Drought tolerance

Why does it matter? And what should you do about it?

Jon Banks

Aim

- To understand drought and drought tolerance.
  - Drought associated pathogens
- Why drought tolerance might be useful to you?
- Why it might not be useful?
- Bartlett drought recovery program

Species Selection for Gre × | Tree Selection for Green I ×

org.uk/species-selection-for-green-infrastructure.html

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Species Selection for Green Infrastructure: A Guide for Specifier

How can we improve species selection so that we can provide our towns and cities with diverse and resi
trees that are capable of thriving in challenging urban environments? Due to be released in July 2018, t
guide will offer for the first time in the UK a comprehensive decision-making support tool for enhancing
services provision through tree species selection. Designed as a user-friendly searchable resources, th
provide research-based informations on characteristics, natural habitat, environmental tolerances, orn
issues to be aware of, notable varieties and use potential of a wide range of tree species.

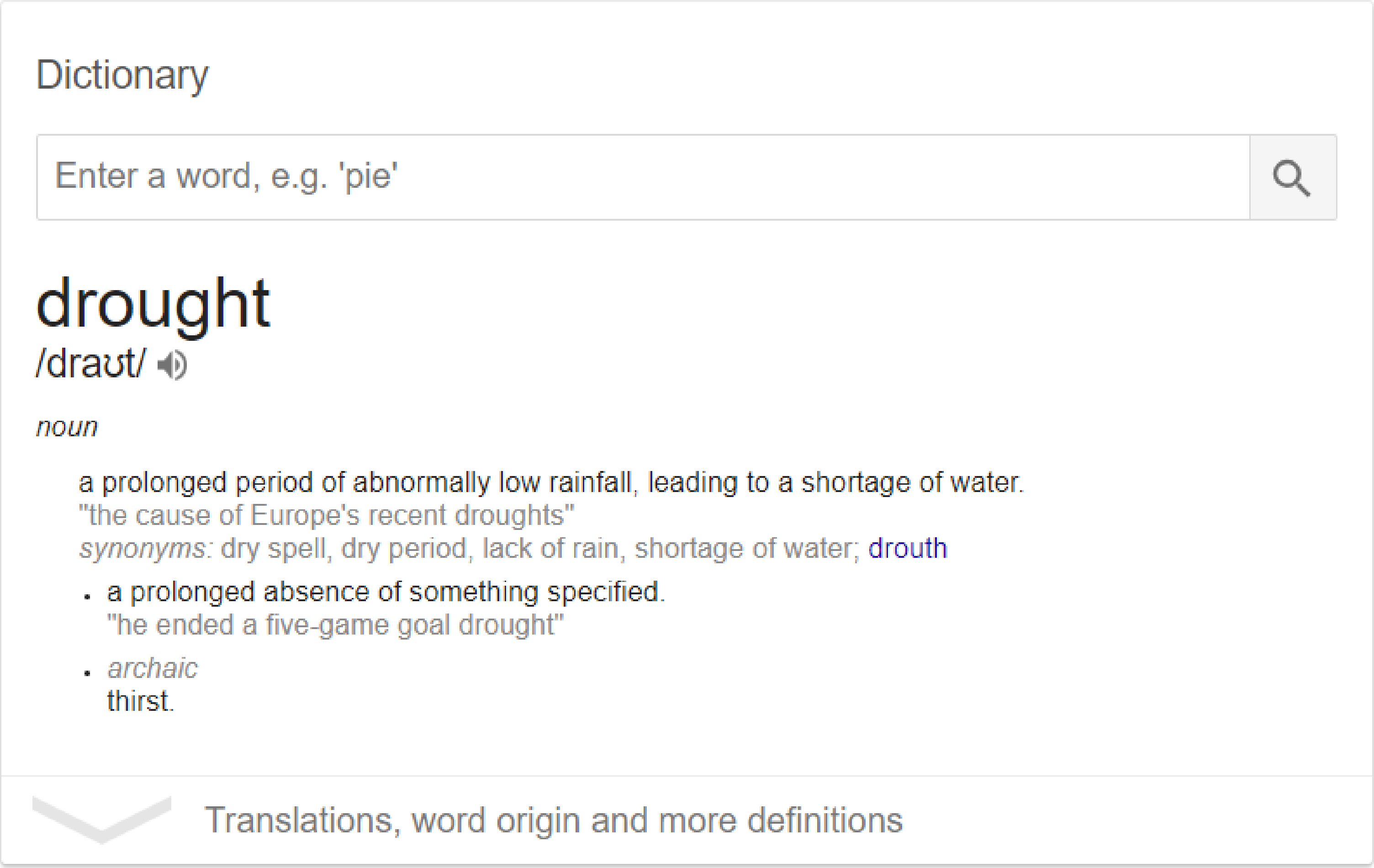
To be notified as soon as the guide is released, please register your interest **here**.

Sign up to receive the guide as soon as it is published.

Email Address

jbanks@bartlettuk.com

What is drought?



Dictionary

Enter a word, e.g. 'pie'

drought
/draʊt/

noun

a prolonged period of abnormally low rainfall, leading to a shortage of water.
"the cause of Europe's recent droughts"
synonyms: dry spell, dry period, lack of rain, shortage of water; drouth

- a prolonged absence of something specified.
  "he ended a five-game goal drought"
- *archaic*
  thirst.

Translations, word origin and more definitions

What is drought?

- “Drought … prevents plants from realizing their **full genetic potential**”

(Zhu 2002. Salt and Drought Stress Signal Transduction in Plants. Annu Rev Plant Biol. 2002 ; 53: 247–273. (4475 citatons))

- “Dimensions of drought: (1) when a percentage of normal rainfall is received, (2) when **operations** are affected, (3) when a definite amount of rainfall is received, and (4) the **timeliness** of rainfall.

(Dagel 1997. Defining Drought in Marginal Areas: The Role of Perception. Professional Geographer. Volume 49, Number 2, May 1997

- “**Insufficient** water to meet **needs**.”

(Redmond. 2002. The Depiction of Drought. American Meteorological Society)

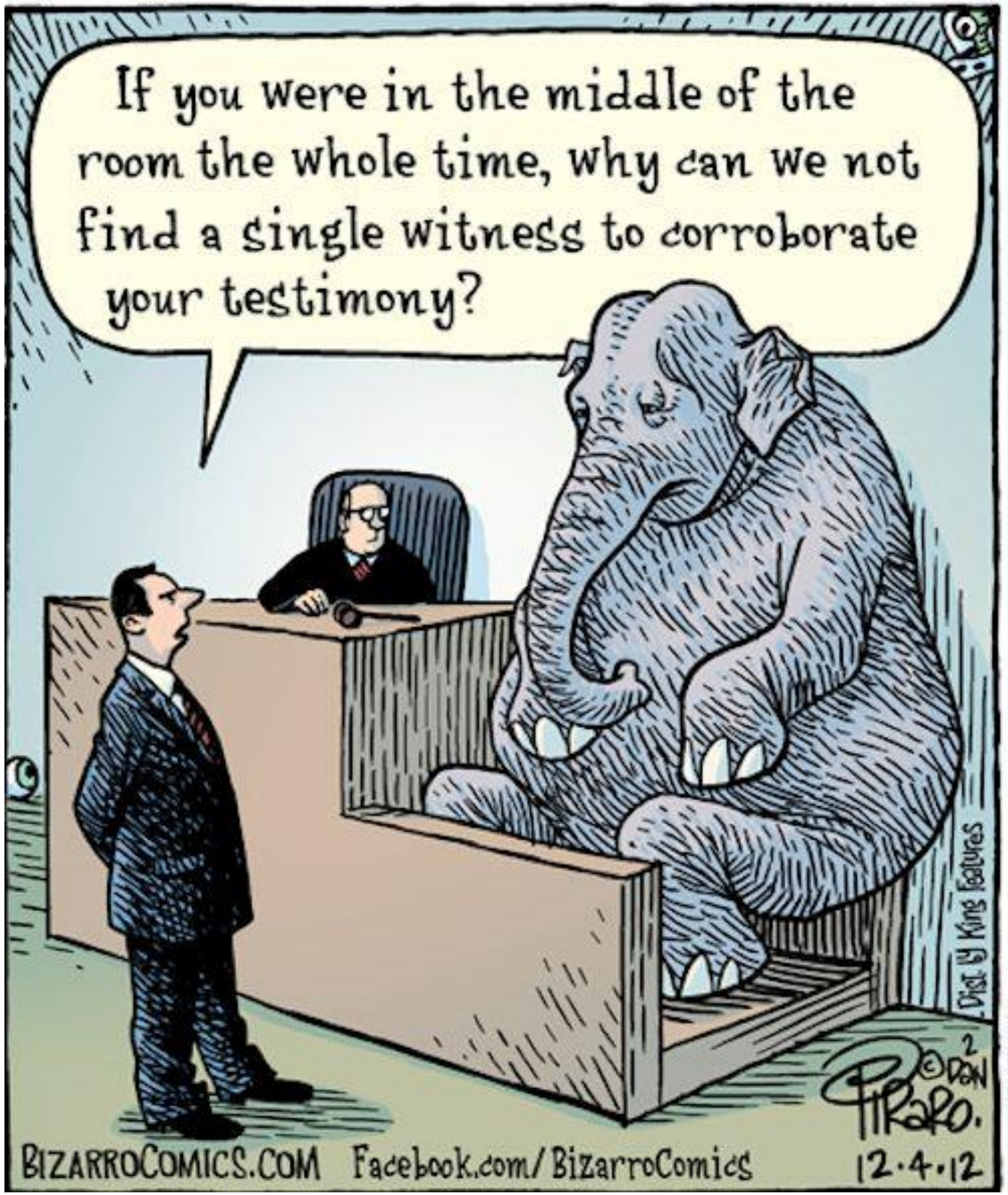
Why Drought?

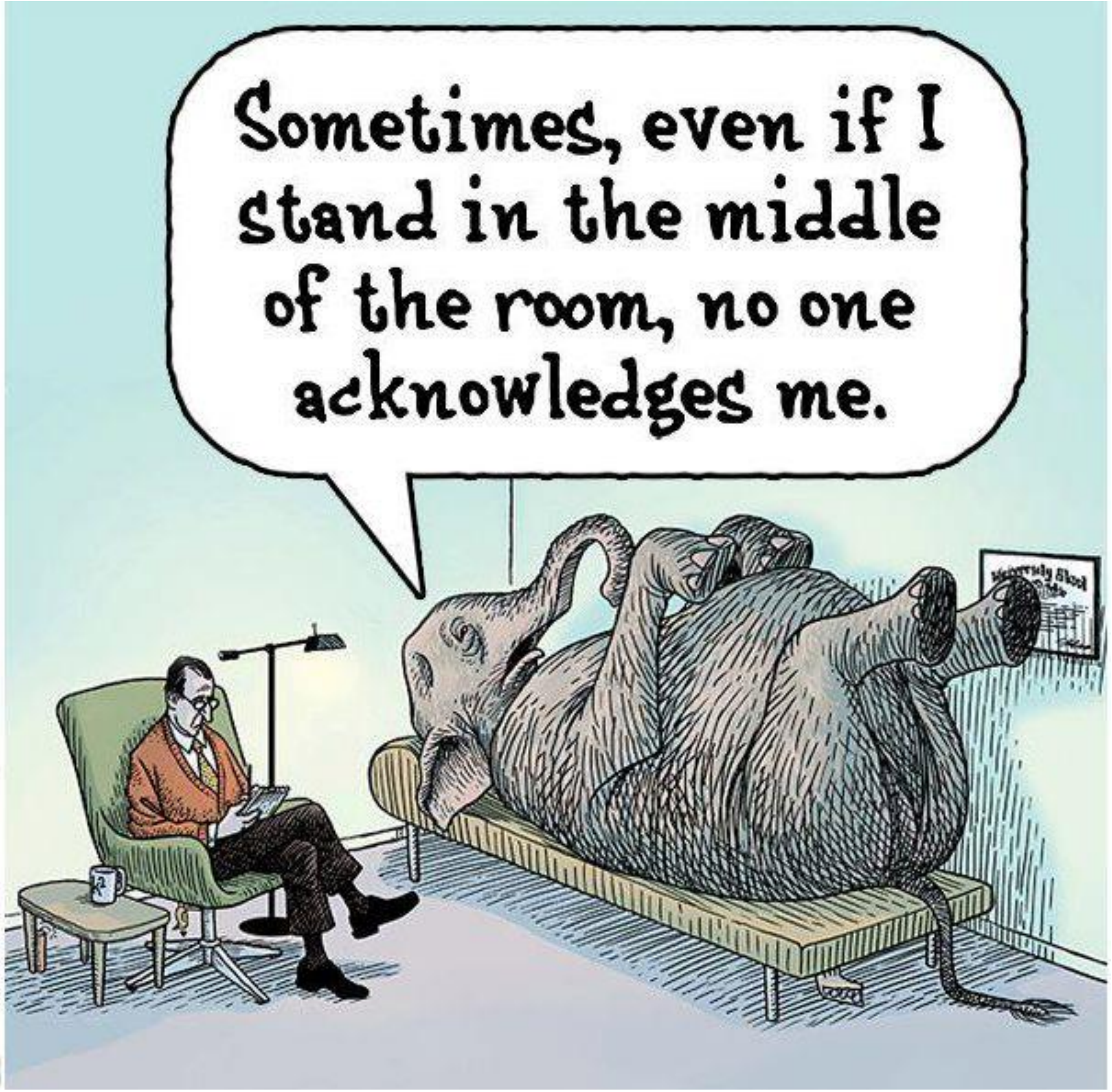
- Drought is the most common and most significant disorder affecting tree establishment and growth (Aranda et al. 2012; Lopez et al. 2012; Kaushal and Aussenac 1989).

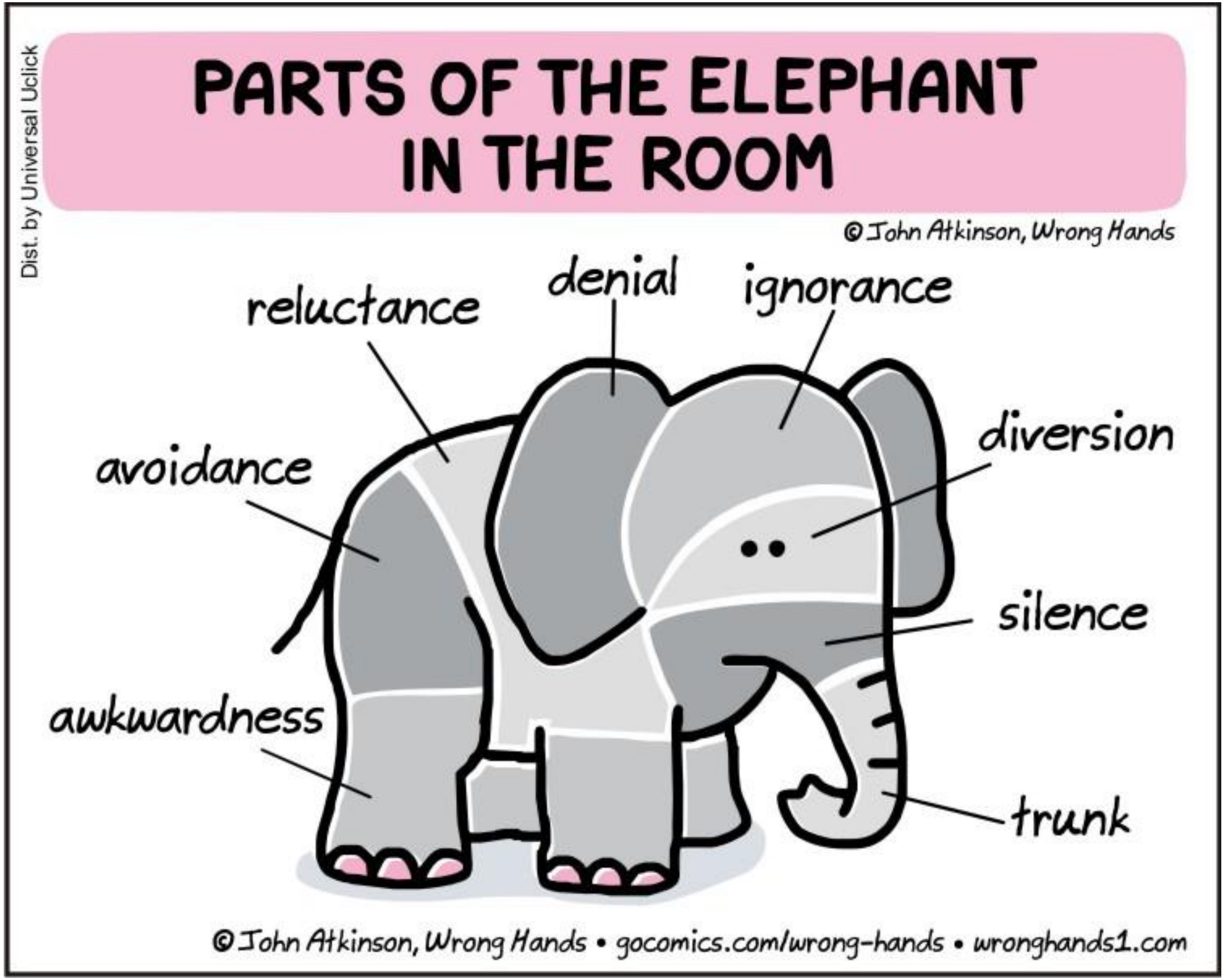
- "15% of the worlds natural disasters originate from drought" (Dagel 1997).

- Foliar symptoms of drought are the most common issue diagnosed in the UK & US Bartlett Tree Diagnostic Laboratories.

- Drought resistance also displays cross-resistance (Taiz and Zeiger 1991).


If you were in the middle of the room the whole time, why can we not find a single witness to corroborate your testimony?
Dist by King Features
© Dan Piraro 2
BIZARROCOMICS.COM Facebook.com/BizarroComics
12.4.12


Sometimes, even if I stand in the middle of the room, no one acknowledges me.


