

# Soil Moisture: The Most Important Factor for the Survival of Street Trees

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America's  
**SEED FUND**  
SBIR.STTR

# Factors Affecting Tree Survival in Urban Environments

- Most common causes of death of newly planted trees
  - Overwater and underwater Soil Moisture
  - Gilman's research work
  - Watering efficiency
    - runoff, evaporation, weed competition, leakage
    - Watering more often is better than amount each time
  - Dynamics of water movement in different soil type, slope, underground infrastructure (water pipe, sewer line, subway, etc)
- Other factors
  - Roots
    - Healthy root growth, Girdling roots, mulch volcano
  - Soil Quality(Snow Melt, Construction Debris...)
  - Site (slope, soil etc)
  - Soil and Air Temperature
  - When trees are planted (summer is not preferred, but...)



# USDA/Forest Service Sustaining America's Urban Trees and Forest (2010)

## URBAN AMERICA

(lower 48 states)

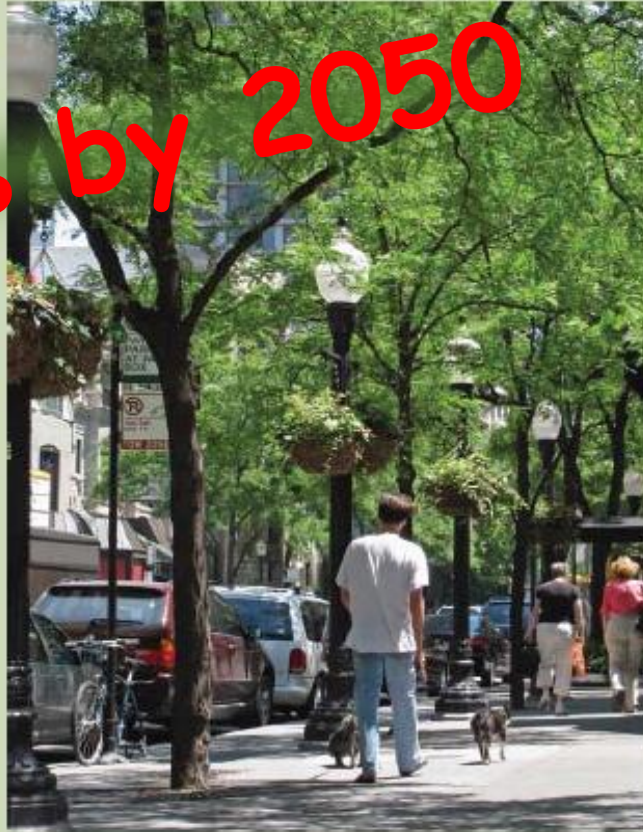
~~3.5%~~

of land mass

82%

of population

8.1% by 2050



Urban forests provide green space in the urban landscape.

## America's Green Infrastructure

America's forests are sometimes referred to as "green infrastructure" to emphasize the critical public benefits they provide. The term has been defined as "an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations" (Benedict and McMahon 2002). Urban forests are an integral part of this structure, providing a lattice of green in an otherwise artificial landscape. "The value of an urban forest is equal to the net benefits that members of society obtain from it" (McPherson et al. 1997).

*"... urban forests will become increasingly critical to sustaining environmental quality and human well-being in urban areas."*



# Urban Forestry

“Every dollar spent on planting and caring for a community tree yields benefits that are two to five times that investment—benefits that include cleaner air, lower energy costs, improved water quality and storm water control, increased property values, and health of citizens.”

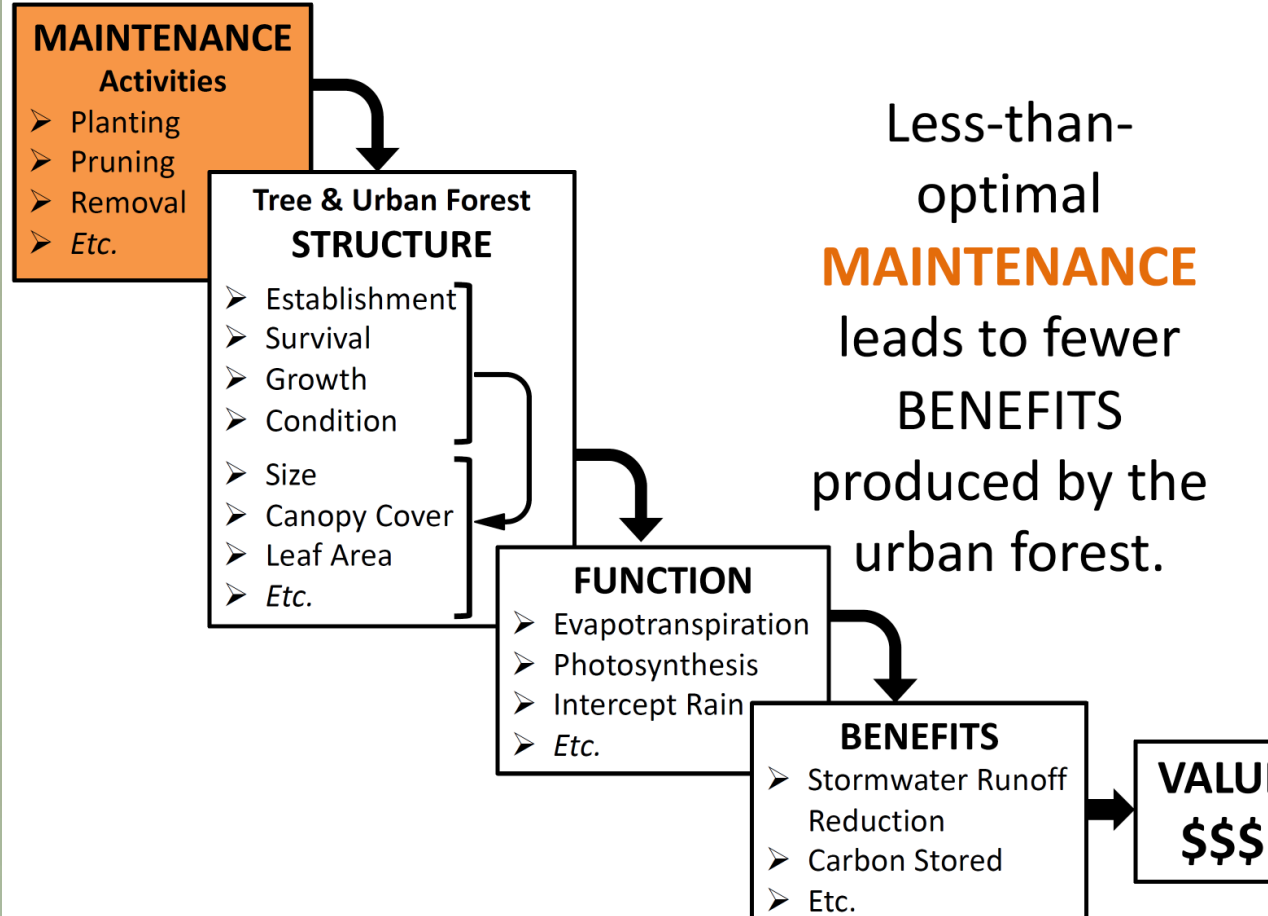
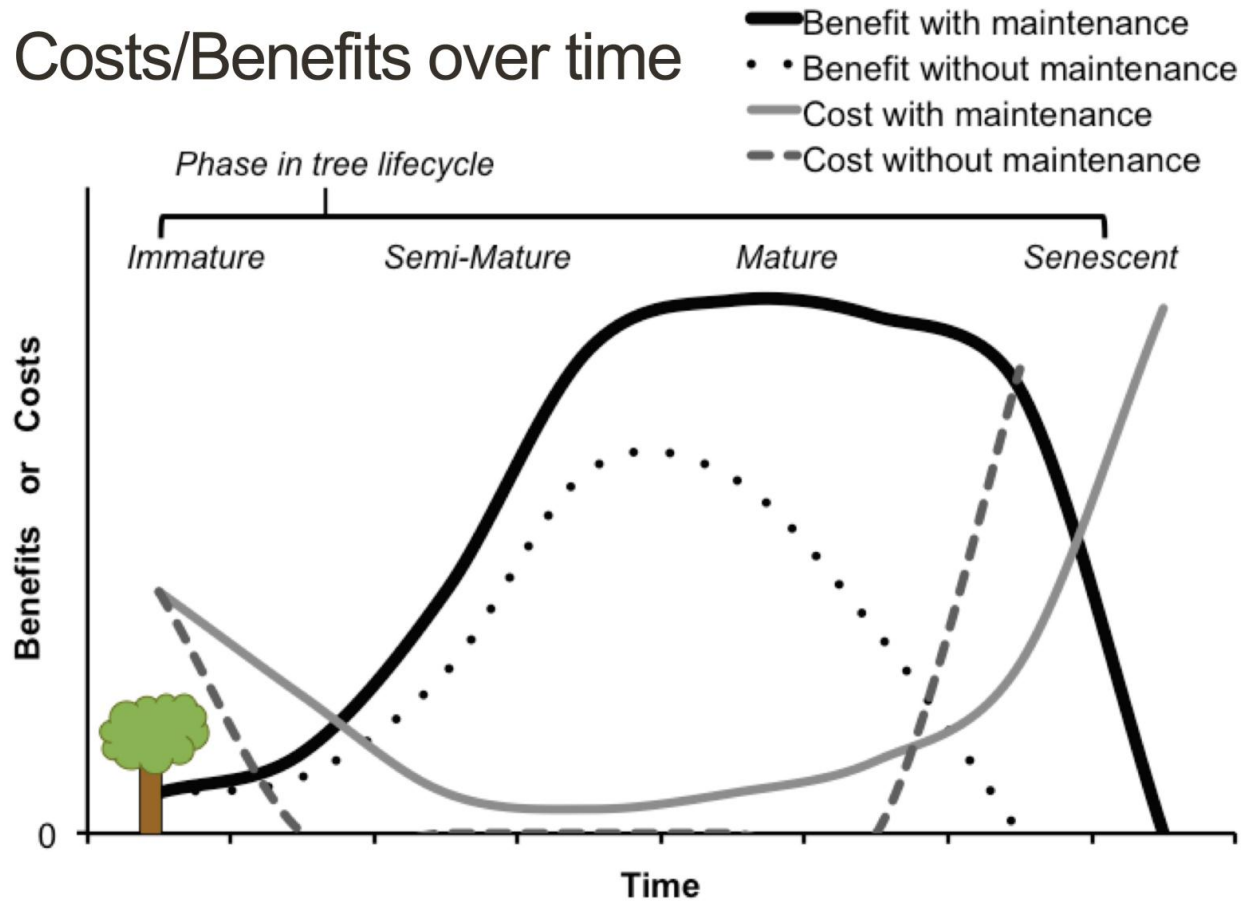
*-2011 study by the U.S. Forest Service.*





