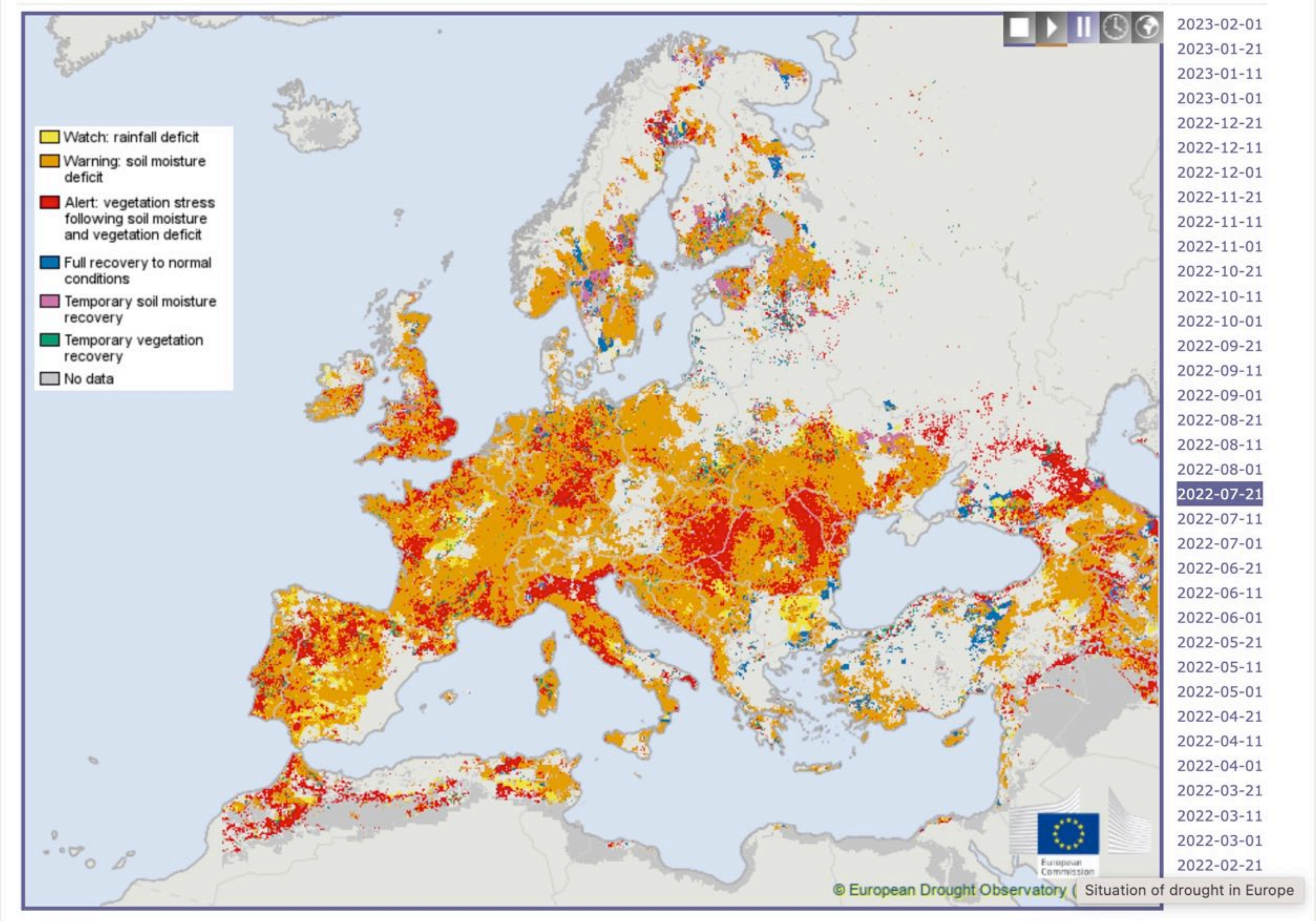
Biochemical and physiological aspects of (urban) trees tolerance to climate extremes



UNIVERSITÀ DEGLI STUDI FIRENZE
DAGRI DIPARTIMENTO DI SCIENZE E TECNOLOGIE AGRARIE, ALIMENTARI, AMBIENTALI E FORESTALI

Francesco Ferrini – DAGRI, University of Florence, Italy

3-4 March 2023 , Norwegian ISA Chapter Annual Conference Trondheim

NATIONAL BIODIVERSITY FUTURE CENTER

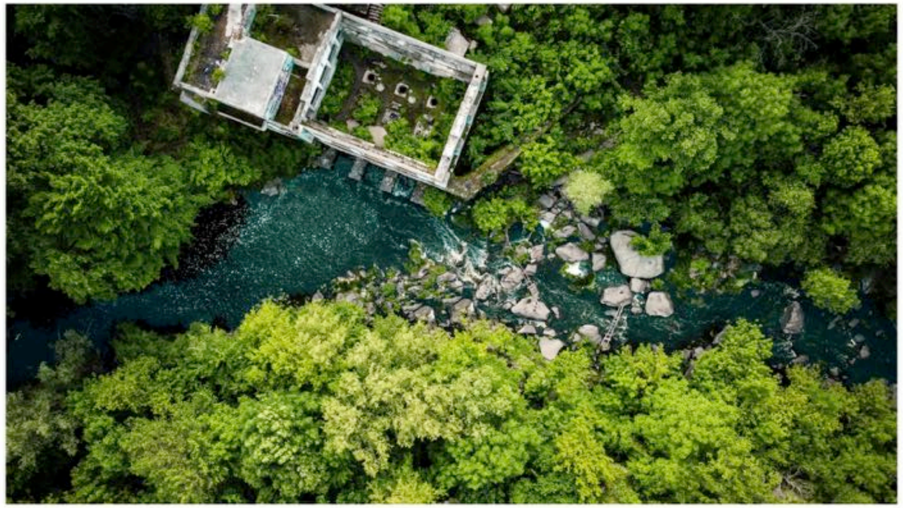
Drought in Norway? Is it a real problem?

Europe's Scorching Summer Puts Unexpected Strain on Energy Supply

The dry summer has reduced hydropower in Norway, threatened nuclear reactors in France and crimped coal transport in Germany. And that's on top of Russian gas cuts.

Give this article 502

Drought in Norway Newest Energy Threat

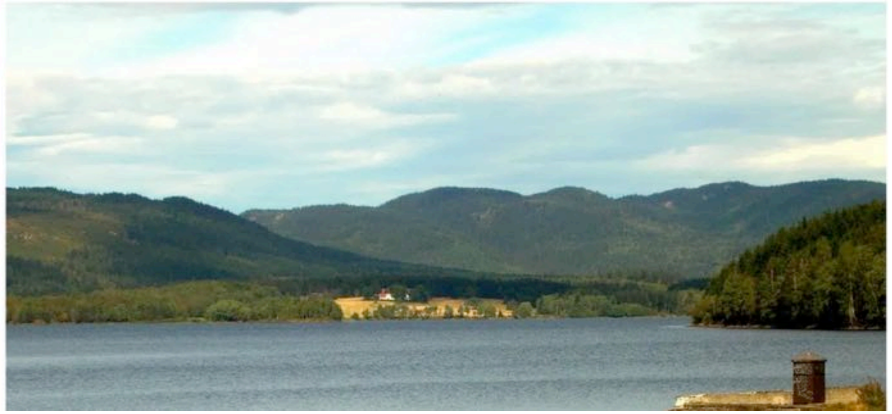


Norway is warning that it may cut the rest of Europe off from its energy exports, exacerbating the energy crisis on the continent.

Drought has Oslo on edge of critical water shortage

The Norwegian capital saw only half an inch of rain in March and April, less than 15% of normal for the period.

LASSE SØRENSEN / May 3, 2022



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Views and news from Norway

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Tag: drought

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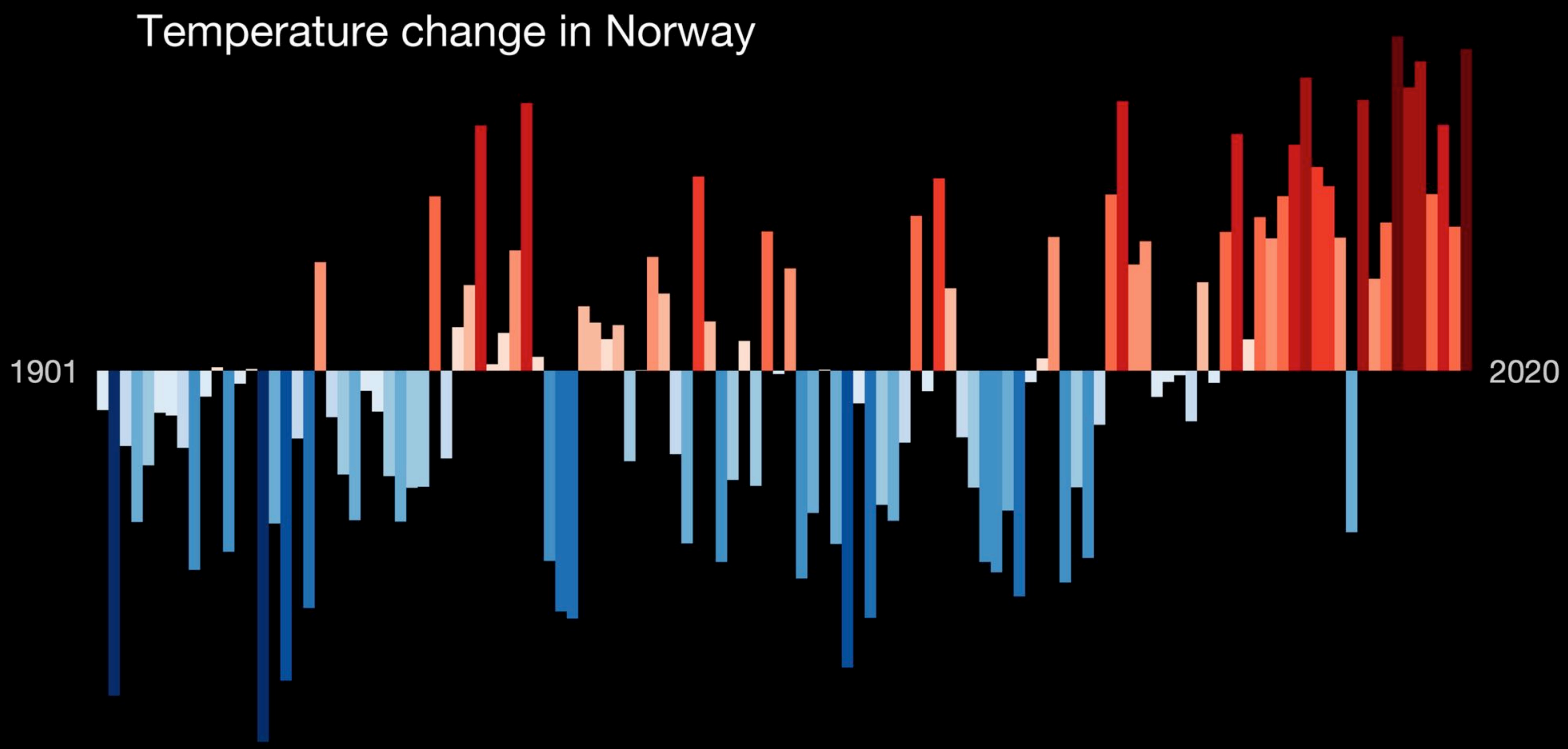
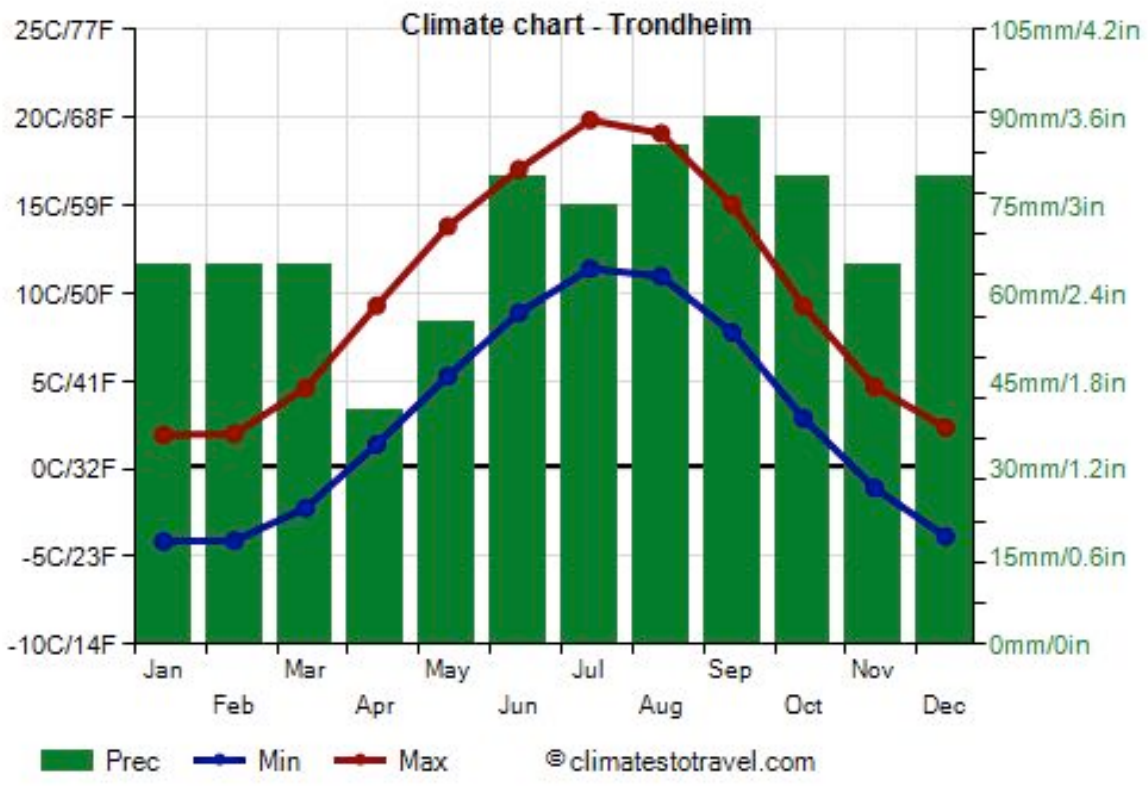
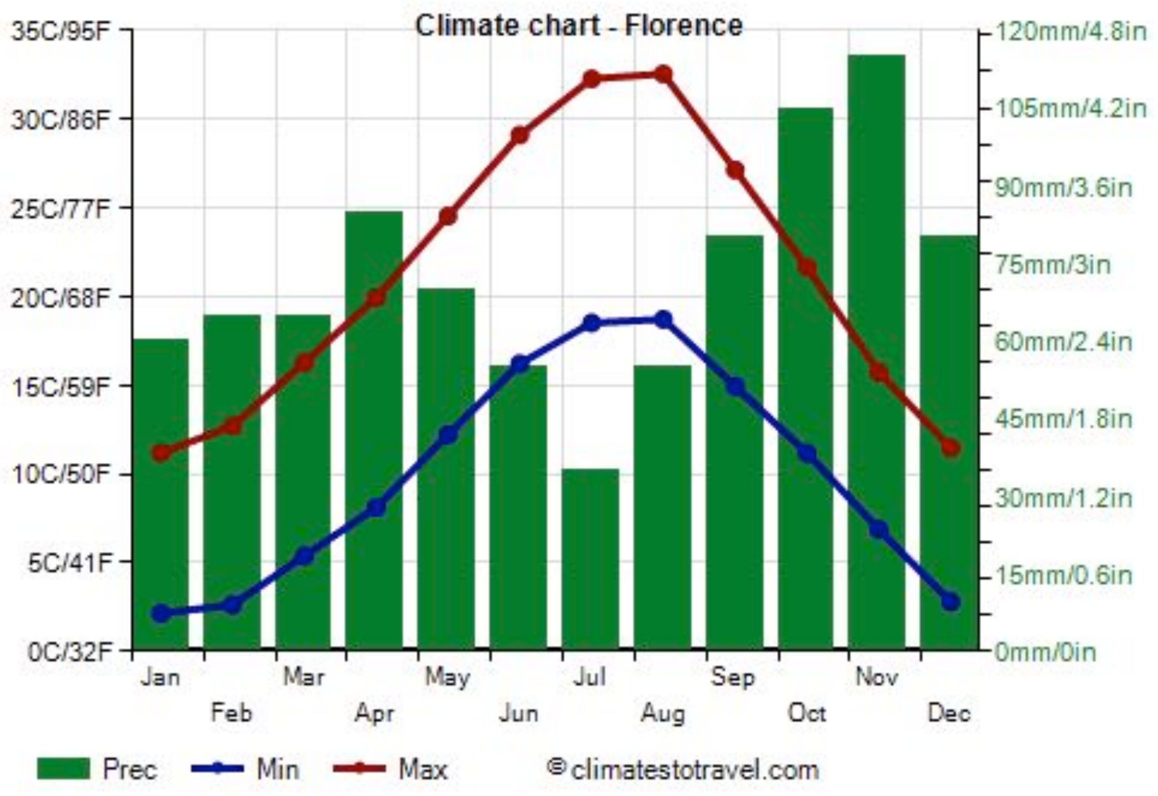


https://en.wikipedia.org/wiki/Climate_change_in_Norway#/media/File:Temperature_Bar_Chart_Europe-Norway--1901-2020--2021-07-13.png





In Trondheim, precipitation amounts to **845 millimeters per year**. It ranges from 40 mm in the driest month (April) to 90 mm in the wettest one (September).

In Florence precipitation amounts to **870 millimeters per year**. It ranges from 35 mm in the driest month (July) to 110 mm in the wettest one (November).

2020	2021	2022
685	736	662

https://www.climatestotravel.com/climate/italy/florence


Milan July 2022

…and even when it rains in summer…

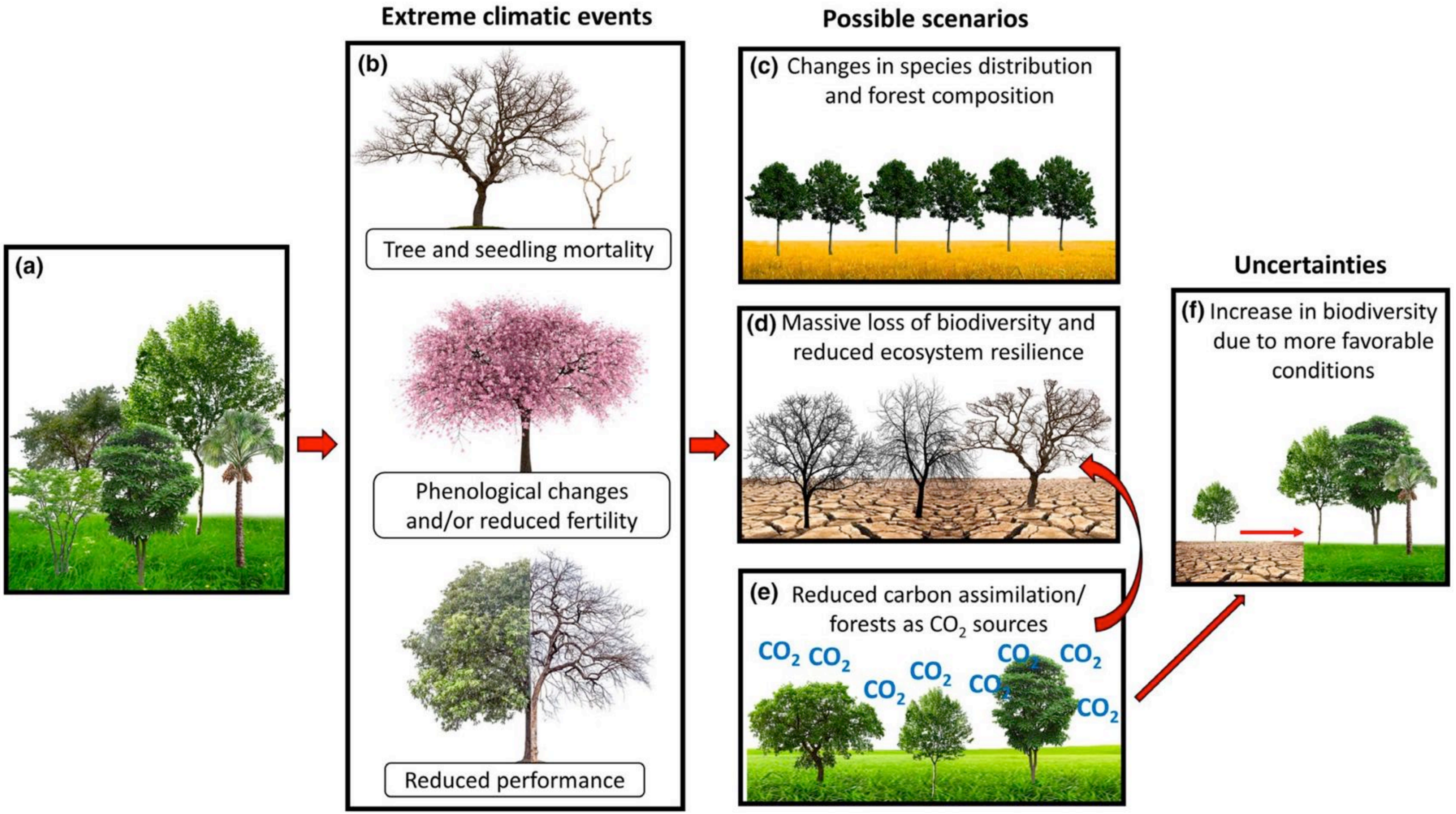
Most of our veteran trees were planted during a climate that itself is becoming historic"