PARTS OF THE ELEPHANT IN THE ROOM
© John Atkinson, Wrong Hands
Dist. by Universal Uclick
reluctance
denial
ignorance
avoidance
diversion
silence
awkwardness
trunk
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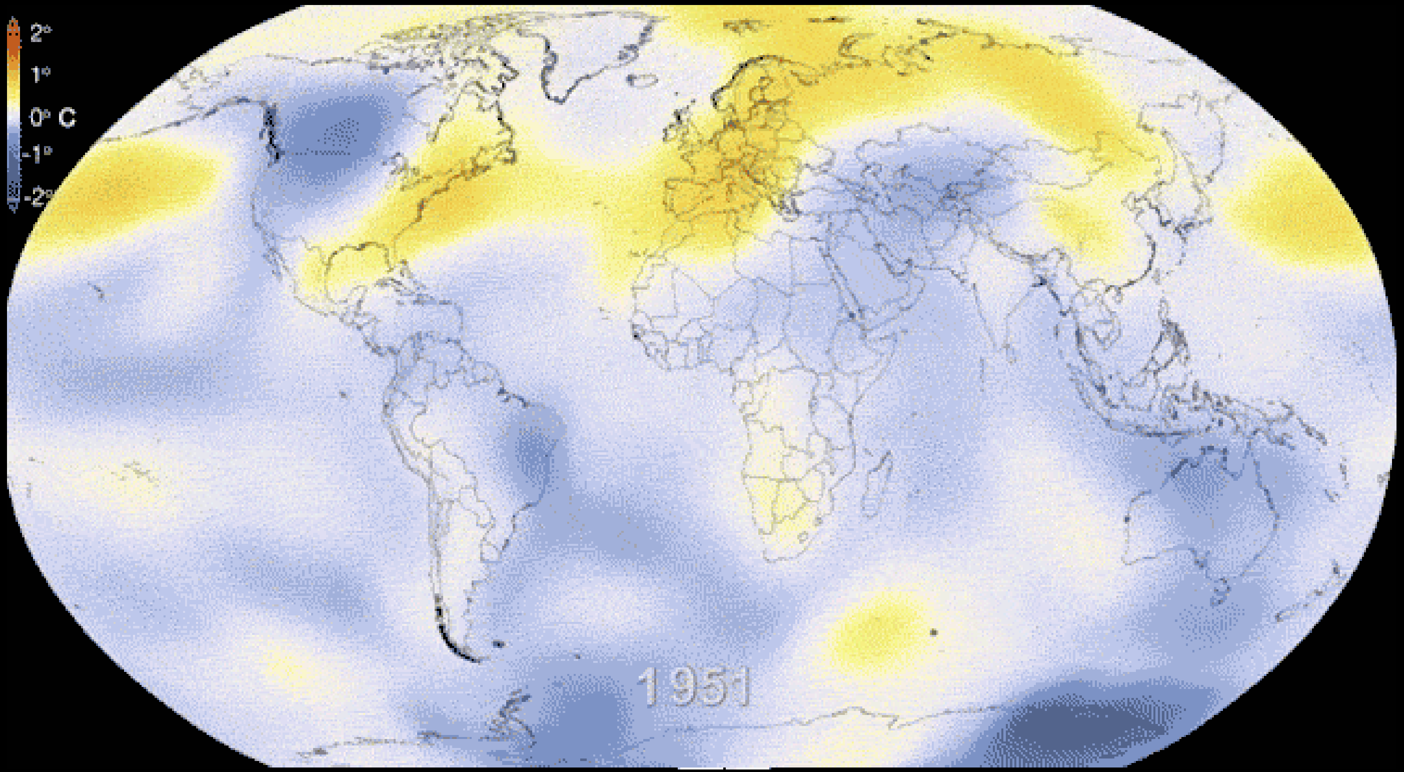
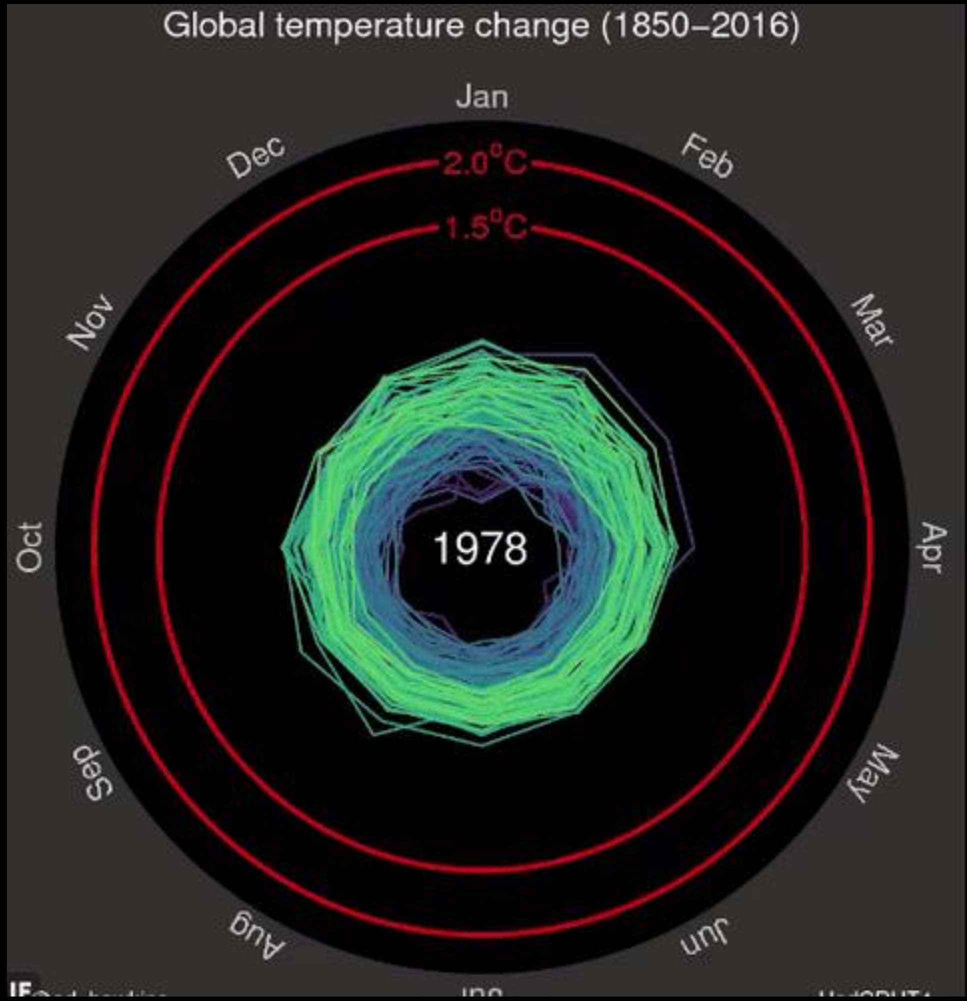
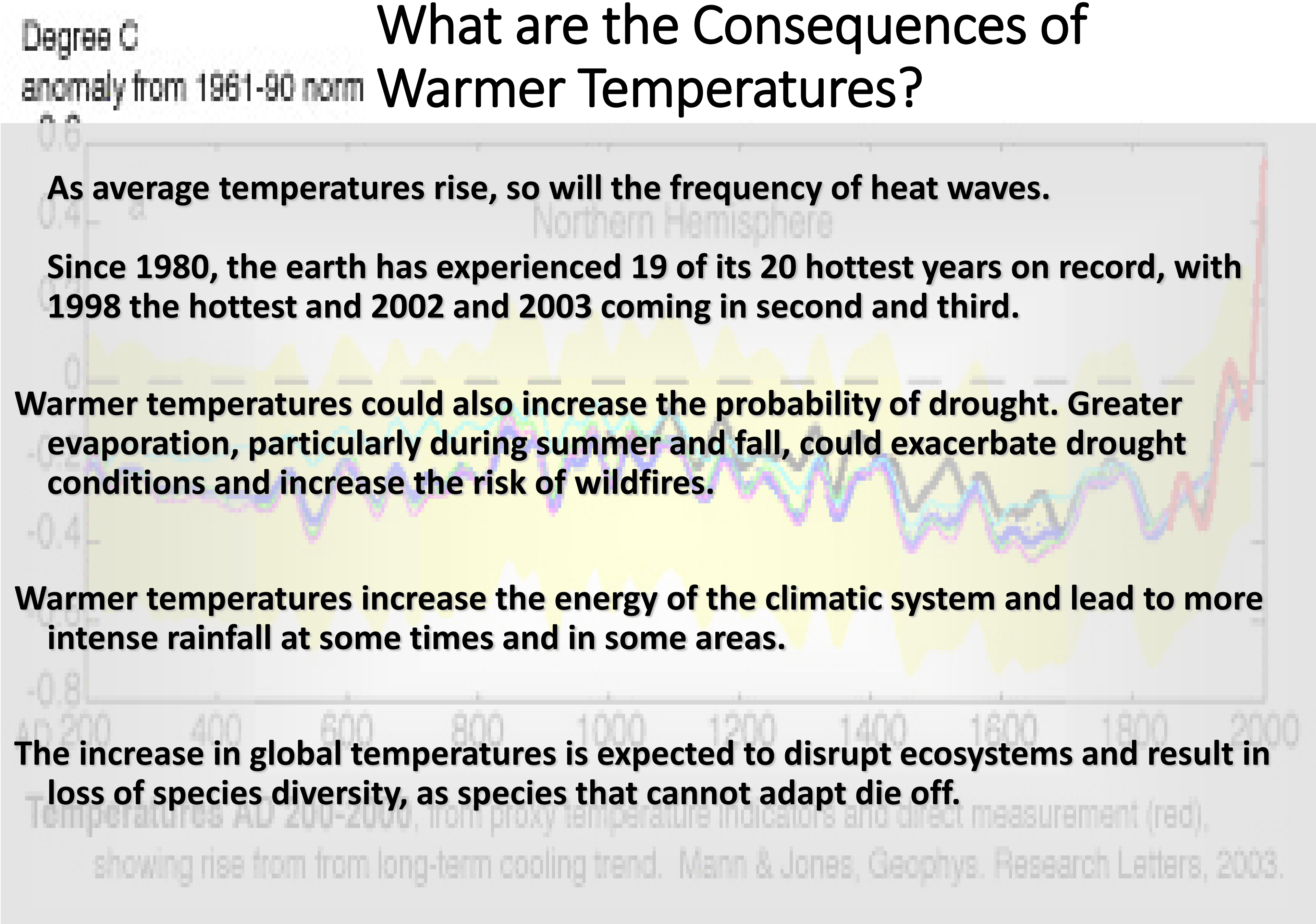


2°
1°
0° C
-1°
1951



Global temperature change (1850–2016)
Jan
Feb
Mar
Apr
May
Jun
Aug
Sep
Oct
Nov
Dec
2.0°C
1.5°C
1978

What are the Consequences of Warmer Temperatures?



As average temperatures rise, so will the frequency of heat waves.

Since 1980, the earth has experienced 19 of its 20 hottest years on record, with 1998 the hottest and 2002 and 2003 coming in second and third.

Warmer temperatures could also increase the probability of drought. Greater evaporation, particularly during summer and fall, could exacerbate drought conditions and increase the risk of wildfires.

Warmer temperatures increase the energy of the climatic system and lead to more intense rainfall at some times and in some areas.

The increase in global temperatures is expected to disrupt ecosystems and result in loss of species diversity, as species that cannot adapt die off.

Temperatures AD 200-2000, from proxy temperature indicators and direct measurement (red), showing rise from from long-term cooling trend. Mann & Jones, Geophys. Research Letters, 2003.

“But that’s temperature?”

“What about soil moisture?”

Climate Change Deniers?


Positive proof of global warming.
18th Century
1900
1950
1970
1980
1990


Lets talk trees:

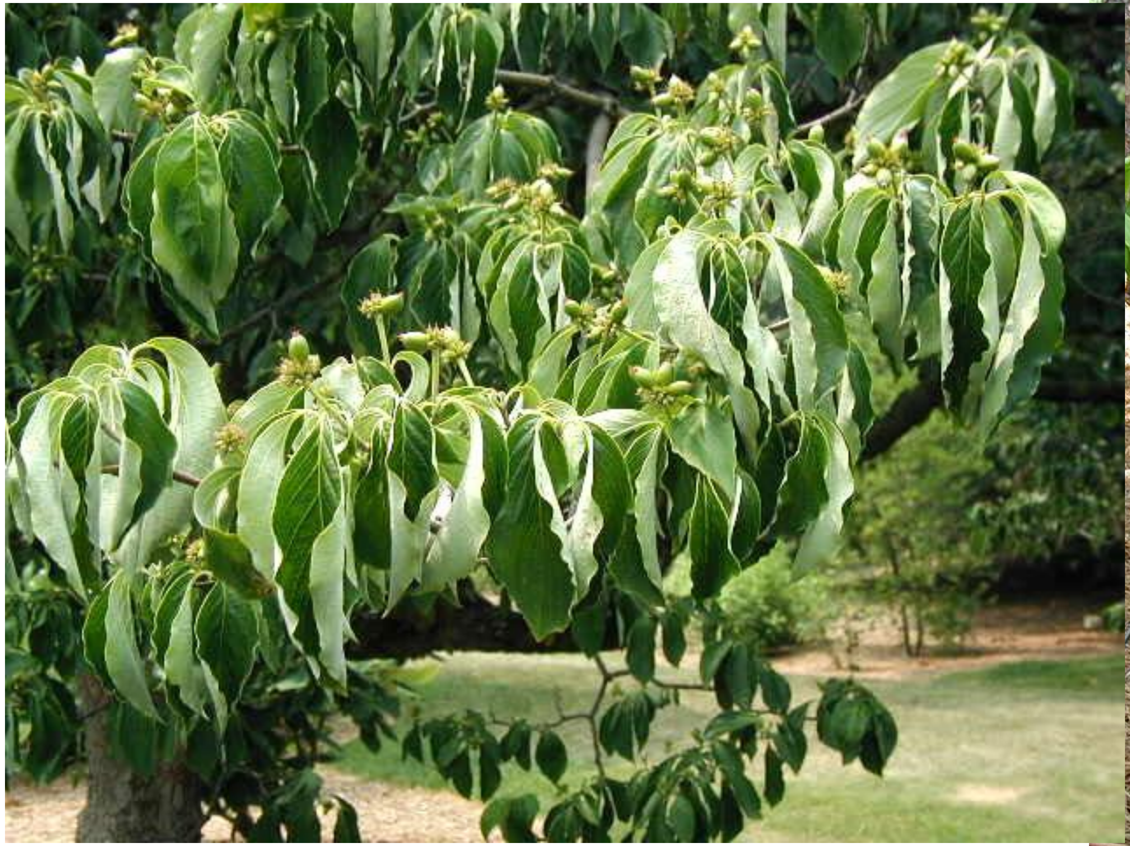
Symptoms:

- Short term:
  - Foliage wilting / rolling
  - Necrosis
  - Leaf loss
  - Branch shedding & drooping
  - P&D susceptibility
  - Death

Dry soil

- Long term:
  - Reduced leaf size
  - Reduced extension growth
  - Root proliferation
  - Plant water relations disturbed
  - Reduces water-use efficiency (variation in dry weight / water used)
  - P&D susceptibility
  - Death

Foliage Wilting is a Typical Symptom of Drought



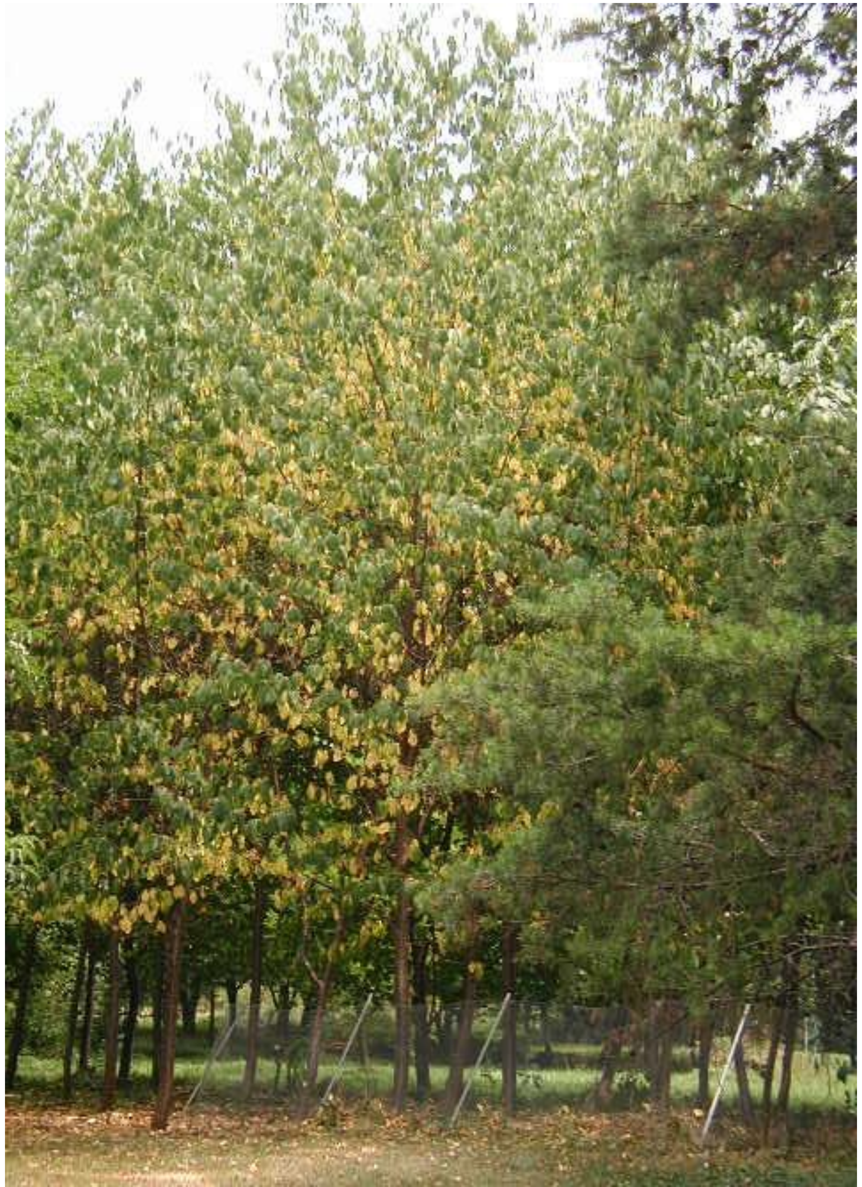
Leaf Scorch is a Common Symptom of Drought

