Water is the Link for Soil, Plant, and Atmosphere Continuum

Soo-Hyung Kim, Ph.D.
Assistant Professor
UW Botanic Garden / School of Forest Resources
College of the Environment
University of Washington
Overview

- Soil-Plant-Atmosphere Continuum
  - Function of water in plants
  - Plant response to water stress
  - Plant adaptation to water stress
- Redistribution of water by plants
- Methods to mitigate water stress
- Questions
Water and plants

- Water availability limits the productivity in many ecosystems

- Functions within a plant
  - Most of plant fresh weight comes from water (up to 90%)
  - Provide structure and support
  - Source of oxygen release from photosynthesis
  - Medium for transporting nutrients, metabolites, and plant hormones

- Lost by **transpiration** through **stomata**
  - Inevitable consequence of photosynthesis
Leaf gas-exchange
Stomata

Opening and closing are dynamically regulated
Ascent of Sap: How does water move to the tree top?

- “By suction”
- Where does the driving force for this suction come from?
- Water in the xylem is under tension
  - Water evaporating from the leaves (transpiration) creates this tension (i.e., suction)
  - Cohesion among water molecules provides a continuous water column
- Dixon and Joly (1894)
  - Cohesion-Tension theory

Soil-Plant-Atmosphere Continuum (SPAC)

Outside air $\Psi$ = $-100.0$ MPa

Leaf $\Psi$ (air spaces) = $-7.0$ MPa

Leaf $\Psi$ (cell walls) = $-1.0$ MPa

Trunk xylem $\Psi$ = $-0.8$ MPa

Root xylem $\Psi$ = $-0.6$ MPa

Soil $\Psi$ = $-0.3$ MPa
How can we test this theory?  
Use a pressure chamber (aka, pressure bomb)
Soil water movement

- Evapotranspiration (ET)
  - Transpiration stream towards plants
    - Nutrients tag along
  - Surface evaporation

- Runoff

- Infiltration and seepage
Plant responses to water deficit

- Cell expansion slows down in the leaves
- Close the valves (stomata)
- Plants send more carbon to roots
- Shed leaves
- Accumulate solutes and hormones in the cells
  - Osmotic adjustments
- If dehydration continues?
  - The water column breaks (cavitation)
Plant adaptation to limited water

- **Drought tolerators**
  - Many evergreen perennials
  - Sclerophyllous leaves, osmotic adjustment, conservative water use

- **Drought avoider**
  - Annuals, drought deciduous perennials
  - Timing of activities

- **Drought escaper**
  - Phreatophytes (deep rooted)
  - Reach water unavailable to other plants
  - Hydraulic lift, hydraulic redistribution
Plant adaptation to limited water

- Xylem vessel diameter

![Graph depicting xylem vessel diameter and water pressure relationship for different species.](image-url)
Plant adaptation to limited water

- Drought escapers and hydraulic redistribution of water

Artiumis tridentata (sagebrush)
Water redistribution to neighboring plants

Windriver Gifford Pinchot Forest

Brooks et al., 2006
Really redistributed by plants?

**Figure 7.** Profiles of deuterated water in soil samples collected at three distances from the watering site 36 d after the application of deuterated water began. 

Brooks et al., 2006
Interesting findings but implications?

- Potential pathways
  - Liquid and vapor transport through soils
  - Through plant roots
  - Through mycorrhizal network

- Potential ideas for plant selection in water-wise landscapes
  - Mix in hydraulic redistributors in the landscape
  - Drip irrigate those plants for redistribution
  - Disclaimer: *This idea has not been tested!*
Methods to Reduce Water Stress of Conifer Seedlings in Seattle Forests

Lisa Ciecko, MSc

University of Washington
School of Forest Resources
Center for Urban Horticulture
EXPERIMENTAL TREATMENTS

WOOD CHIP MULCH

DRIP IRRIGATION

IRRIGATION GEL

2 x 3 Factorial:
- control
- irrigation gel
- drip irrigation
- mulch
- mulch + irrigation gel
- mulch + drip irrigation
SPECIES

GRAND FIR > WESTERN RED CEDAR > WESTERN HEMLOCK
LOCATION

West Duwamish Greenbelt

Interlaken Park

Seattle Parks
Measurements

- **Site Conditions**
  - Soil chemical analysis
  - Soil texture
  - Canopy cover
  - Microclimate

- **Soil Moisture**
  - Watermark sensors

- **Tree Health and Growth**
  - Height and diameter
  - Root and shoot biomass
  - Survivorship