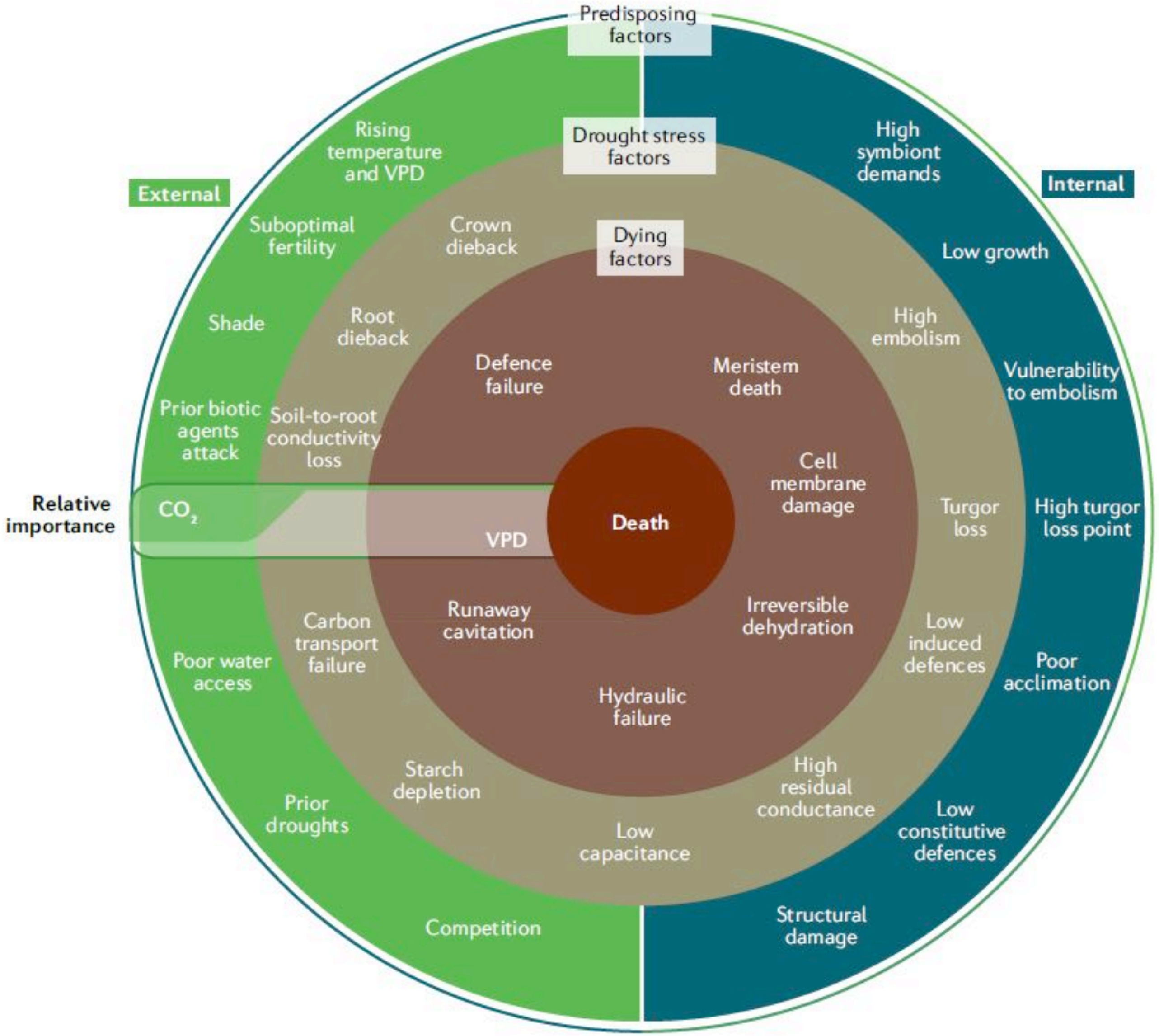
(modified from Bisgrove & Hadley 2002*)*

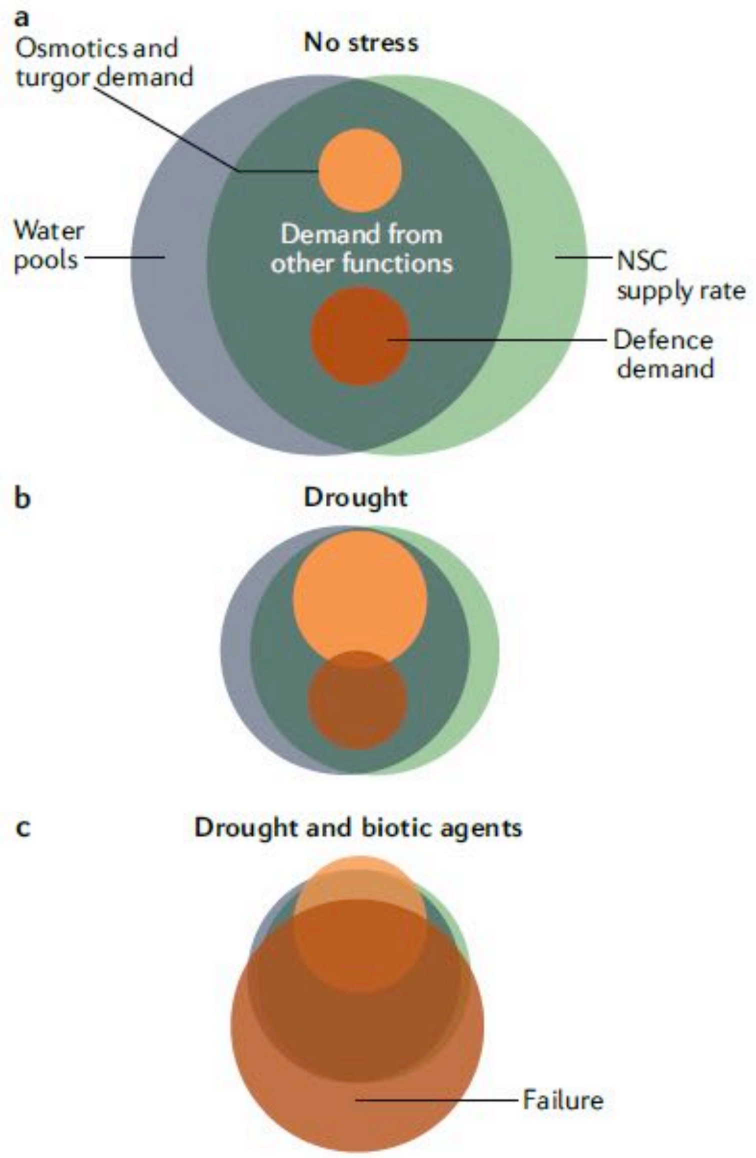
How trees are affected by climate extremes?

Image credit https://www.theguardian.com/environment/2021/mar/10/is-this-the-end-of-forests-as-weve-known-them

Consequences of climate change on growth and survival of tree species through an eco-physiological perspective
(From Menezes-Silva et al., 2019. Ecology and Evolution.9:11979–11999)





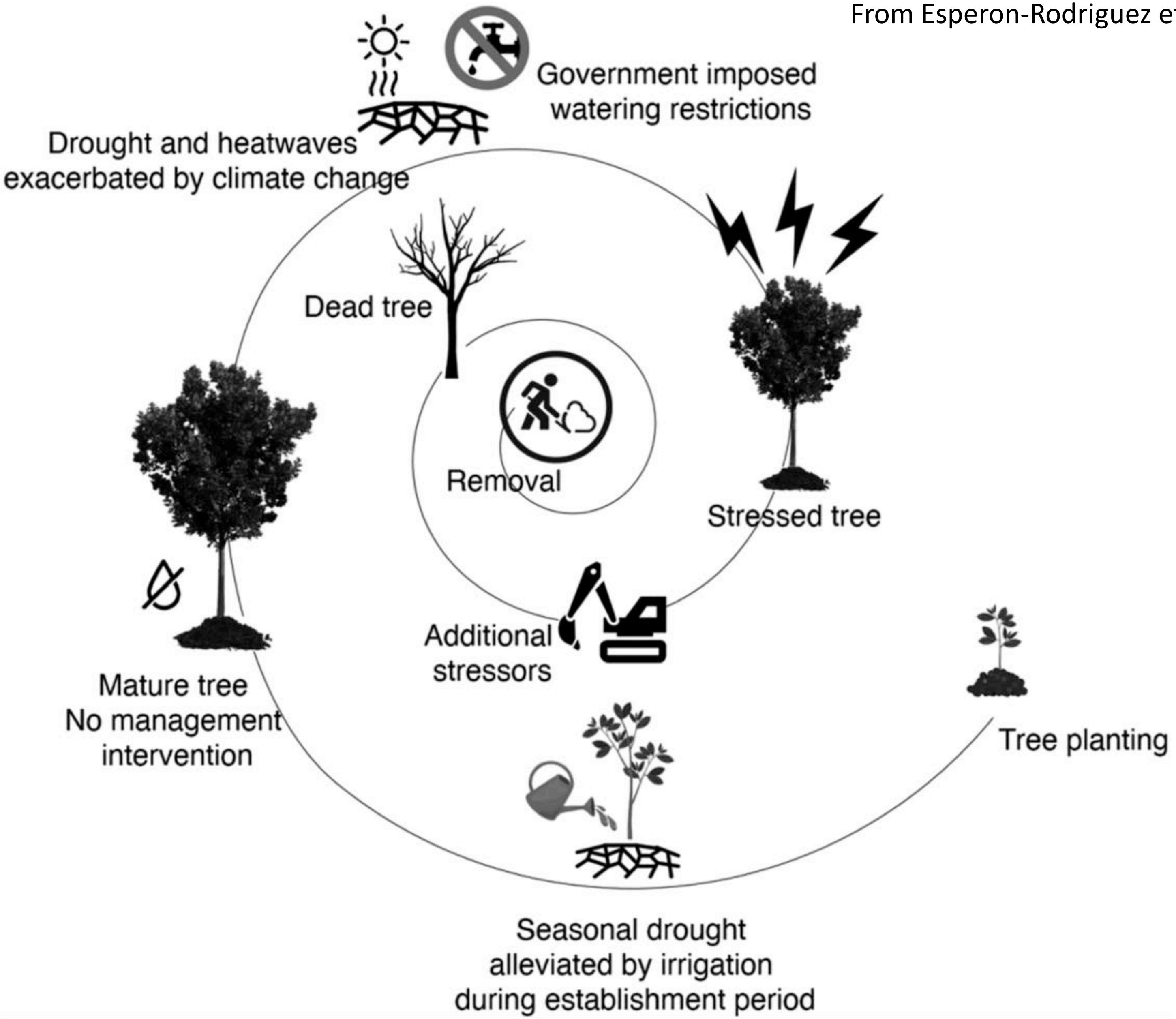


Mortality spiral…

It shows the interactions between the different factors that contribute to tree decline until its death. The predisposing factors in the outer ring are connected to the death of the tree through the mechanisms reported in the second ring, which in turn can induce the exceeding of the critical thresholds reported in the ring in the center, causing tree death.

From McDowell et al. 2022, Nature Reviews Earth and Environment

From Esperon-Rodriguez et al., 2022, DOI: (10.1002/ppp3.10240)



A conceptual example of the tree mortality spiral of urban tree failure and associated biophysical factors and management (adapted from Franklin et al., 1987; Hilbert et al., 2019; Manion, 1981)

How do plants cope with stress?

The responses of plants to cope with stress are defined based on the **intensity** and **duration** of the stress application, as well to the **combination** of the stress factors

timescale

1) “**Temporary physiological adjustments** ” responses to daily and seasonal rhythms and fluctuations
2) “**Acclimation**” (occurring in plant exposed to a single stress factor in controlled conditions) and “**acclimatization**” (occurring in the field as a response to multiple stress factors)**(SHORT TERM)**
3) “**Phenotypic adaptation**” occurs at the population level when plants spend their whole lifespan growing and reproducing in harsh environments
4) "**Genetic adaptation**” occurs when populations persist and reproduce over generations in stressful environments, producing adapted genotypes **(LONG TERM)**

Acclimatization (short term) → Acclimatization refers to non-heritable physiological changes that occur during an individual's life

Adaptation (long term) → Adaptation refers to inheritable changes in structure or function that increase the fitness of the organism in the stressful environment. for instance

(Anderson et al., 2011; Fox et al., 2019; Kelly, 2019) adapted and modified

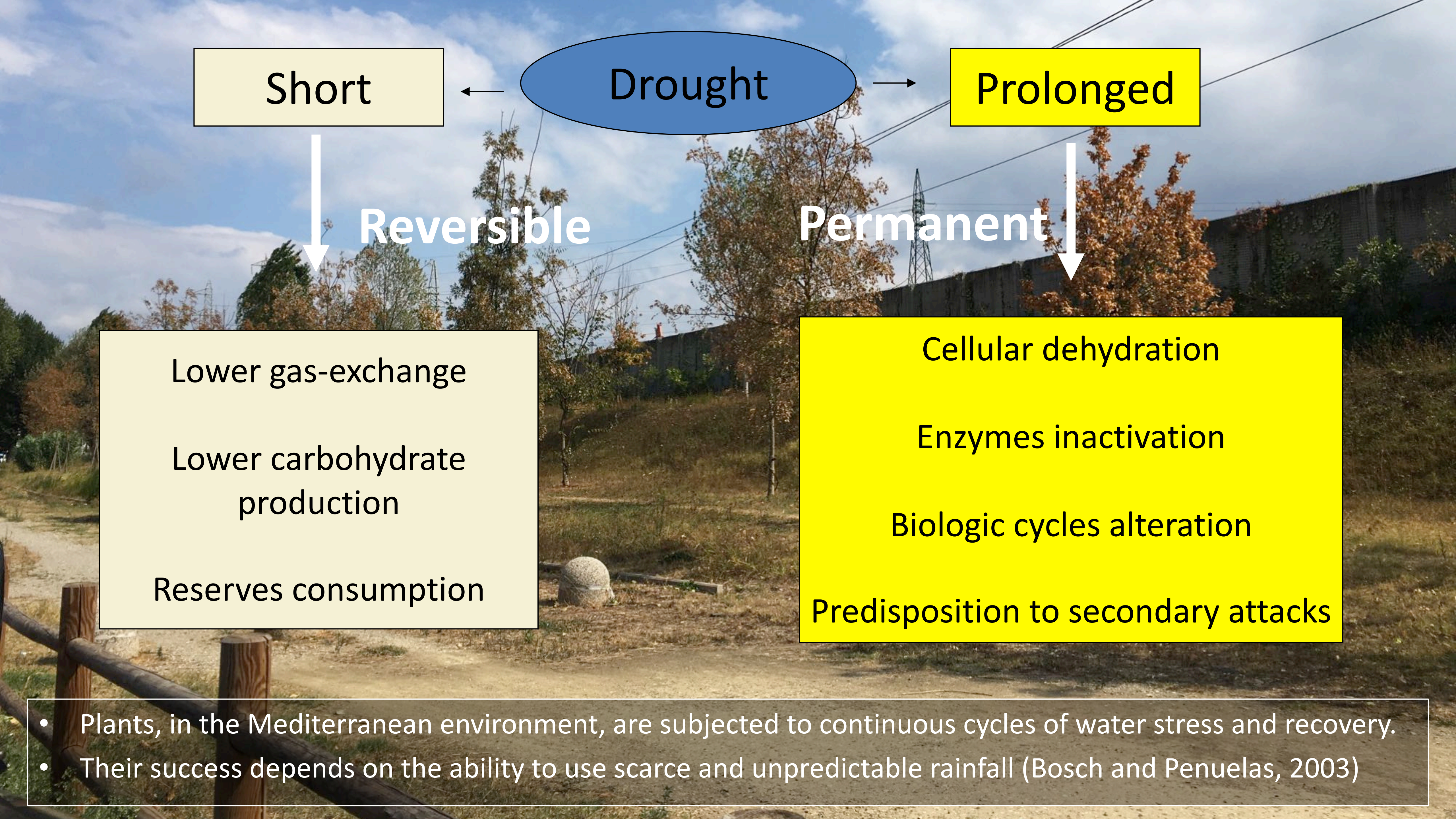
What happens to trees during drought spells

Drought is a multiple stress, involving the interaction of light, temperature and water availability.

Research directed to predict the effects of global change is time and money consuming and, at present, we mostly rely on predictions made on models……but we are sure that in the next future drought, CO_2 levels and temperature might strongly affect tree health and growth performances.

Trees and drought

Milan, Italy – mid July, 2022



Drought

Short → Reversible

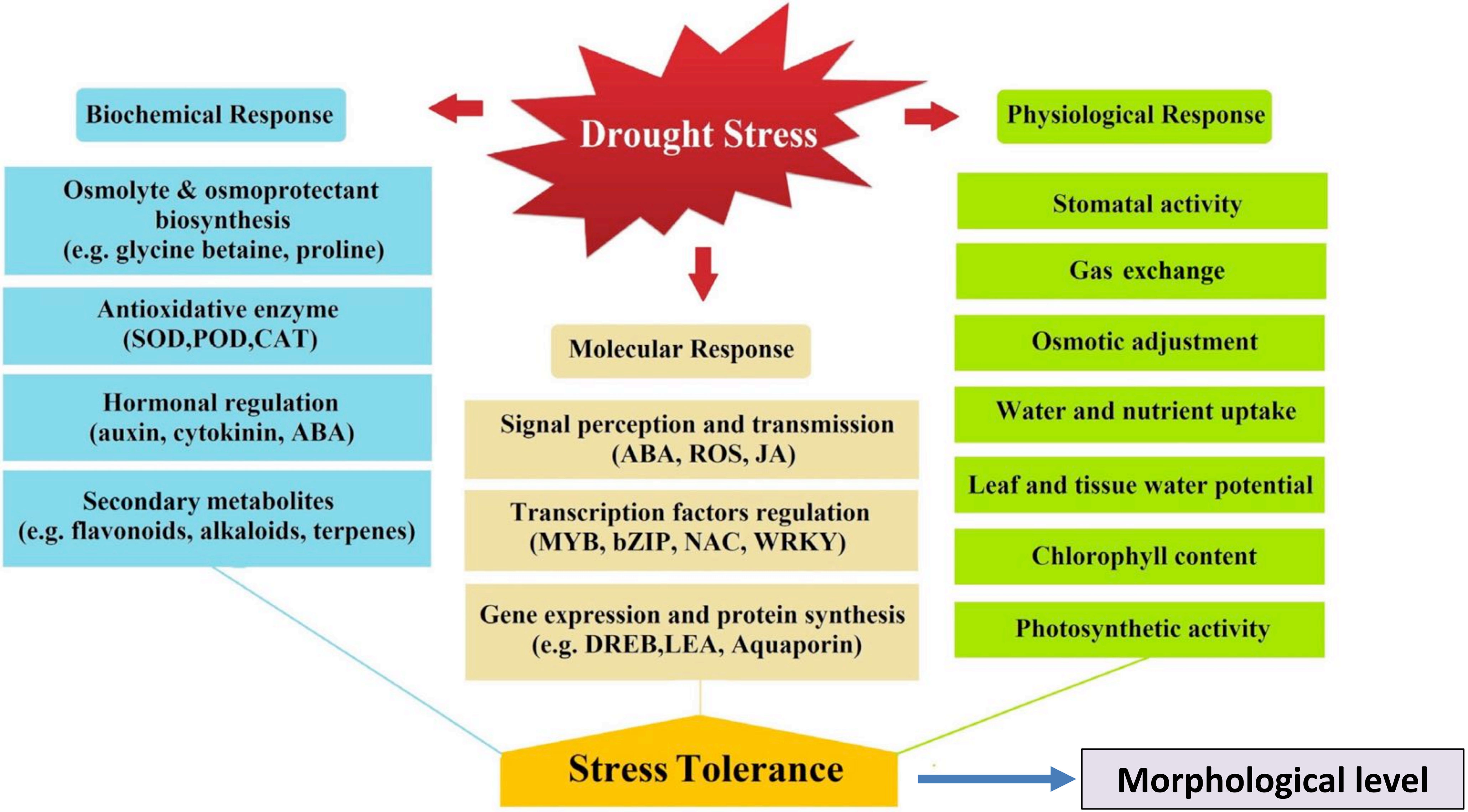
- Lower gas-exchange
- Lower carbohydrate production
- Reserves consumption

Prolonged → Permanent

- Cellular dehydration
- Enzymes inactivation
- Biologic cycles alteration
- Predisposition to secondary attacks

- Plants, in the Mediterranean environment, are subjected to continuous cycles of water stress and recovery.
- Their success depends on the ability to use scarce and unpredictable rainfall (Bosch and Penuelas, 2003)

Plants responses to drought stress



Adapted and modified from Oguz, M.C.; Aycan, M.; Oguz, E.; Poyraz, I.; Yildiz, M. Drought Stress Tolerance in Plants: Interplay of Molecular, Biochemical and Physiological Responses in Important Development Stages. Physiologia 2022, 2, 180–197. https:// doi.org/10.3390/physiologia2040015