Drought Can Induce Foliar Chlorosis

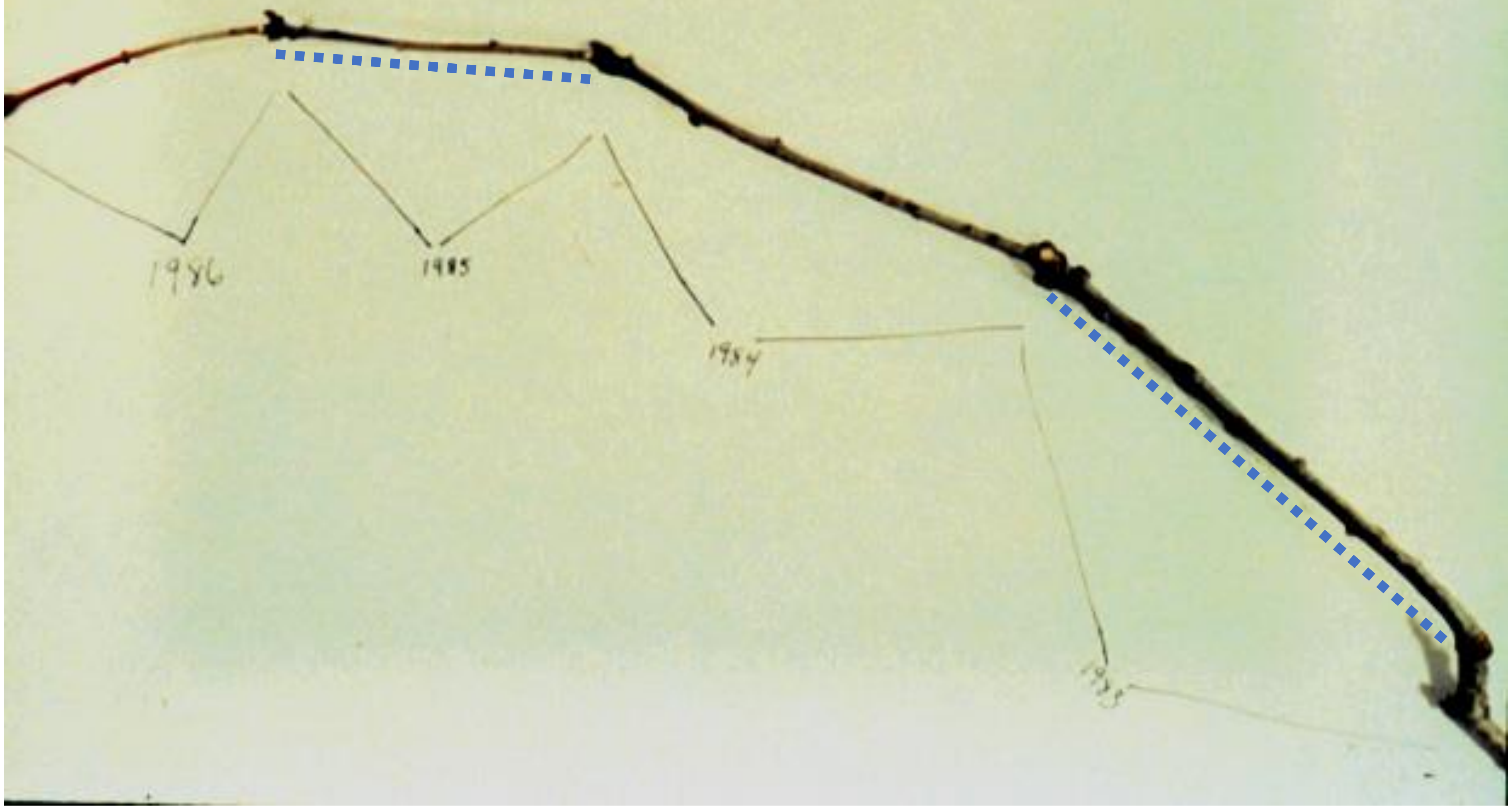
Conifer Dieback and Decline

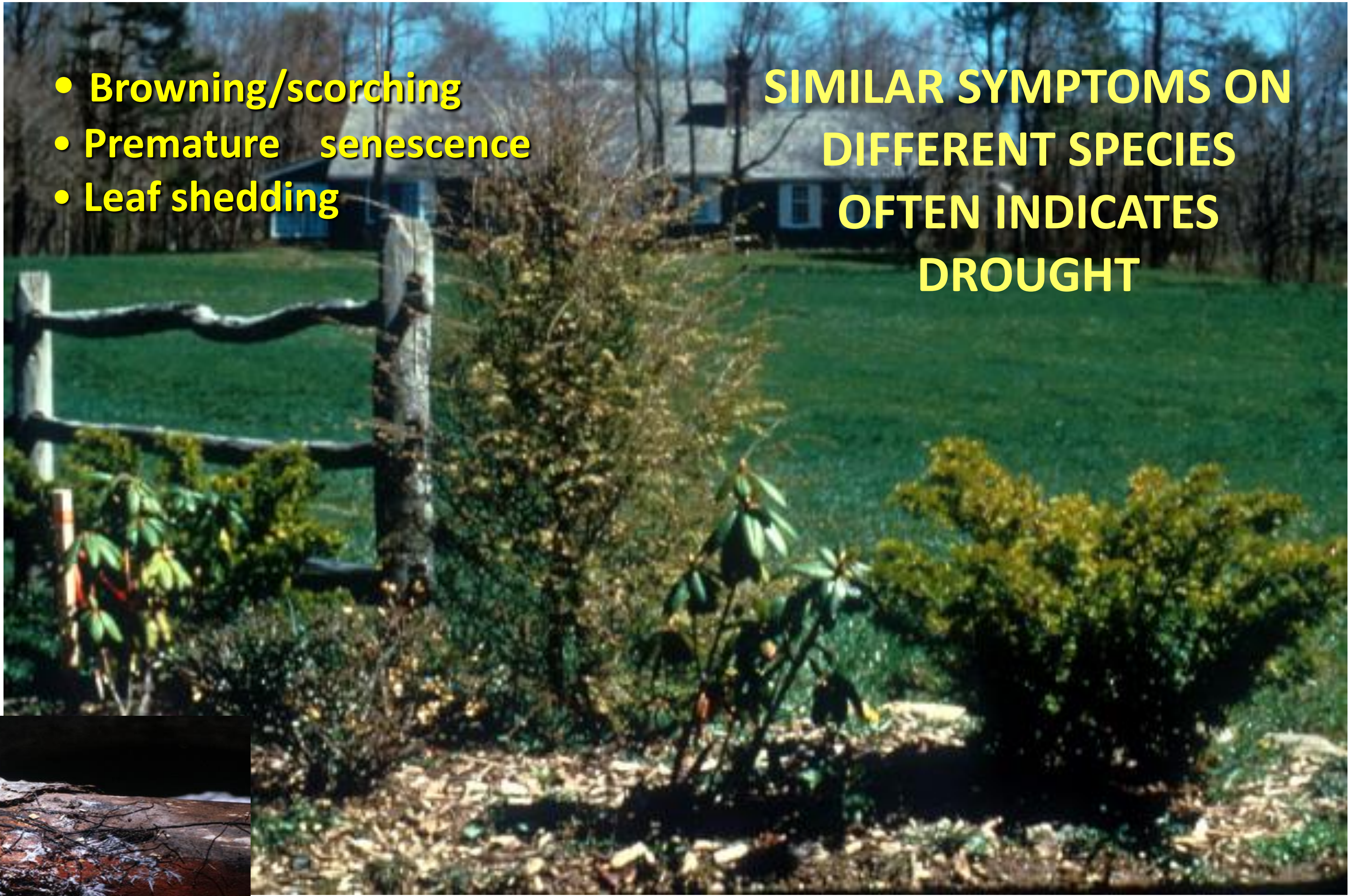
Conifer Dieback and Decline

Premature Defoliation



POOR TWIG GROWTH IS OFTEN A GOOD INDICATOR OF DROUGHT STRESS




• Browning/scorching
• Premature senescence
• Leaf shedding
SIMILAR SYMPTOMS ON DIFFERENT SPECIES OFTEN INDICATES DROUGHT



DROUGHT CAN CAUSE
STARCH DEPLETION IN ROOTS AND TWIGS

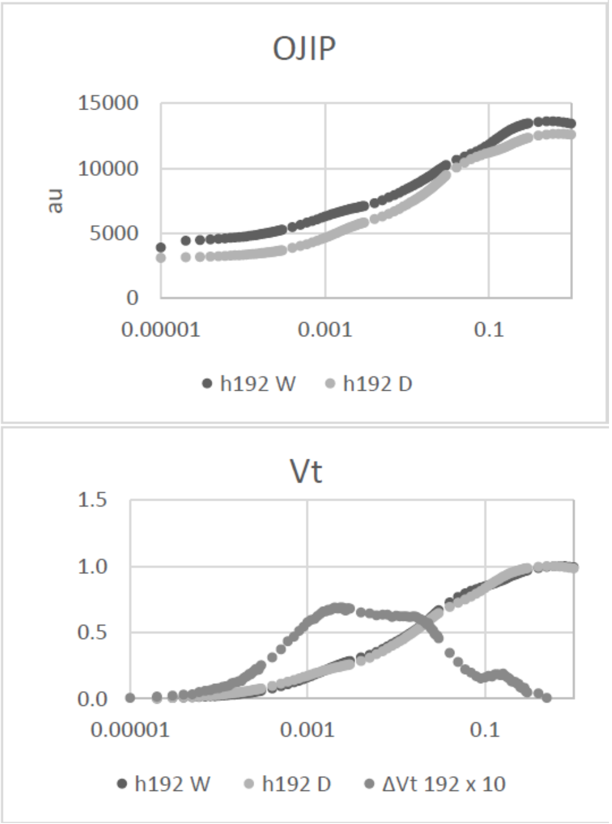
Chlorophyll Fluorescence?

Parameters deemed effective	spp. and source
Fv/Fm	*Fraxinus spp.* (Percival et al. 2006),*Racomitrium sp, Anomodon sp. & Rhytidiadelphus sp.* (Proctor and Smirnoff 2000), *Hordeum vulgare* (Rong- Hua et al. 2006), *Salix sp.* (Ögren 1990), *Quercus petraea* (Epron and Dreyer 1992)
Fv/F_0	*Hordeum vulgare* (Rong- Hua et al. 2006)
F_0	Five woody perennials (Percival and Sheriffs 2002), *Hordeum vulgare* (Rong- Hua et al. 2006)
PI_{ABS}	Triticum aestivum (Živčák et al. 2008)
1-Vi	*Hordeum vulgare* and *Cicer arietinum* (Oukarroum et al. 2009)
DFI	*Hordeum vulgare* (Oukarroum et al. 2007)
DIo, ETo, Tro & ABS	*Fraxinus spp.* (Percival et al. 2006)

Parameters deemed ineffective	spp. and source
Fv/Fm	*Tilia* sp. & *Acer platanoides* cultivars (Fini et al. 2009), Triticum aestivum (Živčák et al. 2008), *Populus maximowiczi* (Desotgiu et al. 2012), Zea mays (Cornic and Fresneau 2002)
Fv/F_0	*Tilia* sp. & *Acer platanoides* cultivars (Fini et al. 2009)
Fp/Fm	*Salix sp.* (Ögren 1990),
F_0	*Tilia* sp. & *Acer platanoides* cultivars (Fini et al. 2009)
qP & qNP	*Populus maximowiczi* (Desotgiu et al. 2012)

Current and Future Possibilities?

Drought



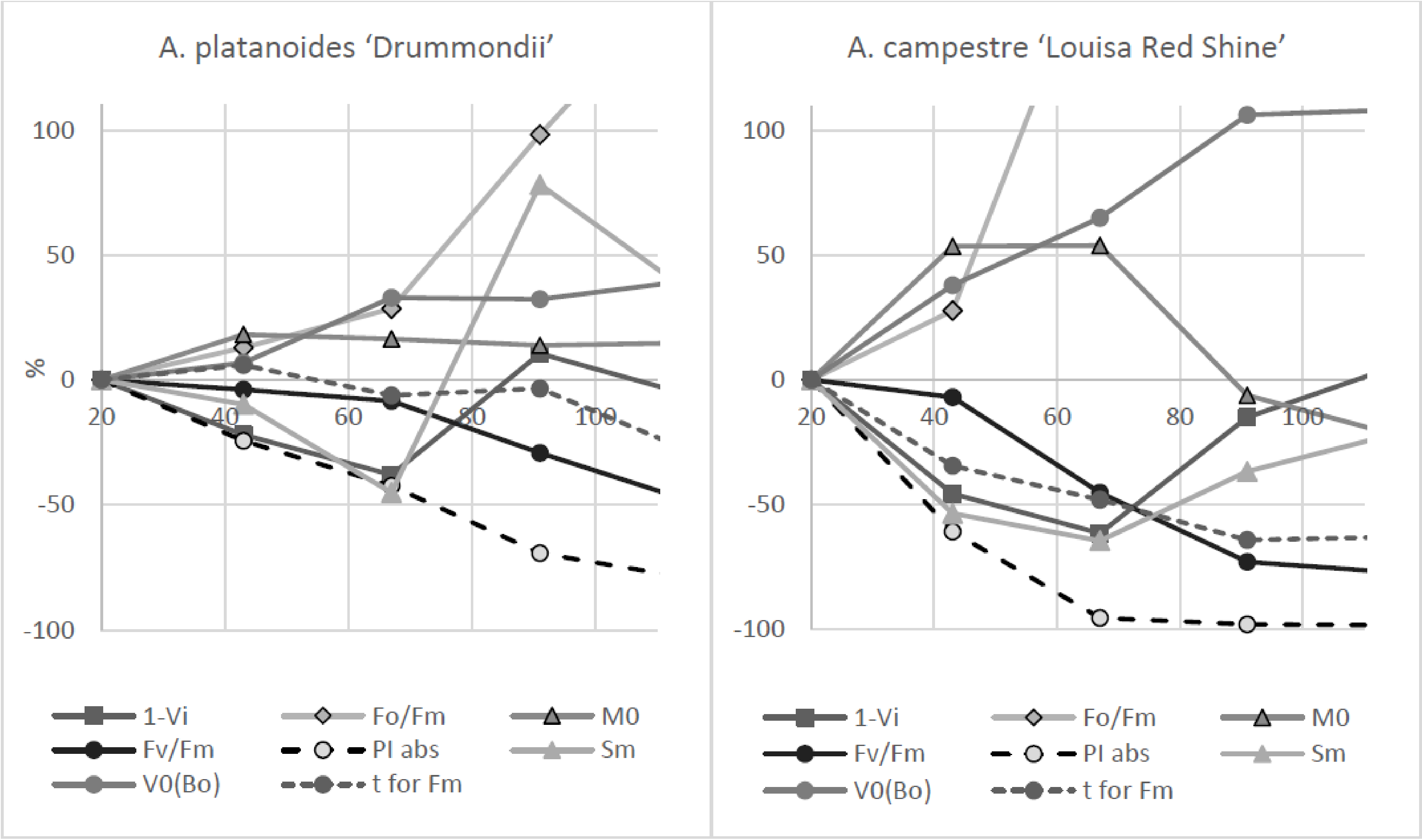
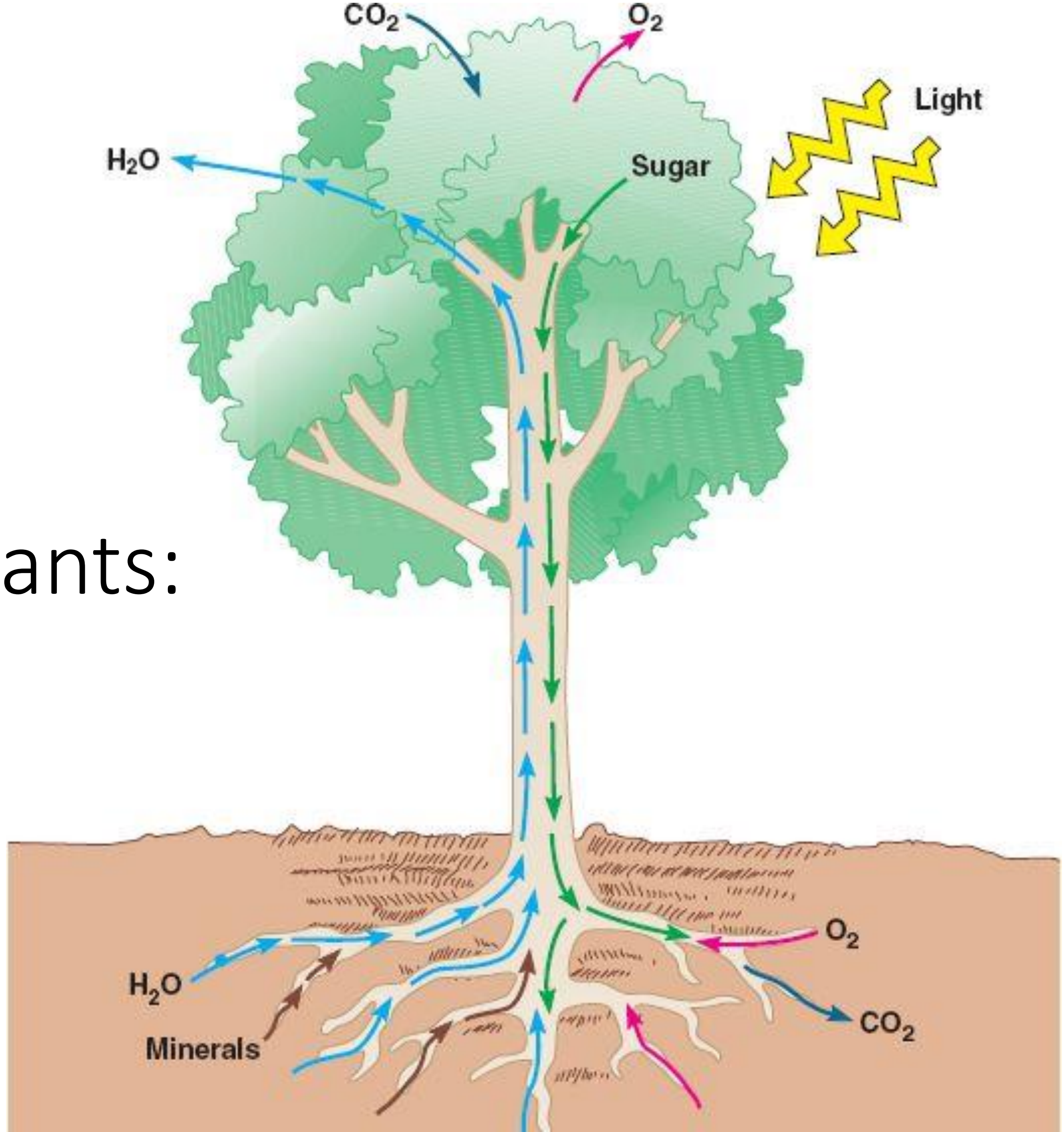
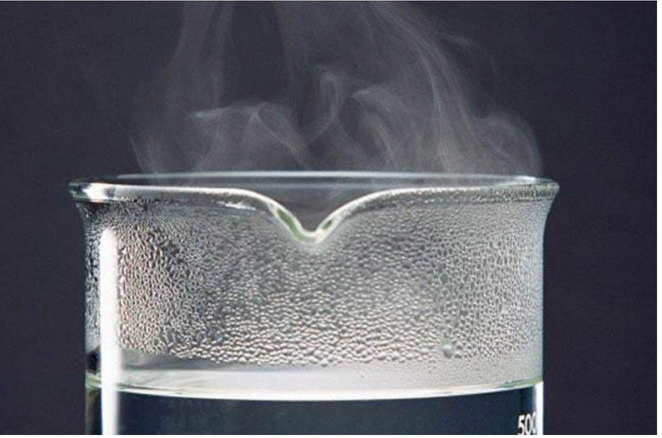


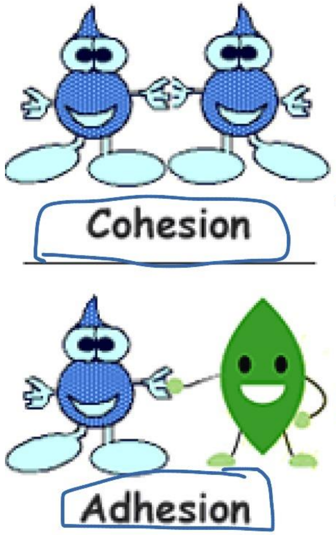
Figure 2 Percentage change in fluorescence parameters in response to desiccation. Results shown for *A. platanoides* 'Drummondii' (drought tolerant) and *A. campestre* 'Louisa Red Shine' (drought sensitive).

Water and Plants:

How does it work?

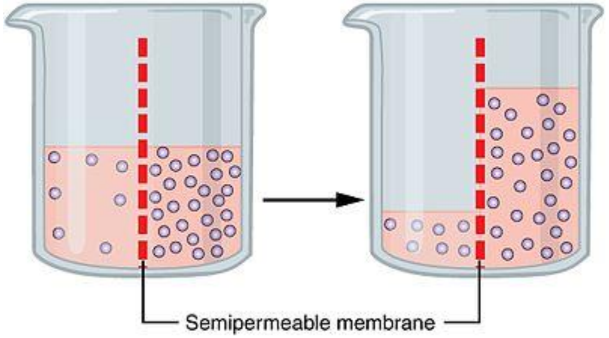


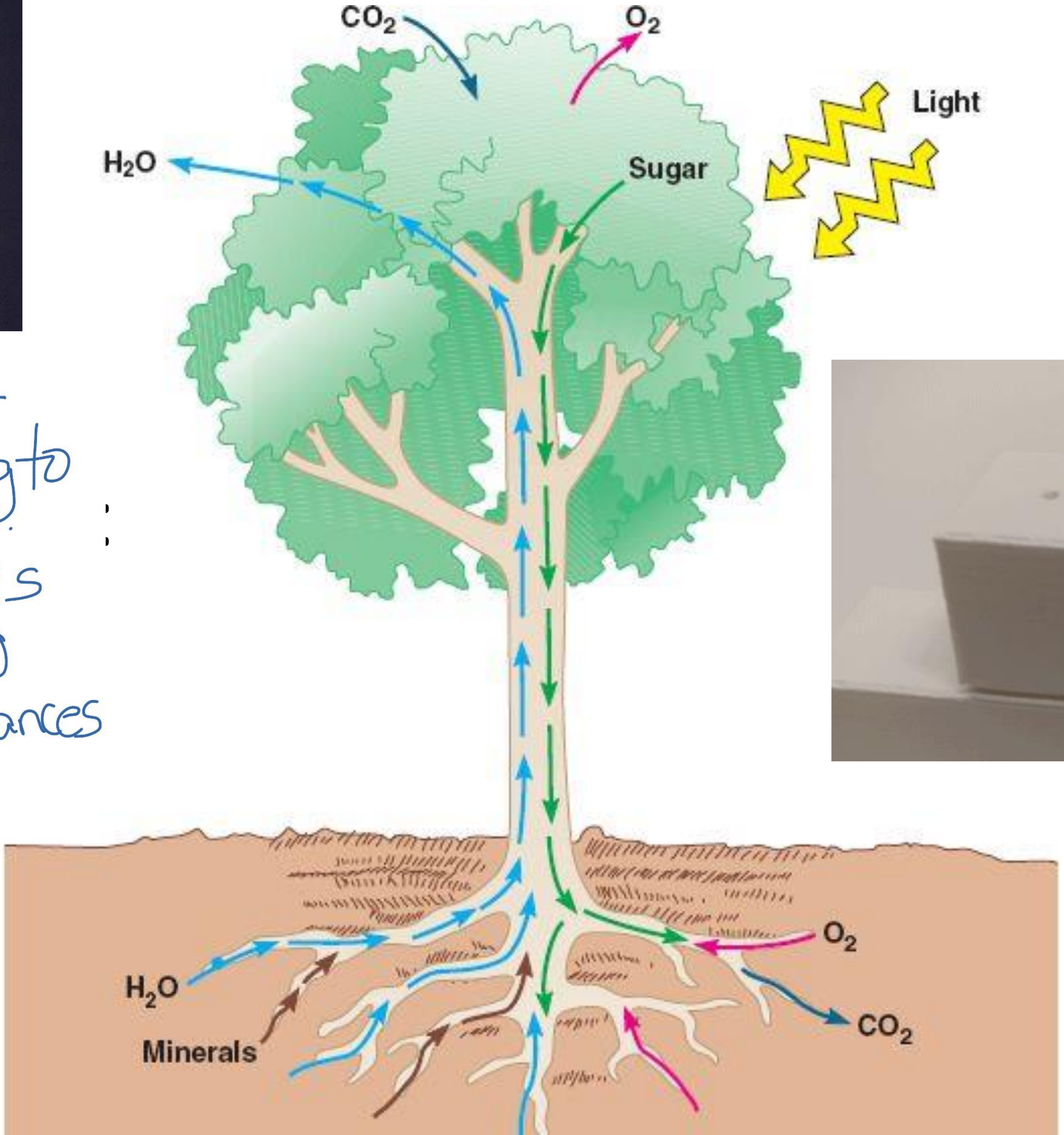




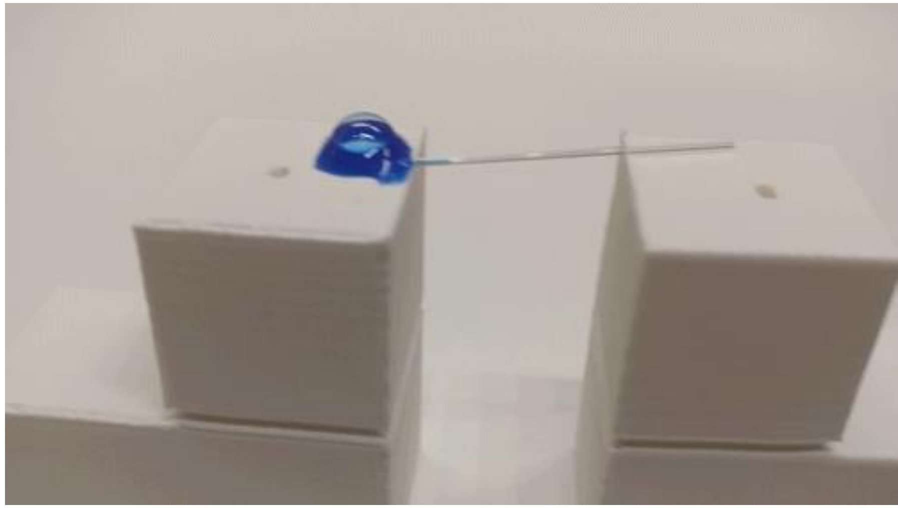
Water sticking to water.

