine to medium-textured soils in the first two passes of vehicular traffic (Brais and Camire, 1998). Soil compaction can also increase in areas with high pedestrian traffic around ball fields, picnic areas, campgrounds, and areas where large crowds gather for various venues (i.e. concerts). Tree species such as English oak (Q. robur) are more tolerate of compacted soils compared to Norway spruce (Picea abies) and little-leaf linden (Tilia cordata). Root distribution is also affected by soil compaction. Roots typically take the path of least resistance and try to make use of old root and earthworm channels, and soil cracks. Some roots may grow towards the surface and into mulch making them much more vulnerable to drying and desiccation during dry periods or drought.

Roots, soil properties, and nutrient uptake and availability. The soil is an important source of nutrients for plants. There are 17 essential (i.e. required) elements required for plant growth; carbon, hydrogen, oxygen, followed by six macronutrients (N, P, K, Ca, Mg, S) and eight micronutrients (copper, iron, manganese, boron, chlorine, zinc, molybedenum, and nickel). The only difference between macro and micro-nutrients is the amount needed by the plant (Brady and Weil, 2010).

One of the main soil factors affecting nutrient availability is pH. pH is a measure of alkalinity (basic) or acidity based on the relative concentration of either H+ (acidity) or OH- (alkalinity) in the soil solution (Brady and Weil, 2010). If the H+ is high, then the soil will be more acidic and if OH- concentration is high, the soil will be more alkaline. Nutrient availability and uptake of plant nutrients is optimized at a pH of 6.0 to 6.5 (Brady and Weil, 2010) (Figure 19).

An **available nutrient** is that portion of any element or compound in the soil that

(continued on page 24)

can be readily absorbed by plant roots and assimilated by growing plants (Brady and Weil, 2010). Nutrient deficiency in plants occurs when there is a lack of an essential nutrient either because it is lacking in the soil and/or the plant cannot acquire and absorb the nutrient (Brady and Weil, 2010). In most cases, our soils have adequate amounts of both macro and micronutrients, but availability can be a problem. This is common with Fe, Mn, and Zn resulting in interveinal chlorosis (green leaf veins, but yellow inter-veinal leaf tissue). Fe/Mn/Zn chlorosis is common on our high-alkaline, fine-textured (i.e. clay) and calcareous soils (pH>7) because these nutrient are pH sensitive and less available (Figure 19)

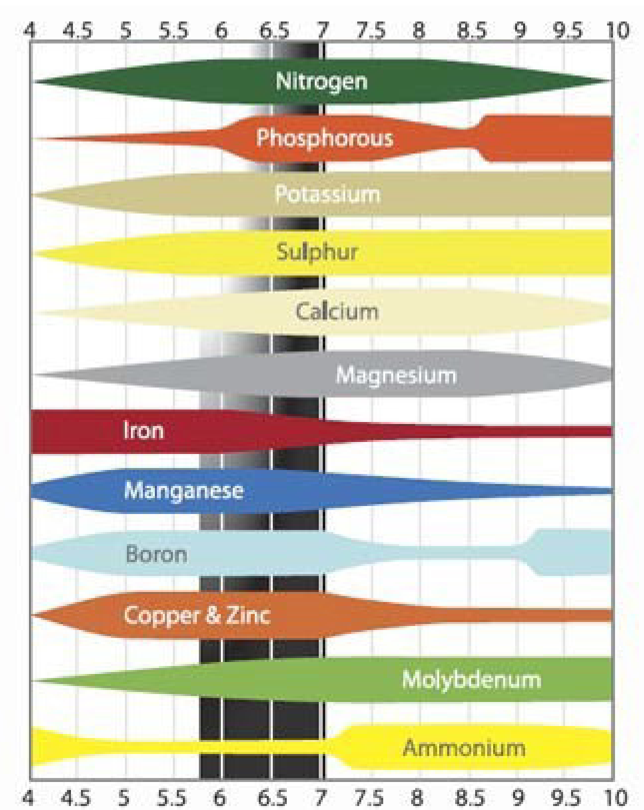

Figure 19: Soil pH and Nutrient Availability

(Costello, et al., 2006, Moreno- Lora, 2020). Symptoms of iron **chlorosis** include narrow bands of green along the veins. With Mn deficiency, the green bands are wider and Zn deficiency gives a more mottled chlorosis pattern accompanied with small leaves and short internodes. Distinguishing between these three nutrients in the field can be challenging as more than one element may be deficient and a range of symptoms may be occur. Proper diagnosis must be followed up with leaf tissue analysis (Costello, et al., 2006). This issue became very apparent in 2020, in a study involving urban, white oak (Q. alba) and some bur oak (Q. macrocarpa) trees that were showing chlorosis, dieback and decline. Soils tests revealed there was adequate levels of Fe, Mn, and Zn, but for soil samples with a pH of 7.0 or greater, these same micronutrients were lacking or deficient in leaf tissue samples (Table 2).

PLANT NUTRIENTS AND CHLOROSIS OF WHITE OAK TREES IN AN URBAN FOREST (Mean pH = 6.9 with 77% above 6.5)

PLANT NUTRIENT	SOIL LEVELS (ppm)	LEAF TISSUE (ppm)
Iron (Fe)	Medium to High	Deficient to Low
Manganese (Mn)	Medium to High	Sufficient
Zinc (Zn)	Medium to Very High	Deficient to Low
Copper (Cu)	High to Very High	Deficient to Low
Phosphorus (P)	Medium to Very High	Sufficient
Calcium (Ca)	Medium	Sufficient
Magnesium (Mg)	High	Sufficient to High
P/Zn Ratio	2.6	2.5X above normal
Ca/Mg Ratio	4.5	

Table 2: Soil Nutrient Levels and Leaf Tissue Analysis for Chlorotic White Oak (Quercus alba) Trees in an Urban Forest

Fe, Mn, and Zn are all very important components in photosynthesis. Additionally, Fe is involved in reduction-oxidation reactions, Mn is important in root growth and lignin synthesis, and Zn is important for plant growth and oxidative stress reduction .