How to measure drought stress

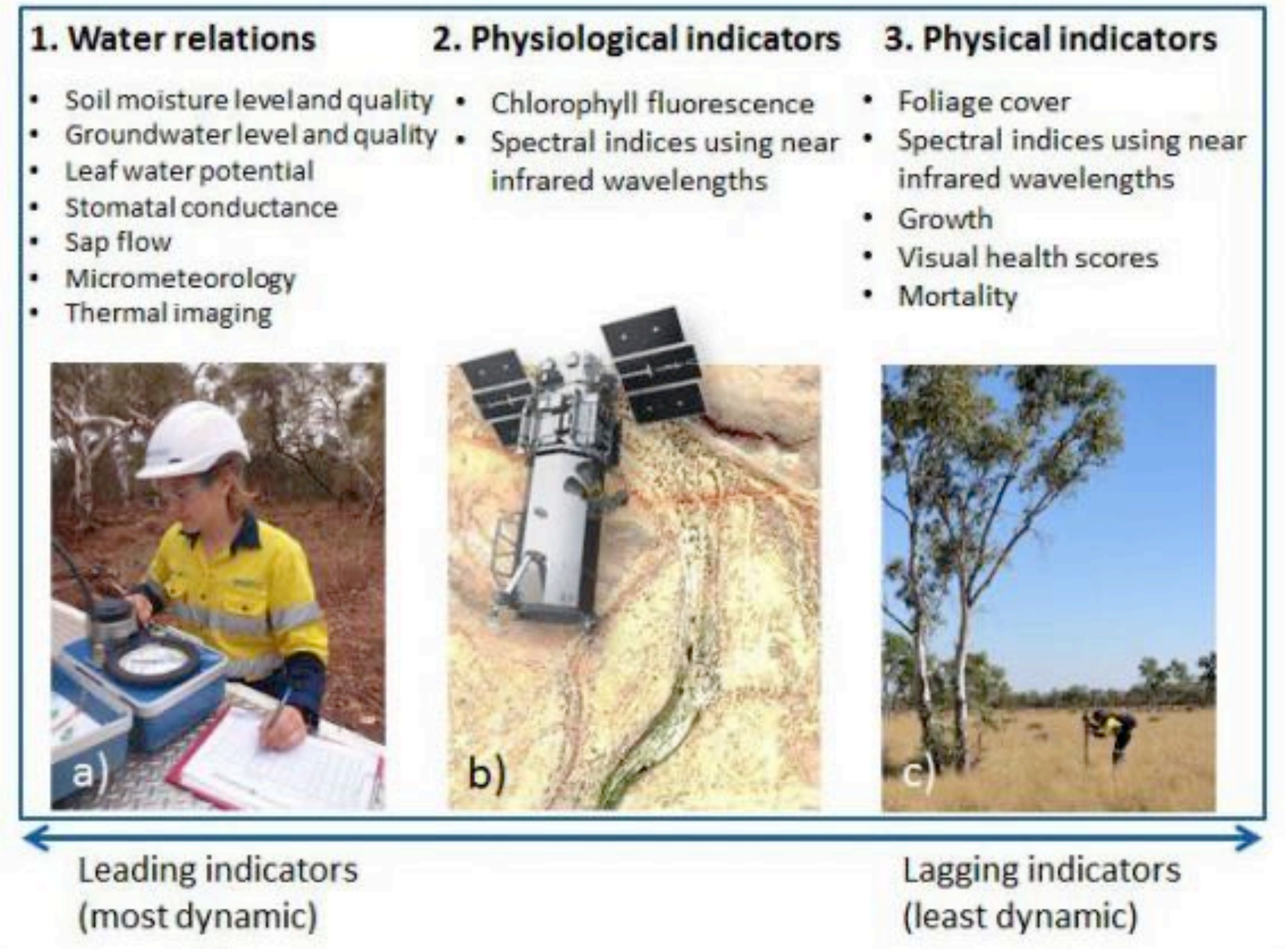
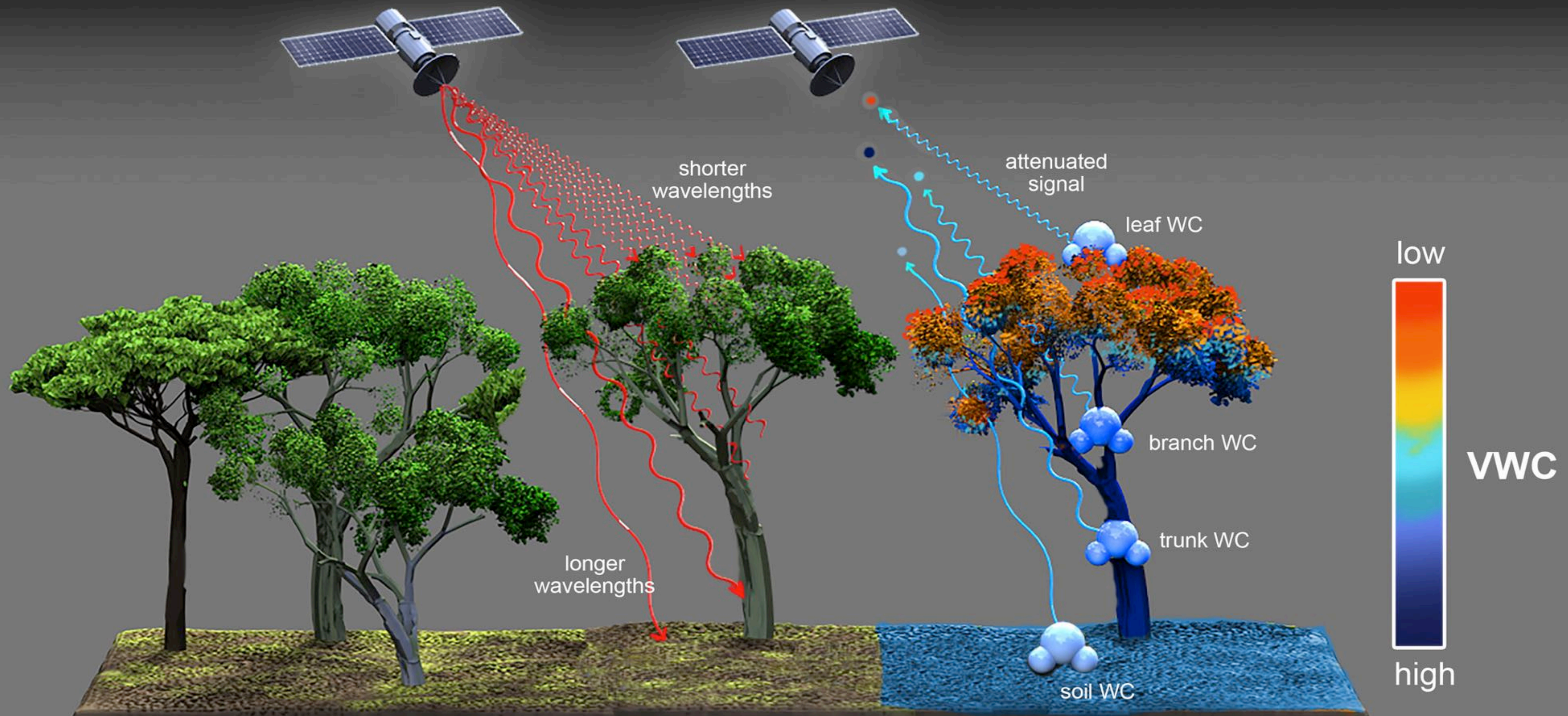


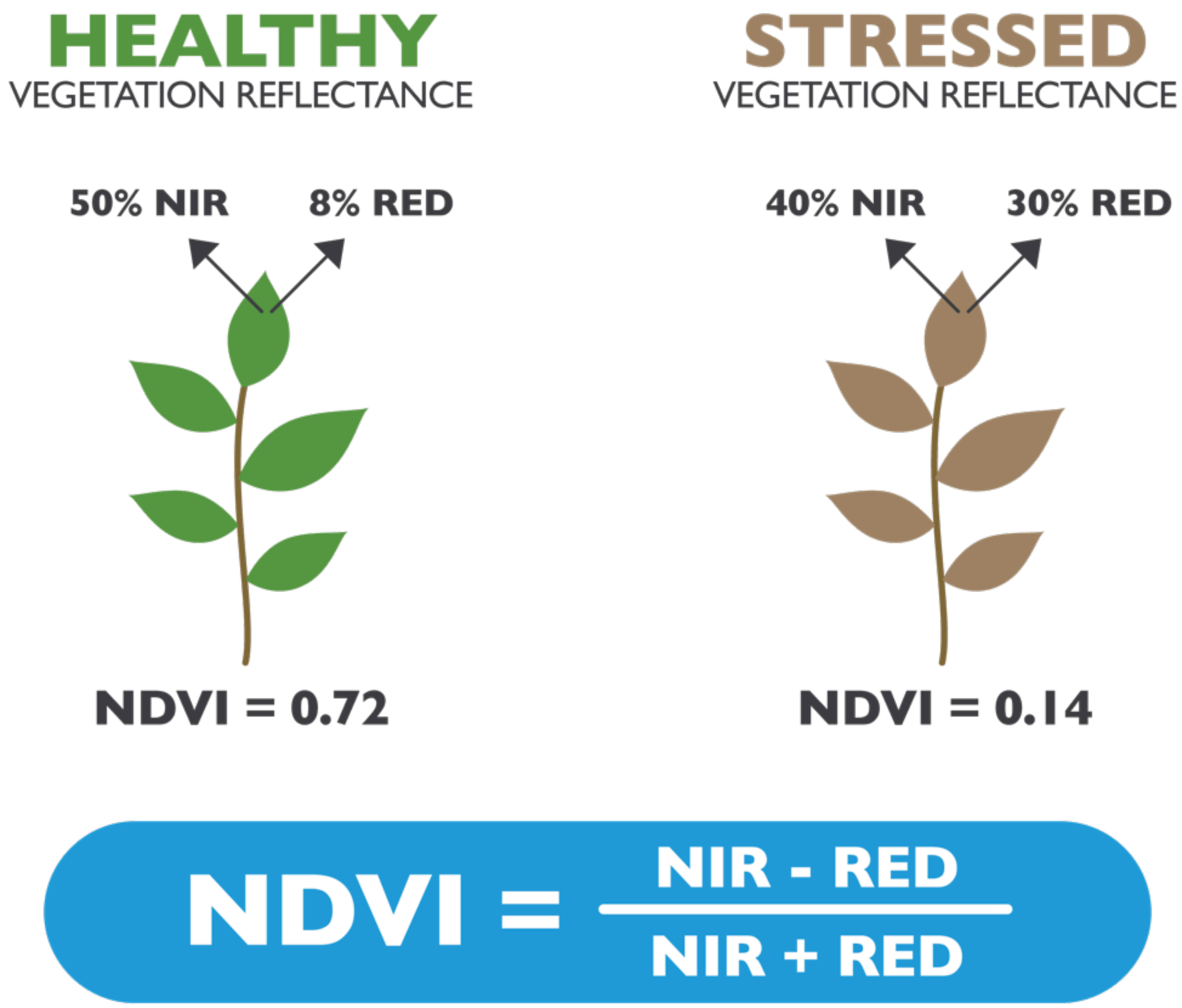
Image credits astron.com.au/news/monitoring-drought-stress-in-native-vegetation/

Detecting forest response to droughts with global observations of vegetation water content



Vegetation Water Content (VWC) can be retrieved from remote sensing measurements, particularly at microwave frequencies using radar and radiometry.

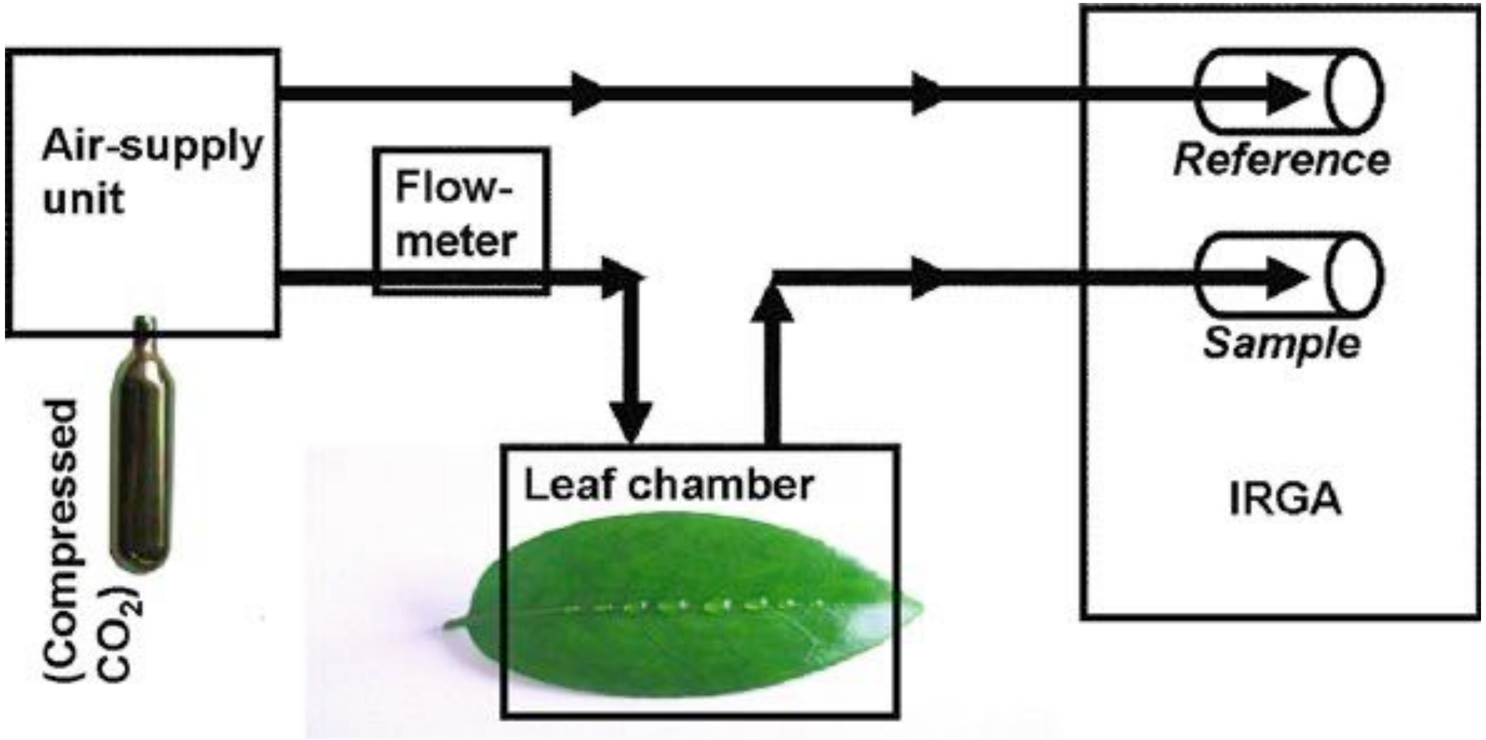
Konings et al., 2021. Global Change Biology, Volume: 27, Issue: 23, Pages: 6005-6024, DOI: (10.1111/gcb.15872)



The most used vegetation index is undoubtedly the NDVI (**Normalized Difference Vegetation Index**): it **describes the vigour level of the crop** and it is calculated as the ratio between the difference and the sum of the refracted radiations in the near infrared and in the red, that is as (NIR-RED)/(NIR+RED).

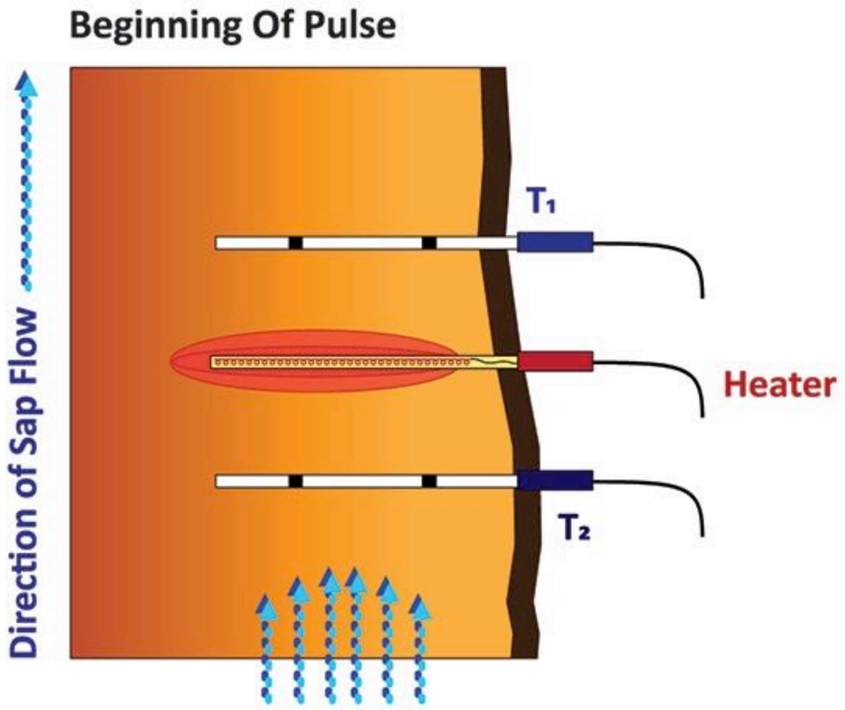
Image credits https://www.agricolus.com/en/vegetation-indices-ndvi-ndmi/

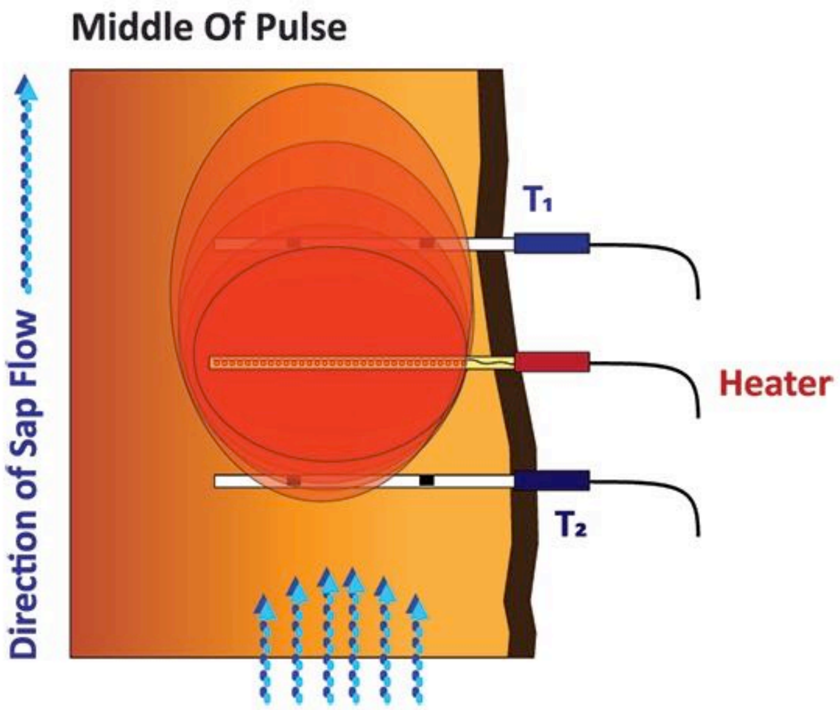
Leaf gas exchange



All photosynthesis gas exchange systems work by enclosing an entire leaf, or part of a leaf, within a chamber or cuvette. Within the chamber the quantity and quality of the photosynthetic photon flux density (PPFD: the amount of photosynthetically active radiation, PAR, arriving at the leaf within the 400–700 nm wavelength spectrum of light), the wind speed or ‘flow’ of air, the relative humidity (RH), temperature (leaf temperature may only be controlled to a degree under variable field conditions where the ambient conditions may diverge considerably from internal conditions within the leaf cuvette), and concentration of atmospheric gases can be controlled to determine the photosynthetic response of the area of leaf contained within the chamber (From Haworth et al., 2018)

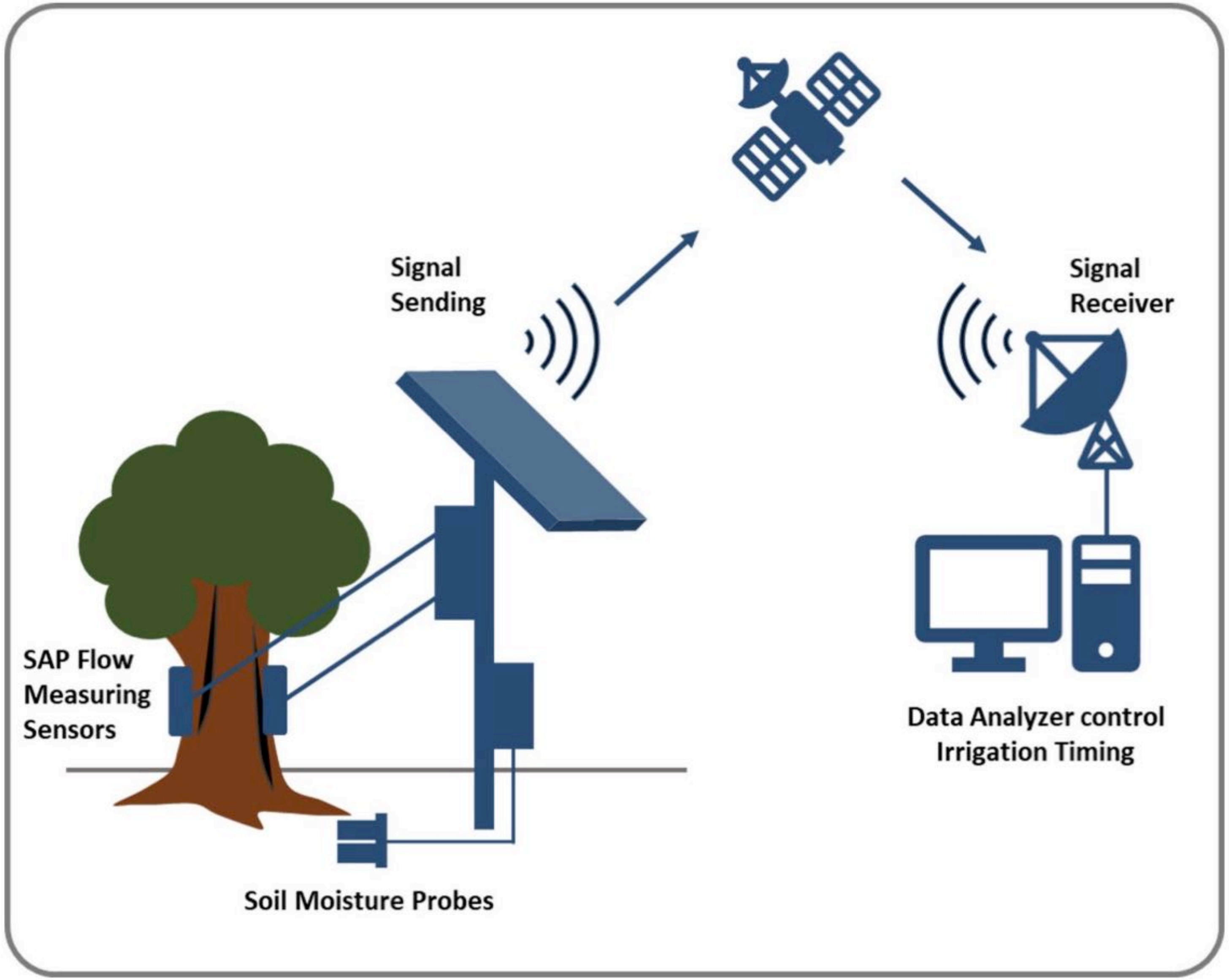
Sap flow measurement is one of the most effective methods for quantifying plant water use. Sap-flow sensors measure transpiration flow as the ascent of sap within xylem tissue; measurements can be made in stems, trunks, branches. Given that transpiration is sensitive to plant water status, with the effect being mediated by stomatal opening sap flow can be used as an indicator of plant water status.





There exist multiple methods to measure sap flow including **heat balance**, **dyes and radiolabeled tracers**. Heat sensor-based techniques are the most popular and commercially available to study plant hydraulics, even though most of them are invasive and associated with multiple kinds of errors. Heat-based methods are prone to errors due to misalignment of probes and wounding, despite all the advances in this technology.