water is sticking other substances



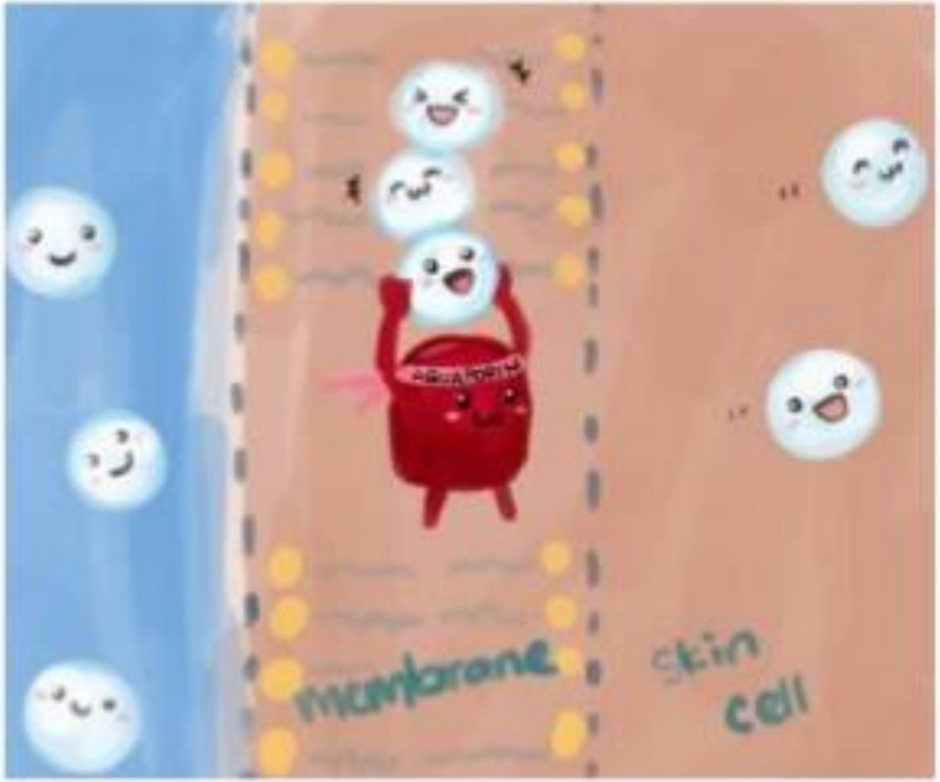


Evapo-transpiration

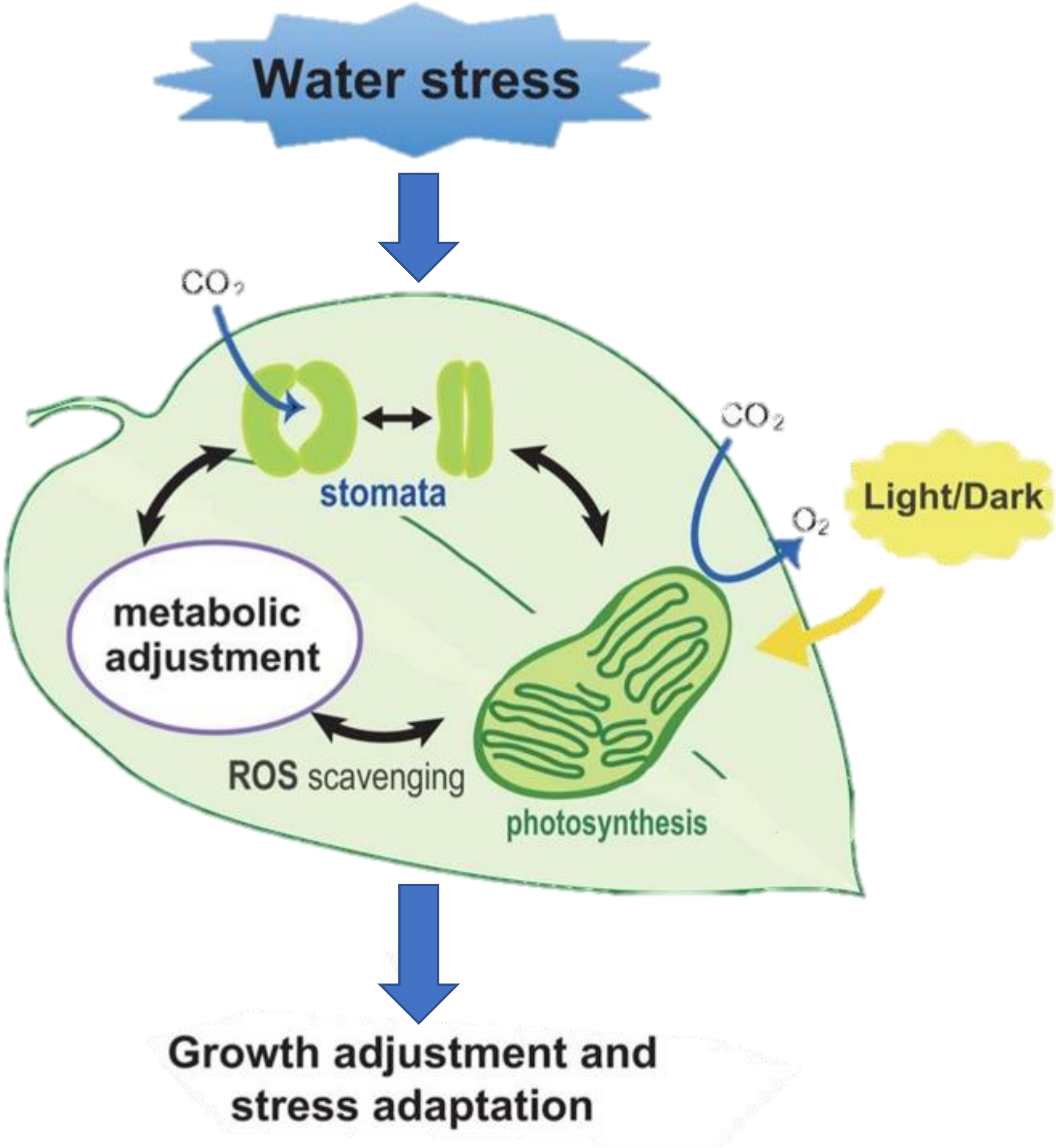


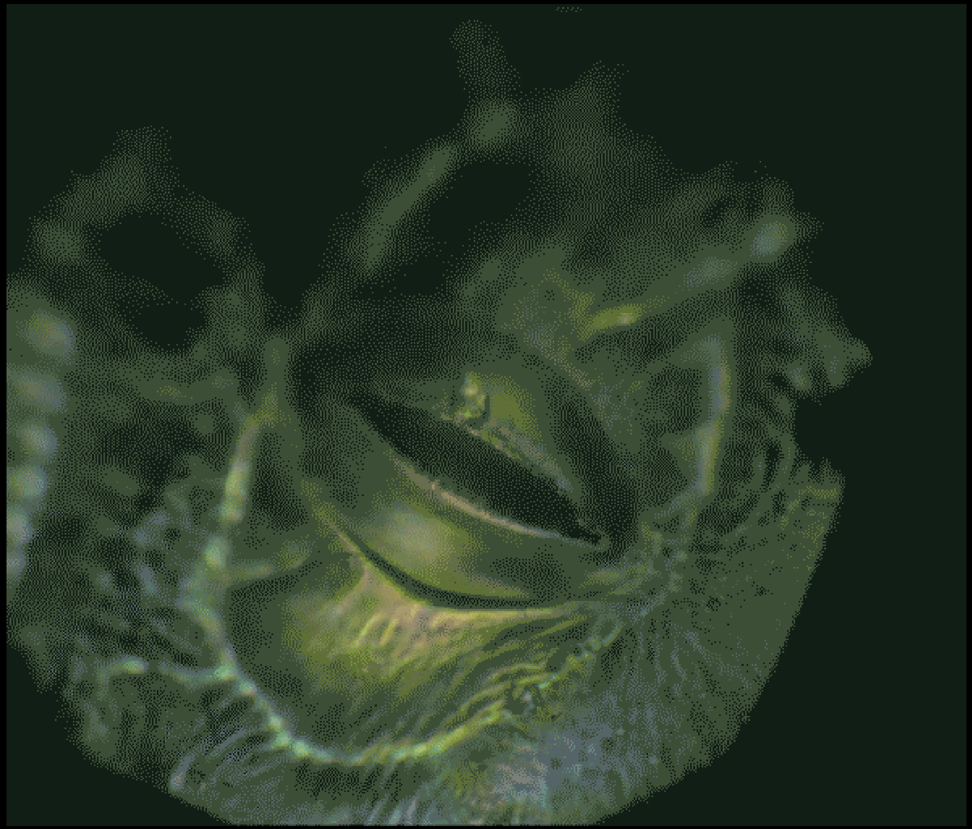
Osmosis

Active water transport - Aquaporins



Water control: *Leaf*



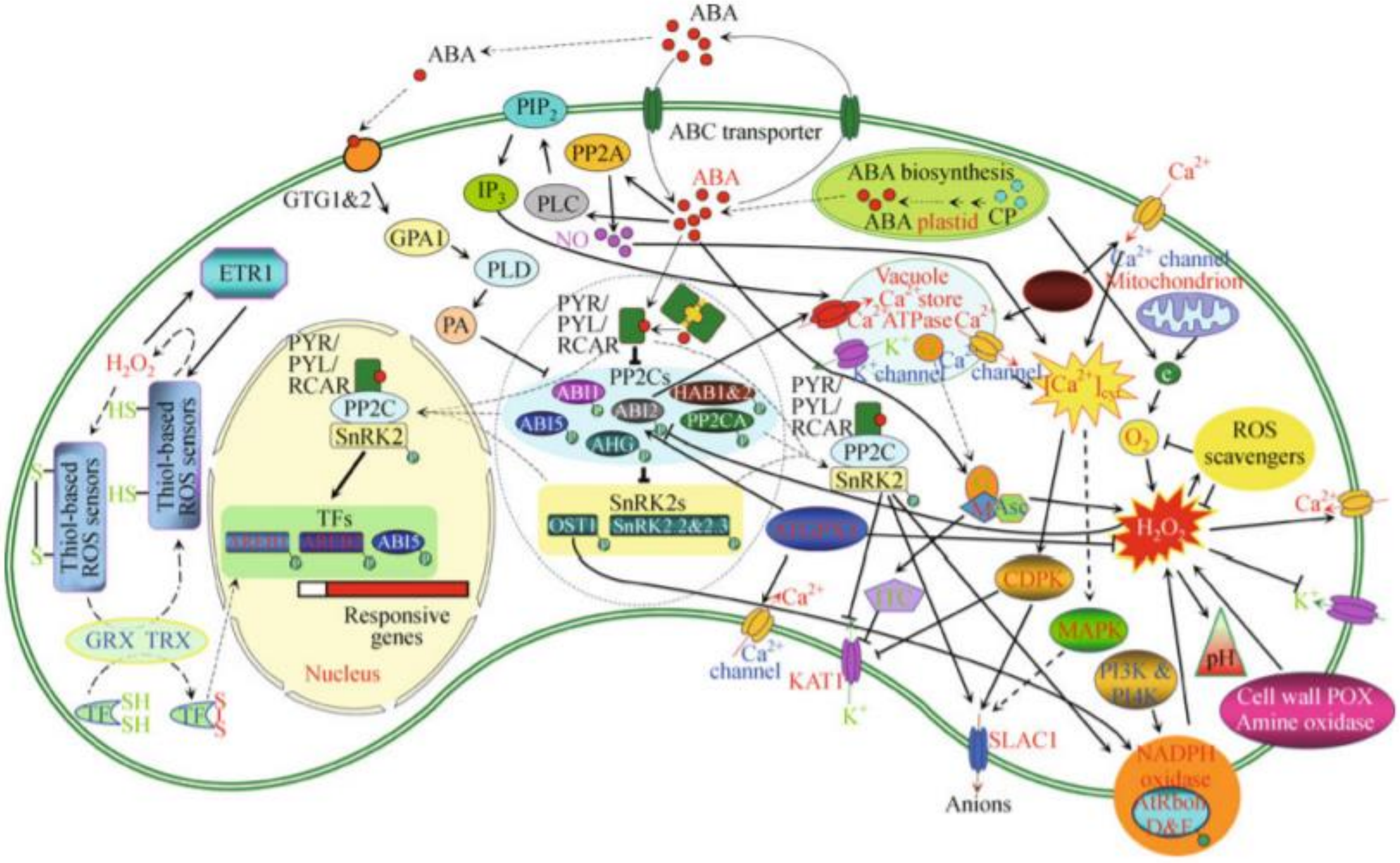
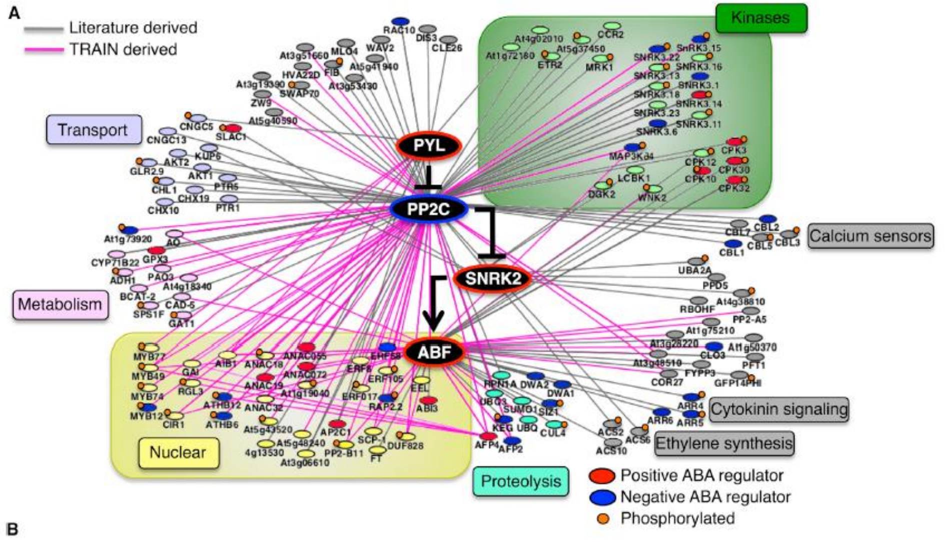
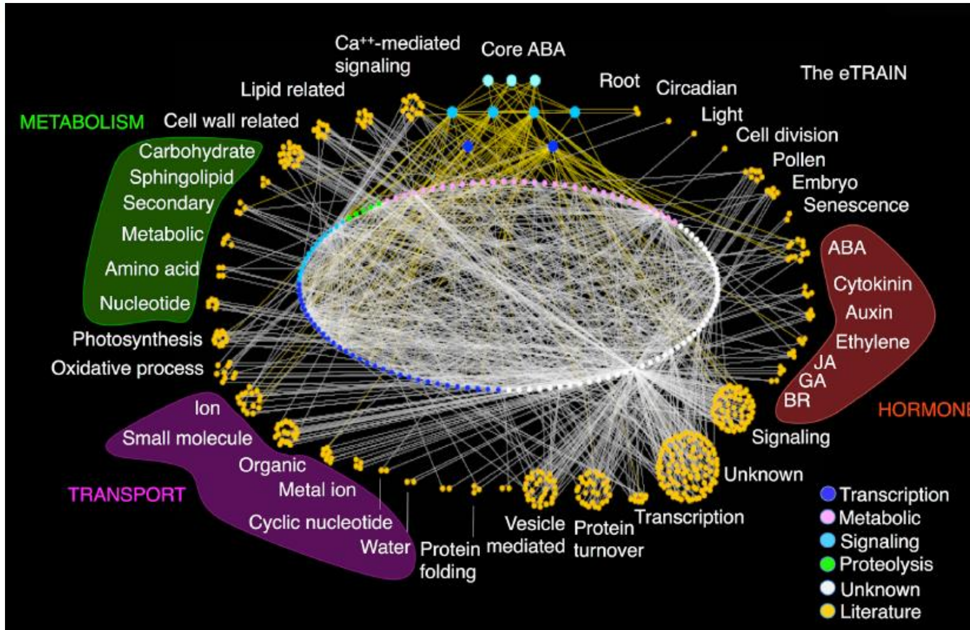


Figure 1 Overview of the ABA signaling networks in guard cells. $[Ca^{2+}]_{cyt}$, cytosolic free Ca^{2+} concentration; ABA, abscisic acid; ABC, ATP binding cassette; ABI1, ABA insensitive 1; ABI2, ABA insensitive 2; ABI5, ABA insensitive 5; AREB 2, ABA responsive element binding protein 2; Asc, ascorbic acid; ATGPX3, *Arabidopsis* glutathione peroxidase 3; AtRboh, *A. thaliana* respiratory burst oxidase protein; CDPK, calcium-dependent protein kinase; CP, carotenoid precursor; ETR1, ethylene response 1; G, glucosinolate; GCA2, growth controlled by abscisic acid 2; GCR2, G protein-coupled receptor; GPA1, *Arabidopsis* α-subunit of the trimeric G protein; GRX, glutaredoxin; HAB1&2, homology to ABI1 1&2; IP_3, inositol trisphosphate; ITC, isothiocyanate; KAT1, potassium channel 1; M, myrosinase; GTG, G protein coupled receptor (GPCR) type protein; MAPK, mitogen-activated protein kinase; OST1, open stomata 1; PA, phosphatidic acid; PI3K, phosphatidylinositol-3-kinase; PI4K, phosphatidylinositol-4-kinase; PIP_2, phosphatidylinositol-4,5-bisphosphate; PLC, phospholipase C; PLD, phospholipase D; POX, peroxidase; PP2A, protein phosphatase 2A; PP2C, protein phosphatase 2C; PYL, pyrabactin resistance-like; PYR, pyrabactin resistance; RCAR, regulatory component of ABA receptor; ROS, reactive oxygen species; SLAC1, slow anion channel 1; SnRK2, sucrose non-fermenting 1-related protein kinase 2; TF, transcription factor; TRX, thioredoxin.