- **Stem Water Potential**
  - Pre-dawn plant water status
Western Hemlock
March 2008

Western Hemlock
August 2008
Soil Moisture: West Duwamish

A) West Duwamish

Soil Water Potential (kPa)

Precipitation (mm)

Irrigation Dates

Precipitation

Mulch

Mulch + Gel

Mulch + Gel + Irrigation

Control

Gel

Irrigation

mulch effect

mulch effect
All mulch increased survival (p = 0.020)

All mulch increased survival (p = 0.062)
Stem Water Potential in Summer of Year 1

**Abies grandis**

- Interlaken
- West Duwamish

**Tsuga heterophylla**

- Interlaken
- West Duwamish

**Thuja plicata**

- Interlaken
- West Duwamish

*Note: Treatment labels and statistical significance indicators (a, b, *, **) are present in the diagrams.*
SUMMARY

- To test the influence of:
  - Coarse wood chip mulch
  - Drip irrigation
  - Irrigation gel

- To understand each treatments influence on water stress

- To characterize environmental conditions at two parks

- Significant park differences

- No treatment influence at West Duwamish

- Mulch treatments had the most influence on at Interlaken

- Soil texture influenced soil moisture
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Thank you

Contact: soohkim@u.washington.edu
Methods for estimating landscape water use

WUCOLS 2000: Water use classification of landscape species
www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf
Weather (ET) based irrigation management

- Concept derived from crop irrigation

- Weather-based irrigation systems determine water requirement based on:
  - ET (Evapotranspiration): Soil evaporation + plant transpiration
    - \( ET = ET_0 \times K_c \)
    - \( ET_0 \): reference (or potential) ET
  - \( ET_0 \): Value available from weather station data
    - Determined by pan evaporation, cool-season turf, or model
  - \( K_c \): Crop coefficient
Adjustments for landscape plants

- Adjust it to meet landscape ET (ET\textsubscript{L})
  - ET\textsubscript{L} is determined in reference to ET\textsubscript{0}
- Adjust it by:
  - K\textsubscript{c} – crop [species] coefficient
  - K\textsubscript{h} – hydrozone [microclimate] coefficient
  - K\textsubscript{d} – density [canopy area] coefficient
- Landscape coefficient (K\textsubscript{L})
  - K\textsubscript{L} = K\textsubscript{c} * K\textsubscript{h} * K\textsubscript{d}
- ET for a landscape planting (ET\textsubscript{L})
  - ET\textsubscript{L} = ET\textsubscript{0} * K\textsubscript{L}
- Amount of water to apply (W)
  - W = ET\textsubscript{L} / AE
  - AE = application efficiency
Worksheet for Estimating Landscape Water Needs

Step 1: Calculate the Landscape Coefficient ($K_L$)

$$K_L \text{ formula: } K_L = k_s \times k_d \times k_{mc} \text{ ......................... } k_s = \text{species factor}$$
$$k_d = \text{density factor}$$
$$k_{mc} = \text{microclimate factor}$$

$k_s = _____$ (range = 0.1-0.9) (see WUCOLS list for values)

$k_d = _____$ (range = 0.5-1.3) (see Chapter 2)

$k_{mc} = _____$ (range = 0.5-1.4) (see Chapter 2)

$$K_L = \frac{_____ \times _____ \times _____}{(k_s) \times (k_d) \times (k_{mc})} = _____.$$  

Step 2. Calculate Landscape Evapotranspiration ($ET_L$)

$$ET_L \text{ formula: } ET_L = K_L \times ET_0 \text{ .............................. } K_L = \text{landscape coefficient}$$
$$ET_0 = \text{reference evapotranspiration}$$

$K_L = _____$ (calculated in Step 1)

$ET_0 = _____$ inches (listed in Appendix A for month and location)

$$ET_L = \frac{_____ \times _____}{(K_L) \times (ET_0)} = _____$$ inches.

Step 3. Calculate the Total Water to Apply (TWA)

$$TWA \text{ formula: } TWA = \frac{ET_L}{IE} \text{ .............................. } ET_L = \text{landscape evapotranspiration}$$
$$IE = \text{irrigation efficiency}$$

$ET_L = _____$ (calculated in Step 2)

$IE = _____$ (measured, estimated, or set) (see Chapter 5)

$$TWA = \frac{ET_L}{IE} = _____$$ inches
$K_L$ values vary with species and environment
$K_L$ values are closely correlated with density factor

Data source: Dr. Roger Kjelgren, Utah State Univ.