Image credits Kumar R, Hosseinzadehtaher M, Hein N, Shadmand M, Jagadish SVK and Ghanbarian B (2022) Challenges and advances in measuring sap flow in agriculture and agroforestry: A review with focus on nuclear magnetic resonance. Front. Plant Sci. 13:1036078. doi: 10.3389/fpls.2022.1036078

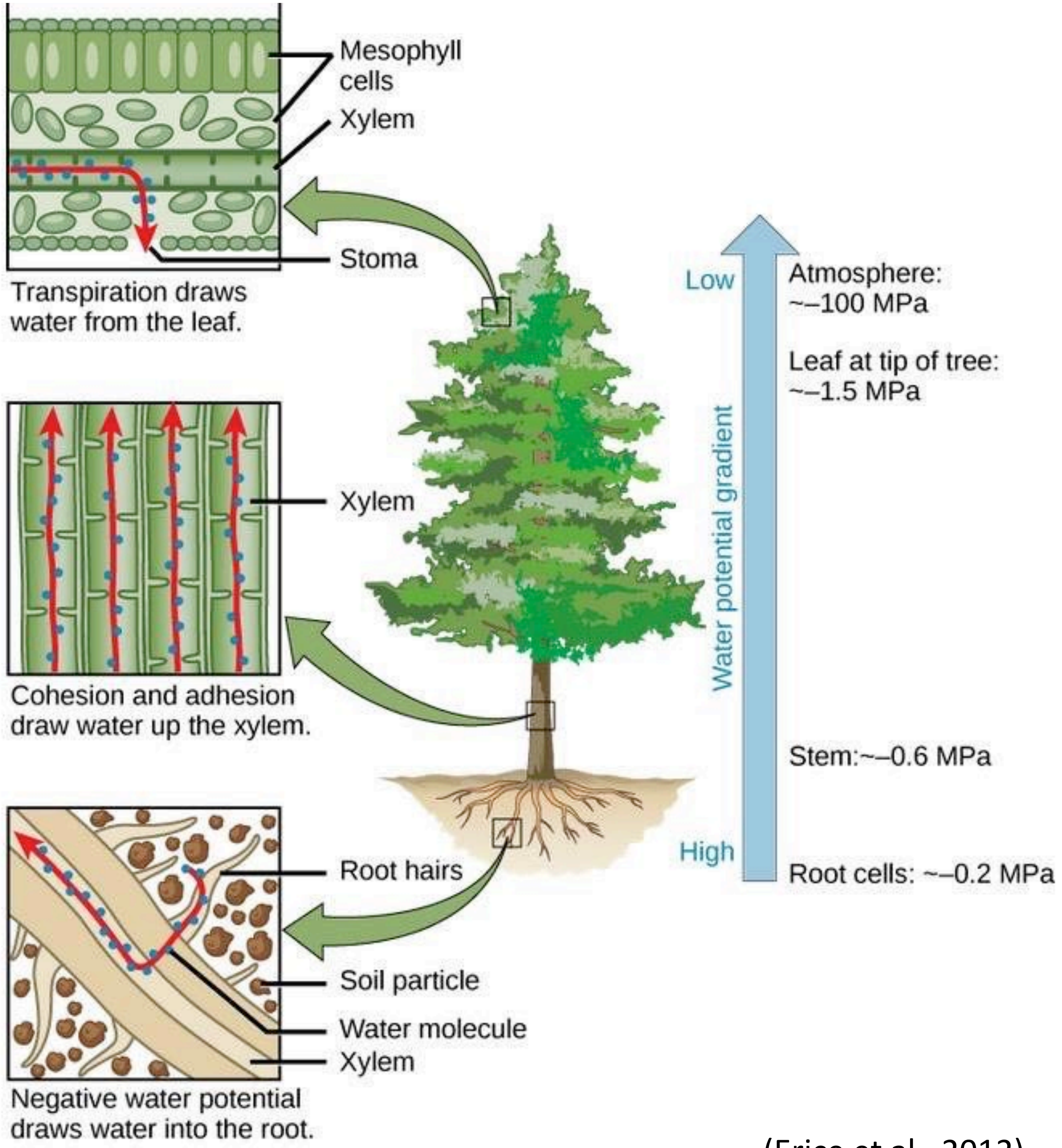


Model for monitoring the water content of plants using NMR combined with remote sensing tools for irrigation time management. In, future we need a portable NMR which can be used in the field and can be remotely controlled and remotely receive the data for the analysis.

Image credits Kumar R, Hosseinzadehtaher M, Hein N, Shadmand M, Jagadish SVK and Ghanbarian B (2022) Challenges and advances in measuring sap flow in agriculture and agroforestry: A review with focus on nuclear magnetic resonance. Front. Plant Sci. 13:1036078. doi: 10.3389/fpls.2022.1036078

Plant Water Relations

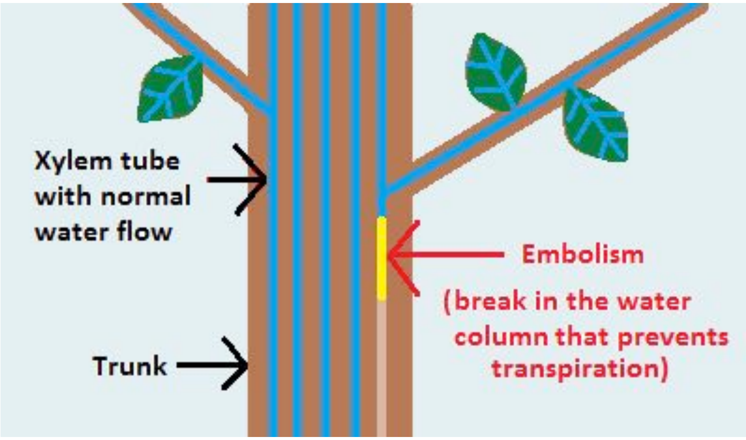
- We could define plant water relations as the study of water in plants, from its entry to the plant by roots until its exit from leaves, including also its transport along the stems and how it is retained in plant tissues.
- High temperatures increase stomatal conductance and leaf transpiration, further **increasing tension in xylem vessels and resulting in greater vulnerability to cavitation and hydraulic collapse.**



(Erice et al., 2012)

Plant Hydraulics

Although the water transport system through the xylem vessels in plants is efficient because it does not require energy costs, it is not always effective…



Reduction in plant hydraulic conductivity due to xylem embolism (Bubbles are formed in liquid phase under relatively Low pressure and break the water transporting in trees)

Cavitation (L. Cavus, hollow) is the phenomenon of gas or vapour filled cavities in liquids in motion in a region where the pressure of the liquid falls below its vapour pressure. **Cavitation occurs in xylem of vascular plants when the tension of water within the xylem becomes so high that dissolved air within water expands to fill either the vessels or the tracheids**. Cavitation reduces the hydraulic conductance then reducing stomatal conductance and can result from both freezing and drought.

Environmental factors leading to embolism formation

- Over a **prolonged drought**, **soil water content progressively declines, leading to a sustained decrease of Ψxyl** This pressure drop can be more or less pronounced as a function of plant structural/functional traits and responses, like rooting depth or stomatal closure under drought, but it has the capacity for inducing massive embolism and, in the worst scenario, **plant desiccation** and **death (from Nardini et al., 2012).**

How to measure xylem embolism?

- Hydraulic techniques
- X-ray microtomography
- Xylem dye staining
- Optical Technique

Hydraulic techniques

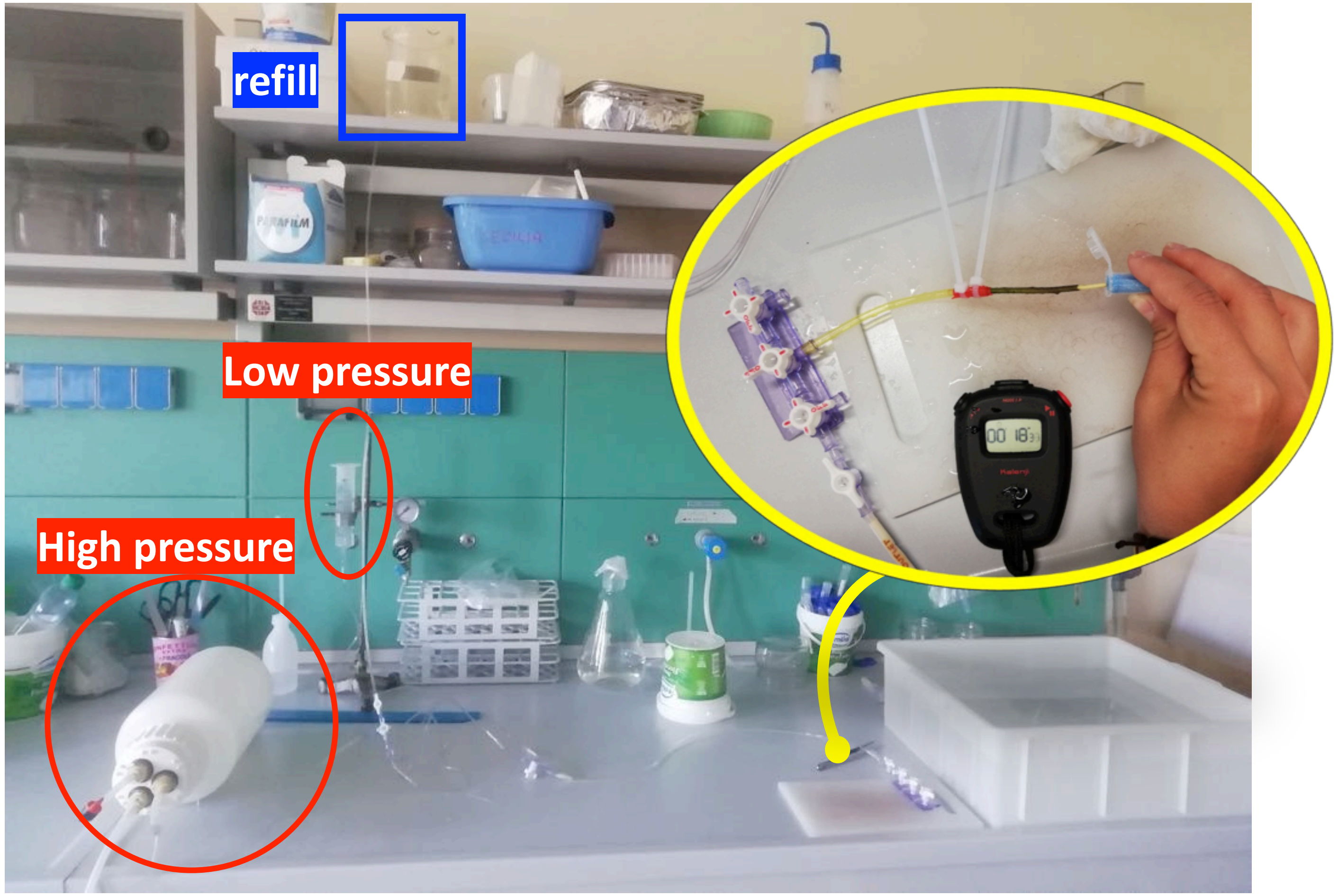
After water potential measurements, the twig is connected to hydraulic apparatus.

The initial hydraulic conductance (K_i) is measured after sample perfusion with a reference solution al low pressure (from 4 to 8 kPa).

Then, samples are flushed at high pressure (150 kPa) to remove embolism, and the maximum hydraulic conductance is measured (K_{max}).

Xylem embolism was quantified as PLC (Percentage Loss of Conductivity), calculated as

$$PLC= [1 - (K_i/K_{max})]*100$$



(Nardini et al., 2017)

Factors inside the plants predisposing them to embolism

- **Plant height:** Koch et al. (2004) observed that the tallest trees (*i.e.* higher than 120 m) are prone to an irreversible loss of hydraulic conductivity

- **Vessel diameter:** The Hagen-Poiseuille equation predicts that hydraulic conductivity of conduit lumens increases with the fourth power of their diameter. One way to improve the xylem hydraulic capacity is to increase xylem conduit diameters, which would decrease xylem hydraulic resistivity. However, different studies have shown that the large early-wood vessels of ring-porous trees are more vulnerable to cavitation than small vessels.

- **Water strategy adopted:** Anisohydric plants are theoretically more prone to die due to hydraulic failure compared to water conservative species. On the other hand, isohydric species that avoid hydraulic failure through stomatal closure, could suffer die due to carbon starvation, which consists of an imbalance between carbon demand and carbon supply. Recent theoretical advances also propose a coupling of carbon starvation and hydraulic failure, suggesting that drought can cause failure of sugar transport in the phloem, limiting carbohydrate utilization and promoting mortality via either mechanism.

There is no a winning water strategy

(McDowell et al. 2008; Vilagrosa et al., 2012)

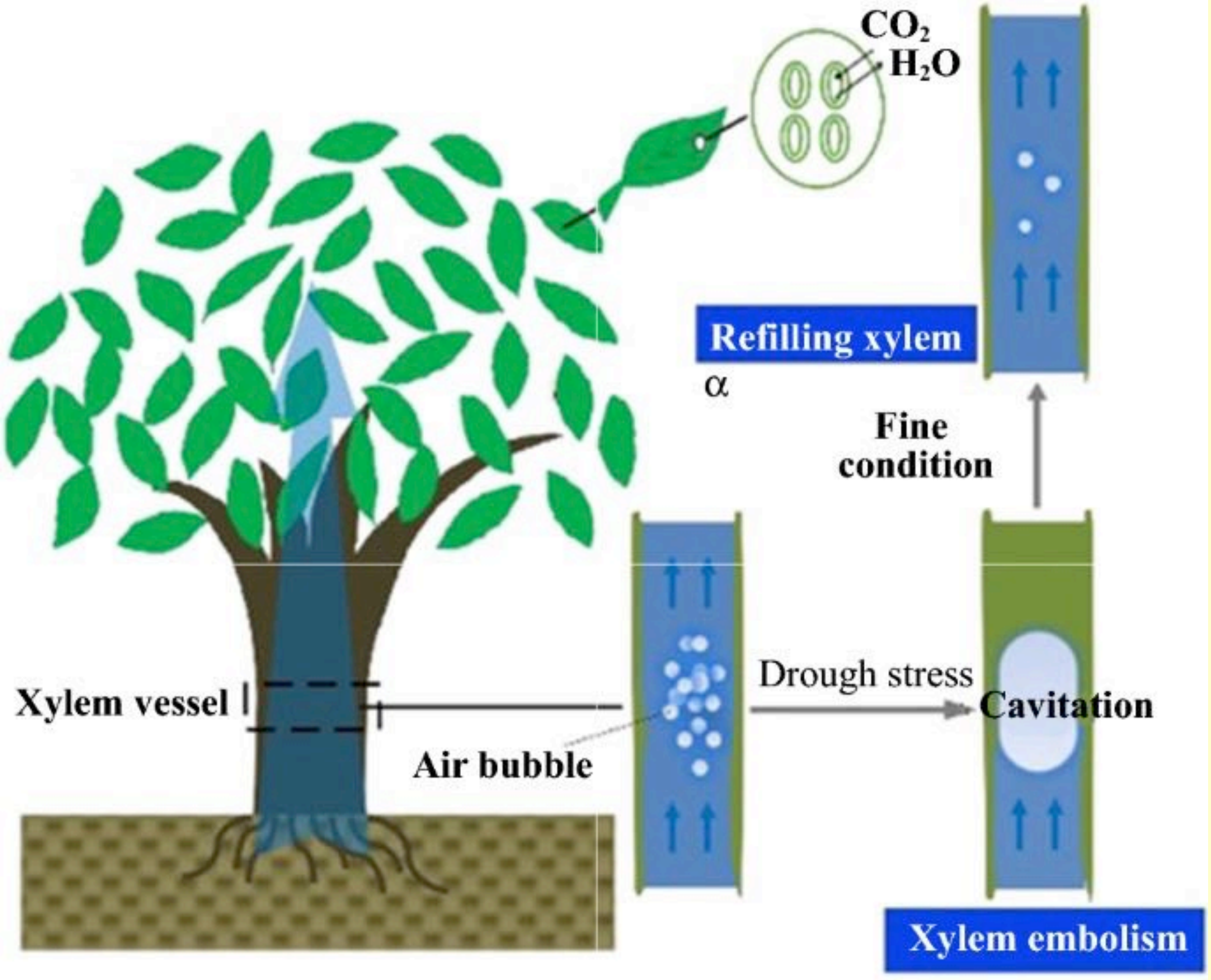
IS THERE ANY CONNECTION BETWEEN DROUGHT AND TREE BIOMECHANICS?

Acta Mechanica Sinica (2020) 36(5):1142–1157
https://doi.org/10.1007/s10409-020-00980-1

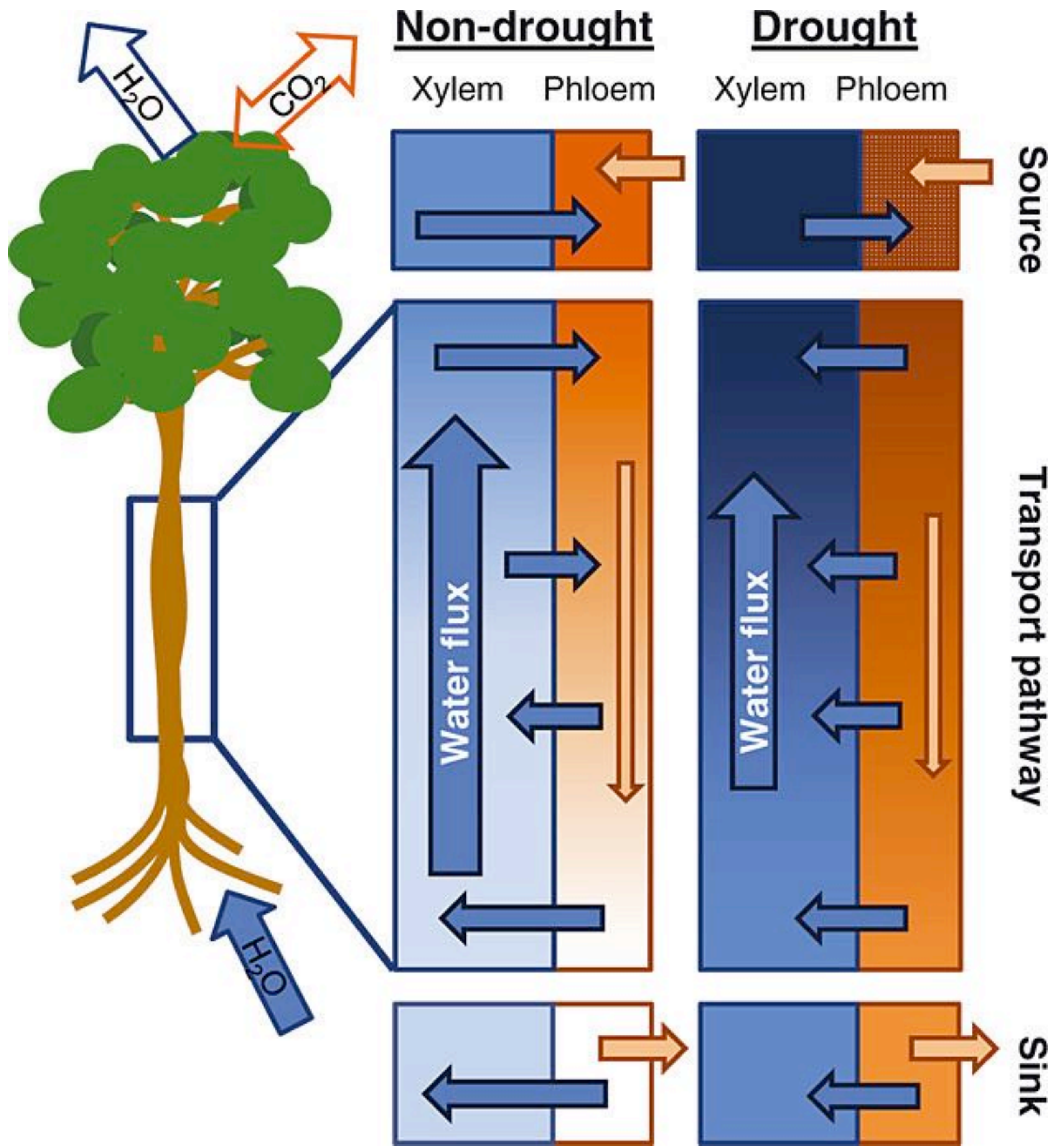
REVIEW PAPER

Biomechanics in plant resistance to drought

Shaobao Liu[1,2] · Han Liu[3,4] · Jiaojiao Jiao[4] · Jun Yin[1,2] · Tian Jian Lu[1,2] · Feng Xu[3,4]



Biomechanics in plant drought resistance at tissue level: Over a **prolonged drought**, **soil water content progressively declines, leading to a sustained decrease of Ψxyl**. This pressure drop can be more or less pronounced as a function of plant structural/functional traits and responses, like rooting depth or stomatal closure under drought, but it has the capacity for inducing massive embolism and, in the worst scenario, **plant desiccation** and **death.**



IS THERE ANY CONNECTION WITH TREE BIOMECHANICS?

A schematic presentation of water and carbohydrate fluxes between a source leaf and a sink in the stem or roots. Fluxes of water and carbohydrate are represented by blue and orange arrows, respectively, and the length of the arrow indicates the size of the flux. Open arrows are gaseous fluxes. Inside the vascular tissue, darker shades of blue indicate more negative xylem water potentials, and dark shades of orange indicate higher phloem solute concentrations. During non-drought conditions, the phloem pulls water from thexylem to support carbohydrate transport. At sinks, carbohydrates are extracted from the transport stream and water returns to the xylem. During drought, increasing solute concentrations are needed in the phloem to prevent excessive water loss to the xylem and allow for phloem turgor maintenance. Image from Clearwater et al., 2015, Cell and Environment, 39,709–725


In hot, dry conditions, changes in the properties of the wood in the cracked section can lead to sudden cracking.
Photo credits https://fondoambiente.it/luoghi/quercia-delle-checche-val-d-orcia?ldc

Lack of full consent because of different causes and different effects:

- Breakages can occur both along the branch and at insertion on the branches of a higher order or on the trunk.
- SBD occurs on both small and large branches, the orientation of the branch can be both horizontal and vertical.
- High distal loads are not a prerequisite.
- If degraded wood is present at the breaking point, can the crack still be considered to be caused by SBD?
- Summer breaks can occur in both windy and calm conditions.
- SBD can also occur on cooler days (temperatures < 27° C).
- The break may also not be "sudden", i.e. it can also take place over a period of hours.