# The Cost and Benefits of Urban Forestry

Costs/Benefits over time





**Chicago suburb**



**Toronto suburb**



**Washington DC**



**Recruiting citizen volunteers**



# Total Cost per Tree Planted

- New York City [tree replacement option](#)

*“...**\$2,000** payment per tree [into NYC Parks Tree Fund] is based on actual tree planting costs incurred by NYC Parks.”*

*<https://www.nycgovparks.org/trees/street-tree-planting/tree-fund>*

- Richmond: \$256 per tree planted only

*“\$256 per tree planted by contractors”, Urban Forestry Department in Charge of Maintenance as of 2013.*

- Montgomery County, MD

Maintenance Section of the DOT's Department of Highway Services can plant more trees in the early spring. With this supplemental appropriation, therefore, the total tree planting appropriation in FY17 would be \$190,608. **Planting a street tree costs about \$300**, on average. Thus, the total appropriation will allow DOT to have planted about 635 street trees in FY17.

**Planting a street tree costs about \$300**



**What are main challenges to make a city tree survive and thrive?**

**What are the true problems?**

**Why are these trees cost so much?**

**Are there better ways to save tax payers' money?**



# Factors for the Survival of Newly Planted Trees



- Water
- Quality of Stock
  - Root (girdling root, planting depth, healthy root development)
  - Diseases
- Planting/Mulching
- Soil/Site
- Weather/Climate



# Newly Transplanted Trees Need Water for 2-3 yrs

- Transplanted trees do not have root system supporting them.
  - Trees produced in ground farms have their root system established on the farm, but they lost most roots when dugged out of ground
  - Container-grown trees may not lose much roots, but the root system are limited to the container size, They survive and thrive very well with the irrigation system.
- Integretion into the new environment takes time
- Not all (actually most) planting sites do not have the ideal growing condition for trees.
  - Medians or roadsides surrounded by asphalt or concrete
  - Parks without irrigation
  - Sustained regional drought
  - Arid climates, e.g. Southwest U.S.
  - Heat Island Effect

***As the world becomes more urban, interest in green spaces -- including trees, lawns, flowers and hedges -- is increasing in cities around the globe, driving demand for landscaping services.***

***Dun & Bradstreet 2017 First Research***





# Richmond Virginia

(Right after I-95 North merges with I-64 West)



# Google Map Image...August 2013



I-95  
Richmond, Virginia

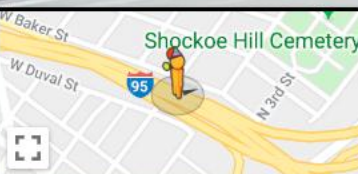
Google, Inc.

Street View - Aug 2013



Currently shown: Aug 2013

2011 2017



Google



# Google Map Image...April 2014



I-95  
Richmond, Virginia

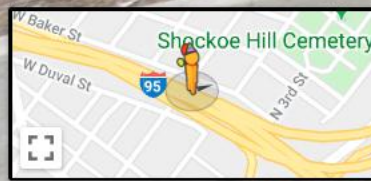
Google, Inc.

Street View - Apr 2014



Currently shown: Apr 2014

2007 2018



Google



# Google Map Image...April 2015



I-95  
Richmond, Virginia

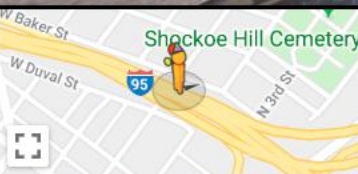
Google, Inc.

Street View - Apr 2015



Currently shown: Apr 2015

2011 2018



Google



# Google Map Image...January 2016





# Google Map Image...June 2017





# Google Map Image...June 2018





# Our pictures...

August 1st 2017





# Our Pictures...

August 1st 2017





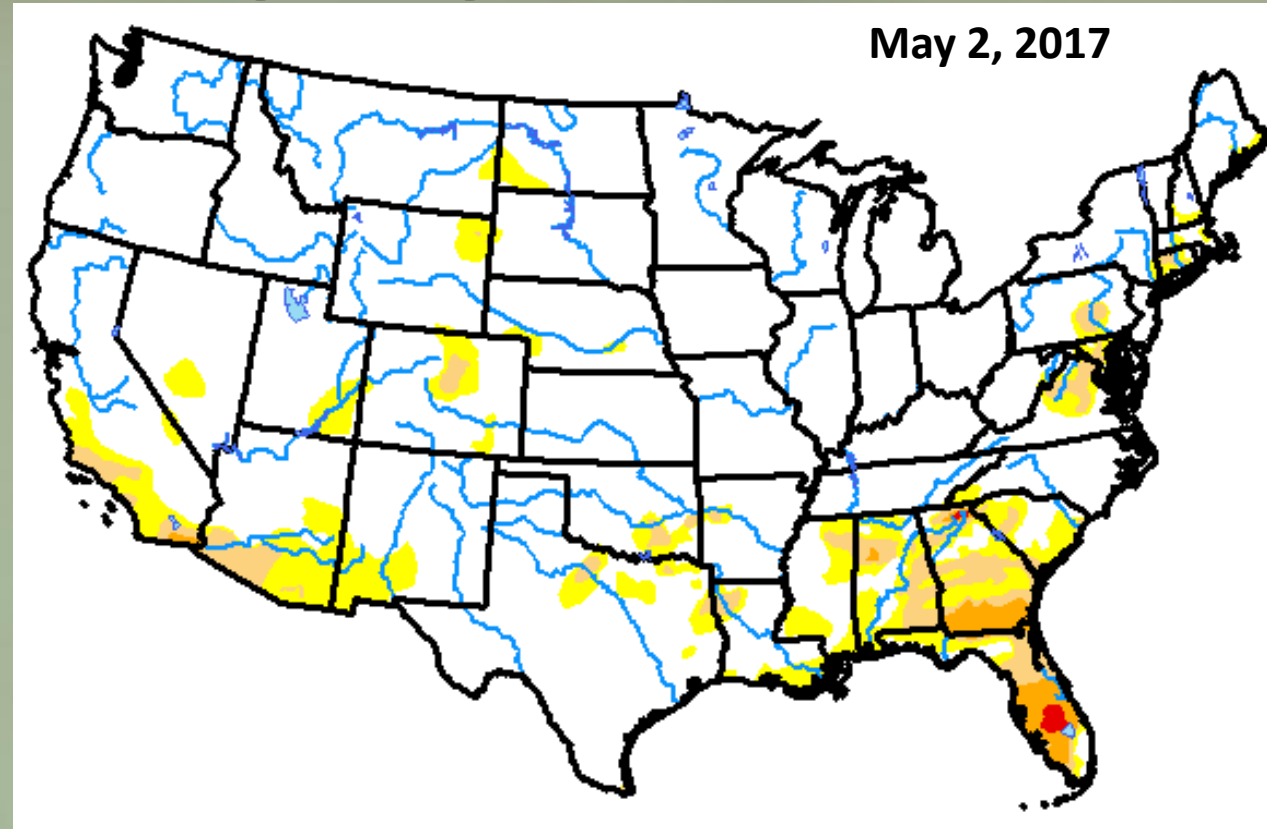
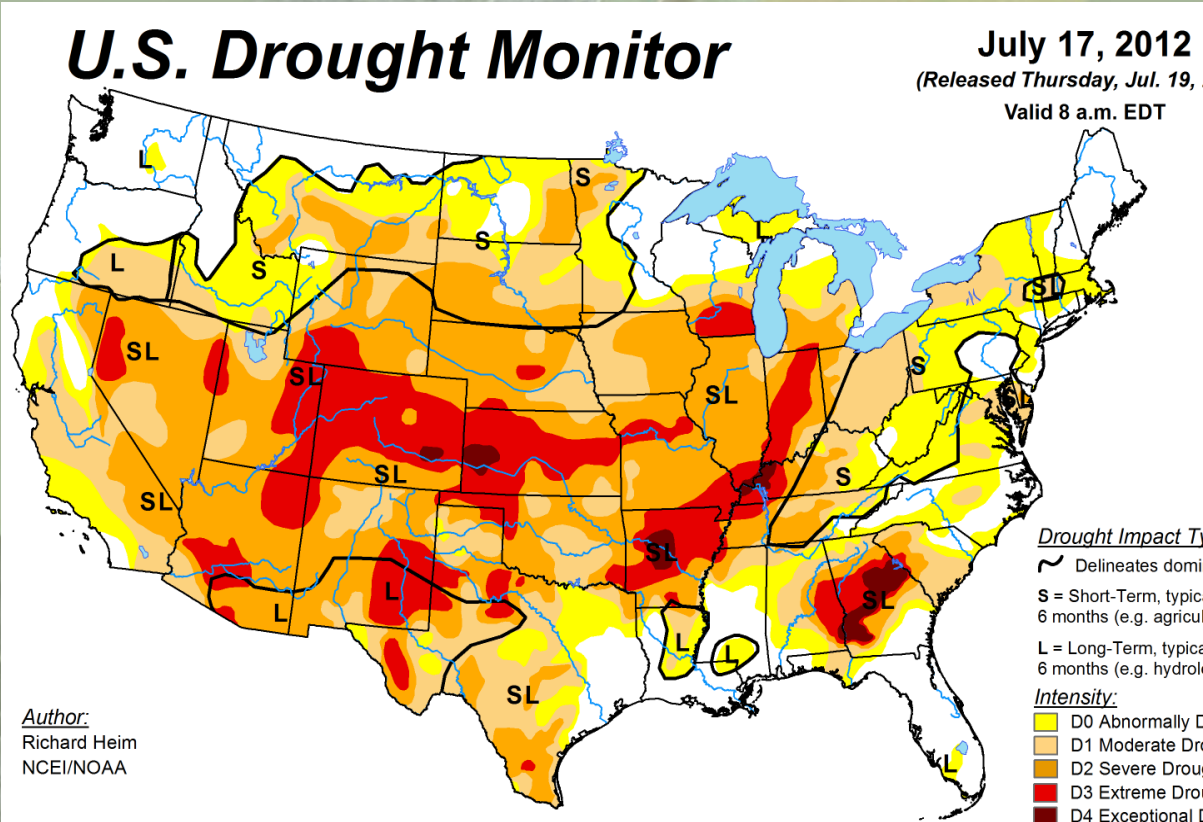
# Average Rainfall Map