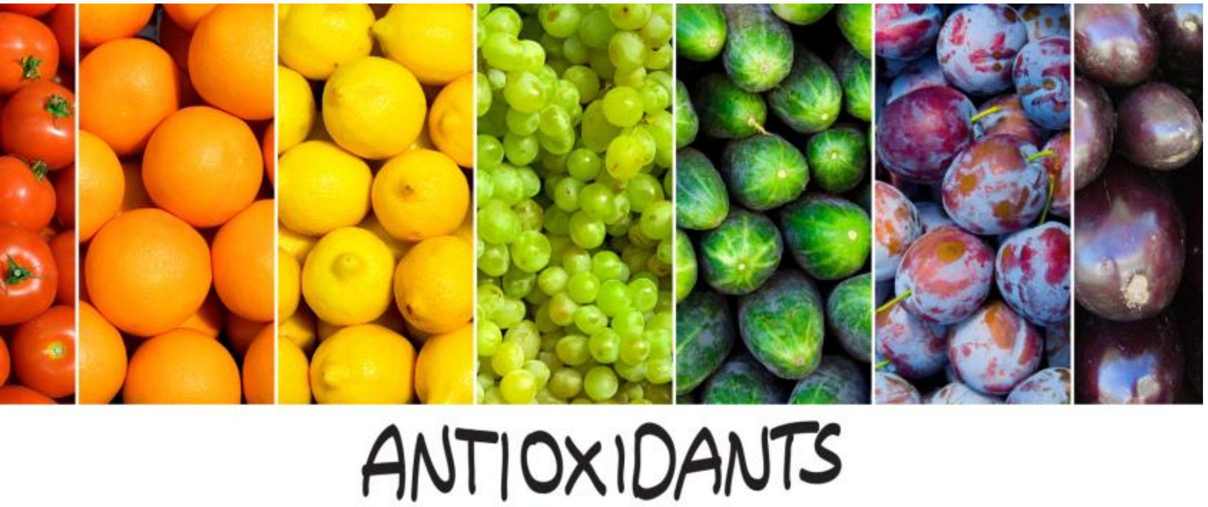


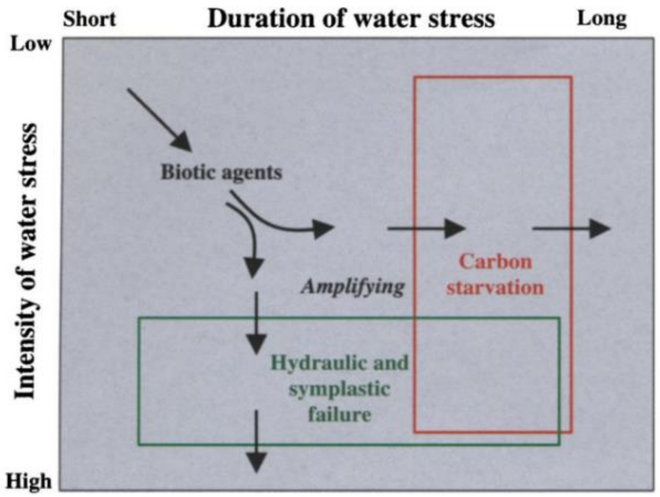
Trees control water use, so what's the problem?

- Water is used for photosynthesis & respiration (carbon)
- Water is used for cell expansion (pressure)

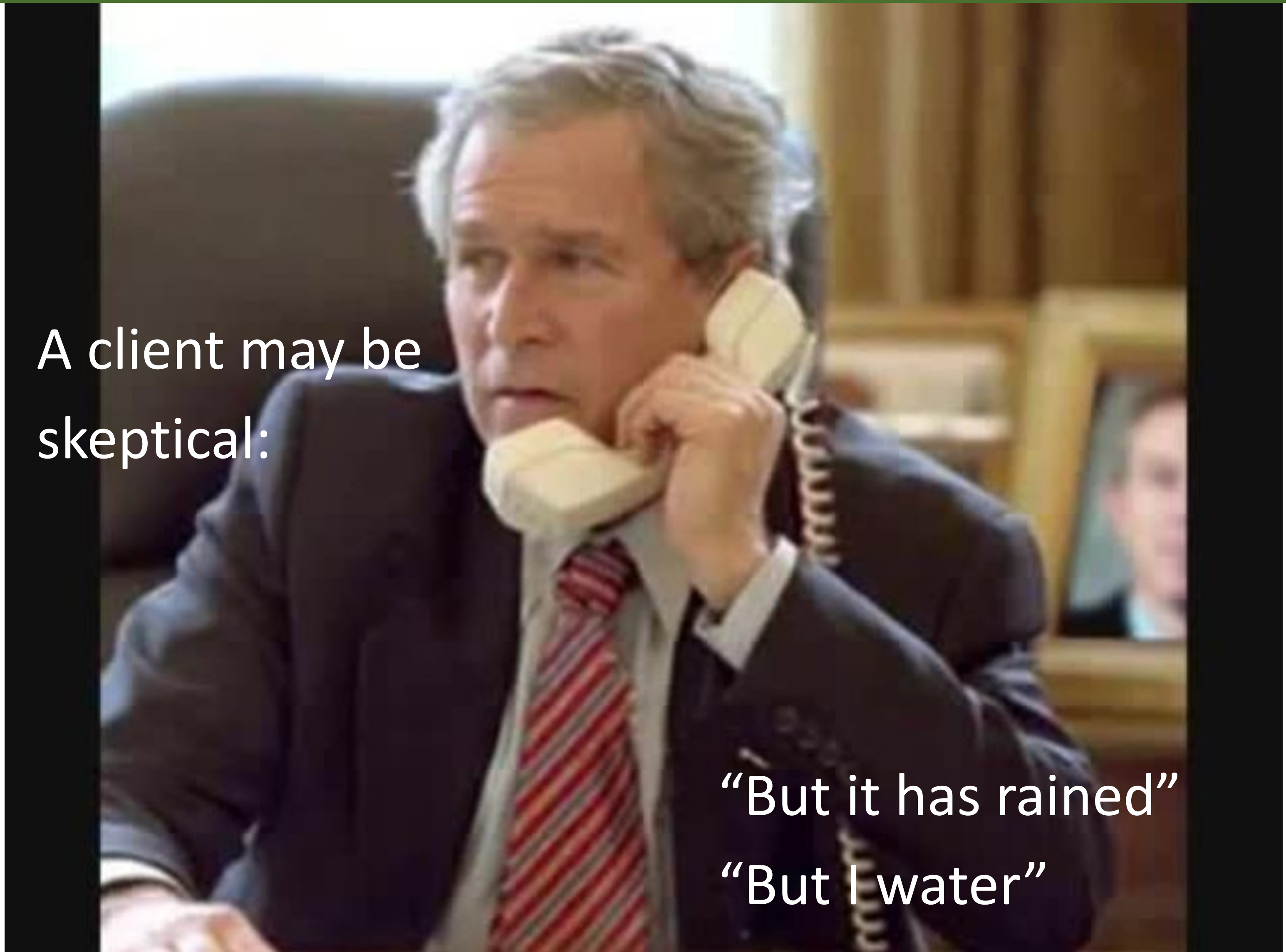
Carbon starvation vs hydraulic failure is still a huge subject of debate

- Closed stomata = photooxidative damage (using oxygen rather than $C0_2$) = production of H_20_2 = oxidative damage (bleaching)





Drought can be hard for an arborist to explain to a client:




Subtle Differences
In Sun and Shade
Can Modify Drought Impacts


SYMPTOMS - FOLIAGE BROWNING BUD MORTALITY
MOST SEVERE ON SOUTH TO SOUTHWEST OF PLANT.

Seasonality: WINTER DRYING

Plants Highly Susceptible to WINTER DRYING

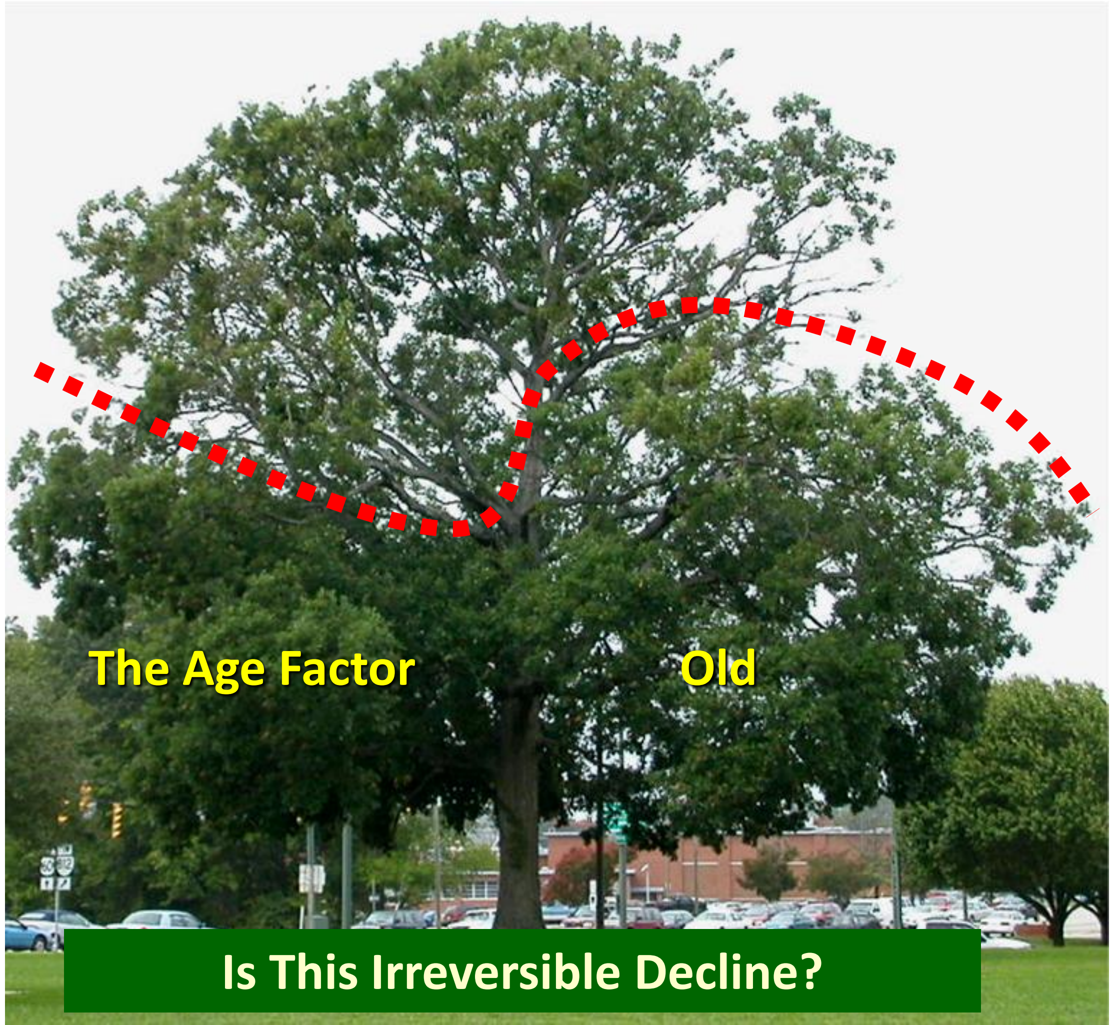
- **Broadleaf evergreens**
- **Transplants**
- **Plants in exposed locations**

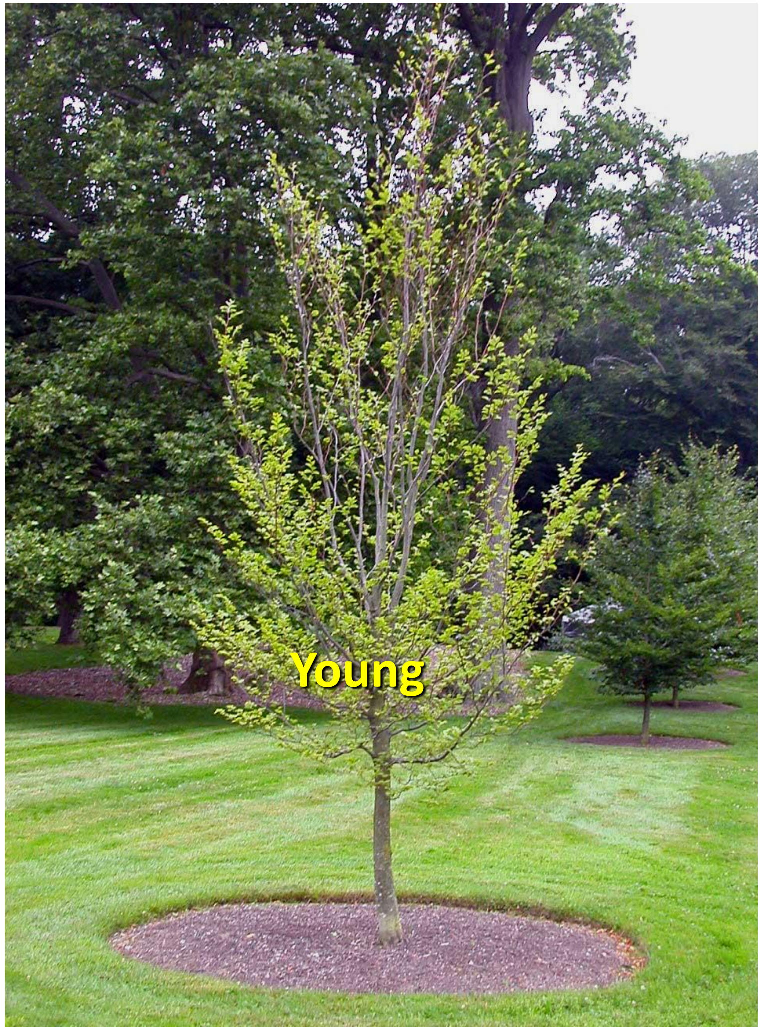
The *scary* part:

Symptoms may not appear until one or two years later (as reserves are depleted)

The scarier part is that effects may last for years – up to a decade!

Is This Drought-Related Decline?





FACTORS THAT CAN INFLUENCE DROUGHT STRESS

Short-Term Factors
Moisture Extremes
Frost/Cold Injuries
Lightning & Storms

Long-Term Factors
Age
Soils & Site
Climate
Air Pollution
Competition
Species

Contributing Factors
Insect, Disease, & Abiotic
Borers
Bark Beetles
Cankers
Root Disease
Construction Damage &
Other Root Abuses

Precautionary note - Dieback Can Have Many Causes

Other pathogens associated with water stress?

Phytophthora

Phytophthora root rot is most severe when rainy periods follow periods of severe water stress.

PHYTOPHTHORA

ACUTE SYMPTOMS:

Rapid wilting

& death

Collar Rot:
Reddish-brown lesion
extending up the stem

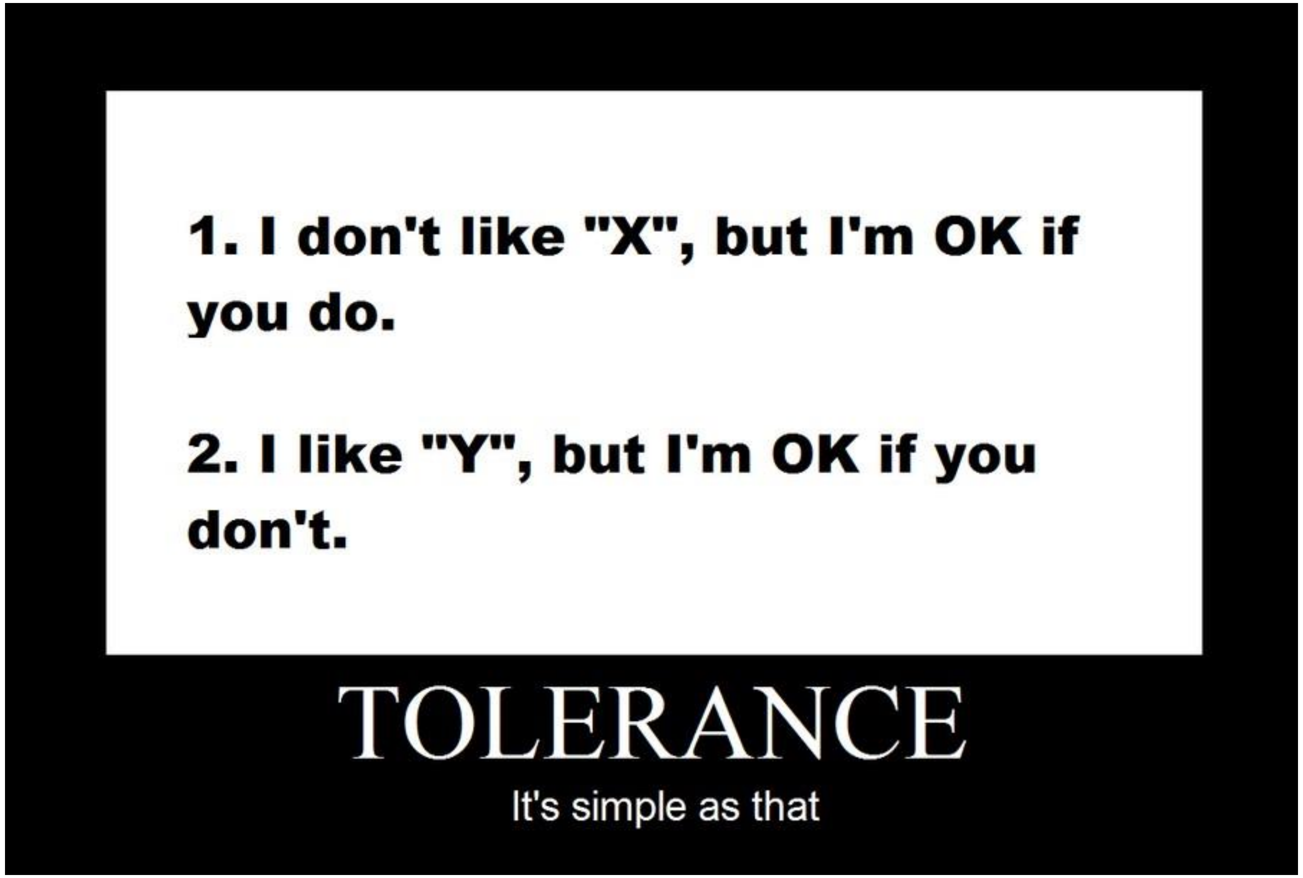
PHYTOPHTHORA

Is a fine-root disease

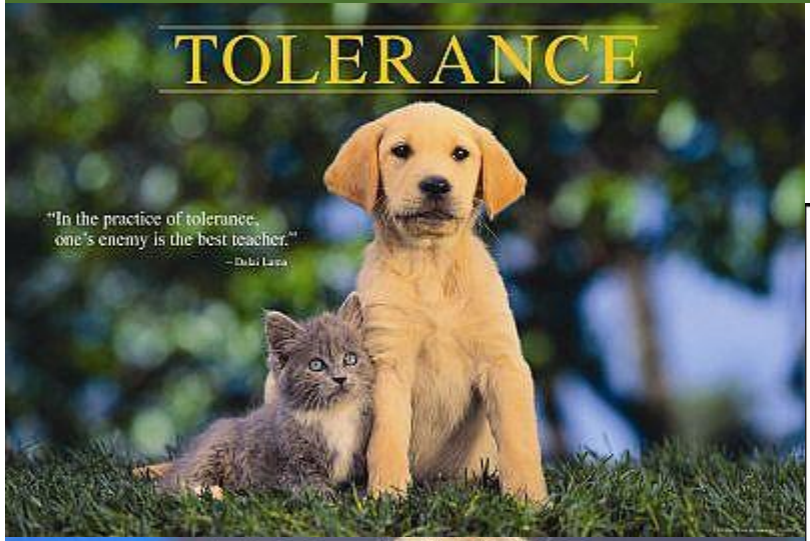
Plants are often loose in the ground from rotting away of fine roots