How trees manage water stress

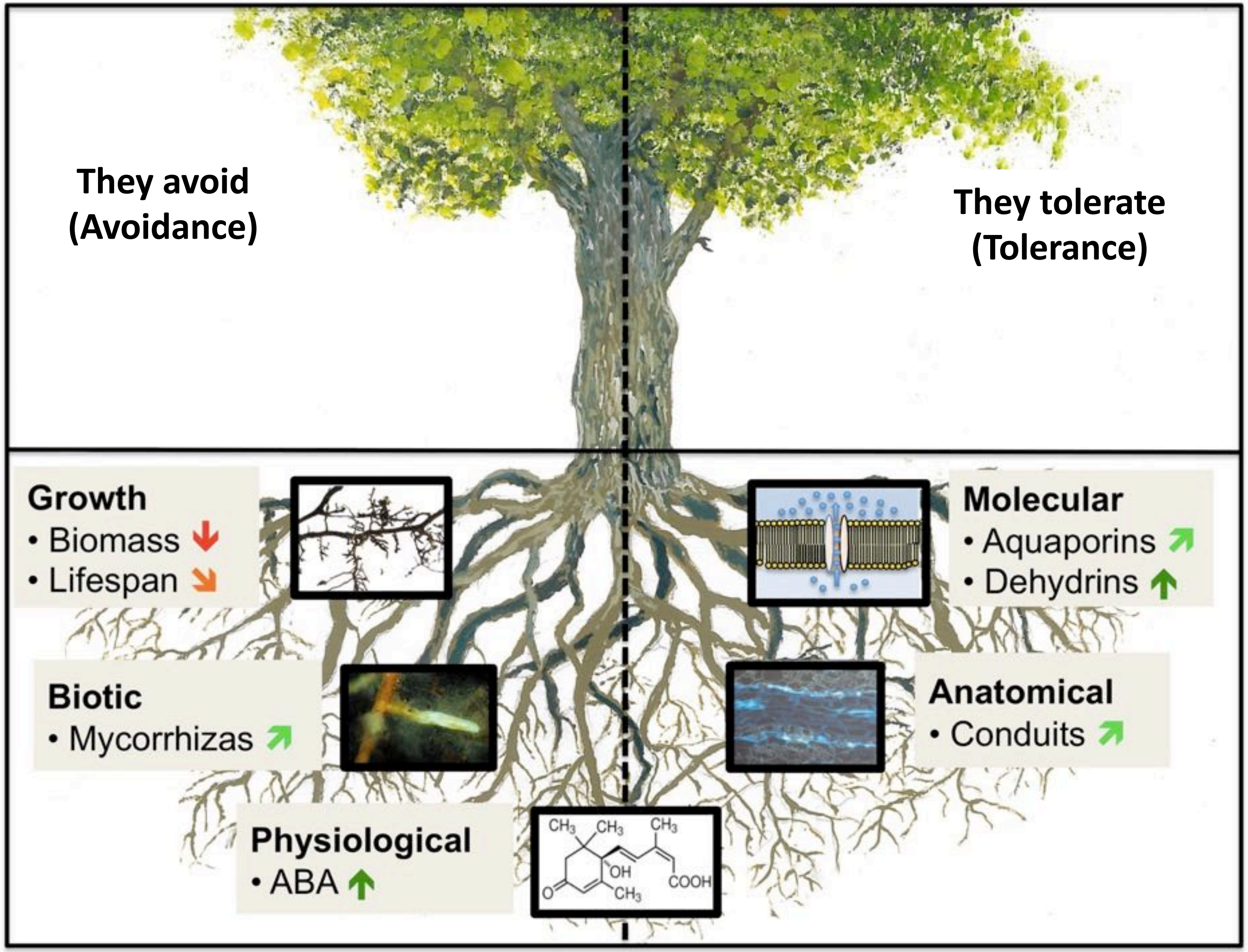


Image from Brunner I, Herzog C, Dawes MA, Arend M and Sperisen C., 2015. How tree roots respond to drought. Front. Plant Sci. 6:547. doi: 10.3389/fpls.2015.00547

Main adaptations of tree species in conditions of water scarcity

(modified from Sansavini et al., 2012)

Morphoanatomical adaptations	Physiological adaptations
Thickening of the leaf cuticle	Increase of stomatal and cuticular resistance
Decrease in the size of the epidermis and mesophyll cells and increase in cell density	Resistance and efficiency of the photosynthetic apparatus
Photoprotection mechanisms	Biochemical mechanisms
Decrease in the size of the stomata	Production and accumulation of abscisic acid
Increase in the number of trichomes	Osmotic adjustment
Increased stiffness of cell walls	Production of antioxidant compounds and enzymes
Suberification of the exodermal and endodermal cells of the roots	Activation of water channels in the roots (aquaporins)
Reduction of leaf growth and increase of the root / leaf ratio	Increase in the pH values of the xylem solution and leaf apoplasty

Stress escape: plant escapes the damage of stress by regulating its life cycle to avoid encountering stress.

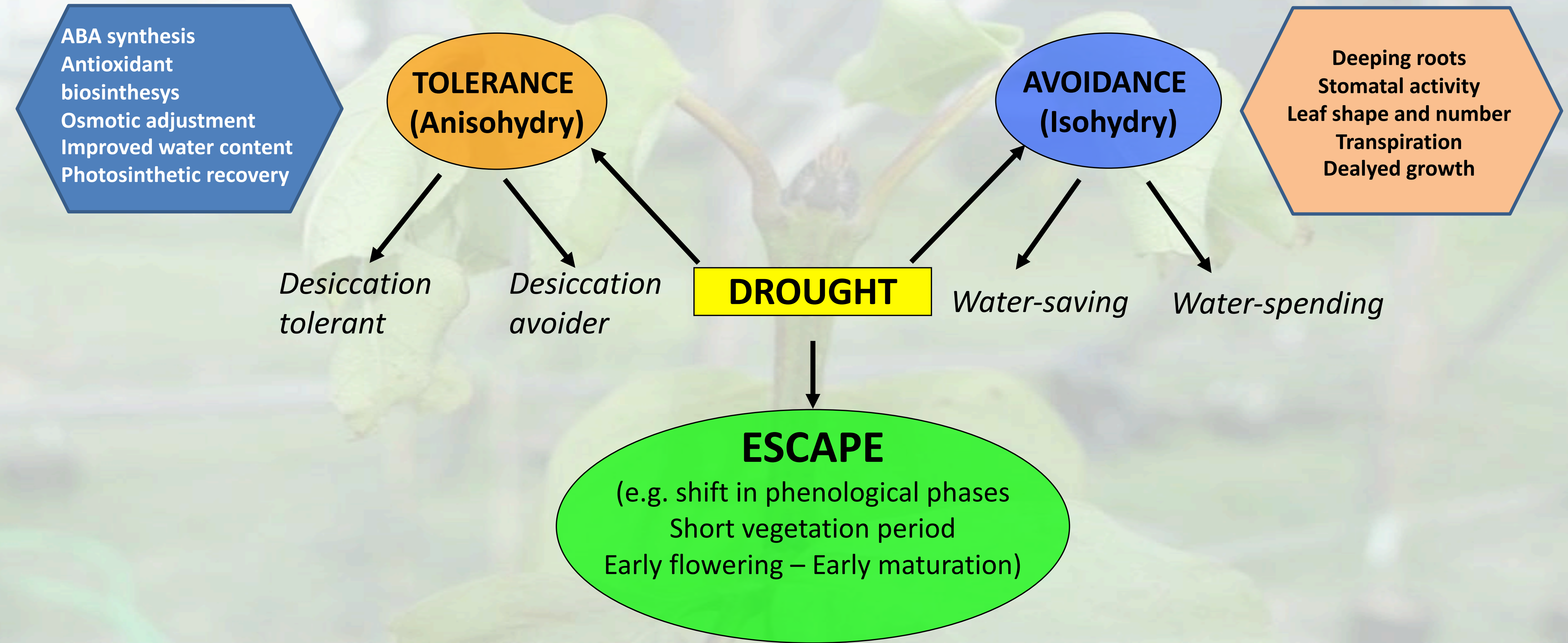
– For instance. some short-lived desert ephemeral plants germinate, grow, and flower very quickly after seasonal rains. Thus, they complete their life cycle during a period of adequate humidity and form dormant seeds before the onset of the dry season.

- Stress avoidance: Plants avoid stress-related damage by building a barrier to prevent stressors from entering the plant.
  - Some species survive in arid habitats by producing deep root systems that penetrate the aquifer.
  - Some halophytes secrete salts out of the leaf, thereby reducing the salt content in the leaf itself.

Tolerance strategies (Levitt, 1980; Chaves et al., 2002; Nardini et al., 2014)

Anisohydric *(having loose stomatal control and no discernable threshold of water potential maintenance)(Maseda and Fernandez, 2006)*

Isohydric *(having tight stomatal control and a minimum threshold of water potential that cause stomata to close)*



Isohydric species

They avoid or prevent an excessive decrease in water potential during drought events (ψw and RWC decreased slightly)

Water spending: **Species with deep roots** (> 1m, up to 50 m) which can absorb water in deep soil layers, although there is no water available on the surface. Require high conductance in woody organs. They contribute to the redistribution of water during the night.

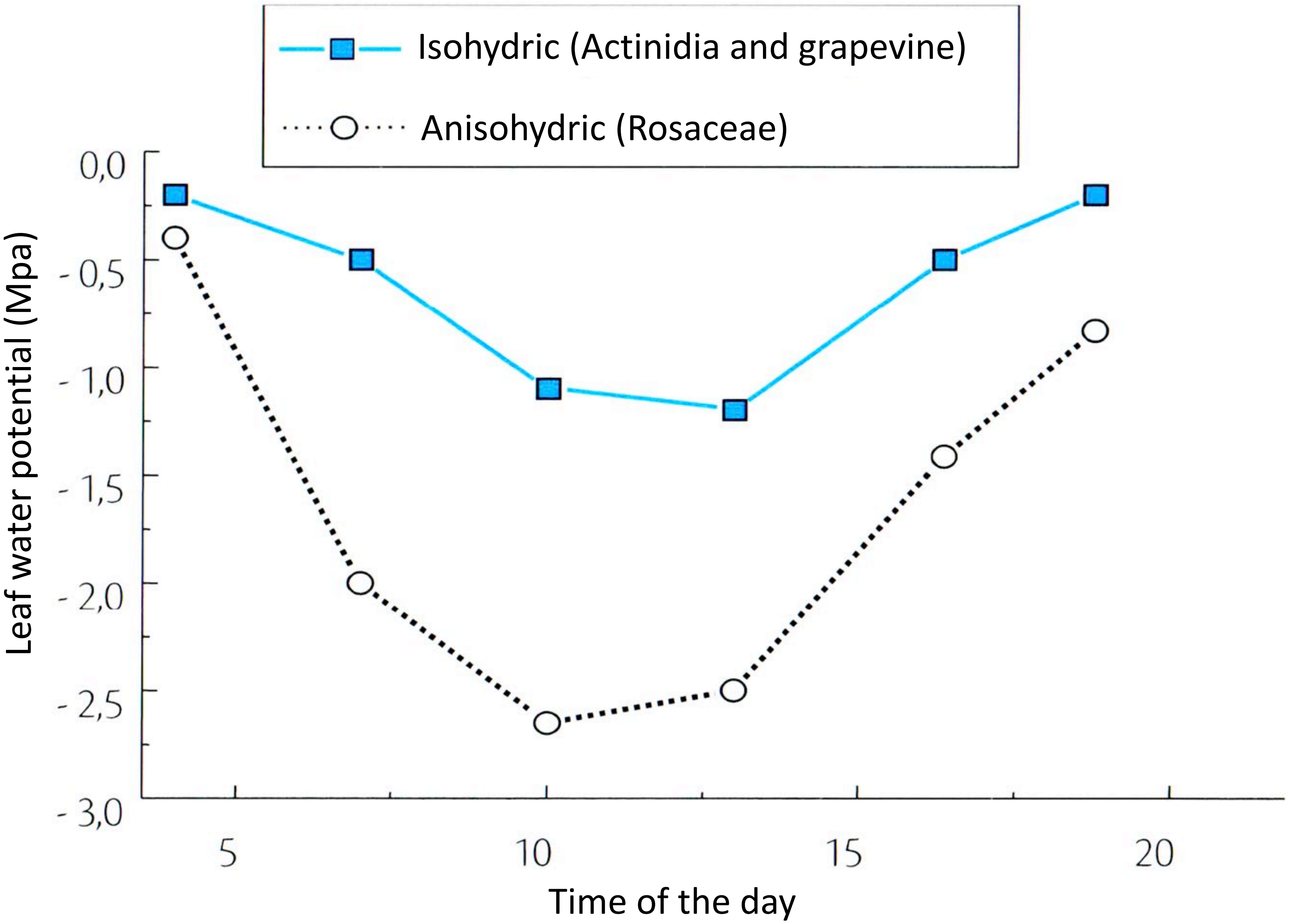
Water saving: Water saving: species that through the **early stomatal closure and other morpho-anatomical expedients**, reduce water loss during dry periods, thus compromising the assimilation of CO_2. Generally "shallow rooted"

Anisohydric species

They tolerate substantial decreases in water potential during drought events, without inhibition of metabolic processes. Osmotic Adjustment (OA) and Evaporation (E) variations and are typical features of this strategy.

Dehydration avoider: they maintain a high RWC at decreasing water potential

Dehydration tolerant: species which can stand a lower water potential and RWC.



Daily trend of the leaf water potential in species with isohydric behavior and others with anisohydric behavior (da Corelli et al., 2012)

Which strategy is more effective?

- The strategy describes the adaptations implemented by a species to survive drought
- Identify the strategy of a species is a prerequisite for genetic improvement and for its (their) proper use in the landscape **(i.e., do not use water spenders in the presence of a little volume of soil available for roots)**
- Probably, avoidance strategies are most effective in arid areas and deserts

Do not confuse the strategy with the degree of tolerance!

Which are the main characteristics that influence drought tolerance? (Engelbrecht, 2007)

DROUGHT AVOIDANCE	
Deep roots	Pinheiro et al., 2005
Early stomatal closure	Bonal and Guehl, 2001
High WUE	Farquhar et al., 1982
Water storage in tissues	Holbrook and Sinclair, 1992
Leaf shedding	Slot and Poorter, 2007
DROUGHT TOLERANCE	
Low vulnerability to cavitation	Hacke et al., 2001
Low turgor loss point	Tyree and Hammel, 1972
Osmotic adjustment	Peltier et al., 1997
Antioxidant activity	Lima et al., 2002

Ranking trees for drought tolerance?....it depends

In this context, the species-specific capacity to maintain leaf functionality during drought (i.e. avoid wilting, cavitation and photoinhibition) is likely to determine the relative abundance in urban plants community in a changing climate

High tolerance to water stress	**Low tolerance to water stress**	**Species capable of osmotic adjustment**
Acer campestre	*Acer rubrum*	*Citrus sinensis*
Ginkgo biloba	*Amelanchier spp.*	*Cornus florida*
Gleditsia triacanthos	*Betula spp.*	*Eucalyptus spp.*
Koelreuteria paniculata	*Cercidiphyllum japonicum*	*Fraxinus spp.*
Pyrus calleryana	*Corylus colurna*	*Juglans nigra*
Quercus pubescens	*Liriodendron tulipifera*	*Celtis occidentalis*
Robinia pseudoacacia	*Liquidambar styraciflua*	*Olea europaea*
Styphnolobium japonicum	*Carpinus spp.*	*Populus spp.*
Ulmus parvifolia	Flowering *Prunus*	*Quercus spp.*

Table 1 Tree and shrub species suitable for different soil types, and their relative drought tolerances.

Scientific name	Common name	Native	Acidic soil (pH<7)	Alkali soil (pH>7)	Sandy soil	Loam	Heavy soil/ clay	Drought tolerance index	Drought tolerance
		Ref: 1	Refs: 1,2,3,6,7	Refs: 1,2,3	Refs: 1,4	Refs: 1,4	Refs: 1,4,6,7	Ref: 5	
Acer campestre	Field maple	✓	●	●	●	●	●	2.93	Moderate
Acer ginnala	Amur maple		●	●	●	●	●	2.88	Moderate
Acer negundo	Box elder		●	●	●		●	3.03	Tolerant
Acer platanoides	Norway maple		●	●	●	●	●	2.73	Moderate
Acer pseudoplatanus	Sycamore		●	●		●	●	2.75	Moderate
Acer rubrum	Red maple		●				●	1.84	Intolerant
Acer saccharinum	Silver maple		●	●			●	2.88	Moderate
Alnus cordata	Italian alder			●	●	●	●		Intolerant
Alnus glutinosa	Common alder	✓	●	●		●	●	2.22	Moderate
Alnus incana	Grey alder		●	●		●	●	1.89	Intolerant
Betula pendula	Silver birch	✓	●	●	●	●	●	1.85	Intolerant
Carpinus betulus	Common hornbeam	✓	●	●	●	●	●	2.66	Moderate
Castanea sativa	Sweet chestnut		●		●		●	3.46	Tolerant
Cornus mas	Cornelian cherry		●	●	●	●	●	3.17	Tolerant
Cornus sanguinea	Dogwood	✓		●	●	●	●	3.04	Tolerant
Corylus avellana	Hazel	✓	●	●	●	●		3.04	Tolerant
Corylus colurna	Turkish hazel		●	●	●	●	●	3.13	Tolerant
Cotinus coggygria	Smoketree		●	●	●	●	●	3.74	Tolerant
Cotinus obovatus	Chittamwood		●	●	●	●	●	3.69	Tolerant
Crataegus laevigata	Midland hawthorn	✓	●	●	●	●	●	2.90	Moderate
Crataegus x *lavallei*	Hybrid cockspur thorn		●	●	●	●	●	3.46	Tolerant
Crataegus monogyna	Hawthorn	✓	●	●		●	●	3.69	Tolerant

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Continue….

Table 1 Tree and shrub species suitable for different soil types, and their relative drought tolerances.

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		Ref: 1	Refs: 1,2,3,6,7	Refs: 1,2,3	Refs: 1,4	Refs: 1,4	Refs: 1,4,6,7	Ref: 5	
Fagus sylvatica	Beech	✓	●	●	●	●		2.40	Moderate
Fraxinus americana	White ash			●	●	●	●	2.38	Moderate
Fraxinus excelsior	Ash	✓	x	●		●	●	2.50	Moderate
Fraxinus pennsylvanica	Green ash		●	●	●	●	●	3.85	Tolerant
Gleditsia triacanthos	Honey locust		●	●	●	●	●	4.98	Moderate
Hippophae rhamnoides	Sea buckthorn	✓		●	●			3.46	Tolerant
Ilex aquifolium	Holly	✓	●	●	●	●	●	3.04	Tolerant
Morus alba	White mulberry		●	●	●	●	●	2.88	Moderate
Pinus sylvestris	Scots pine	✓	●	●	●	●	x	4.34	Very tolerant
Populus alba	White poplar		●	●	●		●	2.67	Moderate
Prunus avium	Wild cherry	✓		●	●	●	●	2.66	Moderate
Prunus padus	Bird cherry	✓		●	●	●	●	1.93	Intolerant
Pyrus communis	Wild pear		●	●	●		●	2.73	Moderate
Quercus ilex	Holm oak			●	●	●	●	4.72	Very tolerant
Quercus petraea	Sessile oak	✓	●		●		●	3.02	Tolerant
Quercus robur	Pedunculate oak	✓	●	●	●		●	2.95	Moderate
Quercus rubra	Red oak		●	●	●		●	2.88	Moderate
Rhamnus cathartica	Common buckthorn	✓		●	●	●	●	3.46	Tolerant
Salix caprea	Goatwillow	✓	●	●	●		●	2.24	Moderate
Sorbus aria	Whitebeam	✓	●	●	●	●	●	3.55	Tolerant
Sorbus aucuparia	Rowan	✓	●	●	●	●	●	2.11	Moderate
Sorbus intermedia	Swedish whitebeam			●	●	●	●	2.21	Moderate
Tilia cordata	Small-leaved lime	✓		●	●	●	●	2.75	Moderate
Tilia tomentosa	Weeping silver lime			●	●	●	●	2.81	Moderate
Viburnum lantana	Wayfaring tree	✓		●	●	●	●	3.46	Tolerant

● = tolerant; blank = unknown; x = intolerant

FR(JD-KD)/GG-PDF/Dec15/0055

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Table 1: Classification of the selected tree species according to their heat and drought tolerances (based on literature review).

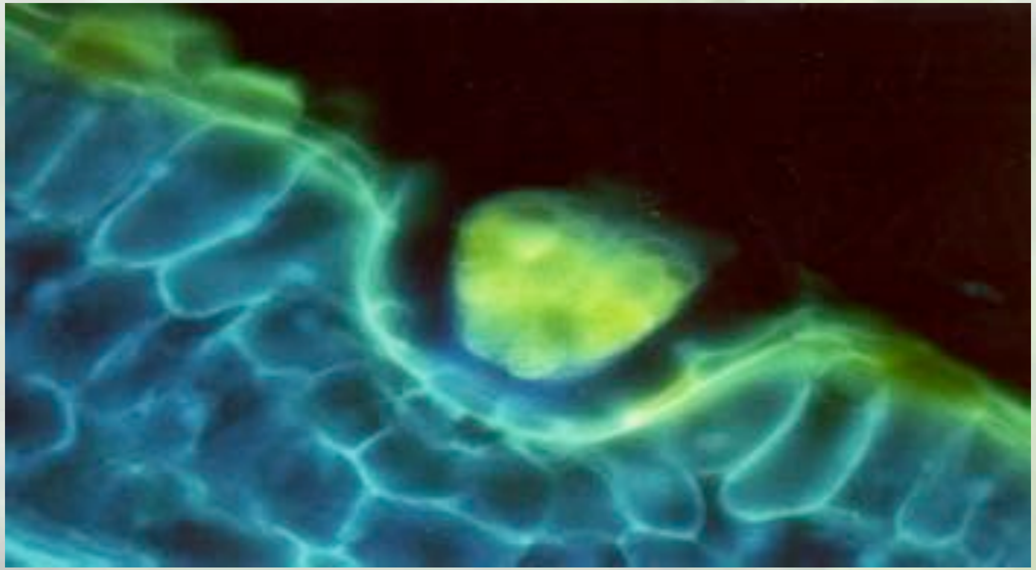
From Brune (2016): Urban trees under climate change. Potential impacts of dry spells and heat waves in three German regions in the 2050s.