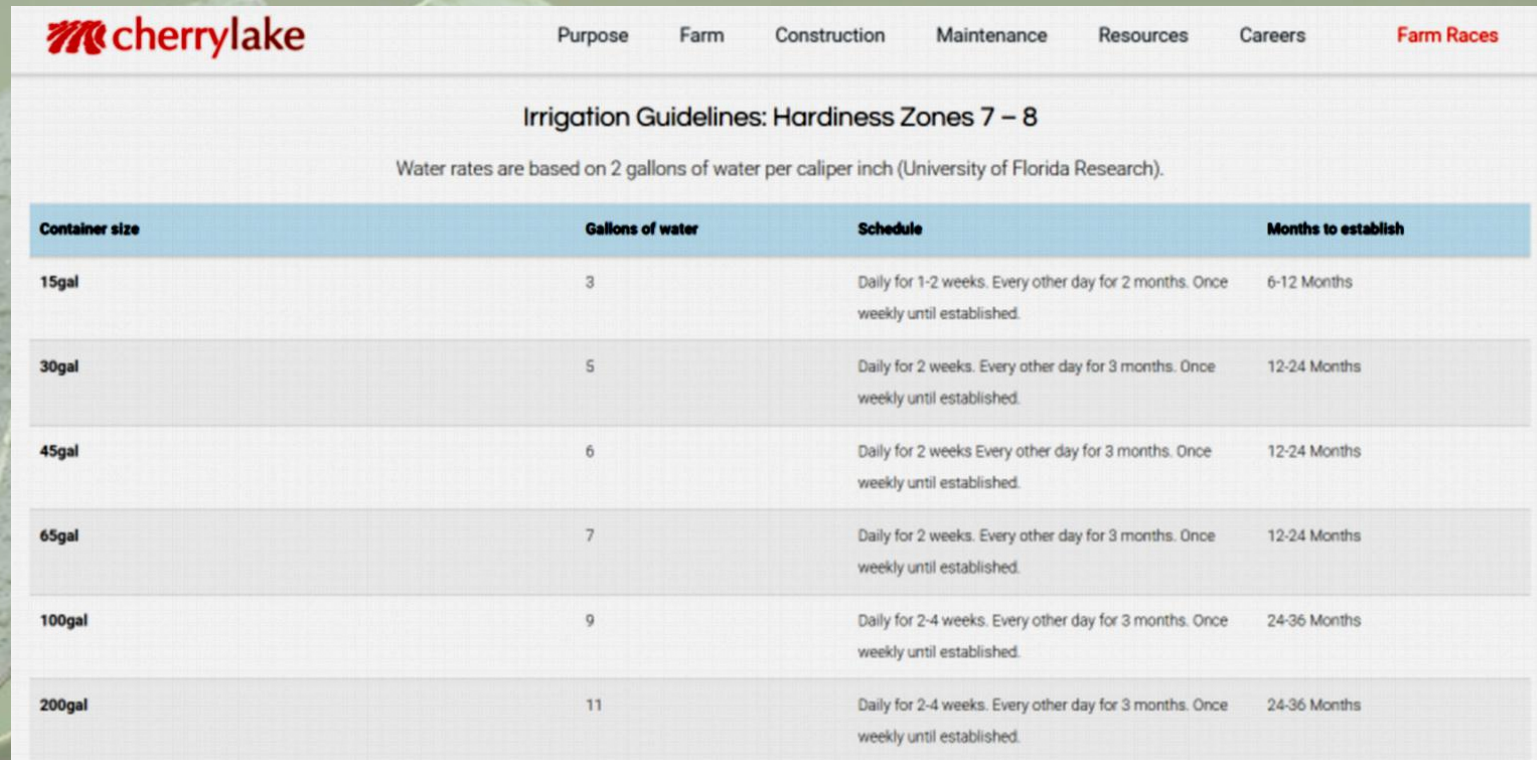
# U.S. Drought Monitor: A moving target

<http://droughtmonitor.unl.edu/>





# Water Prescriptions



**cherrylake** Purpose Farm Construction Maintenance Resources Careers **Farm Races**

### Irrigation Guidelines: Hardiness Zones 7 - 8

Water rates are based on 2 gallons of water per caliper inch (University of Florida Research).

Container size	Gallons of water	Schedule	Months to establish
15gal	3	Daily for 1-2 weeks. Every other day for 2 months. Once weekly until established.	6-12 Months
30gal	5	Daily for 2 weeks. Every other day for 3 months. Once weekly until established.	12-24 Months
45gal	6	Daily for 2 weeks. Every other day for 3 months. Once weekly until established.	12-24 Months
65gal	7	Daily for 2 weeks. Every other day for 3 months. Once weekly until established.	12-24 Months
100gal	9	Daily for 2-4 weeks. Every other day for 3 months. Once weekly until established.	24-36 Months
200gal	11	Daily for 2-4 weeks. Every other day for 3 months. Once weekly until established.	24-36 Months

<http://hort.ifas.ufl.edu/woody/irrigation2.shtml>

<https://csfs.colostate.edu/colorado-trees/selecting-planting-and-caring-for-trees/watering/>

<https://www.bigtrees4u.com/watering-guide/>

<https://extension.umn.edu/planting-and-growing-guides/watering-newly-planted-trees-and-shrubs>

<https://www.mrt.com/lifestyles/article/Formula-calculates-how-much-water-each-tree-needs-7432435.php>

<http://www.deeproot.com/blog/blog-entries/how-much-should-you-water-your-tree>

[http://cherrylake.com/installation\\_best\\_practices/](http://cherrylake.com/installation_best_practices/)



# Water Prescriptions



<u>Size of tree</u>	<u>Quantity of water per week<sup>1</sup></u>
1 inch	10 gallons
2 inch	15 gallons
3 inch	20 gallons
4 inch	25 gallons
5 inch	30 gallons

Alan Siewert: “The volume calculation are based on 1 inch of rain falling on the root ball.”

“The volume recommended, to my knowledge, has not been studied.”<sup>2</sup>

1. “Watering Newly Planted Trees and Shrubs” By Alan Siewert, Urban Forester ODNR Div. of Forestry <https://www.bigtrees4u.com/media/documents/Watering-Guide.pdf>
2. personal communication



# Water Prescriptions

Professor Gilman's site <http://hort.ifas.ufl.edu/woody/irrigation2.shtml>



“2 inch oak trees in southern climates need 2 to 3 gallons of water every day.”

Size of nursery stock	Irrigation schedule for vigor <i>1,3</i>	Irrigation schedule for survival <i>2,3,4</i>
< 2 inch caliper	Daily for 2 weeks; every other day for 2 months; weekly until established.	Twice weekly for 2-3 months
2-4 inch caliper	Daily for 1 month; every other day for 3 months; weekly until established.	Twice weekly for 3-4 months
> 4 inch caliper	Daily for 6 weeks; every other day for 5 months; weekly until established.	Twice weekly for 4-5 months

**A single 2 inch caliper (trunk diameter) tree would require approximately 20 gallons of water per week.**

**[www.treegator.com](http://www.treegator.com)**



# *How much of the water do trees actually get?*



Nation  
<https://>

nt



# What is missing in the water prescription

- Consideration of losses
  - Runoff, evaporation from surface, competition from surrounding vegetation, water need of species, etc
- Site information
  - surrounding environment: road median, park, residential, tree well, buildings etc
- Soil Type
  - Clay soil versus sandy soil
    - water holding capacity, drainage, leakage
- Climate
  - monsoon-mediterranean-desert-continental
  - drought, temperature, humidity, wind, etc

Most water prescriptions were developed based on a certain set of parameters or based on experiences of arborists. If the parameters change, the water prescriptions should change.