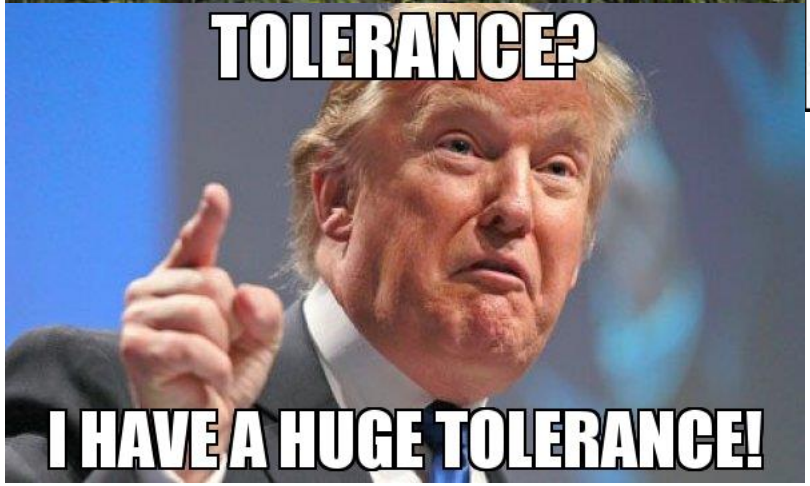
Pytophthora is often worst when drought is followed by excessive soil moisture

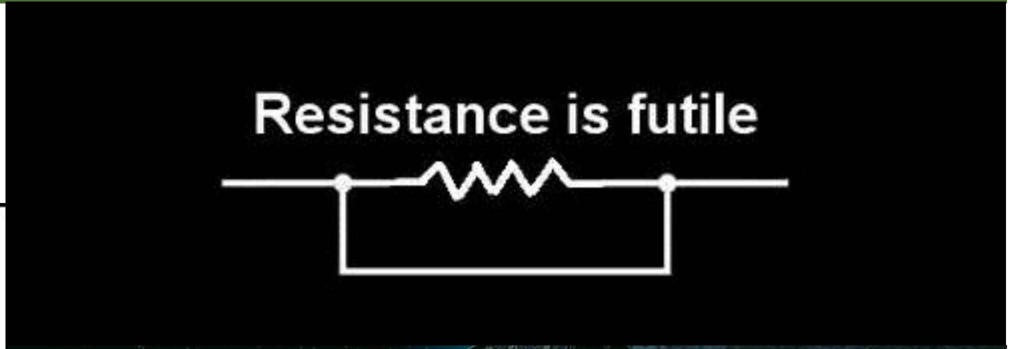
Drought "Tolerance" Strategies



Drought "Tolerance" Strategies



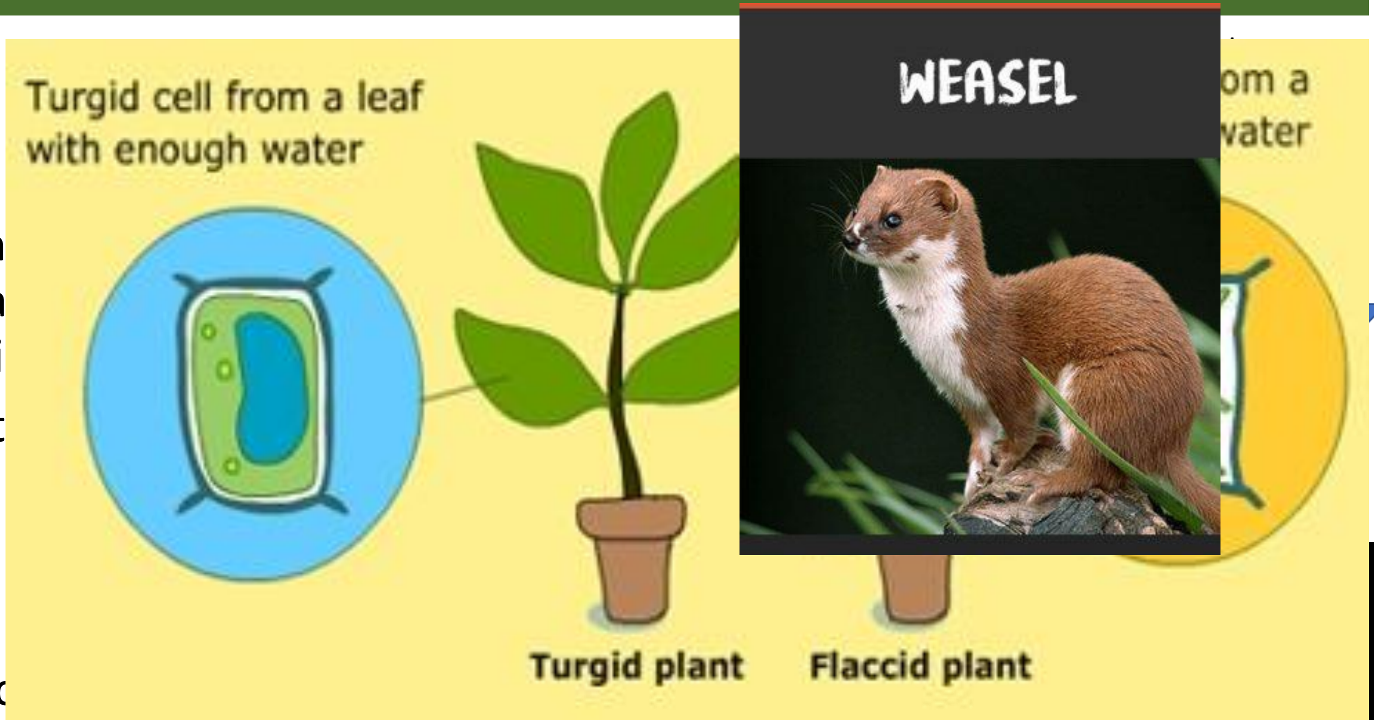




Drought Avoidance vs Tolerance

- Avoidance
  - Cannot withstand low water content
  - Involves various morphological and an
  - Increase stomatal and cuticular resista
  - Changes in leaf area, anatomy, and ori

Mechanisms: physical adaptations, deep root



- Tolerance / Resistance
  - Can <u>tolerate</u> low water content
  - <u>Better photosynthesis</u> under drought c
  - Maintains adequate cell **turgor** but prevents disruptions to cellular metabolism

mechanism - osmotic adjustment (involving inorganic ions, carbohydrates, and organic acids), and changes in cellular/tissue elasticity

Touchette et al 2007. Drought Tolerance Versus Drought Avoidance: A Comparison Of Plant-water Relations In Herbaceous Wetland Plants Subjected To Water Withdrawal And Repletion. Wetlands 27(3):656-667.

Strategies

- Isohydric (conservative)
  - Conserve water (close stomata)
  - Maintain Ψ throughout the day/stress

- Anisohydric (risk taking)
  - Use water (keep stomata open)
  - Ψ declines
  - Photosynthetic rates higher for longer periods

HOWEVER: Biological strategies are often not black and white



Tree Selection

Tree Selection for Drought Tolerance?

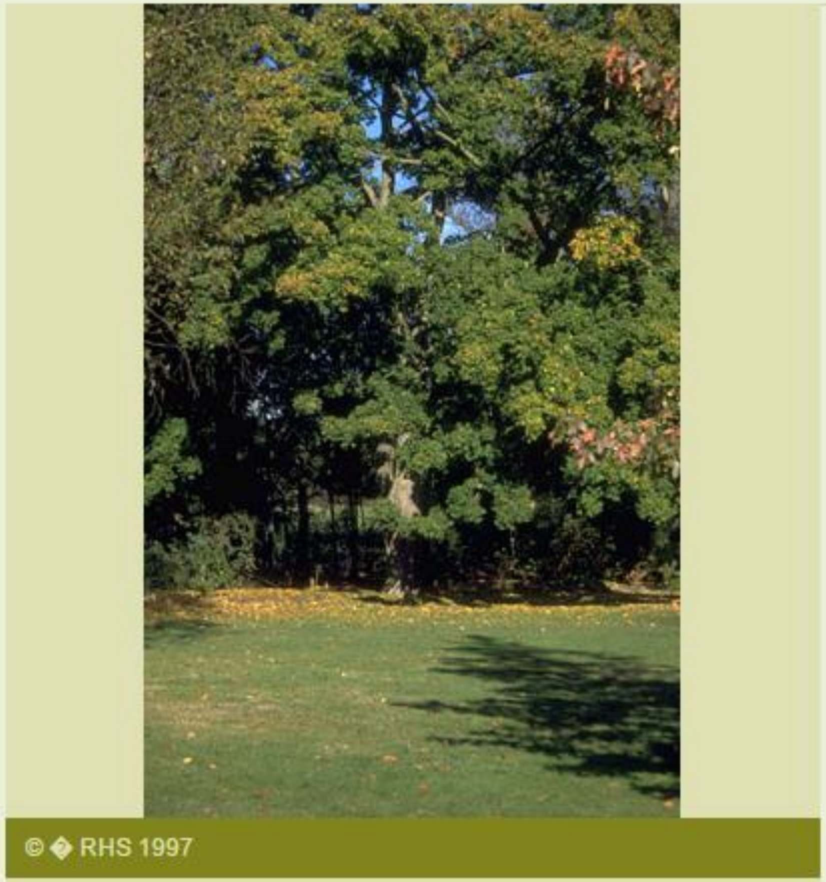
What are the current options for tree selectors?

Tree Selection for Drought Tolerance?

What are the options to tree selectors?

Royal Horticultural Society
Sharing the best in Gardening

Acer platanoides
Norway maple



Sunlight

Full Sun
Partial Shade

Aspect
North-facing or East-facing or South-facing or West-facing

Exposure
Exposed or Sheltered

Soil

Chalk
Clay
Sand
Loam

Moisture
Well-drained, Moist but well-drained

Soil
Chalk, Clay, Sand, Loam

pH
Acid, Alkaline, Neutral

Size

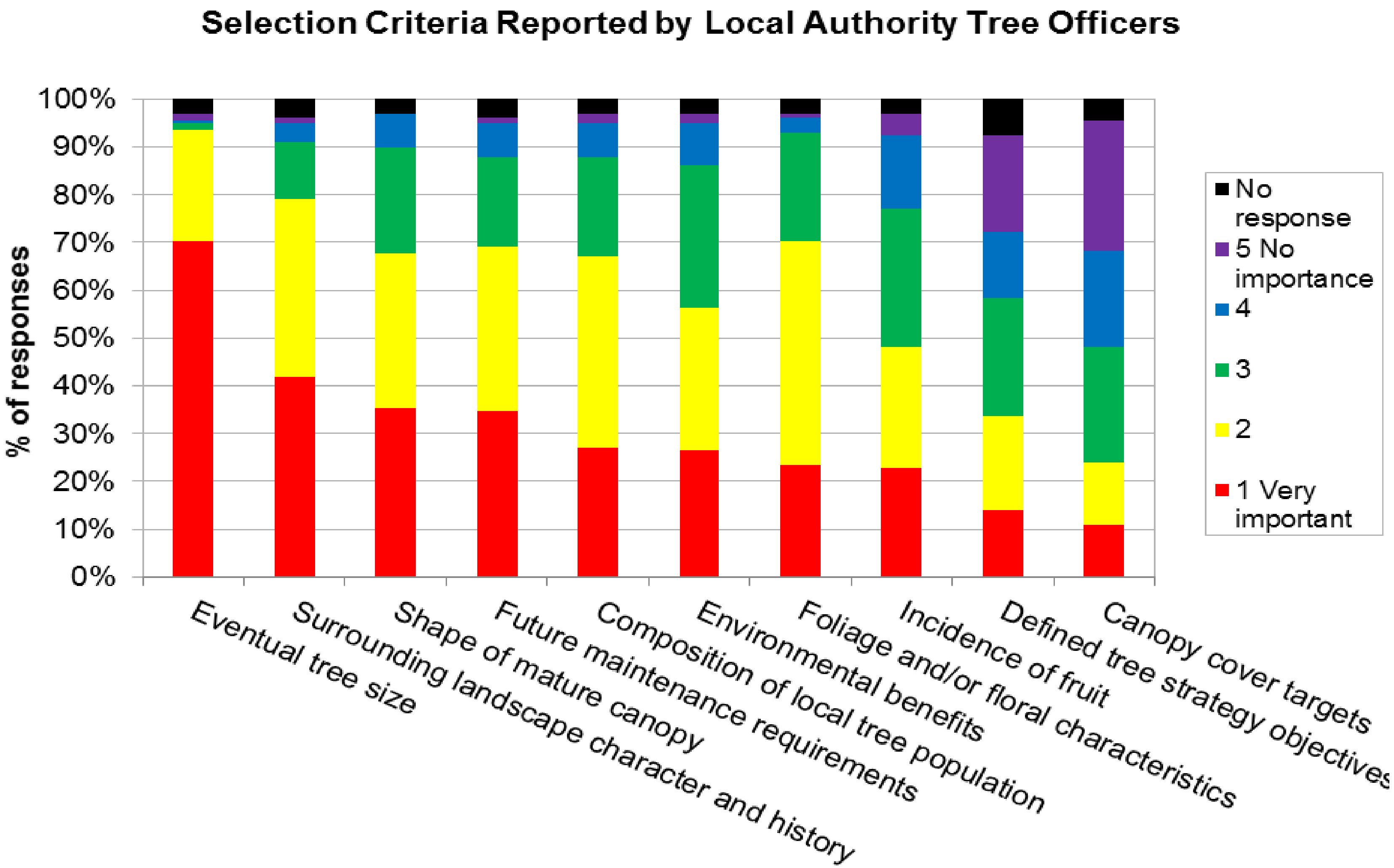
Ultimate height
Higher than 12 metres

Ultimate spread
wider than 8 metres

Time to ultimate height
20-50 years

What is Currently Selected For?

- Conspicuous absence of drought, or any abiotic/biotic stressor.



Responses of 158 Local Authority tree officers to the question "Which of the following factors are considered when selecting the tree species to be planted?" (Data adapted from Keith Sacre, Barcham Trees 2012).

Result = Urban tree deaths*

*Not all urban tree deaths are caused by drought or selection error, many factors are at play here but the overriding conclusion in most studies is the causal agent is drought

Issues

- Tree selectors chose genotypes that they are familiar with, without taking into account the effect of species or cultivar on drought tolerance.
- Substantial deaths are caused through incorrect species or cultivar choice.

Tree officers do not have the information available to distinguish between the characteristics of different species or cultivars

Solution

- To develop an empirical drought tolerance ranking system to improve the information available to those selecting amenity trees.

Disclaimer

We do still need to take care of trees and consider rooting environments

Sorry

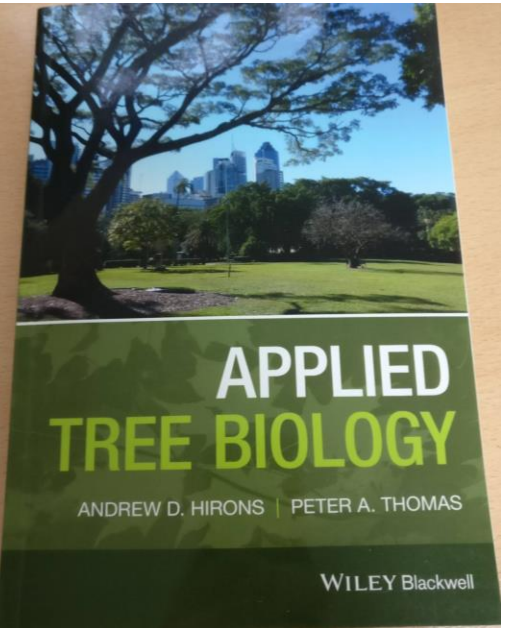
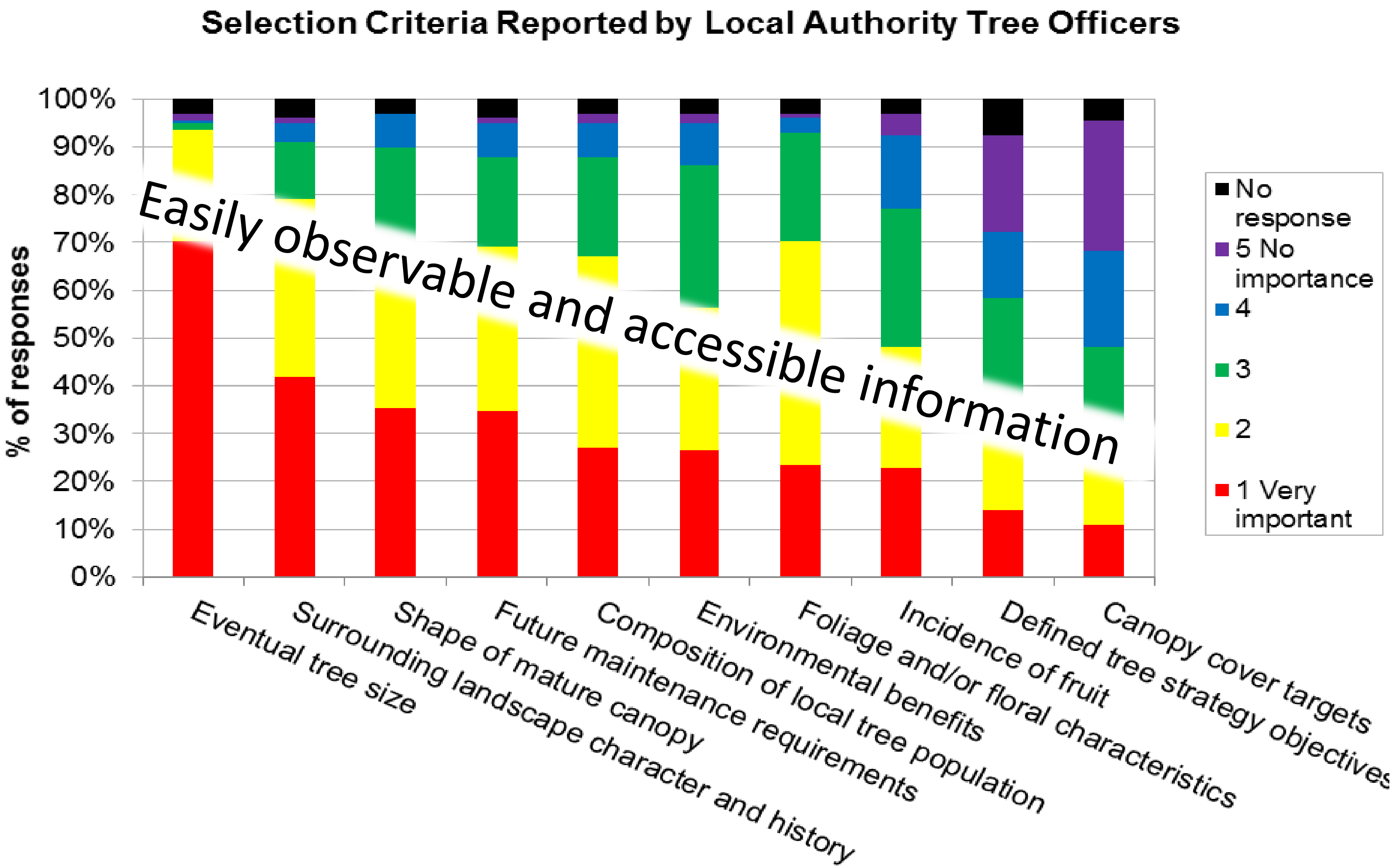


Figure 4.30 The impact of rooting environment on tree growth in a car park in Gelsenkirchen, Germany. Trees planted in central areas have minimal soil volume; trees around the edge of the car park share a more expansive soil volume and so have grown larger. *Source:* Courtesy of Johan Östberg

What Can We Learn Form What is Currently Selected For?