	Drought stress	Heat stress
Very tolerant (++)	Silver Birch	Silver Birch, European Ash
Moderately toler-ant (+)	Norway Maple, European Ash, Pedunculate Oak	Horse-Chestnut, Norway Maple, Pedunculate Oak
Moderately sensi-ble (-)	Horse-chestnut, Sycamore Maple, European Beech	Sycamore Maple, European Beech
Very sensitive (– –)	Black Alder, Black Poplar, White Willow	
Insufficient information		Black Alder, Black Poplar, White Willow

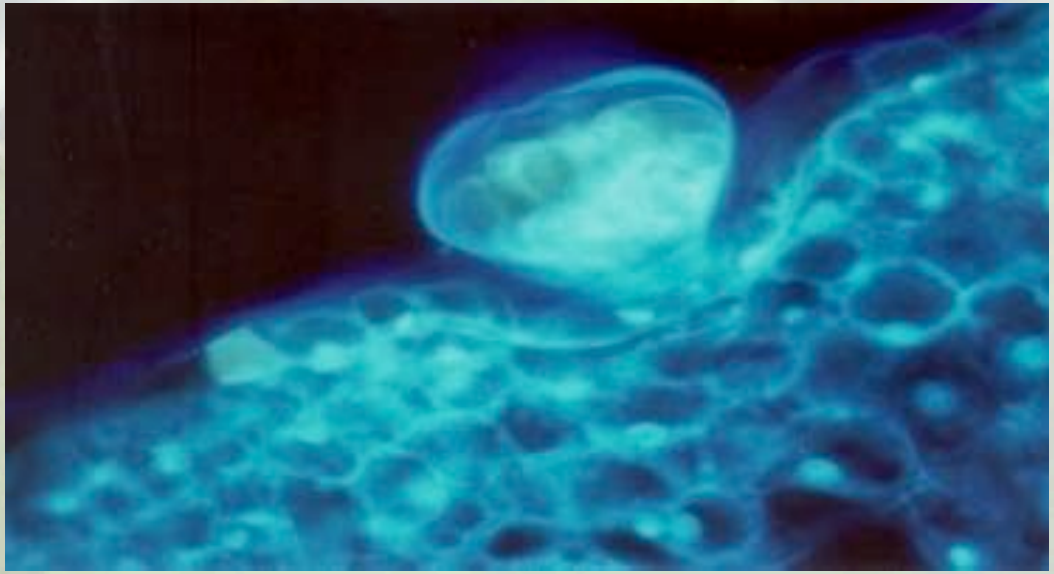

Photo credits F. Ferrini
Are physiological adaptations sufficient to survive in these conditions?

Morphological adaptations

Stomatal crypts: the stomata are sunken in the epidermis in order to limit transpiration (eg oleander)



Stomatal crypt (TOLERANT)



Normal stoma (SENSITIVE)

Morphological adaptations

Quercus hypoleucoides

Morphological adaptations

Microphyllous and compound leaves: since the thickness of the boundary layer depends on the size of the leaf, the leaves are smaller and more easily dissipate heat by convection, overheating less.

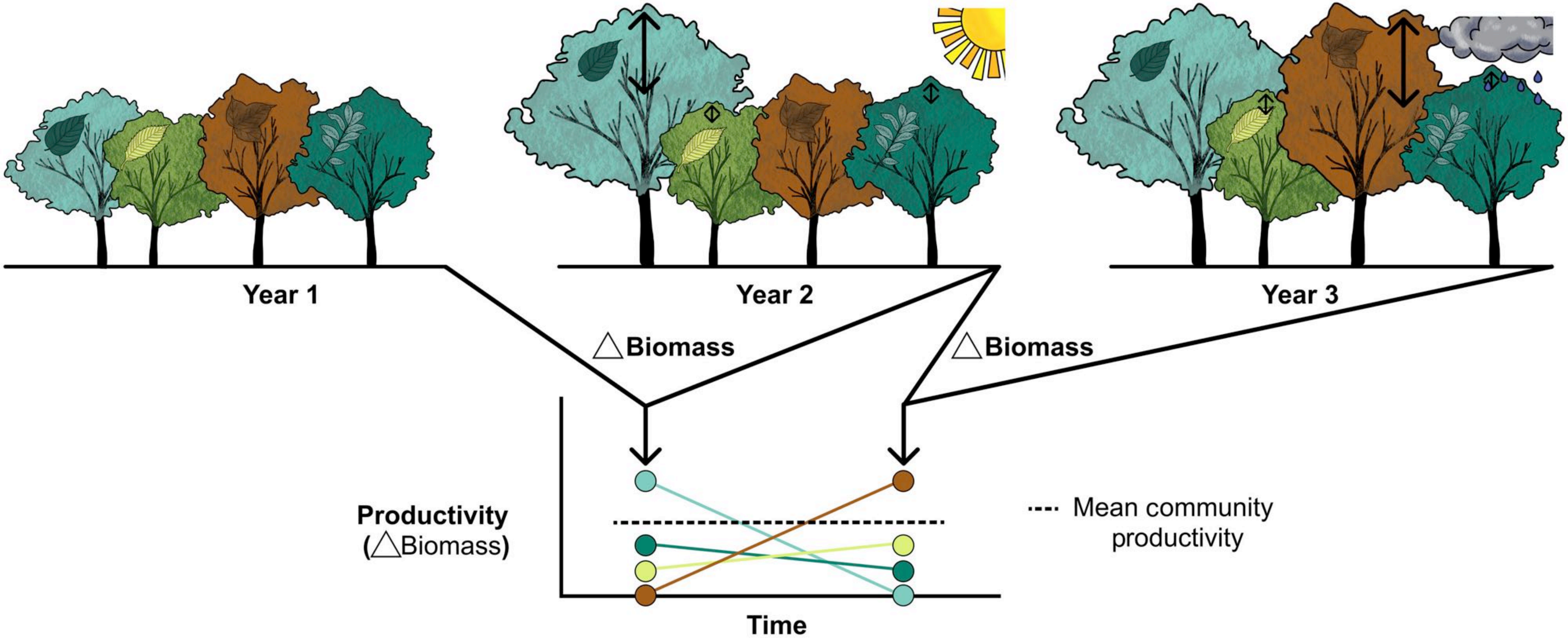
Morphological adaptations

Alteration of leaf insertion angle: this reduces the incident radiation by reducing the temperature and the oxidative stress caused by excess radiation

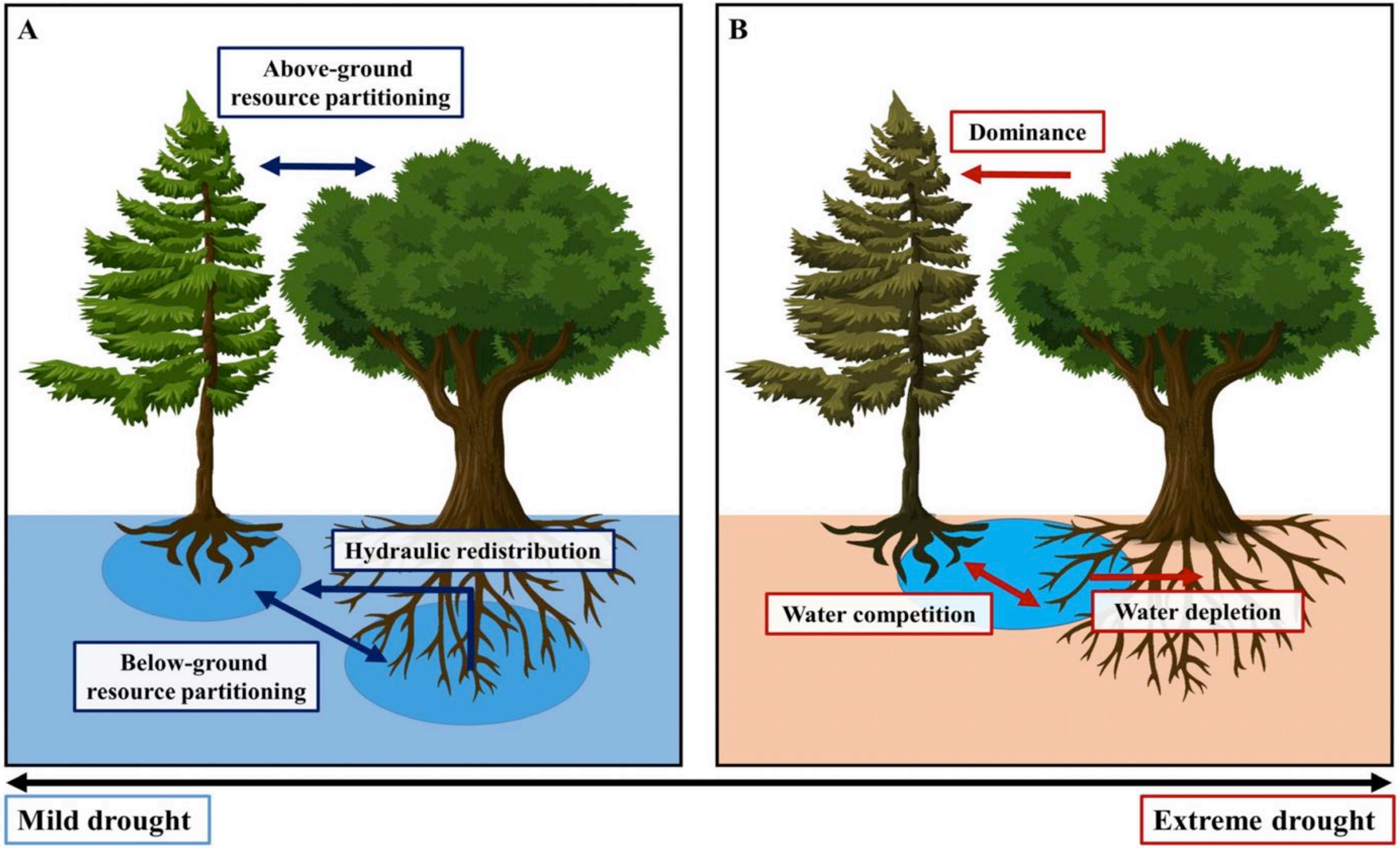
Normal condition = 90°

Stress conditions= 45°

The importance of biodiversity

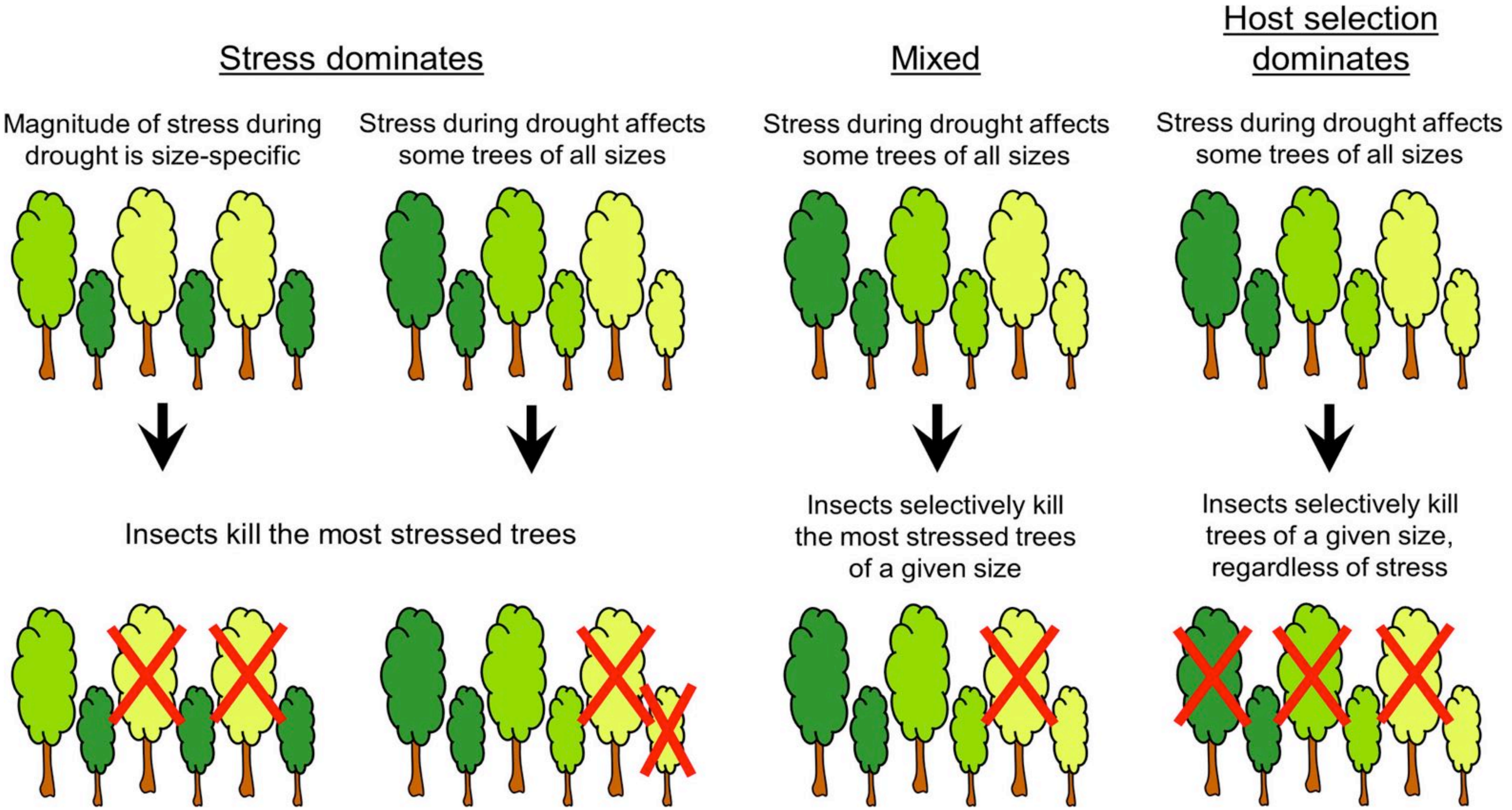


The tree community experiences a "normal" (year 1), an exceptionally dry (year 2), and an exceptionally wet (year 3) year, which result in distinctly different productivity responses of the participating species but the same community productivity due to compensatory dynamics (From Schnabel et al., 2021)



Species interactions caused by mild (A) and extreme (B) drought stress in forest ecosystems. With increasing drought stress, the impact of species interactions on tree transpiration shifts from beneficial to detrimental.
While it’s important to have a mixed forests for biodiversity , ecosystem servicesor pest resistance, beneficial species interactions may shift under extreme drought (From Haberstroh & Werner, Dec. 2022)

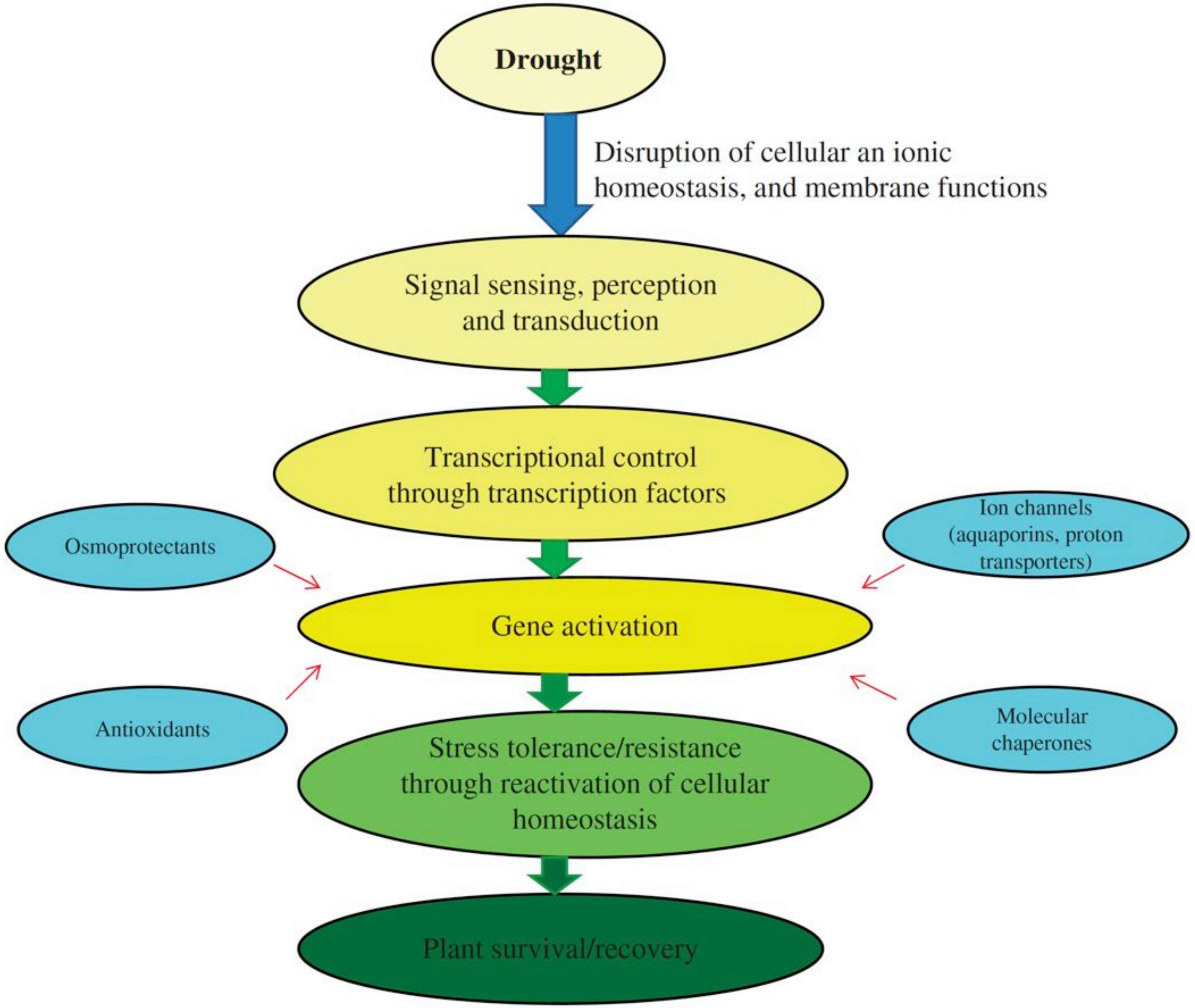
Which trees die during drought? The key role of insect host-tree selection



Stephenson et al., 20919. Journal of Ecology, Volume: 107, Issue: 5, Pages: 2383-2401, First published: 03 April 2019, DOI: (10.1111/1365-2745.13176)


Image credits https://www.nature.com/nature-index/news-blog/bored-bad-conferences-time-demand-more-duncan-green
BORED?

Molecular mechanisms associated with drought tolerance.



Yang, X.; Lu, M.; Wang, Y.; Wang, Y.; Liu, Z.; Chen, S. Response Mechanism of Plants to Drought Stress. *Horticulturae* **2021**, *7*, 50. https://doi.org/10.3390/horticulturae7030050

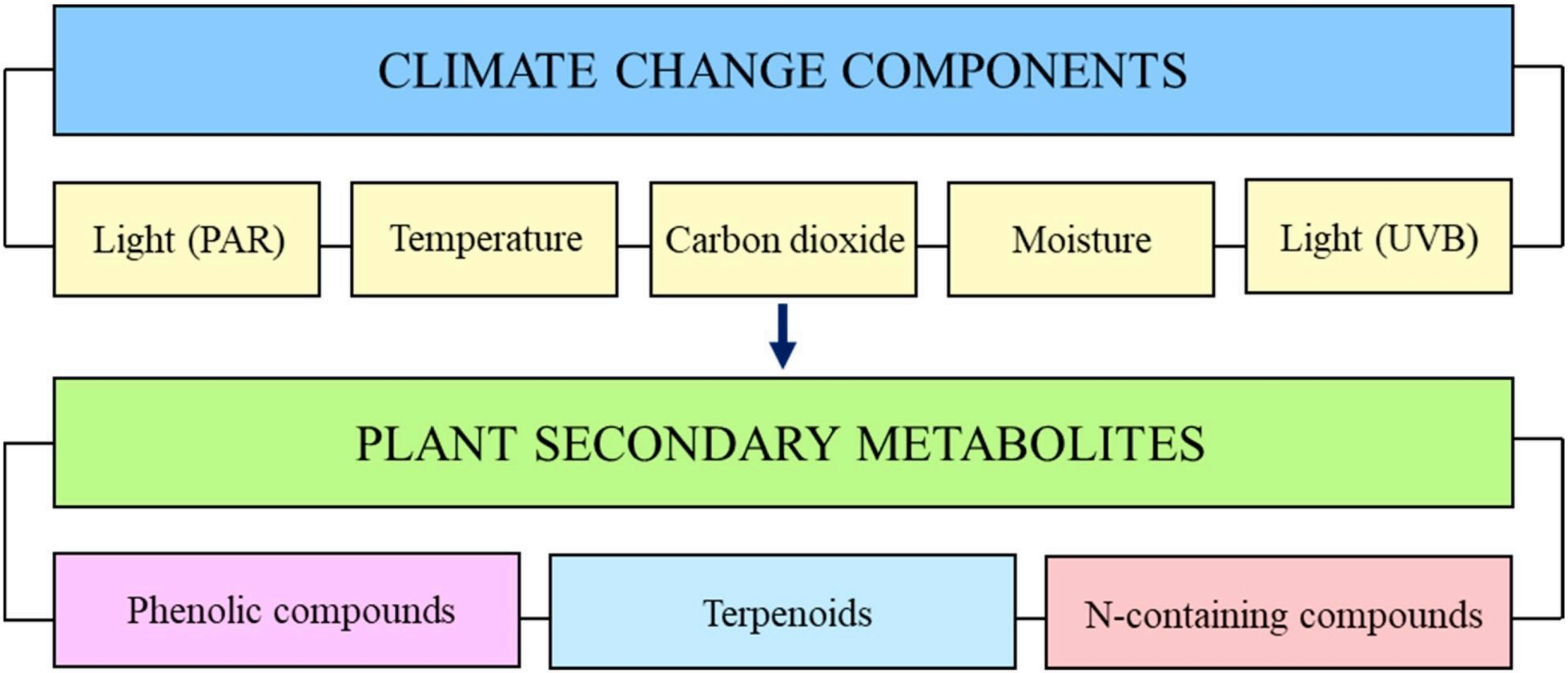
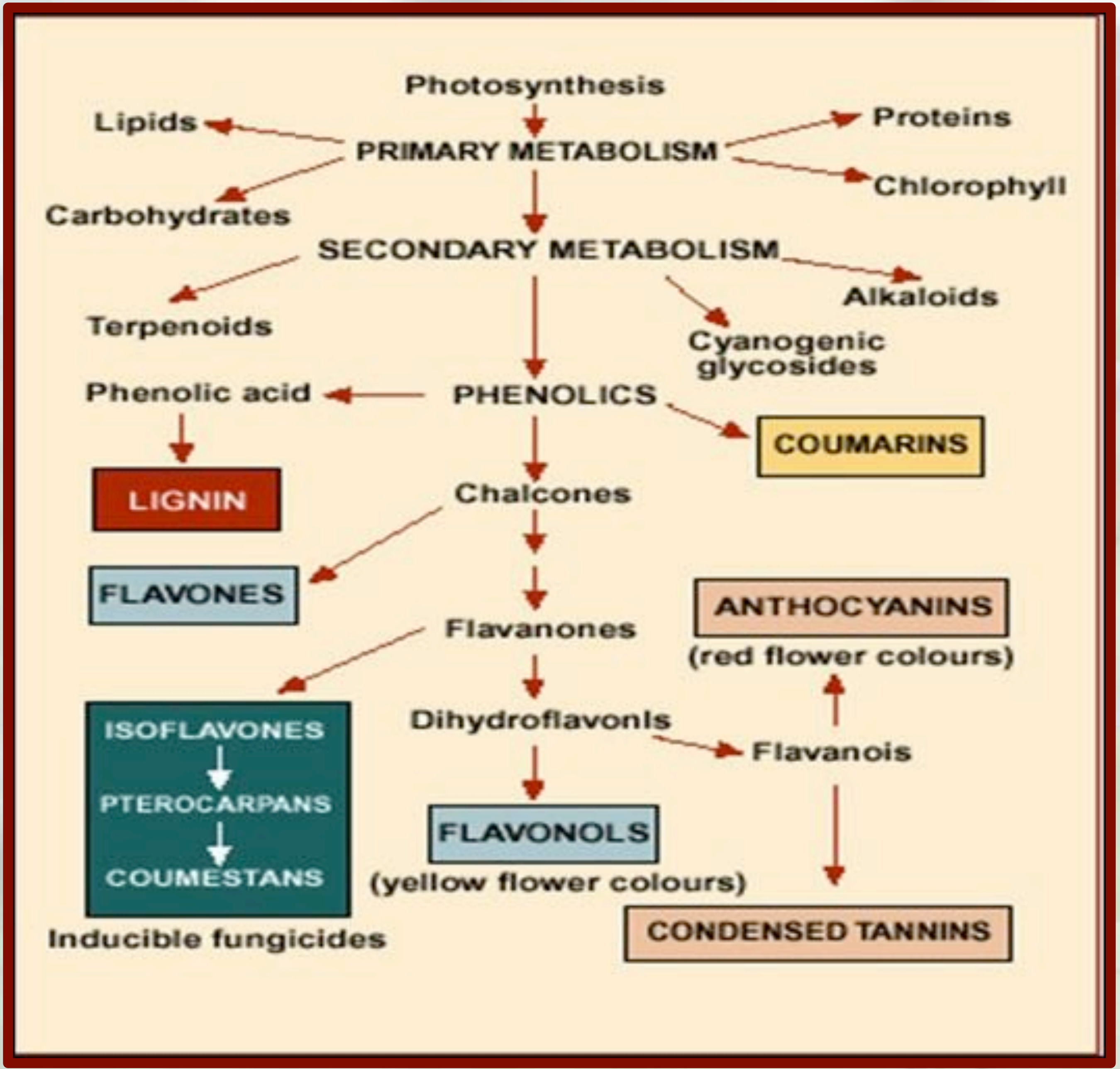


Figure 1. Climate change components that affect plant secondary metabolites.