**Solution!**

**Check the  
Soil Moisture!**



# Case Study 1: Jefferson Davis Hwy, Richmond VA

No trees Aug 2012



No trees May 2012



South of Maury St

Google Map  
Images

Jefferson Davis Hwy  
Richmond, VA

North of Maury St



Live trees April 2014



Weed Control and Moisture Conservation Mat (TreeDiaper) installed in August 2013

South of Maury St

# Google Map Images

Jefferson Davis Hwy Richmond, VA

Live trees April 2014



One of the leftover watering bags

City standard operation (Watering bags)

North of Maury St



Live trees July 2014



Dying trees July 2014



One of the leftover watering bags

Weed Control and Moisture Conservation Mat (TreeDiaper) installed in August 2013  
South of Maury St

Google Map Images

Jefferson Davis Hwy  
Richmond, VA

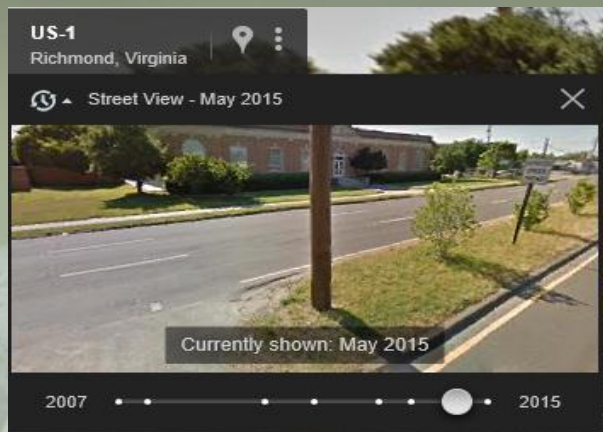
City standard operation (Watering bags)  
North of Maury St



Weed Control and  
Moisture Conservation  
Mat (TreeDiaper)  
installed in August  
2013  
South of Maury St