Nutrient interactions can negatively affect Zn uptake when P levels are elevated. This can be a potential problem in residential landscapes where NPK fertilizers are applied on a regular basis and P levels build up in the soil to high levels (Moreno-Lora, 2020).

(continued on page 25)

Abiotic Stresses & Their Effect on Woody Plants

Problems with **nutrient availability** can also arise with acidic soils (pH<5.5). Mn toxicity can occur resulting in varied patterns of leaf distortion, yellowing, and necrosis. Copper (Cu) toxicity initially appears as reduced plant growth and may contribute to iron chlorosis by depressing iron (Fe) concentration in the leaves (Costello et al., 2006). Zn becomes more bioavailable as pH decreases affecting plant growth and photosynthesis (Tsonev and Lidon, 2012).

Water deficits and drought also impact nutrient uptake and content. During drought, ion movement is slowed, root growth is decreased, and increased root suberization ("water proofing") decreases root permeability (Pitman, 1981; Kramer, 1983). Uptake of N, P, and other elements is reduced (Viets, 1972; Begg and Turner, 1976), and foliar levels of P, Na, Ca, Mg, and Cl increase while P and Fe levels decrease (Abdel Rahman et al., 1971). Additionally, drought also disturbs N and C metabolism which decreases proteins, and depletes sugar and starch levels, respectively.

Plant stress and plant defenses. Plants protect themselves from harmful pests and diseases by using chemical warfare such as the production of **allelochemicals** and other **secondary metabolites**. Production of allelochemicals such as cyanogenic glycosides, glucosinolates, sulfur compounds, alkaloids, and terpenoids tend to increase in water-stressed plants (Figure 20).

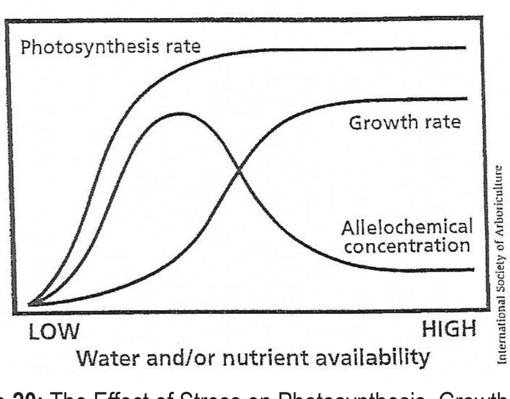

Figure 20: The Effect of Stress on Photosynthesis, Growth Rate, and Allelochemical Concentration

Secondary metabolites are also an important part of chemical defense and may accumulate in foliage due to greater quantities of N and C that would normally be used for growth. Oleoresin exudation pressure (OEP), which is exerted by the xylem,can be detrimental to bark beetles attacking conifers (Vite, 1961; Vite and Wood, 1961; and

Wood, 1962). Water stress lowers the exudation pressure, rate of flow, and total flow of oleoresin in conifers which facilitates the colonization of trees by bark beetles (Vite, 1961; Lorio and Hodges, 1968, 1974; Mason, 1971; Blanche et al., 1985). The composition of the resin is also changed usually increasing alpha-pinene but decreasing myrcene and limonene. Ironically, alpha-pinene is a common bark beetle attractant and limolene and myrcene are deterrents and toxicants. Finally, water-stress also causes plants to heal wounds more slowly and delays first periderm formation (Puritch and Mullick, 1975; Borger and Kozlowski, 1972).

In conclusion, when trees are under drought stress, are trying to grow in poorly drained soils and compacted soils, they lack essential nutrients, or are buffeted by weather extremes, they are not able to perform important physiological functions. One or a combination of the above factors provides a recipe for tree decline and potential death.

Suggested Plant Health Care (PHC) or Best Management Practices (BMPs) for Mitigating Tree Stress

- RIGHT PLANT IN THE RIGHT PLACE!!
- Know the growing requirements of the plants you intend to utilize in a design, and for the ones you are managing in an established landscape
- ake soil samples before you decide which plants you will use in your design or if you are initially diagnosing tree problems
- Keep soil pH within optimum levels (6.0 to

(continued on page 26)

6.5 for most plants and 5.0 to 5.5 for acid-loving plants)
- Be aware of soil drainage issues and conduct a ribbon test to determine soil texture
- Pay attention to weather patterns and trends (i.e. wet springs followed by hot dry summers)
- Encourage clients to water their trees (1 inch equivalent of irrigation per week during hot, dry weather)
- Mulch around trees to reduce turf and weed competition, preserve soil moisture, moderate soil temperatures, minimize mechanical injury, and provide organic matter
- Use wood chips or other mulching materials on heavily-trafficked trails and other high-use human and vehicular traffic areas
- Provide proper pest management where required and know which pests (i.e. EAB, ALB) and pathogens (oak wilt, DED) are lethal, and which ones are non-life threatening to your trees
- Encourage plant species diversity, where possible, when rep-planting or in landscape design
- Avoid plants that require extensive pest and disease management or other tree maintenance measures
- Be aware of plant nutrient interactions and do not over fertilize.

Recommended Readings

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(continued on page 28)

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