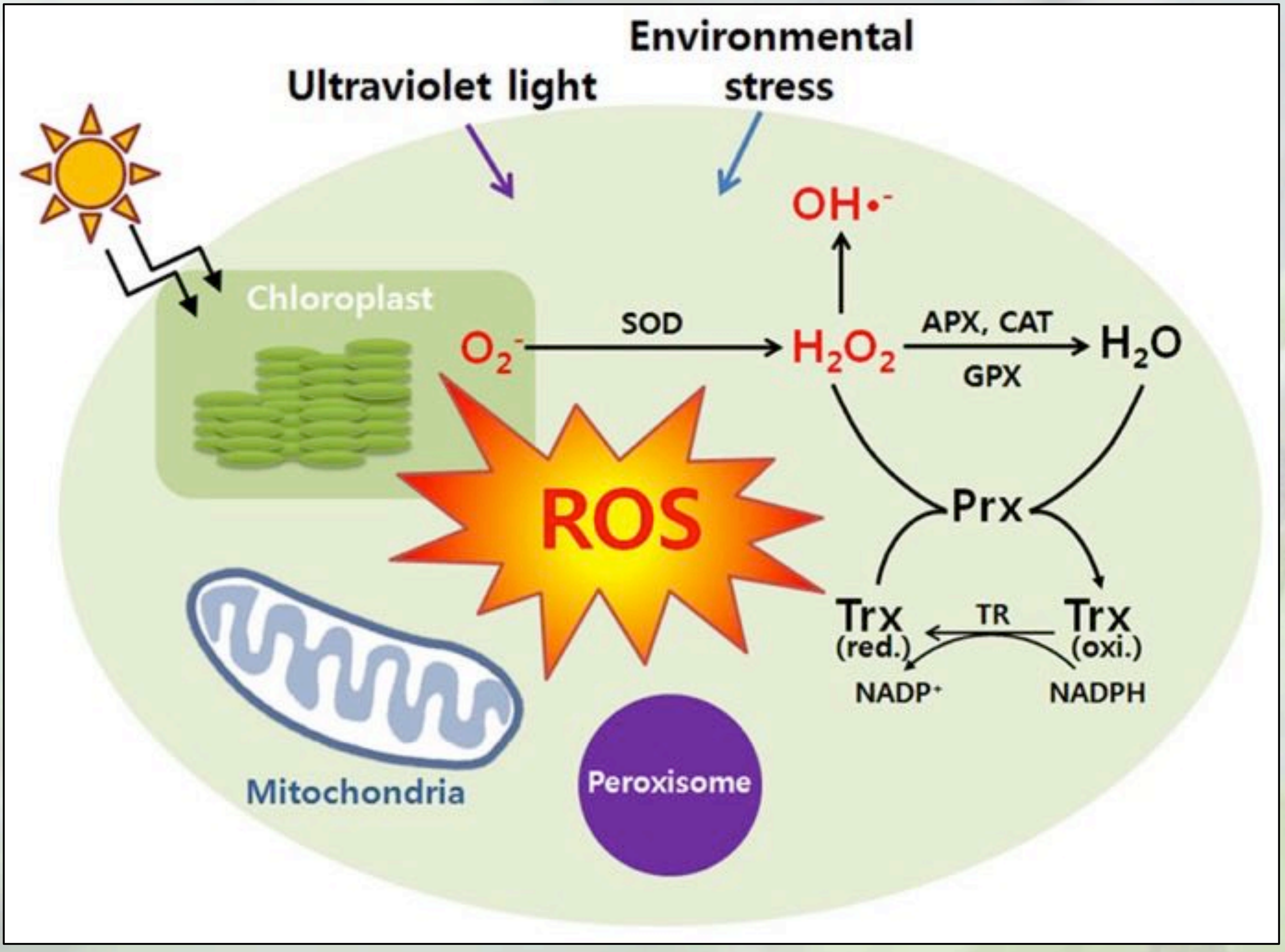
Image from Qaderi et al., 2023. Environmental Factors Regulate Plant Secondary Metabolites. Plants, 12, 447. https://doi.org/10.3390/plants12030447

Recent Issues in our research: Plant secondary metabolism



Plant secondary metabolism produces products that aid in the growth and development of plants but are not required for the plant to survive. Secondary metabolism facilitates the primary metabolism in plants. This primary metabolism consists of chemical reactions that allow the plant to live. In order for the plants to stay healthy, secondary metabolism plays a prominent role in keeping all the of plants' systems working properly.

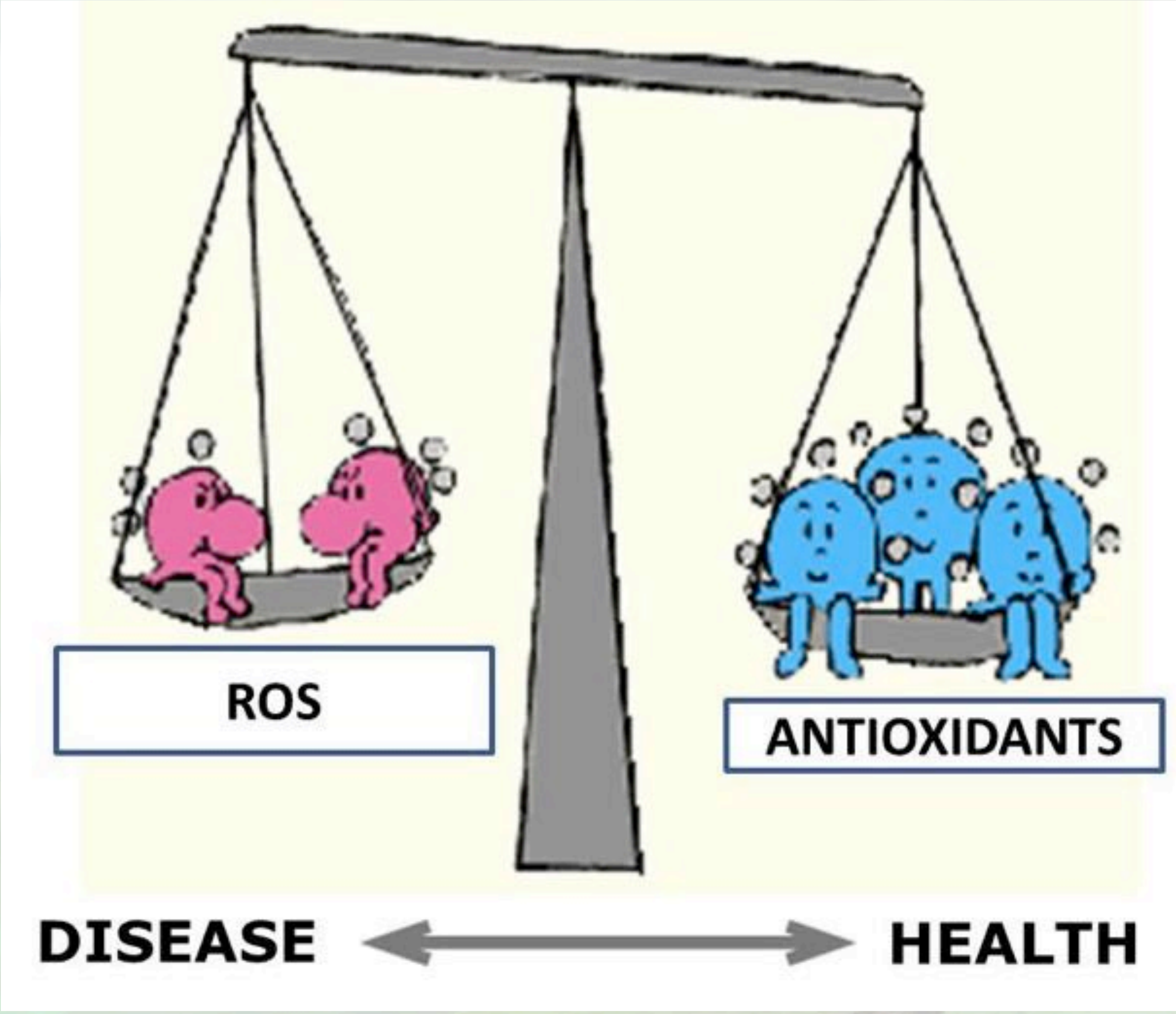
Reactive oxygen species (ROS)



Reactive oxygen species defined with the acronym R.O.S. (Reactive Oxigen Species) include hydrogen peroxide (H_2O_2), superoxide anion (O_2^-), hydroxyl radical (• OH) and other highly oxidizing molecules.

Plants react to environmental stresses such as drought or ultraviolet light by releasing oxygen-containing molecules called reactive oxygen species (ROS) into cells. While ROS are important for normal plant functions such as photosynthesis, pathogen defense and growth, high levels can damage DNA and cell structures, causing oxidative stress.

Reactive oxygen species

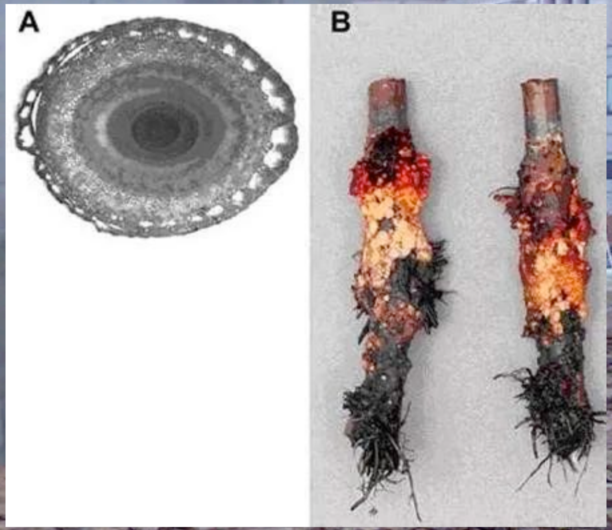


ROS play an important signaling role in plants controlling processes such as growth, development, response to biotic and abiotic environmental stimuli, and programmed cell death

Waterlogging and soil saturation

Waterlogging

- Directly related to compaction
- It quickly leads to radical anoxia
- The soil structure is destroyed
- Toxic ions and compounds accumulate
- Nitrogen is lost in the atmosphere



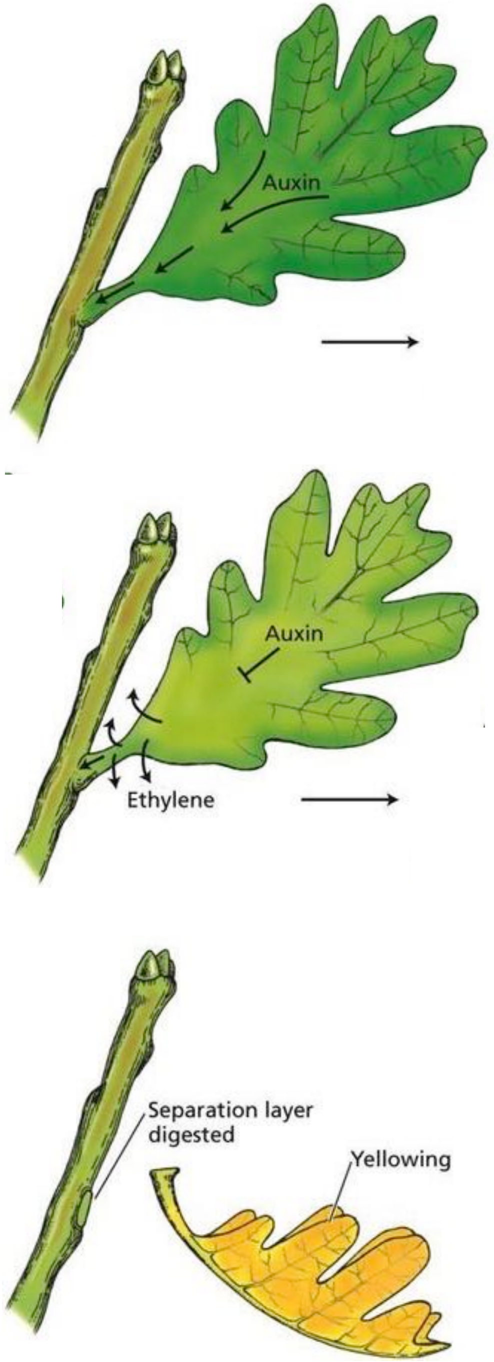
https://plantstress.com/water/

(1) Effects on morphology and anatomy caused by O_2 deficiency: growth ↓, leaf yellowing (nutrient deficiency , epynasty, stem cavity (tissue degradation).

(2) Effects in metabolism caused by oxygen deficiency: photosynthesis ↓, stomata closure, inhibition of CO_2 input. Anaerobic respiration ↑ , production of toxic substances: alcohol , acetaldehyde , NH_3 , lactate, H_2S

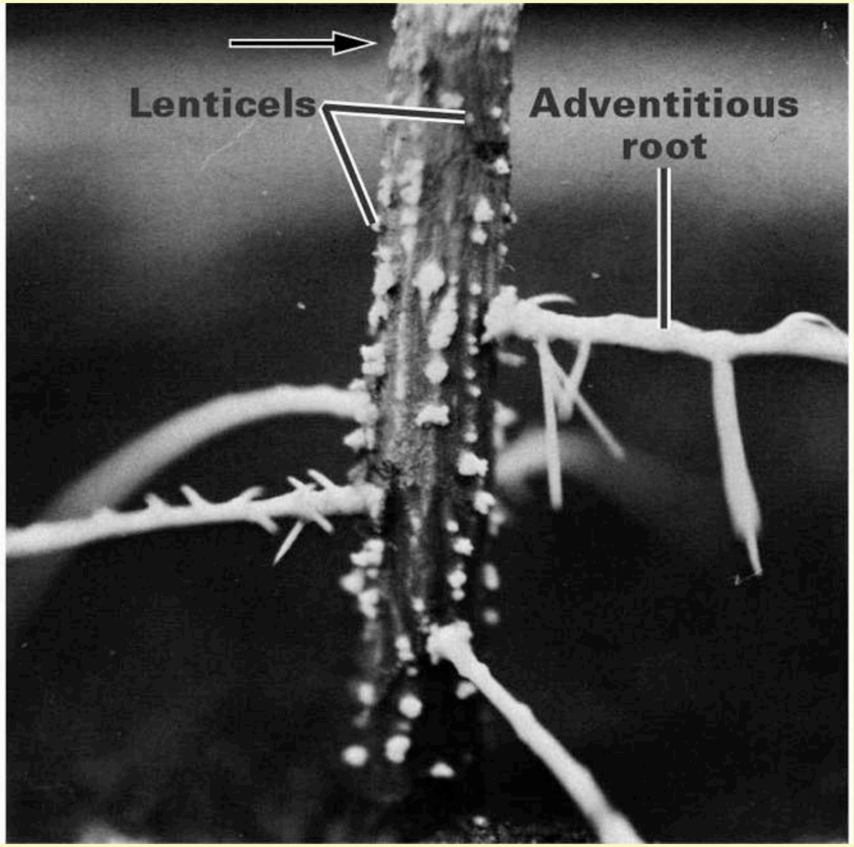
(3) Nutritional problems: absorption ↓ , loss of N, P, K, Ca and formation of H_2S, Fe^{++}, Mn^{++} Al^{++},

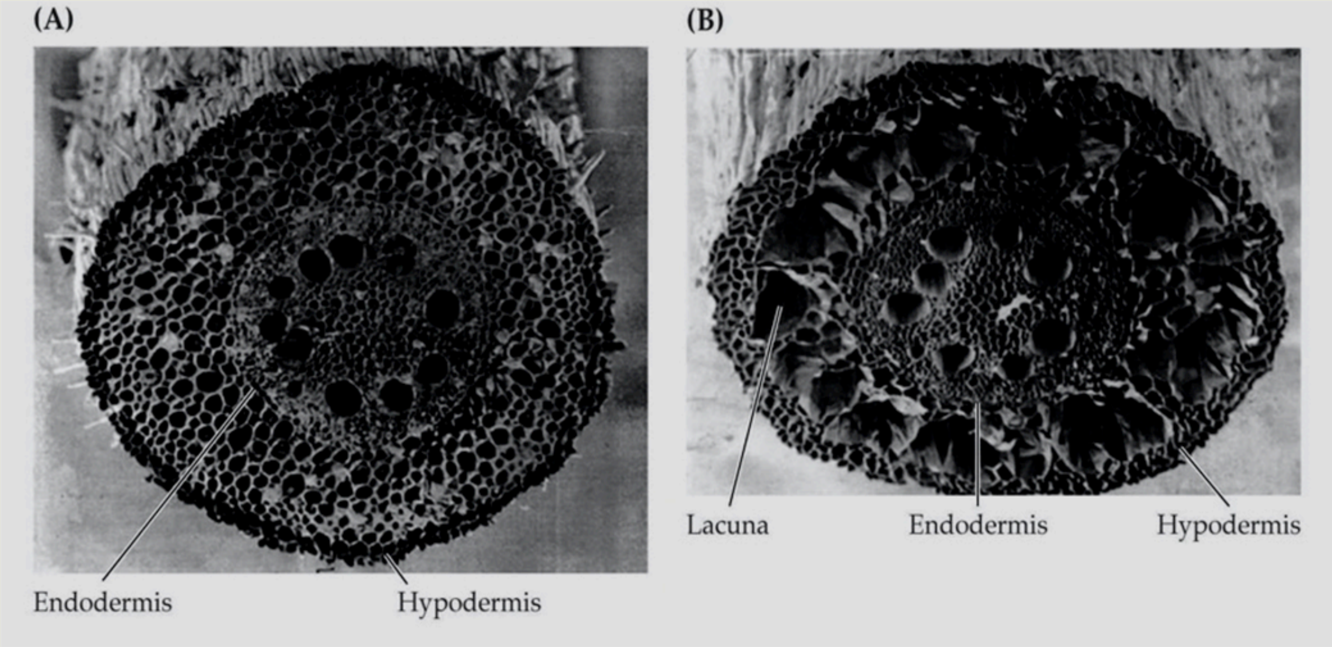
(4) change in hormone balance: IAA and CTK ↓, synthesis of ACC (1-aminocyclopropane-1-carboxylic acid in the roots and release of ethylene in the shoots)



Da Fan Lai,

- Waterlogging tolerance mechanisms
  - Well developed aerenchyma
  - > number of lenticels
  - > adventitious roots





Tolerance to waterlogging of some woody species of urban interest (From Bernatzky, 1978; Kozlowski et al., 1991, Coder, 1997; Bassuk et al., 1998)

Tolerant

Acer saccharinum
Acer negundo
Platanus x acerifolia
Platanus occidentalis
Quercus petraea
Quercus palustris
Gleditsia triacanthos
Populus spp.
Salix spp.
Alnus spp.
Prunus padus
Acer rubrum
Morus alba
Taxodium distichum
*Tilia cordata**
Diospyrus spp.
*Liquidambar styraciflua**

Intolerant

Fagus sylvatica
*Fraxinus excelsior**
*Acer pseudoplatanus**
Acer campestre
*Acer platanoides**
Acer saccharum
Quercus robur
Larix decidua
Cedrus deodara
Cedrus atlantica
Ilex aquifolium
Betula papyrifera
Cornus florida
Crataegus spp.
Magnolia soulangeana
Quercus rubra
*Robinia psudoacacia**
Picea abies
Picea pungens
Thuja occidentalis
*Juglans nigra**

credits https://www.coldstreamfarm.net/product/bald-cypress-taxodium-distichum/

The species marked with an asterisk have been classified differently by various authors. Tolerance or susceptibility was attributed considering the majority of reports.

Image credits https://dailyyonder.com/research-results-who-comes-home/2021/12/07/

a) Light and drought stress in the urban environment: how a green leaf tree and a red leaf one respond to the drought and high light stresses.