Google Map  
Images  
Jefferson Davis Hwy  
Richmond, VA

City standard operation  
(Watering bags)  
North of Maury St



Live trees May 2015



Dead trees May 2015

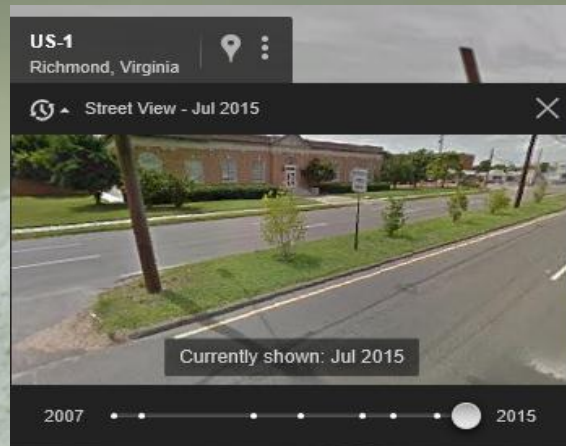




**Weed Control and  
Moisture  
Conservation Mat  
(TreeDiaper) installed  
in August 2013  
South of Maury St**

**Google Map  
Images**  
Jefferson Davis Hwy  
Richmond, VA

**City standard operation  
(Watering bags)  
North of Maury St**



**Live trees July 2015**



**Trees gone July 2015**



**Weed Control and  
Moisture  
Conservation Mat  
(TreeDiaper) installed  
in August 2013  
South of Maury St**



**City standard operation  
(Watering bags)  
North of Maury St**



**Pictures were taken August 27, 2016**



**Weed Control and  
Moisture  
Conservation Mat  
(TreeDiaper) installed  
in August 2013  
South of Maury St**

**Google Map  
Images**  
Jefferson Davis Hwy  
Richmond, VA

**City standard operation  
(Watering bags)  
North of Maury St**



**Live trees May 2018**

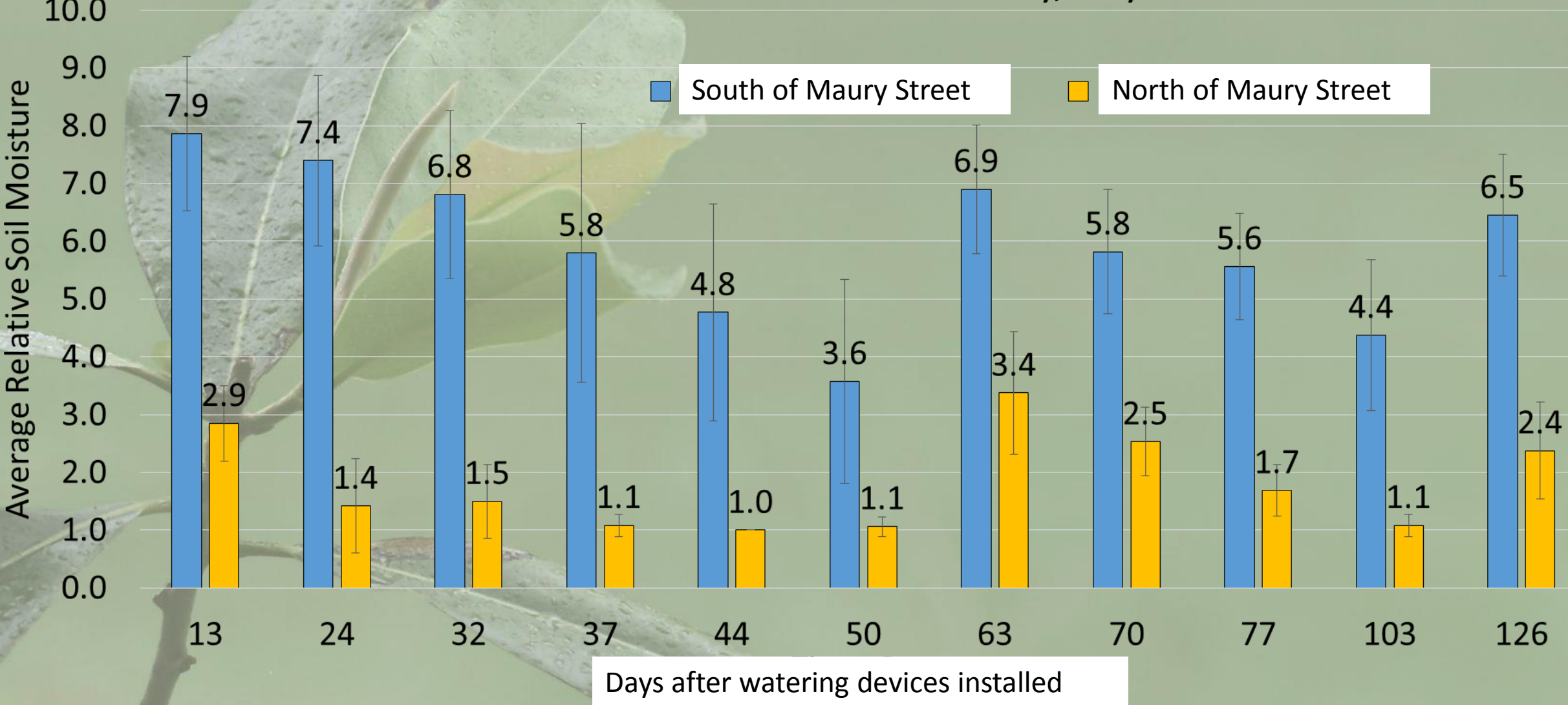


**No Trees May 2018**



# The difference maker: Soil Moisture!

Field Test in the road median of Jeff Davis Hwy, City of Richmond



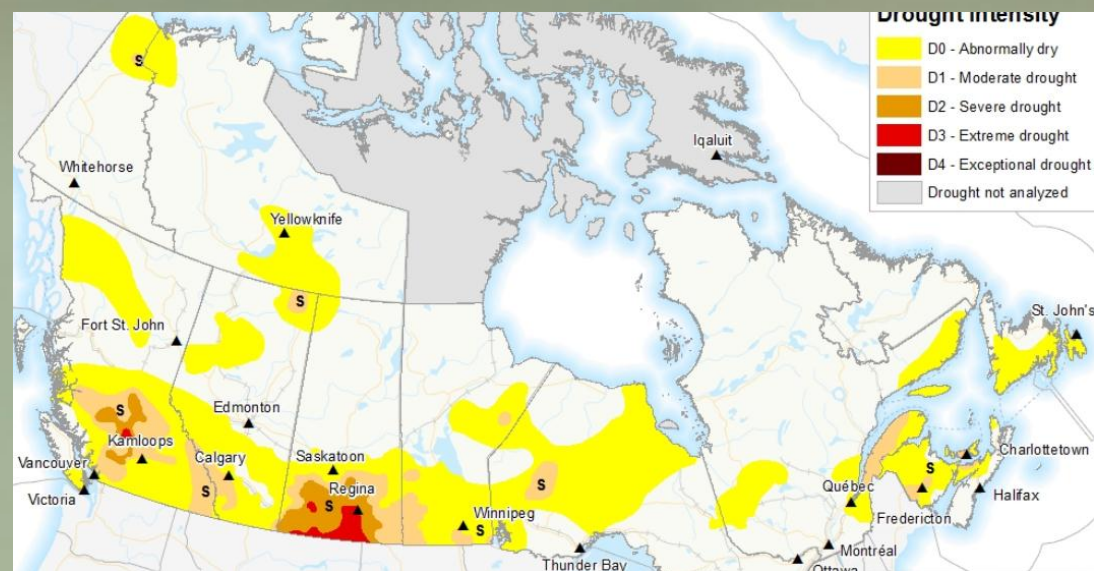
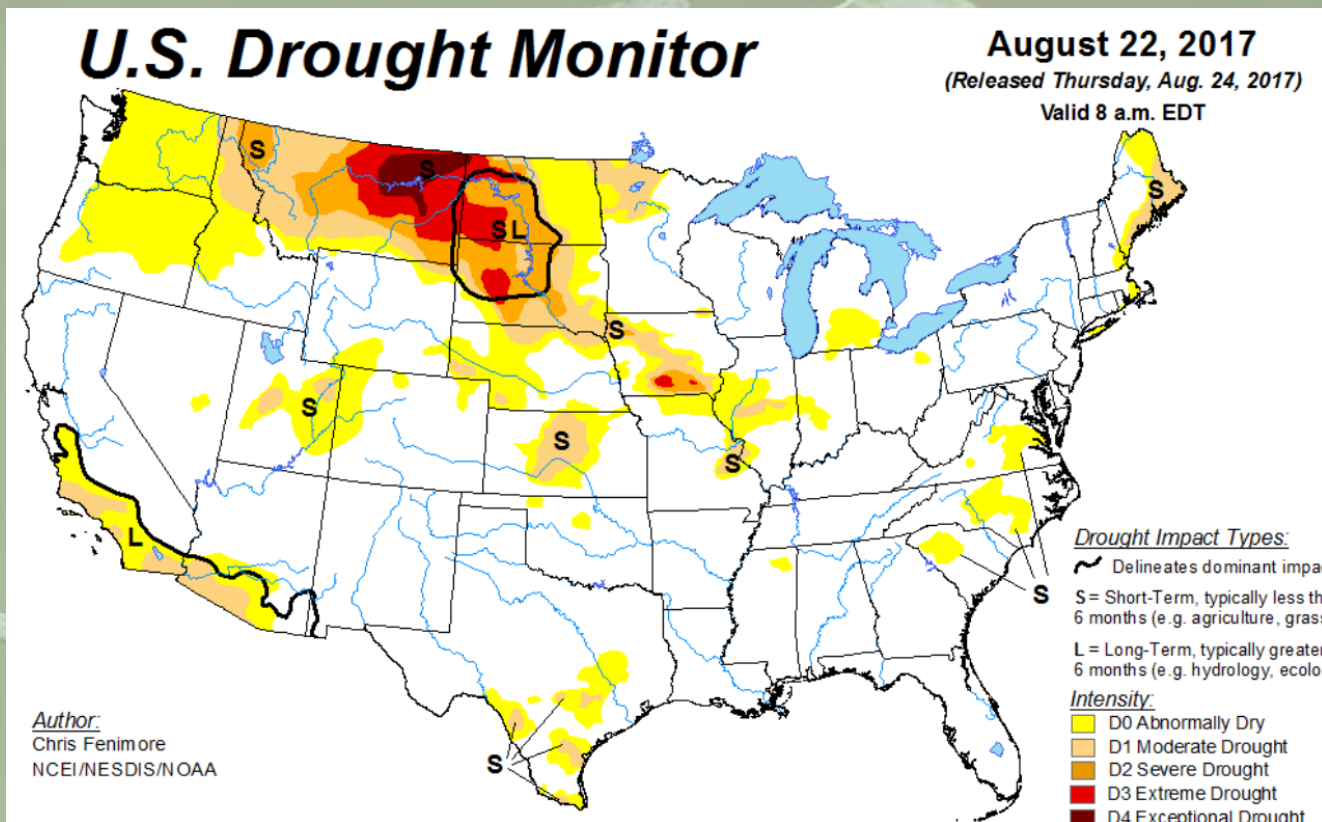


# Watering solutions for Urban Forestry

- Mother Nature!
  - Cities have abundant stormwater (Impervious Surfaces)
  - Low maintenance cost
  - Results depends on Mother Nature!
- Conventional Watering by water hose/truck
  - Low initial costs
  - High labor and material costs
  - Overwatering and Underwatering
- Automatic Irrigation System
  - High innitial Costs
  - Better and more reliable results
  - Not suitable for all situations
- Slow release watering Devices
  - Reduces maintenance cost, save water,
  - Reduces watering frequency
  - High labor and material costs



# Natural Rainfall



Canadian Drought Monitor



- **Mother Nature has her own schedule**



# Hand watering – not saving water or trees

- Easy operation
  - Watering surrounding soil to promote healthy root growth
  - Hard to control water amount
  - Water runoff
  - Overwatering
  - Emmissions
- We sent out a crew to hand watering trees and told them water a tree for 15 minutes. People will easily forget to count the time and lead to overwatering a tree. We have to remove the dead tree later on and found out tons of water underneath of root. - Doug Rodes, James River Nurseries, Inc, Richmond, Virginia.





# Slow Release Watering Bag

- **Reduces watering frequency**
- **Only accept irrigation water**
- **High labor costs**
  - “Everything counted, each filling of 20 gallons of water to a watering bag cost **\$65.**” - James River Nursery, Ashland Va
- **Often overwhelmed during peak season**
  - **Slow refilling process --> Limited number of trees can be watered per day**

“We plant over 2000 trees annually and for years have struggled with watering bags and then back to hand watering year after year.” - Patrick Harwood, Montgomery Parks, MD
- **Rejects natural rainwater**





# Watering bag - Shields off rain water

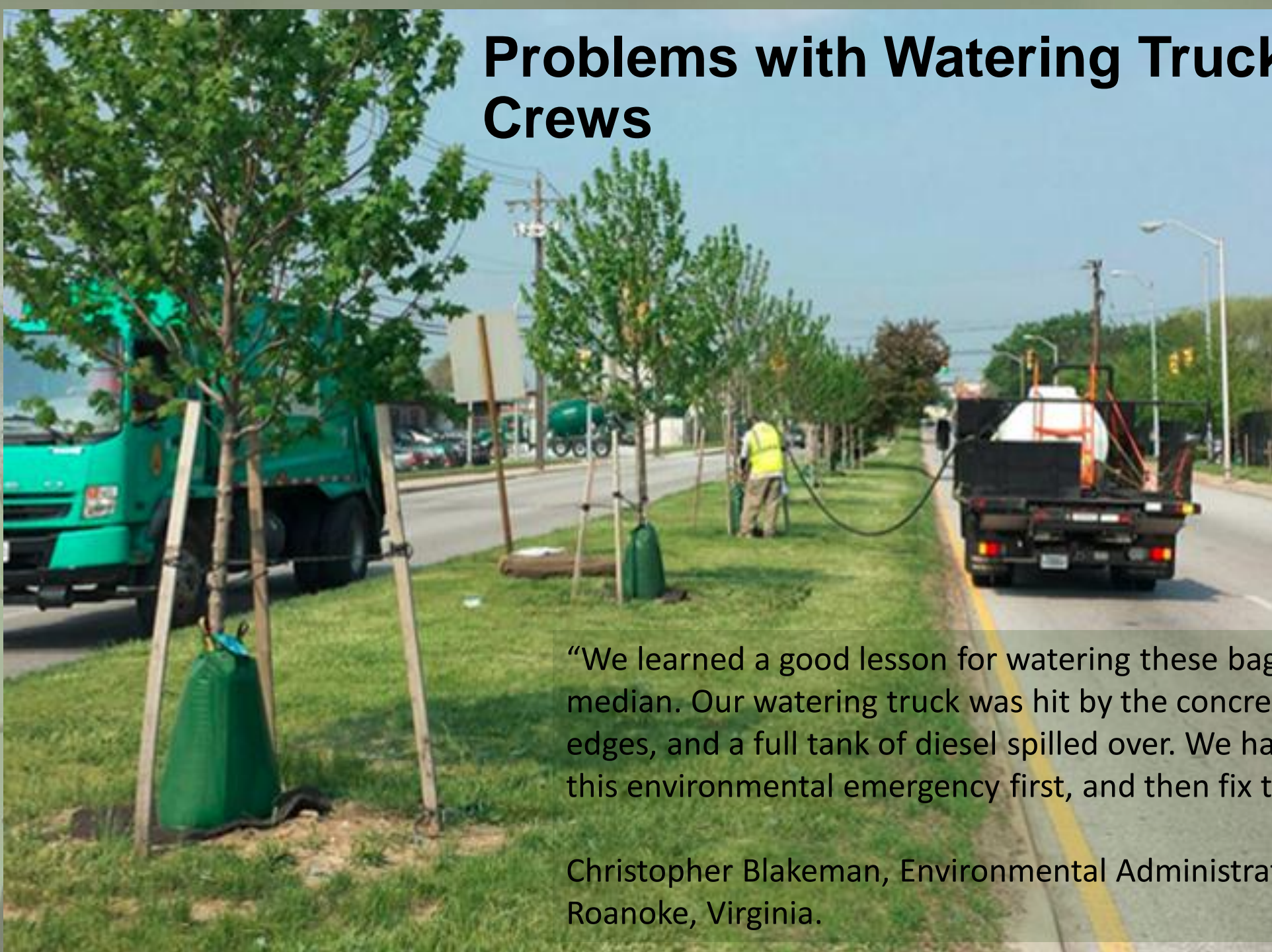


Parks Program Coordinator of Commerce City, CO, Uriel Akiva said:  
“[Watering bags] are only as good as how often staff put water in them, which as we can see, usually results in dead trees.”