- Allows us to select for drought in tandem with current selection criteria



Responses of 158 Local Authority tree officers to the question “Which of the following factors are considered when selecting the tree species to be planted?” (Data adapted from Keith Sacre, Barcham Trees 2012).




Acer/Maple

Acer/Maple

- *Acers* have been chosen because of their apparent **broad diversity between and within species**

- 129 species of *Acer*

- Cultivars in the same sp. have varying traits e.g.:

Acer platanoides:

- 'Crimson King' (dark purple)
- 'Schwedleri‘ (dark purple)
- 'Drummondii‘ (variegated)
- 'Emerald Queen‘ (light green)
- 'Dissectum' (feathery)
- 'Lorbergii‘ (feathery)
- 'Columnare' (narrow and upright)
- ‘Pendulum' (weeping)
- ‘Summershade’ (dark green)

- Commonly used species in both parks and urban environments

Is there much Variation within the Acer genus?

Table 2. Genotypic variation in electron transport (ETo) per maximal cross section (CSm) of photosystem II in Acer species.

Genus	*Sp.*	Cultivar	ETO/CSm
Acer	*pseudoplatanus*	Worley	960.5[h]
Acer	*platanoides*	Fairview	955.6[h]
Acer	*pseudoplatanus*	Spaethii	920.7[gh]
Acer	*campestre*	Arends	874.5[fg]
Acer	*pseudoplatanus*	Negenia	840.6[ef]
Acer	*x freemanii*	Autumn Fantasy	790.6[de]
Acer	*campestre*	Louisa Red Shine	788.9[de]
Acer	*x freemanii*	Autumn Blaze	775.6[cde]
Acer	*platanoides*	Royal Red	762.8[cd]
Acer	*platanoides*	Emerald Queen	761.0[cd]
Acer	*campestre*	Elsrijk	759.4[cd]
Acer	*campestre*	Lineco	741.2[cd]
Acer	*palmatum*		732.8[cd]
Acer	*freemanii*	Armstrong	731.0[cd]
Acer	*griseum*		708.6[bc]
Acer	*platanoides*	Drummondii	658.8[ab]
Acer	*rubrum*	Bowhall	606.6[a]
Acer	*negundo*	Flamingo	602.6[a]
Acer	*platanoides*	Princeton Gold	598.8[a]
			LSD 69.56

60.4% difference

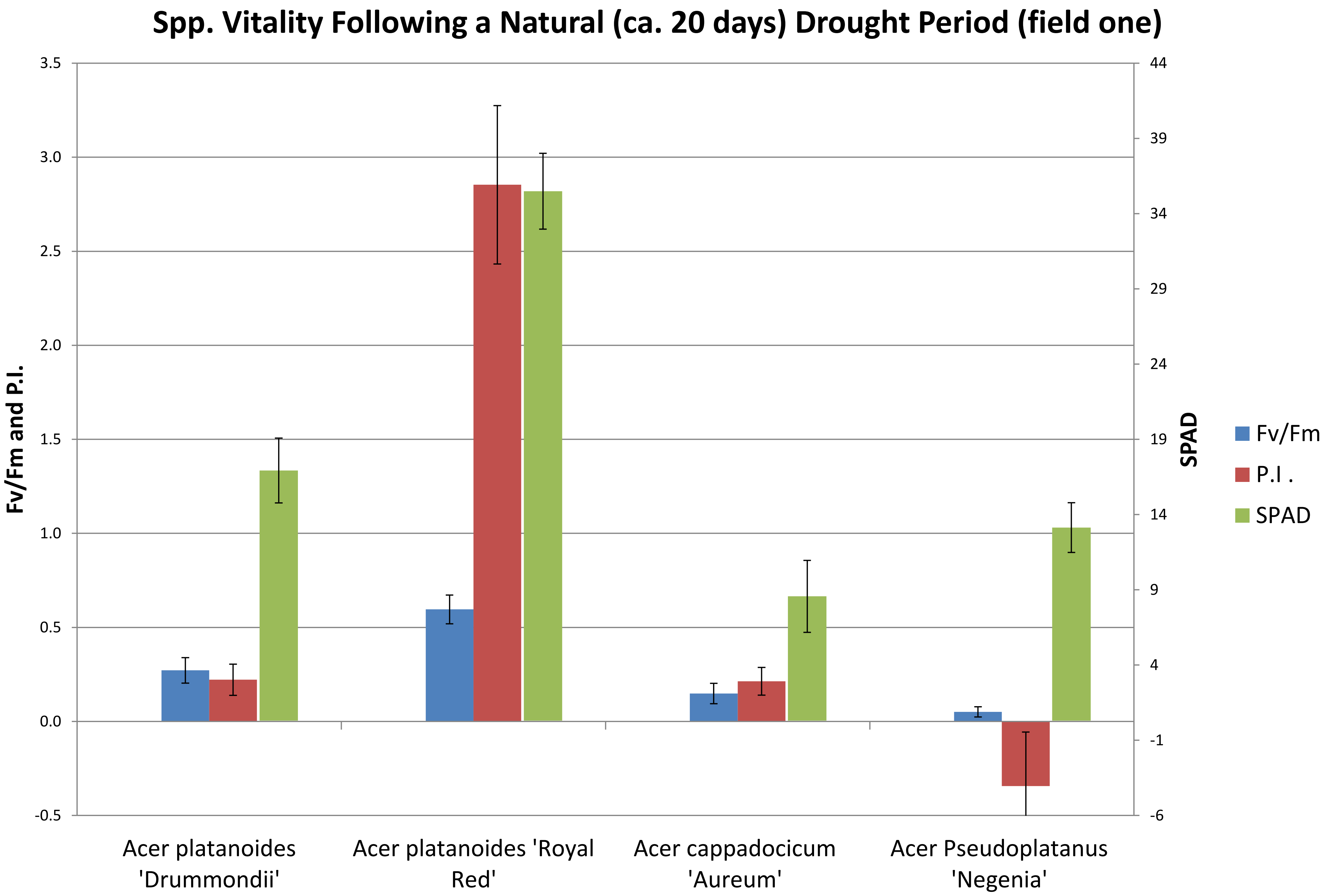
All SPAD and ETO/CSm values are means of five trees, five leaves per tree. Superscript letters indicate significant differences between means based on the least significant difference at $P<0.05$.

Does this variation transfer to actual drought tolerance?

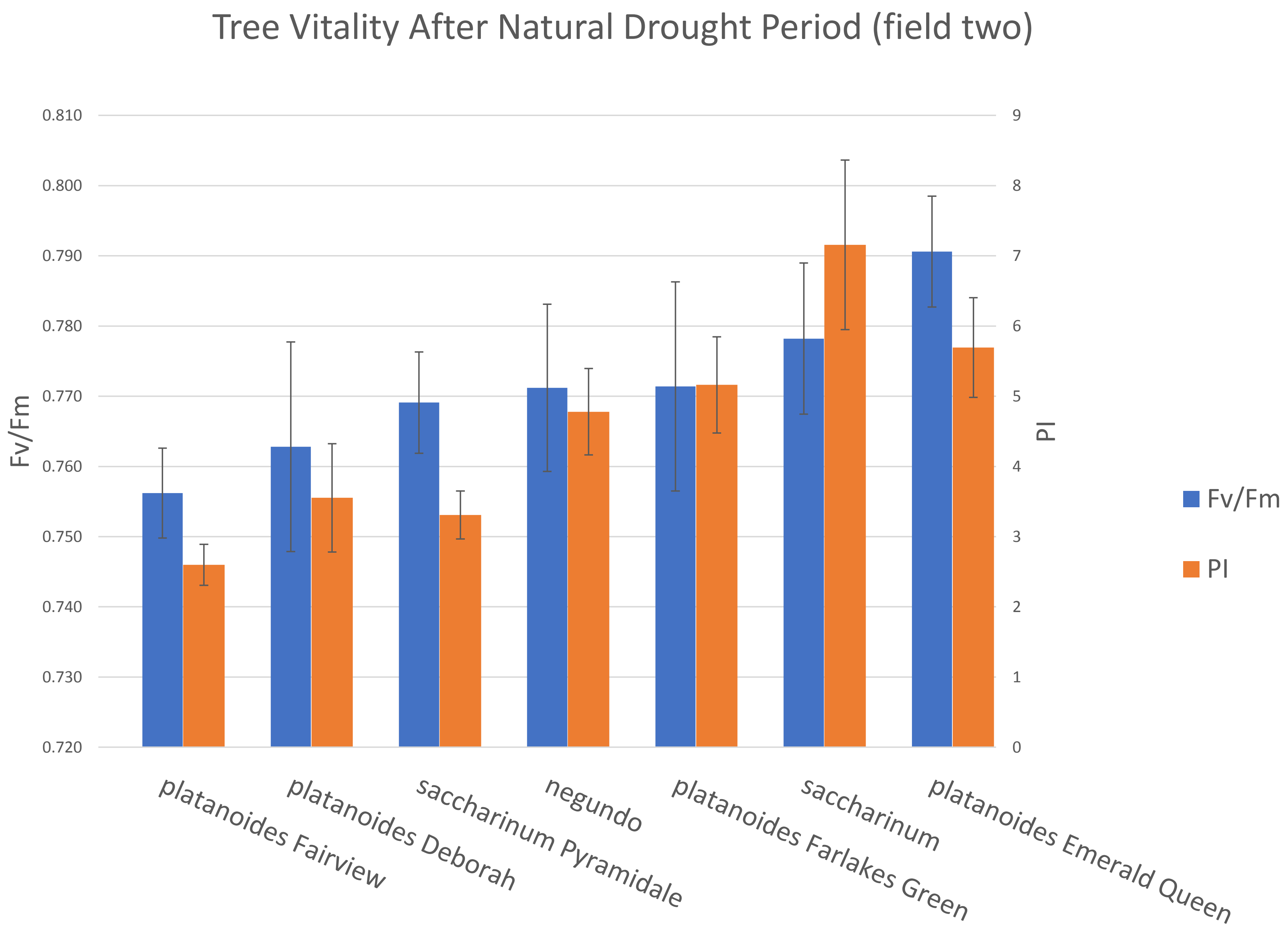
Variation in street tree survival rates

Tree Species.	Estimated % loss across ten years
Acer pseudoplatanus L.	29
Acer rubrum L.	3
Gleditsia triacanthos	3
Liquidambar styraciflua L.	10
Crataegus phaenopyrum Borkh.	98

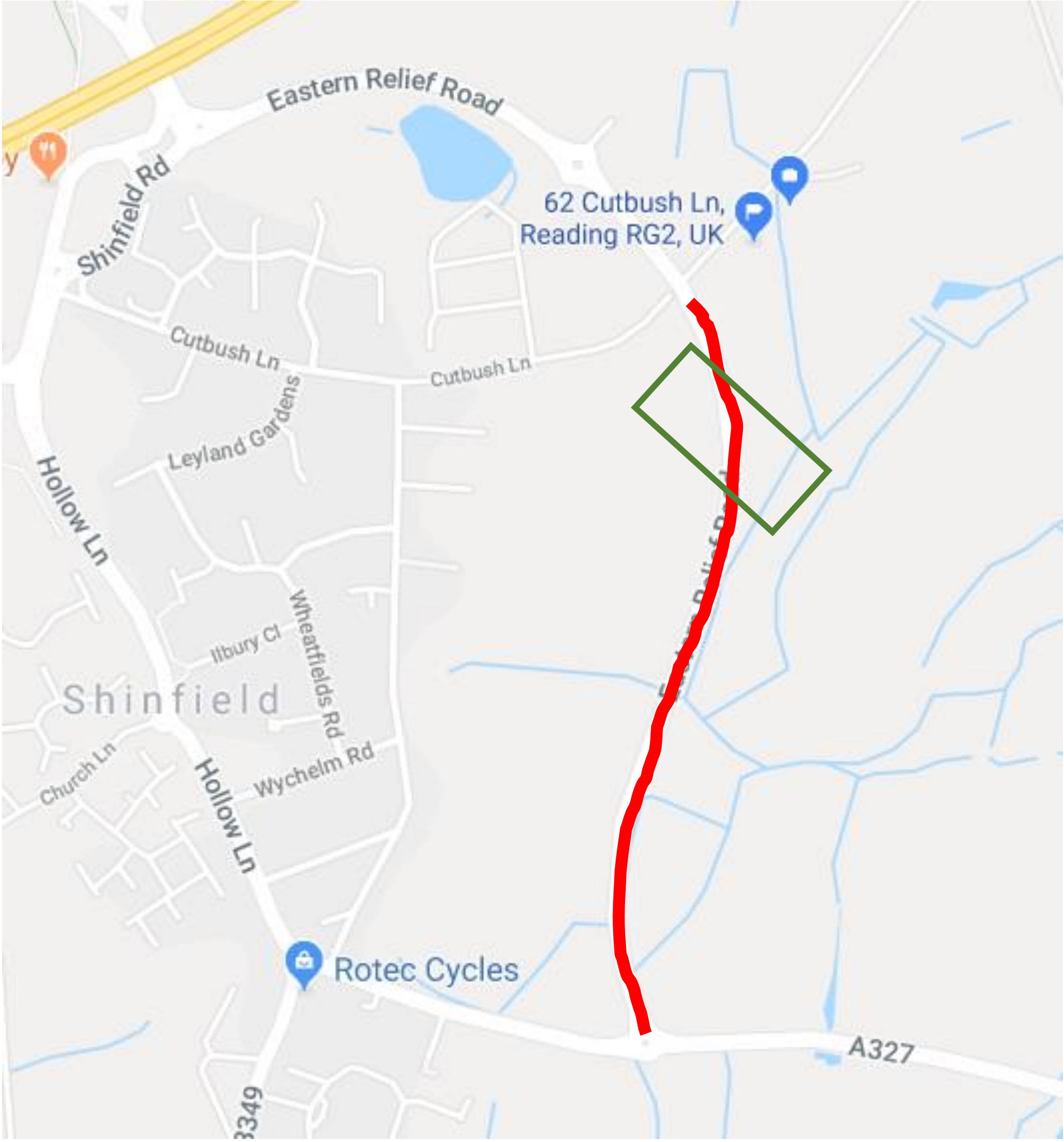
Table 2 *Data adapted from Roman and Scatena (2011) estimating survival across a ten year life expectancy for trees within a study from Cleveland OH, USA by* Sydnor et al. (2010). *Data derived from linear regression analysis estimating annual survival rates.*



Spp. Vitality Following a Natural (ca. 20 days) Drought Period (field one)
Fv/Fm and P.I.
SPAD
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
44
39
34
29
24
19
14
9
4
-1
-6
Fv/Fm
P.I .
SPAD
Acer platanoides 'Drummondii'
Acer platanoides 'Royal Red'
Acer cappadocicum 'Aureum'
Acer Pseudoplatanus 'Negenia'



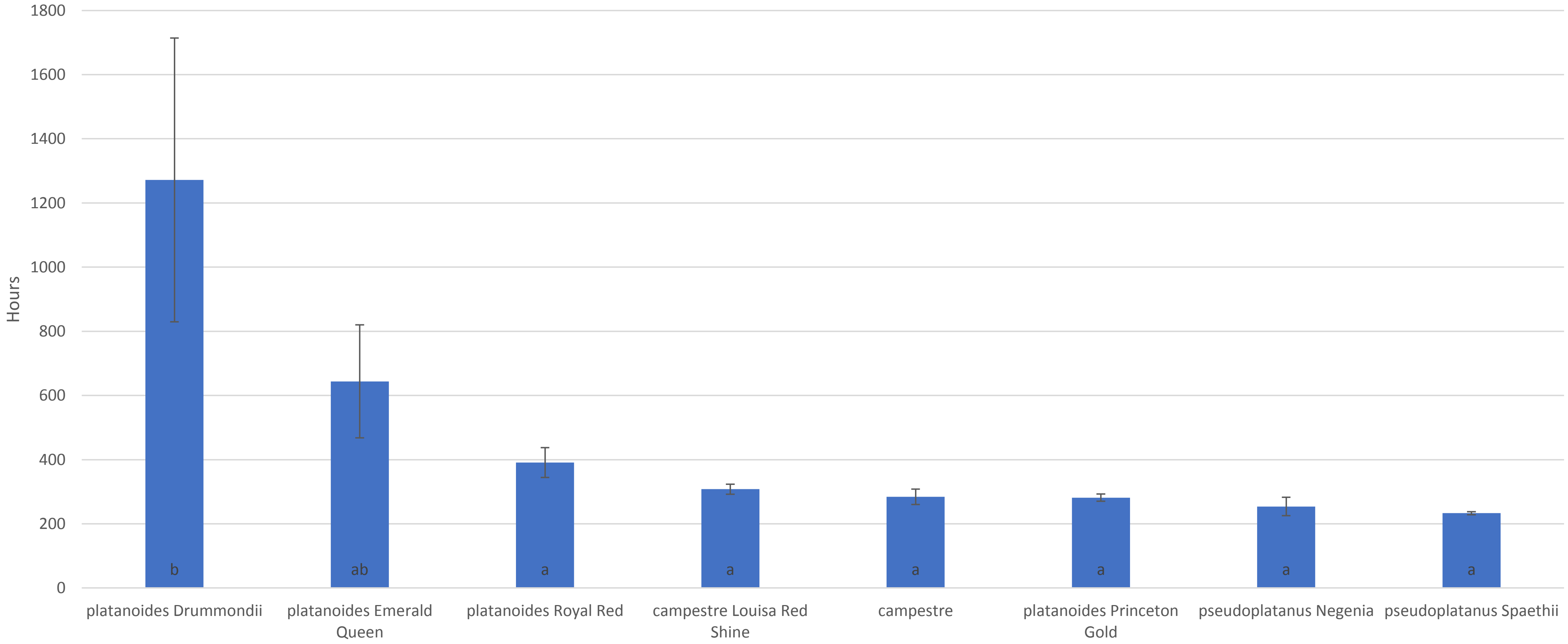
Tree Vitality After Natural Drought Period (field two)
0.810
0.800
0.790
0.780
0.770
0.760
0.750
0.740
0.730
0.720
Fv/Fm
9
8
7
6
5
4
3
2
1
0
PI
platanoides Fairview
platanoides Deborah
saccharinum Pyramidale
negundo
platanoides Farlakes Green
saccharinum
platanoides Emerald Queen
Fv/Fm
PI


Eastern Relief Road
Shinfield Rd
62 Cutbush Ln,
Reading RG2, UK
Cutbush Ln
Cutbush Ln
Leyland Gardens
Hollow Ln
Ilbury Cl
Wheatfields Rd
Shinfield
Church Ln
Wychelm Rd
Hollow Ln
Rotec Cycles
A327


LET ME PLAY YOU A SAD SONG
ON THE WORLD'S SMALLEST VIOLIN

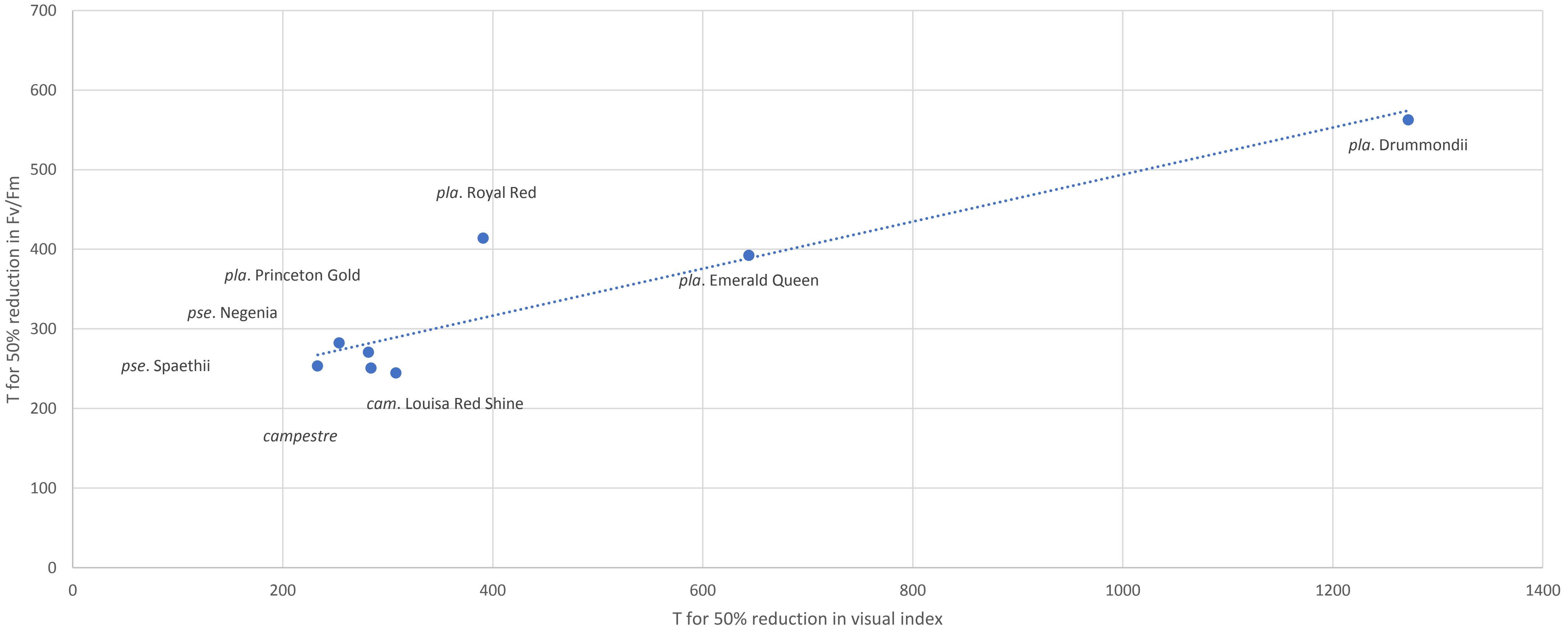
Controlled *in vivo* drought.