Acer platanoides
'Summershade' and
'Crimson King'

Experiment 1: drought induced

- 72 grafted, bare-root plants of *Acer platanoides* 'Summershade' **(SS)** and 'Crimson King' **(CK)** were potted in 20 L pots filled with peat and pumice (3:1)
- Plants were grown outdoor until August, then placed in a tunnel covered with polypropylene sheet, to exclude rainfall
- In the tunnel, plants were arranged according to a randomized block design with six blocks

Experiment 2: light induced stress

- In March 2016, 108 grafted plants of *Acer platanoides* 'Summershade', 'Deborah' and 'Crimson King' were potted in 50 l pots with a peat/pumice substrate (3:1, v:v), and were grown outdoors at the Fondazione Minoprio (Como, Italy, 45°44'N, 9°04'E).
- Control plants (CTRL plants) were grown on a black polypropylene fabric with an albedo of 9%, while high light plants (HL plants) were grown on concrete slabs with an albedo of 30%. The experiment lasted 16 months, from May 2016 to September 2017. Plants were kept well-watered throughout the experiment.
- Paired spectroradiometers (LightScout® 3670I, Spectrum Technologies, Inc.) were used to measure irradiance and albedo throughout the experiment.

Conclusions

- Under optimal water availability, **green leaves are photosynthetically more efficient**
- The more conservative use of light and water by **red leaves allow better tolerance to severe drought stress** compared to green leaves
- Longer lived leaves of sclerophyllous species may benefit to a greater extent from "being red"
- **Cyanic cultivars** are suitable for urban sites with **very high irradiance through the year** (i.e. urban plazas where reflected irradiance sum up to direct sunlight)
- **Anthocyanins are costly for leaves!** Under optimal conditions the cultivars with green leaves provided higher benefits, in terms of CO_2 storage and transpirational cooling than cyanic cultivars

b) Hardening in the nursery – deficit irrigation

We tested the effect of deficit irrigation on *Acer campestre, Tilia cordata, Quercus robur*.

- Deficit irrigation was imposed by reducing watering to 30% of daily transpiration.
- The "conditioning phase" lasted for 2 years

What happened to plants grown for two years under deficit irrigation?

Species	Parameter	Water regime (W)		Significance
		Well Watered	Deficit Irrigation	Water regime
Acer	Plant DW (g)	292.2	195.2	**
	Root:shoot	1.0	0.9	ns
	Leaf area (cm^2)	5859.5	4503.7	*
Tilia	Plant DW (g)	190.3	123.4	**
	Root:shoot	0.9	0.9	ns
	Leaf area (cm^2)	4833.4	3631.5	**
Quercus	Plant DW (g)	233.6	155.8	**
	Root:shoot	0.6	1.0	**
	Leaf area (cm^2)	5715.4	3253.4	**

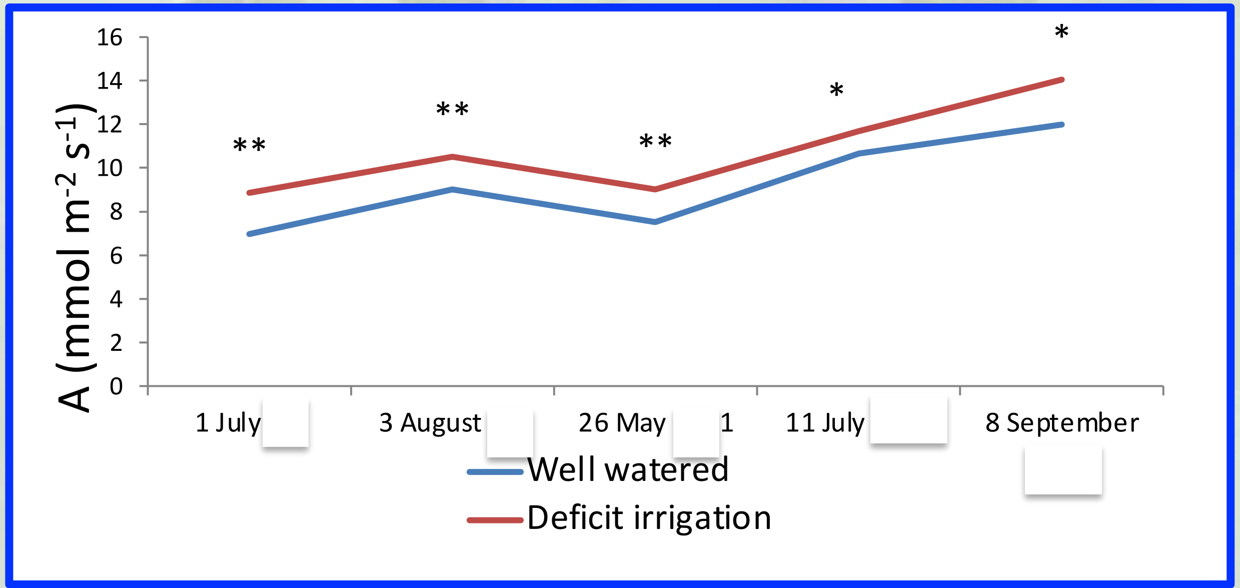
In accordance with other research (Franco et al., 2006), deficit irrigation decreased **whole-plant dry weight** and **leaf area**, and, only in oak, increased **root to shoot** ratio.

But will this tree grow better after planting?
To answer this question, we planted the trees in the field, without any irrigation

Maple	Shoot growth (cm)		Diameter growth (mm)
	1st year	*2° year*	*1 to 2 year*
Well watered	14,4 b	52,4 b	13,1 b
Deficit irrigation	20,9 a	69,3 a	15,3 a
P	**	*	*

YES!!!

MAPLE TREES GROWN IN THE NURSERY UNDER DEFICIT IRRIGATION GREW FASTER AFTER TRANSPLANT!!!!!!!



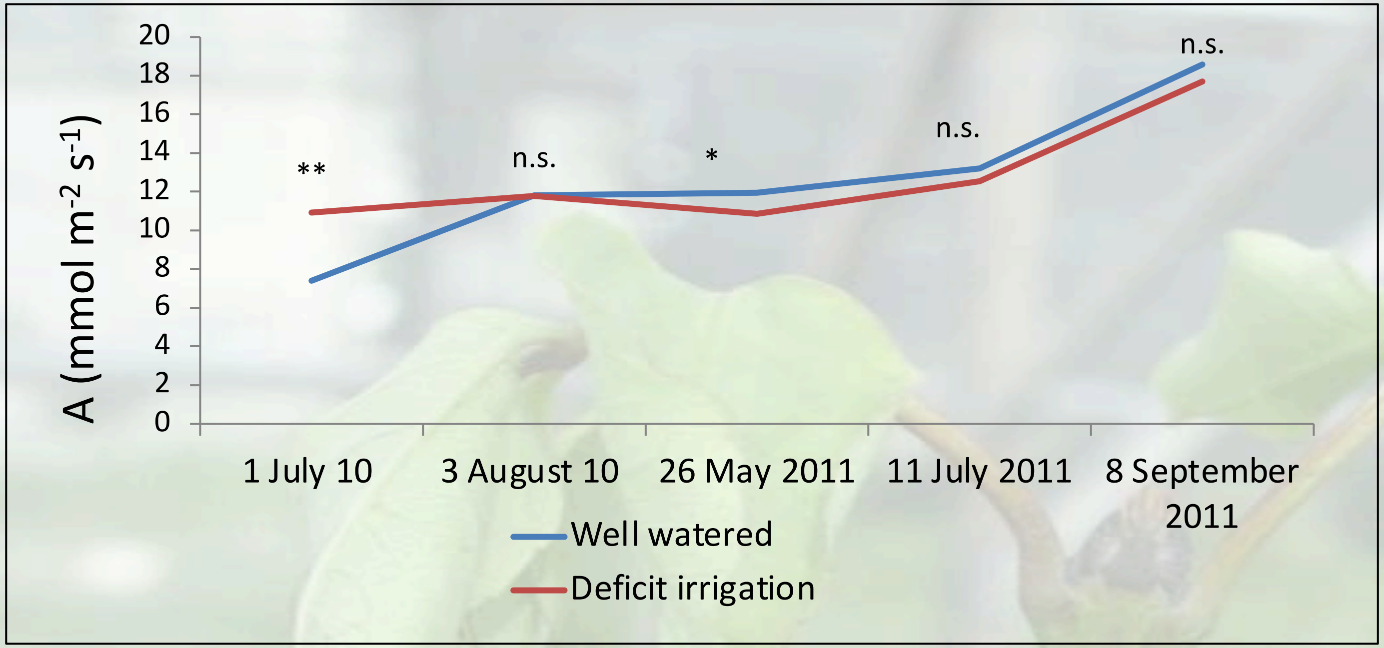
Why did this happen?

In the 18 months after planting, "D.I." maple had
a) higher CO_2 assimilation
b) greater Water Use Efficiency

Acer campestre	Ψw (osmotic potential) (August)	Ψw (May)	Ψw (September)
Well watered	-0,42	-0,41	-0,46
Deficit irrigation	-0,32	-0,34	-0,24
P	**	**	*

Deficit irrigation in the nursery allowed the **maintenance of more favorable water relations** after planting.

Do these findings work on all species? The case of linden



- Little change in CO_2 assimilation
- Little change in pre-dawn water potential

Linden	Shoot growth (cm)		Diameter growth (mm)
	1st year	*2° year*	*1 to 2 year*
Well watered	19,1	78,4	19,2
Deficit irrigation	13,1	69,5	16,6
P	**	*	n.s.

Growth was slightly depressed in “deficit irrigation” linden

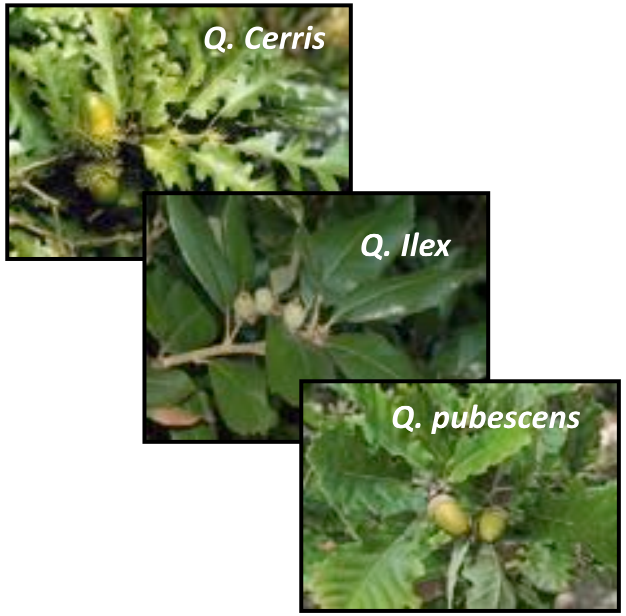
Deficit irrigation in the nursery
take home message

Deficit irrigation may work differently in **drought-tolerant** and **drought-avoider** species:

- In the former (as maple), gas exchange is maintained at decreasing water potential
- In the latter (as linden), gas exchange decline steeply during stress, in order to save water and maintain water potential

Deficit irrigation can reduce growth and yield in drought-avoider species (species which maintain a high RWC at decreasing water potential) as also reported by *Fini et al. (2013 J. Arid Environ.*), **but it may not be recommendable**, whereas it effectively improves post-transplant performances in drought-tolerant species

Other finished projects



Study of the response mechanisms of three *Quercus* species to drought and heat stress: ***Quercus ilex*, *Q. cerris* e *Q. pubescens*.**

Quercus species widely employed or potentially to be employed in urban forestry

to evaluate the most suitable species to use in our cities in a scenario of climate changes

The results of this research suggest that *Quercus ilex* exhibits greater plasticity and adaptation under higher CO_2 and temperature conditions foreseen for 2050 and may therefore perform more favourably under future climatic conditions

Urban Forestry & Urban Greening 31 (2018) 26–37

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journal homepage: www.elsevier.com/locate/ufug

Photosynthetic and morphological responses of oak species to temperature and [CO_2] increased to levels predicted for 2050

D. Killi[a,*], F. Bussotti[a,d], E. Gottardini[b], M. Pollastrini[a], J. Mori[a], C. Tani[c], A. Papini[c], F. Ferrini[a,d], A. Fini[e]


Common results when you plant by numbers (cit. Keith Sacre)

Evaluating the drought tolerance of *Quercus ilex* L. through its physiological and biochemical responses to severe water stress and rewatering: is this species suitable for our future cities?

Francesca ALDEROTTI[1*], Cecilia Brunetti[1,2], Dalila Pasquini[1], Francesco Ferrini[1,2,3] and Antonella Gori [1]

[1]Department of Agriculture, Food, Environment and Forestry, Section Woody Plants - University of Florence, Florence, Italy
[2]Institute for Sustainable Plant Protection, National Research Council of Italy, Florence, Italy,
[3] Laboratorio Value SOI-UNIFI

Ecophysiological monitoring of the declining holm oak at Regional Natural Park of Maremma

- Seasonal measurements of gas exchanges, water relation, and PLC
- Daily changes in Ψ_w (predawn and midday)
- Study of *Quercus ilex* vulnerability to xylem embolism (VC-curves)

On-going research
Ecophysiological monitoring of the declining holm oak at Regional Natural Park of Maremma

- Seasonal measurements of gas exchanges, water relation, and PLC
- Daily changes in Ψ_w (predawn and midday)
- Study of *Quercus ilex* vulnerability to xylem embolism (VC-curves)

Task 1.3 – Tree physiology in the urban environment

Selection of ecotypes tolerant to abiotic stress typical of the urban environment through the study of physiological indicators

- Species were selected in order to prefer native species commonly used in the urban environment in Italy

Acer pseudoplatanus, Quercus robur, Tilia cordata
Some mediterranean oak species i.e. *Quercus trojana, Quercus vallonea*

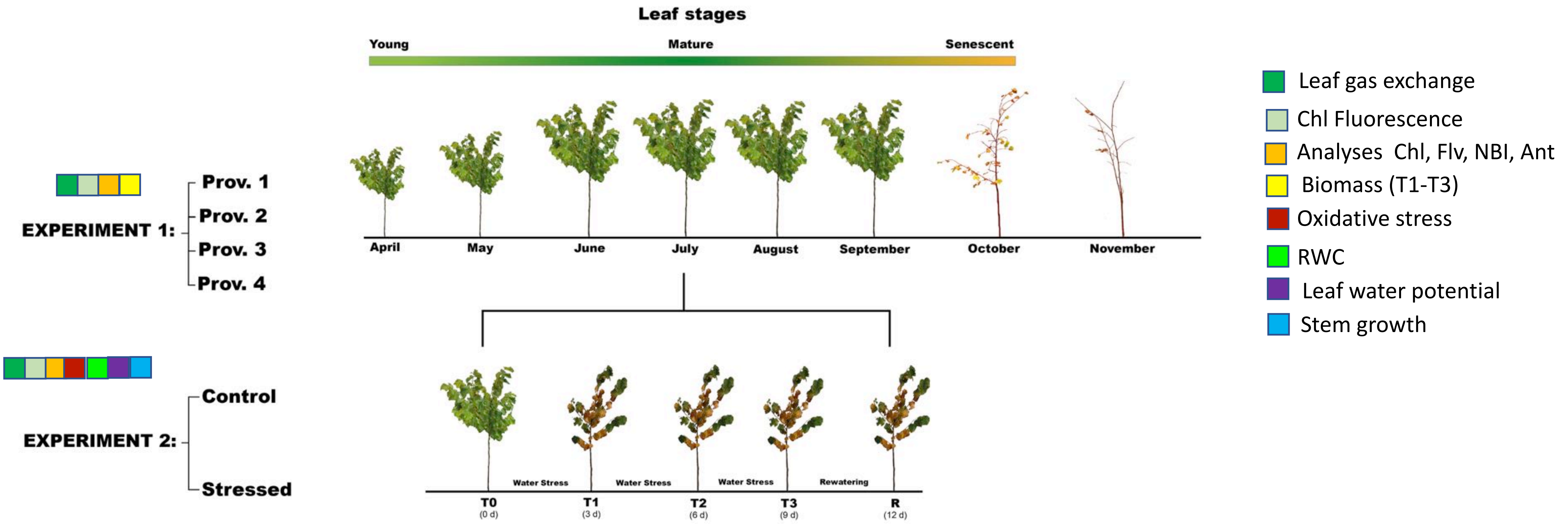
- Parameters to be monitored: Leaf gas exchange (P_N, gs, C_i, iWUE), Chlorophyll content (Dualex), Chlorophyll fluorescence (Handy-PEA), oxidative stress (MDA), RWC, leaf water potential, biomass, stem growth (dendrometers).

Acer pseudoplatanus

Quercus robur

Tilia cordata

Experiment setup: Use of different origins within the tree species examined. Two parallel experiments will be carried out: the first aimed at analyzing, during the growing season, the possible growth differences of tree species from different Italian regions; the second aimed at evaluating whether the different origin, within the species, can influence the resistance to a stress typical of the urban environment such as water stress.



Characterization of innovative multileaf spectral sensors for agriculture and precision irrigation

The aim of the project is to establish whether plant species used in ornamental nurseries can be subjected to controlled water stress in order to reduce the use of water without altering the quality of nursery production or even improving its growth performance.

UNIVERSITÀ DEGLI STUDI FIRENZE
IPSP
FSC Fondo per lo Sviluppo e la Coesione
Regione Toscana
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Some plant species are grown in a water deficit regime (reduction of water up to 50% usually given by nursery) and monitored using innovative sensors with "proximal sensing" technology (LWM sensors, Leaf Water Meter, Brunetti et al. 2022 STOTEN). In particular, this technology is able to monitor the hydration status of plants in real time in a non-invasive and continuous way. Simultaneously, the response of plants to irrigation treatments will be periodically monitored through eco-physiological surveys, such as measurements of water relations (water potential and relative leaf water content) and of photosynthetic activity (gas exchange and chlorophyll fluorescence).

Working group

- **Francesca Alderotti**
- **Barbara Baesso Moura (IBE-CNR)**
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- **Cassandra Detti**
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- **Francesco Ferrini**
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- **Ermes Lo Piccolo**
- **Lucrezia Muti**
- **Dalila Pasquini**





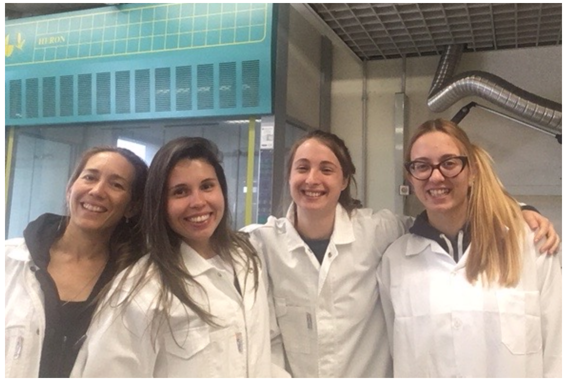


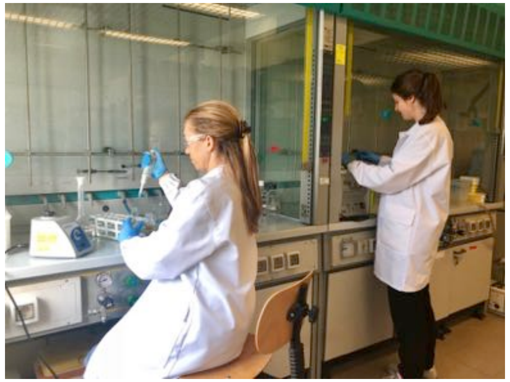


Denise Corsini, Postgraduate student UNIMI, Alessio Fini, Prof. Università di Milano, Irene Vigevani, PhD

Publication list related to drought stress 2021-2023

1. Pasquini D., A., Gori A, M. Pollastrini, F. Alderotti, M. Centritto, F.Ferrini, C. Brunetti, **2023**. Effects of drought-induced holm oak dieback on BVOCs emissions in a Mediterranean forest. **Science of the Total Environment**. Volume 857, Part 3, 159635, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2022.159635
2. Gori A., Moura B. B., Sillo F., Pasquini D., Alderotti F., Balestrini R., Ferrini F., Centritto M., Brunetti C., **2023**. Physiological and biochemical mechanisms underlying holm oak responses to severe water stress and rewatering: is carbon reserve consumption necessary to maintain xylem hydraulic functionality. Accepted for the publication in **Science of the Total Environment**
3. Alderotti F., Pasquini D., Stella C., Gori A., Centritto M., Ferrini F., Righele M., Brunetti C., **2022**. On-line monitoring of plant water status: validation of a novel sensor based on photon attenuation of radiation through the leaf. **Science of the Total Environment**. Jan 5;152881. doi: 10.1016/j.scitotenv.2021.152881.
4. Corsini D., Vigevani I., Oggioni S.D., Frangi P., Brunetti C., Mori J., Viti C., Ferrini F., Fini A., **2022**. Effects of controlled mycorrhization and deficit irrigation in the nursery on post-transplant growth and physiology of *Acer campestre* and *Tilia cordata*. **Forests** 2022, 13, 658.https://doi.org/10.3390/f13050658
5. Baesso Moura B., E. Paoletti, O. Badea, F. Ferrini, Y.Hoshika, **2022**. Visible foliar injury and ecophysiological responses to ozone and drought in oak seedlings. **Plants**, July 13;11(14):1836. doi: 10.3390/plants11141836.
6. Pasquini D., A. Gori, F. Ferrini, and C. Brunetti, **2021**. An improvement of SPME-based sampling technique to collect volatile organic compounds from *Quercus ilex* at environmental level. **Metabolites**, 11 (6), art. no. 388, DOI: 10.3390/metabo11060388
7. Baesso Moura B., C. Brunetti; M. R. Gonçalves da Silva Engela; Y. Hoshika; E. Paoletti; F. Ferrini, 2021. Experimental assessment of ozone risk on ecotypes of the tropical tree *Moringa oleifera*. **Environmental Research**, Volume 201, **2021**, 111475, ISSN 0013-9351, https://doi.org/10.1016/j.envres.2021.111475.
8. Gori, A.; Brunetti, C.; dos Santos Nascimento, L.B.; Marino, G.; Guidi, L.; Ferrini, F.; Centritto, M.; Fini, A.; Tattini, M. **2021**. Photoprotective Role of Photosynthetic and Non-Photosynthetic Pigments in *Phillyrea latifolia*: Is Their "Antioxidant" Function Prominent in Leaves Exposed to Severe Summer Drought? **Int. J. Mol. Sci.**, 22, 8303. https://doi.org/10.3390/ijms22158303





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