Tree is dying with 2.5” rain from Aug 8-12 2017! We wondered why?



# Problems with Watering Trucks Road Crews



“We learned a good lesson for watering these bags on road median. Our watering truck was hit by the concrete of median edges, and a full tank of diesel spilled over. We had to deal with this environmental emergency first, and then fix the truck later”

Christopher Blakeman, Environmental Administrator of City of Roanoke, Virginia.



# What are those bags on all the trees?

August 23, 2010 by SDOT Blog Leave a Comment



City-owned trees decked out in Gator bags.



Urban Forestry staffers are filling 2,200 bags every week!

If you've noticed these strange looking dark green bags wrapped around the city-owned trees, take a closer look. Called "Tree Gators," they irrigate the SDOT's Urban Forestry crews are hopping busy watering nearly 2,200 newly planted trees every week. Watering trees for the first two to three summers after planting ensures the trees will survive and thrive. While our temperatures have been up and down for the past two months, the trees continue to need a steady supply of water and the tree gator bags do just that - they release water slowly into the ground around the trees. The bags, which hold 20 gallons of water, drain for about five hours, which allows water to infiltrate deeply to promote healthy root development.

Three of Urban Forestry's tree trimmers have been specially licensed to operate the 2,000 gallon water trucks while three gardeners fill the water bags. No easy task, the crews must hurry to fill the 2,200 bags once every week. For more info about watering trees click [here](#).



# Ouch.

If you've noticed these strange looking dark green bags wrapped around the base of city-owned trees, take a closer look. Called "Tree Gators," they irrigate the trees. SDOT's Urban Forestry crews are hopping busy watering nearly 2,200 newly-planted trees every week. Watering trees for the first two to three summers after planting ensures the trees will survive and thrive. While our temperatures have been up and down for the past two months, the trees continue to need a steady supply of water and the tree gator bags do just that - they release water slowly into the ground around the trees. The bags, which hold 20 gallons of water, drain for about five hours, which allows water to infiltrate deeply to promote healthy root development.

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Urban Forestry staffers are filling 2,200 bags every week!

# Seattle DOT



# Watering bags – other issues

- **Dump water on the root ball that promotes girdling roots**
  - promoting girdling roots growth
- **Attract animals and insects**
  - fireants, squirrels, spiders, moths
- **Bake the tree trunk in sunny days**
  - “We tried gator bags but it was not successful. Wrapping a cylinder-shaped bag around a tree burnt the trunk in hot summers of Texas”.- Lara Schuman, Program Manager of Urban Forestry in Parks and Recreation of Austin, Texas
- **Require extra labor to install and remove each year!**
- **Trash collection**

Gypsy moth egg





# Desired Solution to Replace Water Prescriptions

Use Soil Moisture as the only indicator about for watering schedule

Save some of the Abundant Stormwater in Cities and Combine with Slow Release Irrigation





# But not too much water each time!

*Gilman et al:* "...it was more important to irrigate transplanted trees frequently than it was to apply a large volume of water..." J. Arboriculture **1998**, 24(1): 1-9

- Root system need oxygen to breath.
- Root rot problem.
- Overwatering kills trees much faster than underwatering!!!
  - Most tree species have developed ways to protect them against drought: shedding leaves, reduce water consumption
  - Root rot damage are permanent and hard to recover
- Most land-based plants like a soil moisture level from 3-9 on a scale of 0-10
  - Below 2 → water stress
  - Above 9 → rot root if soil is soaked
  - Find literature and cite literature





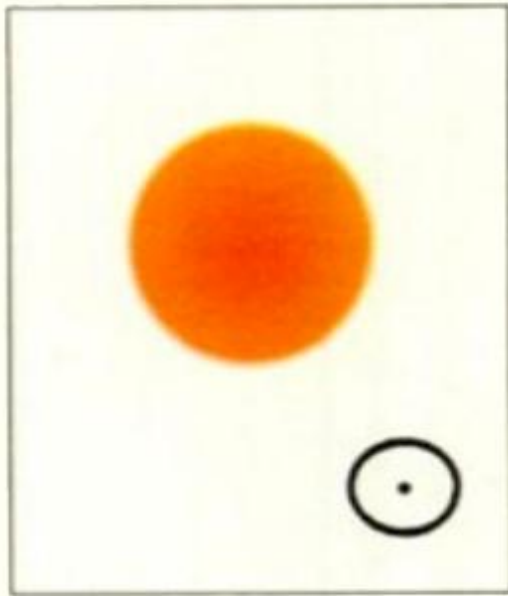
# Tree Roots

Root Establishment => Tree Establishment

Healthy Tree Roots => Healthy and Resilient Trees

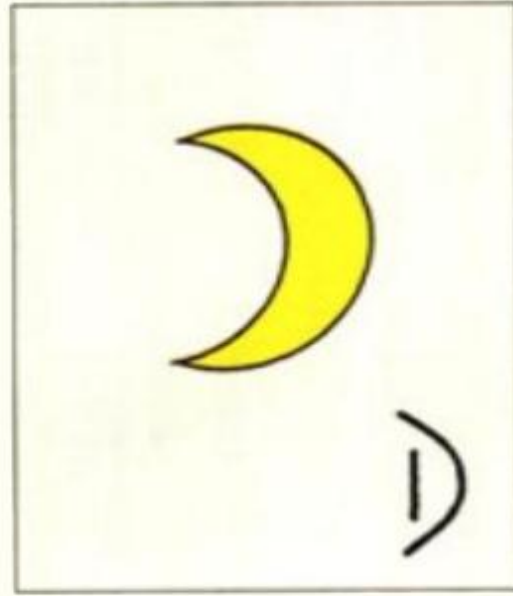


# Chinese is an ancient Language Hieroglyphs/Logograms/Pictographs



ri  
日

Sun



yuè  
月

Moon



huǒ  
火

Fire



yǔ  
雨

Rain



Which Chinese Character Represents a Tree?



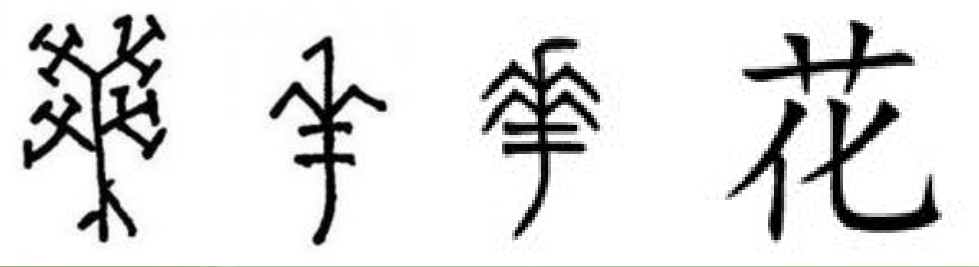
A



Tree



B



Flower



C



Bull

D

There is no such a character.

Most Popular Answer

















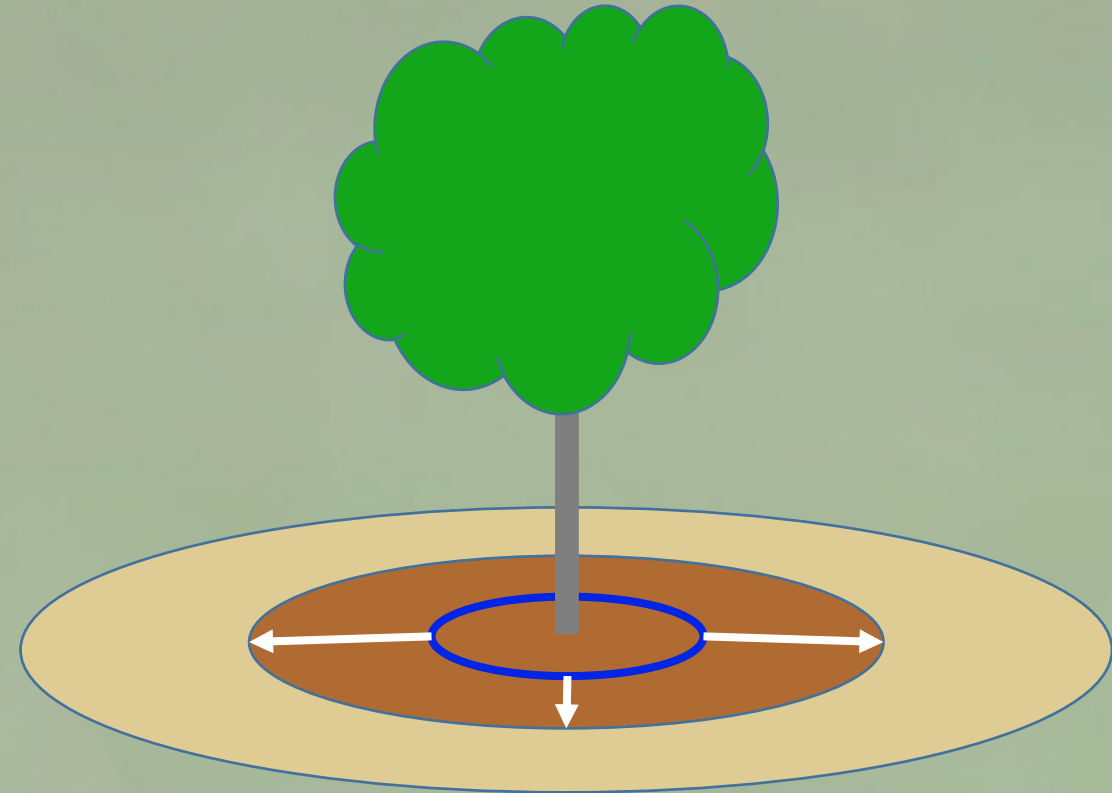
# Girdling Roots





# How to promote healthy root growth?

- Cut circling roots before plant
  - Mainly for container grown
- Don't just water the root ball, water the surrounding soils too.
  - Promotes outward root growth
- Mulch Ring
  - No Mulch Volcano!
- Don't plant too deep



These easy and low cost practices can get rid of the majority of root problems!