Barcham
The Tree Specialists



Mean time for 50% reduction in visual index per tree. Error bars show standard error (n = 5). Letters denote significant differences between cultivars at the 95% confidence interval. Overall mean time = 458 hours.

(These are very closely related species)



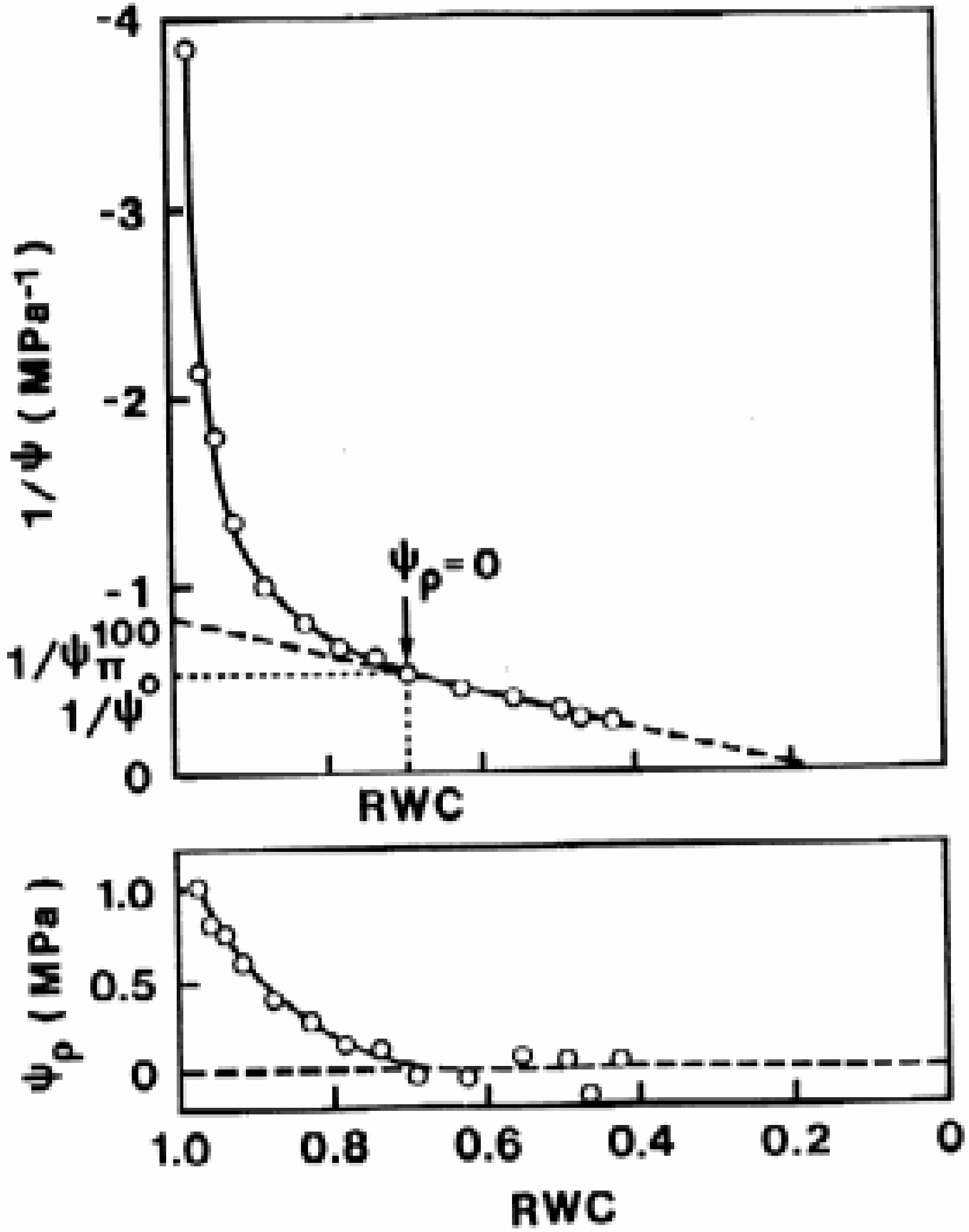
Average position of cultivars, relative to visual and chlorophyll fluorescence drought tolerance rankings. (y = 0.2953x + 198.5 R^2 = 0.8492). Species are: *pla. = A. platanoides, cam = A. campestre, pse. = A. pseudoplatanus.*

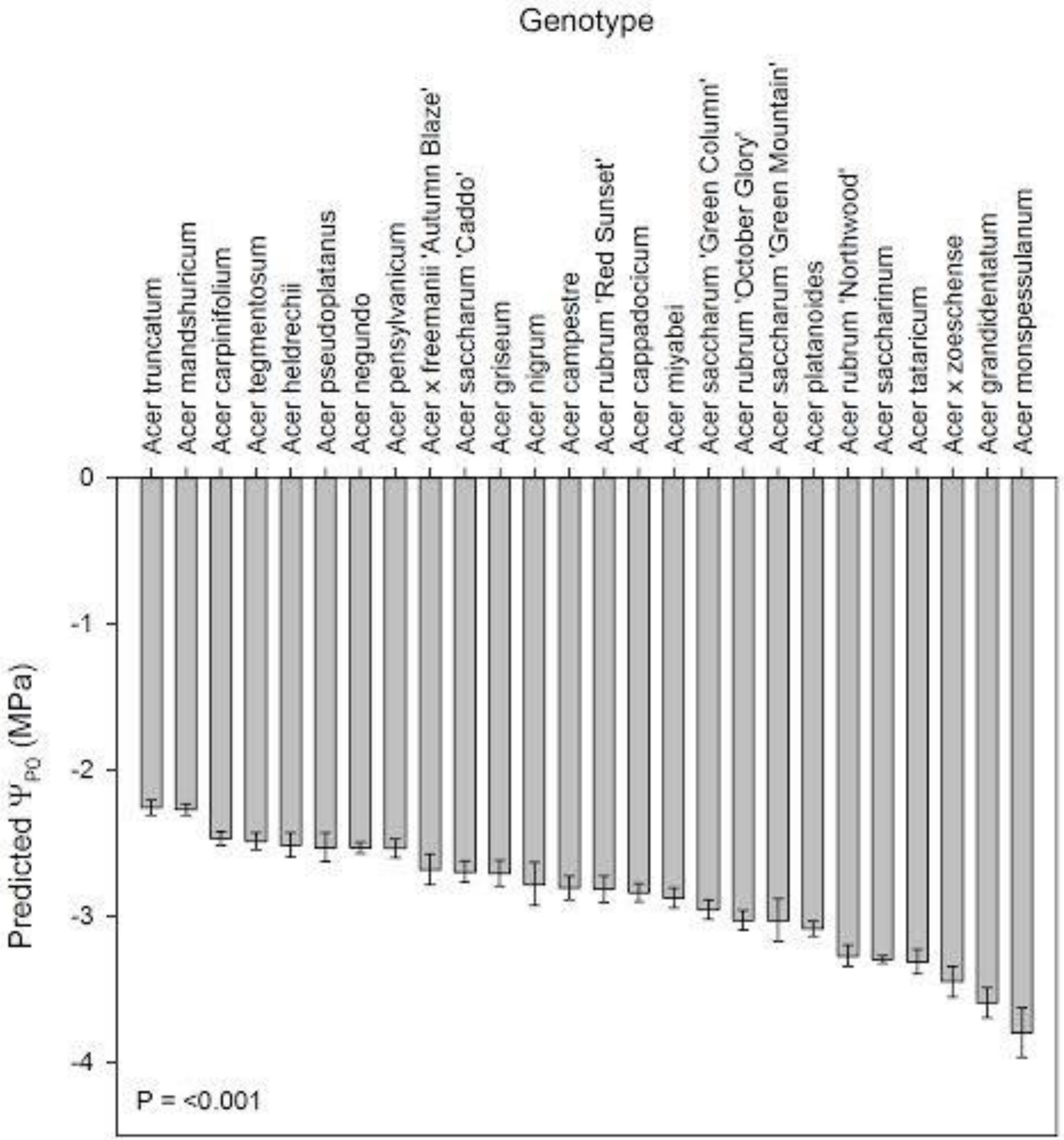
Can This be Estimated *In Vitro*?

62% rank similarity
to the drought trial

Acer sp. Cultivar	Summer Foliar Dehydration (hours)	
pseudoplatanus 'Spaethii'	94.0	a
campestre 'Louisa Red Shine'	96.9	a
campestre	106.0	ab
pseudoplatanus 'Negenia'	112.4	b
platanoides 'Drummondii'	121.4	bc
platanoides 'Royal Red'	127.9	cd
platanoides 'Emerald Queen'	130.7	cd
platanoides 'Princeton Gold'	140.5	d
P =		<0.001

52% similarity





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Seasonal effect

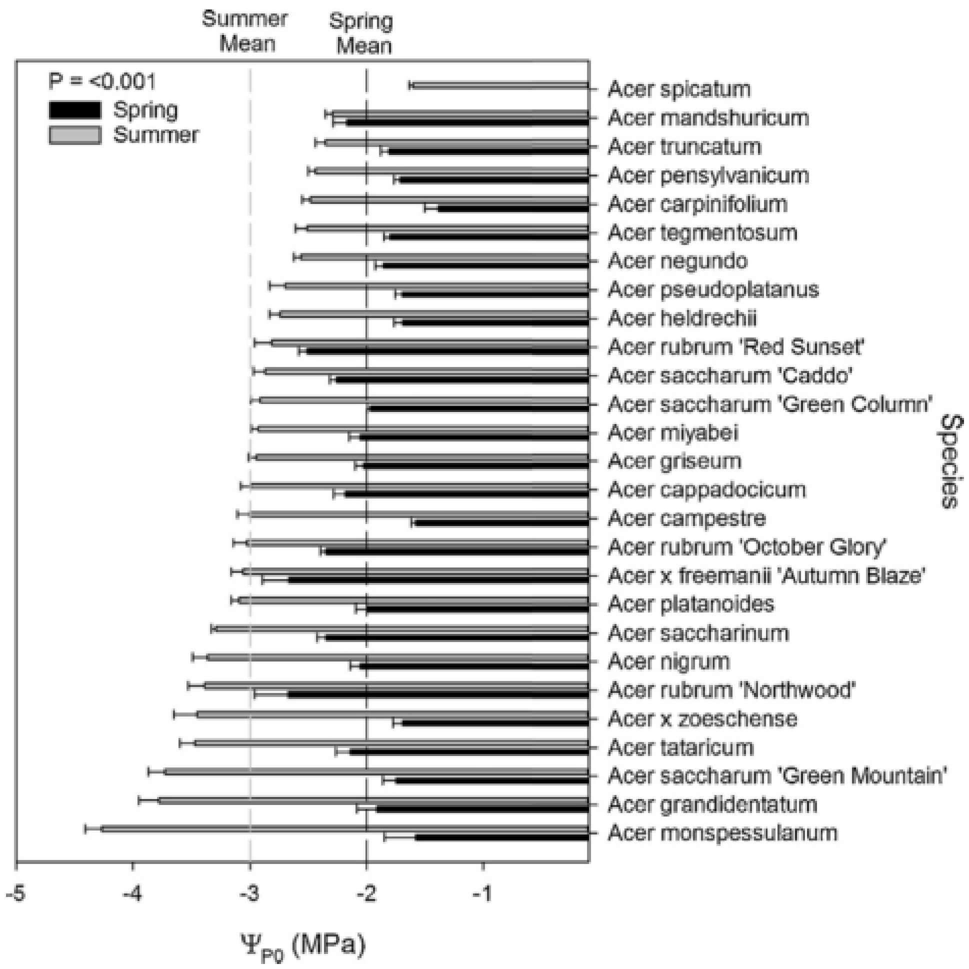

Fig. 2. Predicted turgor loss of leaves in summer based on the assessment of osmotic potential at full turgor of 27 *Acer* genotypes. Dashed lines represent mean for all genotypes. Bars show SE, $P < 0.001$ across species for spring and summer datasets as determined by the GLM, n = see Table 1. Genotypes have been ranked by summer Ψ_{P0}.

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Seasonal Droughts and comparison between methods

		1	2	3	4	5
Leaf dehydration (spring)	1	1				
Leaf dehydration(summer)	2	0.17	1			
Leaf dehydration (autumn)	3	0.45	0.81	1		
π_{tlp}	4	-0.19	-0.64	-0.74	1	
Whole tree drought	5	**-0.21**	**0.62**	**0.52**	**-0.60**	1

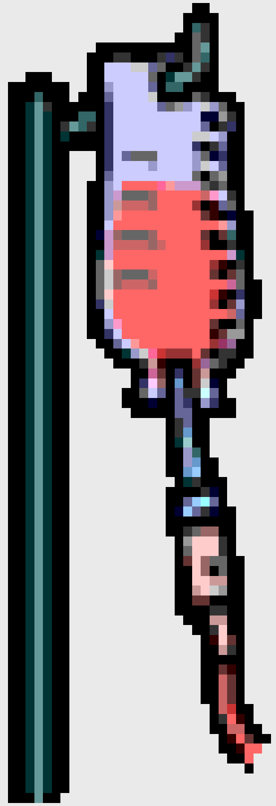
Drought Mitigation

Bartlett's Five Point Drought Recovery Program will help offset the effects of drought and consist of:

*Irrigation
*Mulching
*Soil and Nutrient Management

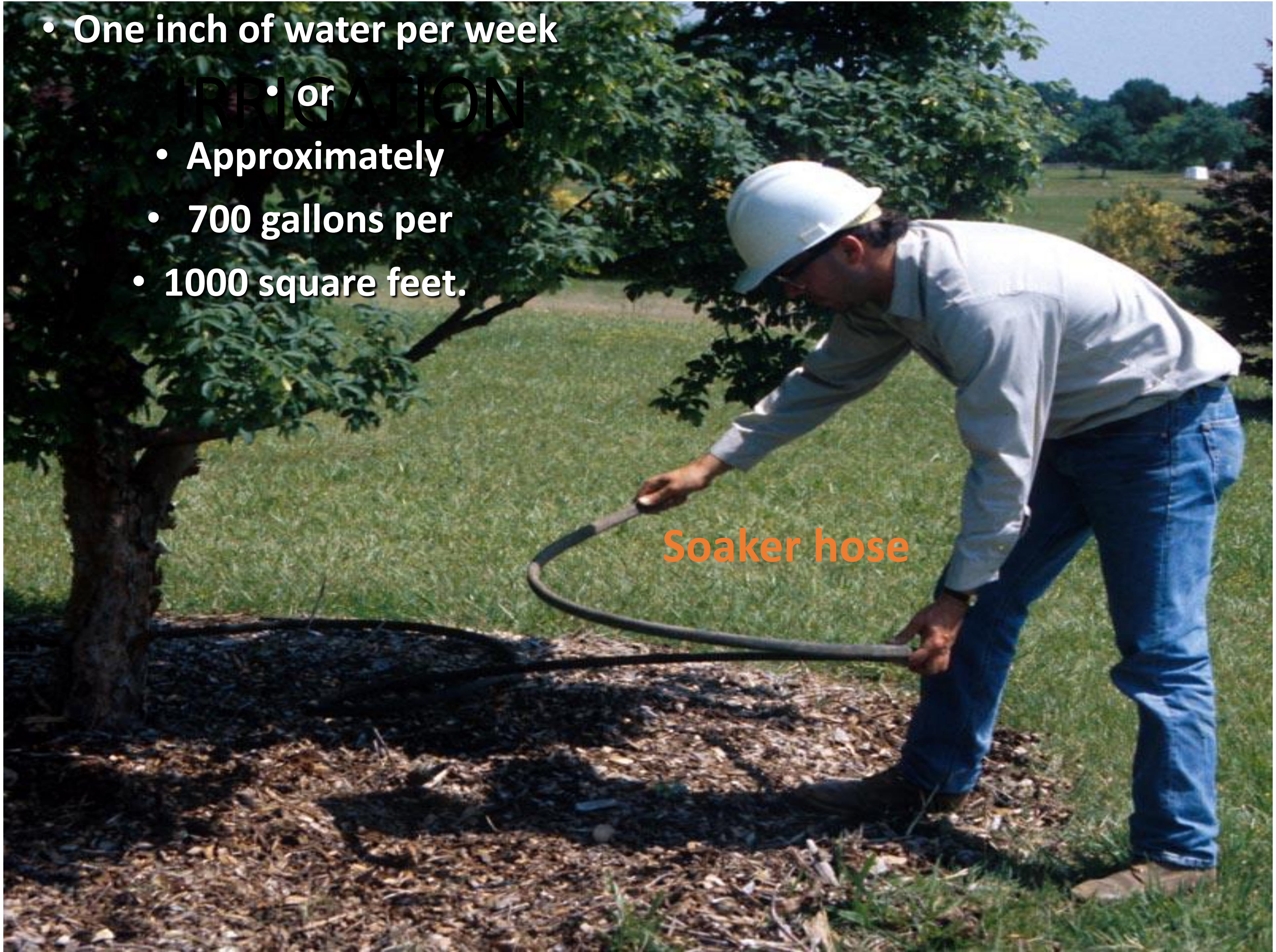
ROOTS!

*Pruning
*MoniTor® IPM Program



IRRIGATION

- One inch of water per week
- or
- Approximately
- 700 gallons per
- 1000 square feet.




Fill It—And Forget It!
One Treegator Unit



Mulching

Mulch benefits

Eliminates competition with grass

Reduces compaction

Conserves soil moisture

Moderates soil temperatures

Provides organic matter and nutrients

Protects stems

You can't make this stuff up.....

The goal of Root Invigoration is to improve fine root growth by improving soil conditions - A key to recovery from stress

FIVE TIMES Fine Root Growth in Three Years

Should We Prune Stressed Trees?

Remove All Dead, Dying, Diseased and Defective Limbs

Thin Live Branches

Only If Crown is

Extremely Dense

Do Not Strip Interior Branches

DEALING WITH UNCERTAINTY:
Integrated Pest Management

One Example:
CULTURAL MANAGEMENT OF FOLIAR DISEASES

- SANITATION –

REMOVE FALLEN LEAVES
PRUNE DEAD TWIGS

SUPPLY DRIP IRRIGATION
THIN DENSE CROWNS

Conclusion

- Drought is one of the most severe and complex tree stresses
- P&D will influence drought (tolerance) and *vice-versa*
- Selecting for drought tolerance can have huge effect on survival and future aesthetics of trees
- Selecting with an appropriate bias for drought tolerance will drastically improve tree survival and condition
  - But all is not lost for the current tree stock, recovery programs are effective