# This may look weird, but it's actually impossible to plant a tree too high--Howard Garrett



- <https://www.dallasnews.com/life/gardening/2018/09/11/may-look-weird-actually-impossible-plant-tree-high>
- Like this large red oak growing on top of a berm, trees can't be planted too high. They love this condition. (Howard Garrett)



# Telephone Poles

- <https://www.dallasnews.com/life/gardening/2018/12/04/tree-debris-yard-nuisance-sign-larger-problem>
- Howard Garrett: Trees with straight trunks at ground level, that look like telephone poles, fence posts or straws stuck in the ground, indicate that the tree is planted too deeply or the soil and/or mulch has been piled on.





# Winter/Summer development of tree roots



- On the Planet Earth, most plants (including trees) like a soil temperature of 0-25 C
  - Result of Evolution, trees managed to survive have adapted to this range
  - Soil Temp  $<0$  C, water is in solid phase and doesn't transport within plants
  - Soil Temp  $>25$  C, occasional and very rare in a rain forest or land shaded by plants!
- Below Freezing, no root development
- 0-5 C, some but limited root development
- 5-25 C, best range for root development
- Above 25 C, little root development
- For the northern part of USA, 6+ months of winter below freezing. If some root development, it means a lot for the survival of trees in the next year.



# Root Zone Temperature

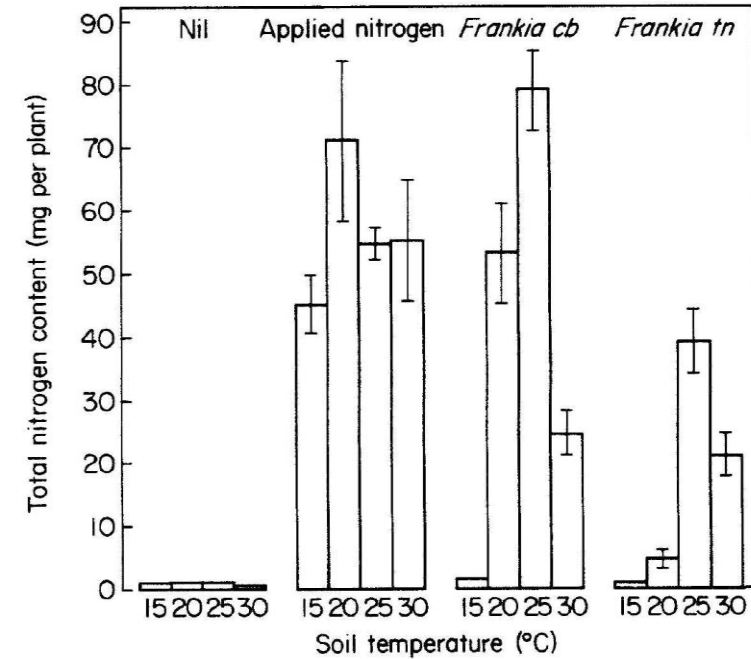
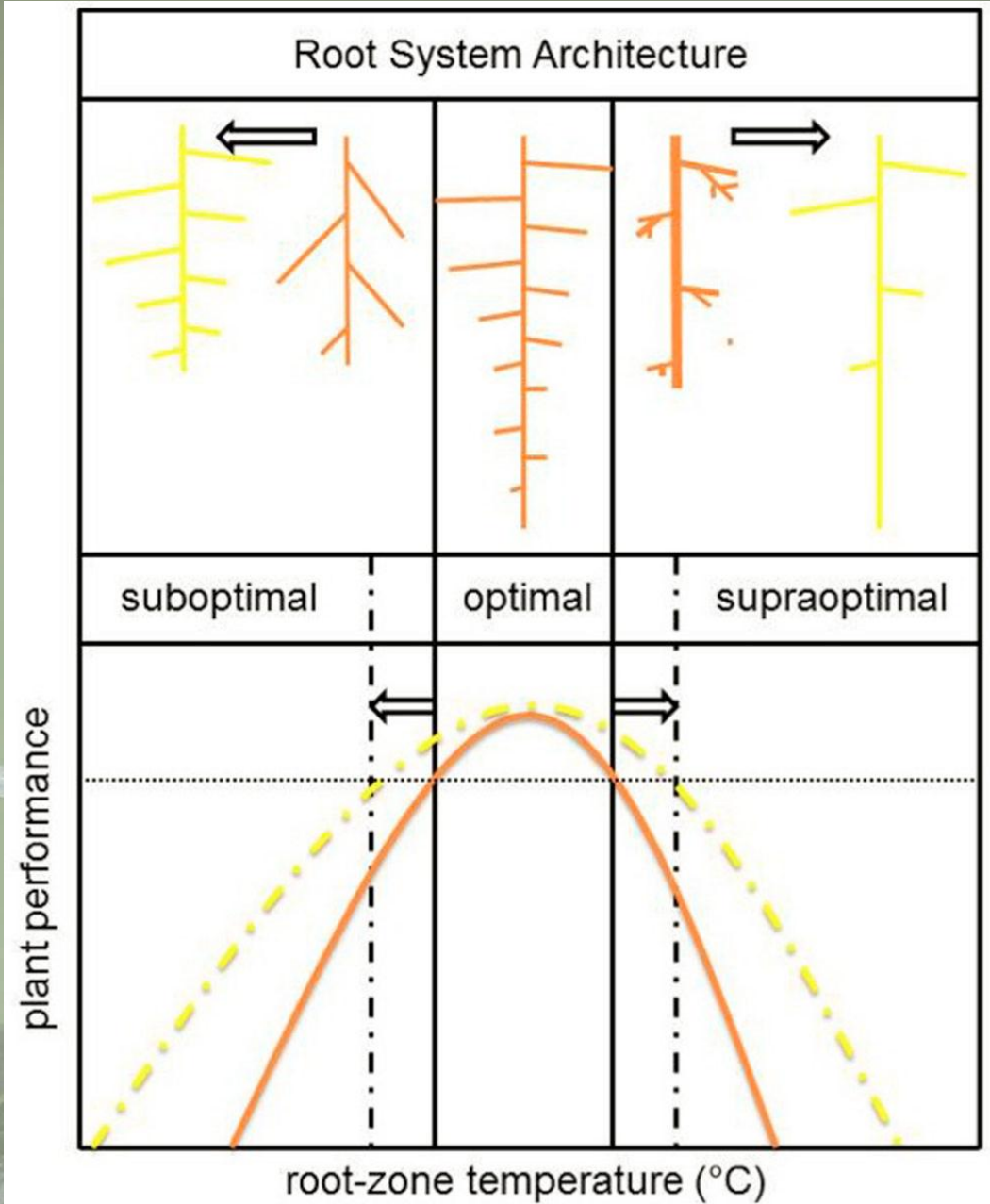


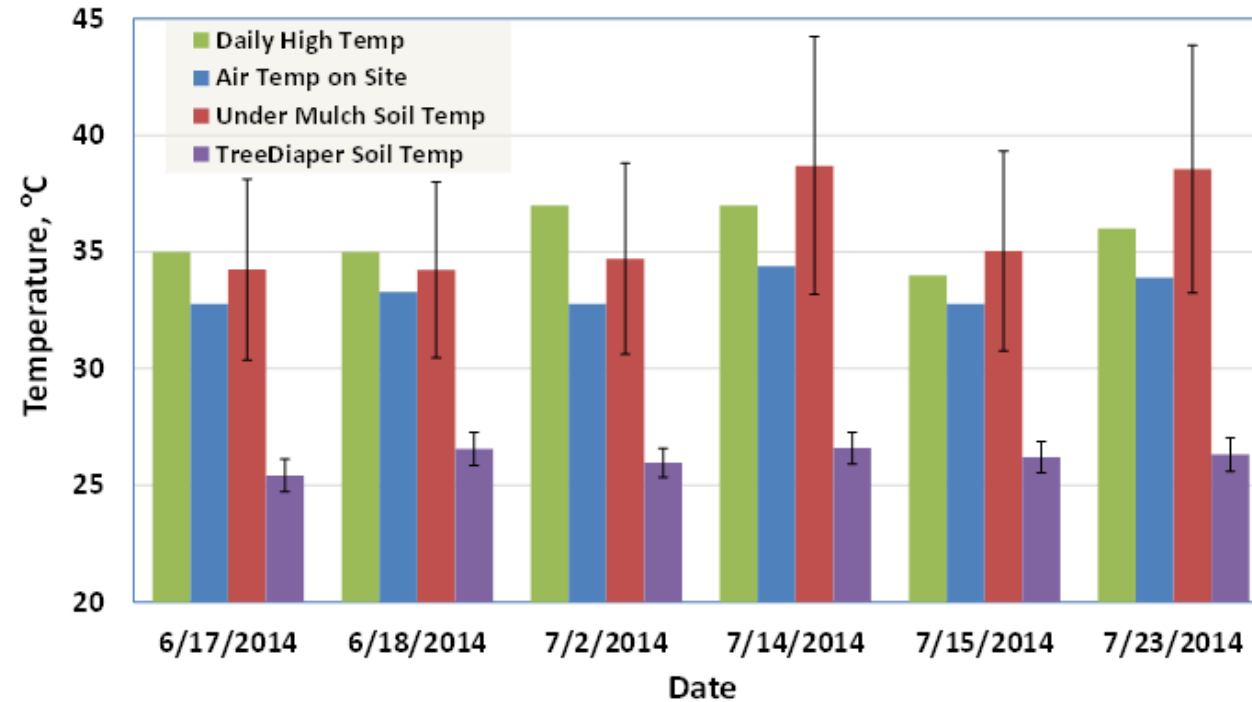
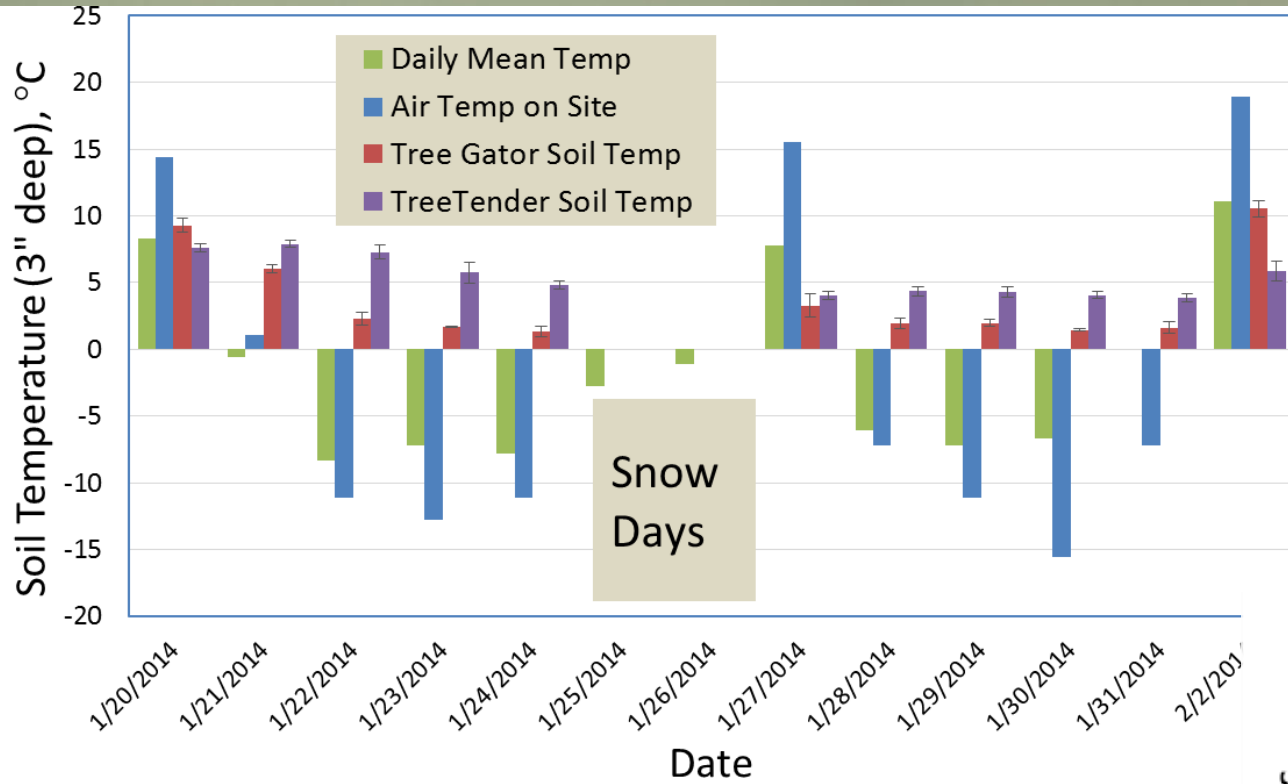
Fig. 5. Effects of four soil temperatures on nitrogen contents of *Casuarina cunninghamiana* seedlings grown with two *Frankia* sources, with applied nitrogen and with no nitrogen source (Experiment 1). Bars indicate standard errors of the mean.

REDDELL, P., BOWEN, G. D. and ROBSON, A. D. (1985), THE EFFECTS OF SOIL TEMPERATURE ON PLANT GROWTH, NODULATION AND NITROGEN FIXATION IN *CASUARINA CUNNINGHAMIANA* MIQ.. *New Phytologist*, 101: 441-450. doi:[10.1111/j.1469-8137.1985.tb02850.x](https://doi.org/10.1111/j.1469-8137.1985.tb02850.x)



# Root Zone Temperature

## Winter and Summer 2014





# Biomass difference with different soil moisture and soil temperature

The vineyard owner observed earlier leafing, later foliage when soil moisture is higher and soil temperature is higher. There may be other factors contributing to this.

When trees shed leaves in fall, it may not only because the temperature is low, it may also because root has a reduced its function in lower temperatures. The reduced function forces trees to shed leaves





# Fire Damage Healthy Roots => Resilience





# Slope, Site



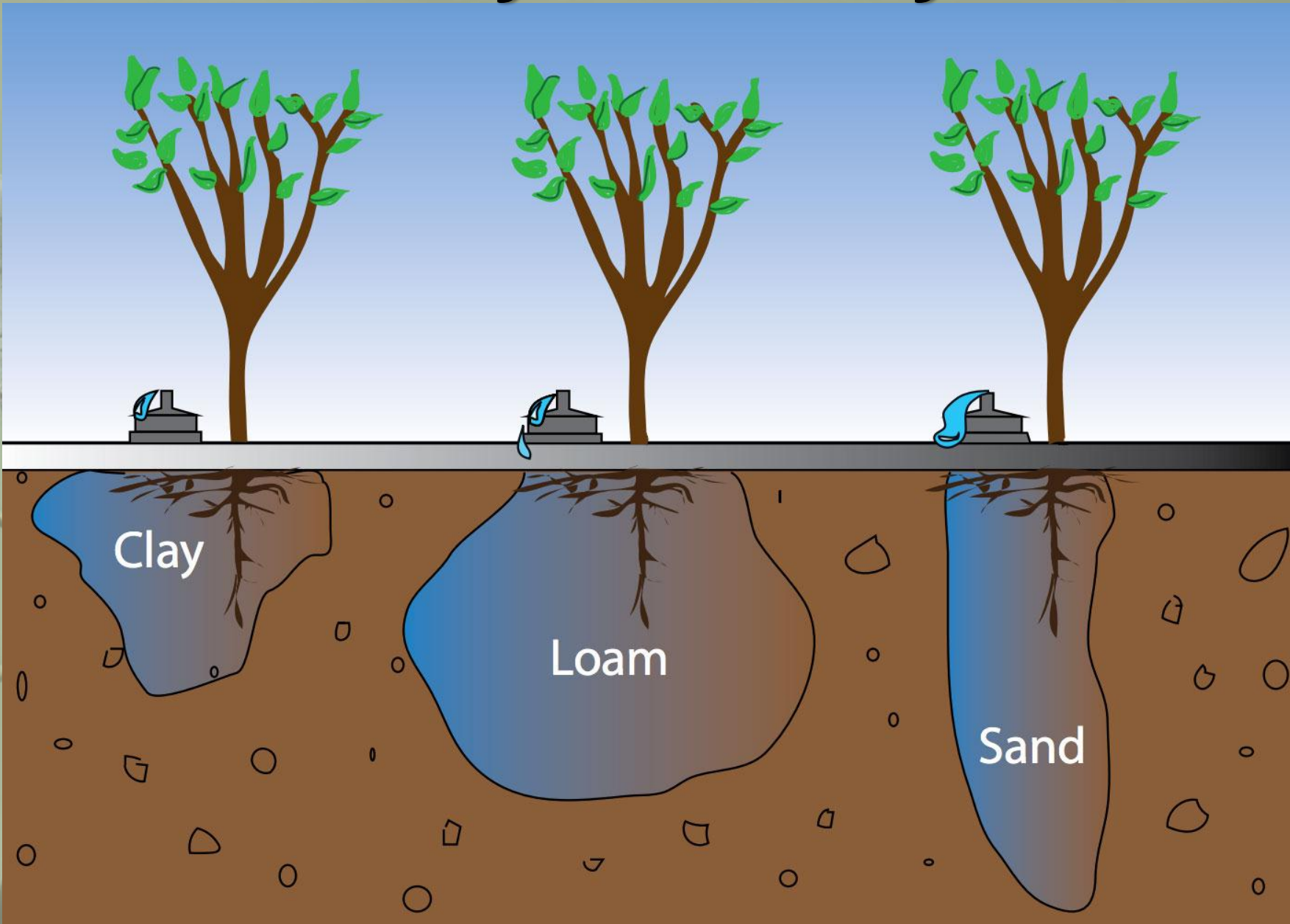


# Limited and compacted soil!





# Sandy Soil: Clay Soil





# Deicing Salt Damages on Plants



Photo by Janna Beckerman



Photo: J. LaForest  
University of Georgia



# On-Going Bioretention Trial against Salts



12/20/2019



# **Solution to Snow Melt Issue: Dissolve, Dilute and Wash off**

Charged super absorbent particles would release water when salt is present because the water absorbency in salt water is lower.

This reaction can be used to help mitigate salt stresses on plants by dissolving, diluting and washing off it from the soil.

**Watch the Demo!**



# Questions

## Important Factors for Tree Survival and Thrival in Urban Environments

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