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Improving transplanting success: species selection and pruning during establishment

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Post-planting stress

is a major challenge to the success of urban tree planting initiatives, because it can lead to the early mortality of up to 20-30% of newly planted trees (*Breger et al., 2019; Wattenhofer and Johnson, 2021*).

It is defined as:

1) a condition of distress from injuries, depletion, and impaired functions caused by handling the plant from the nursery into a new, often less favorable, environment (*Struve, 2009*), or

2) the post-transplant period when a tree is not self-sustaining at its new location and is at heightened risk of decline or death (*Harris and Day, 2017*).

PPS is closely related to drought, because roots of newly planted trees, which might had been severed (B&B stock), are confined within the rootball and can hardly support canopy transpiration (*Peters et al., 2023*).

Tree factors:

- Species
- Plant size
- Quality of nursery stock

Community factors:

- Social cohesion
- Employement rate

Post-planting stress

Site factors:

- Soil quality
- Water stress
- High air T and irradiance

Management factors:

- Irrigation frequency
- Damage during transport
- 1/3 of budget for post-planting care

Vogt et al., 2015, LAUP

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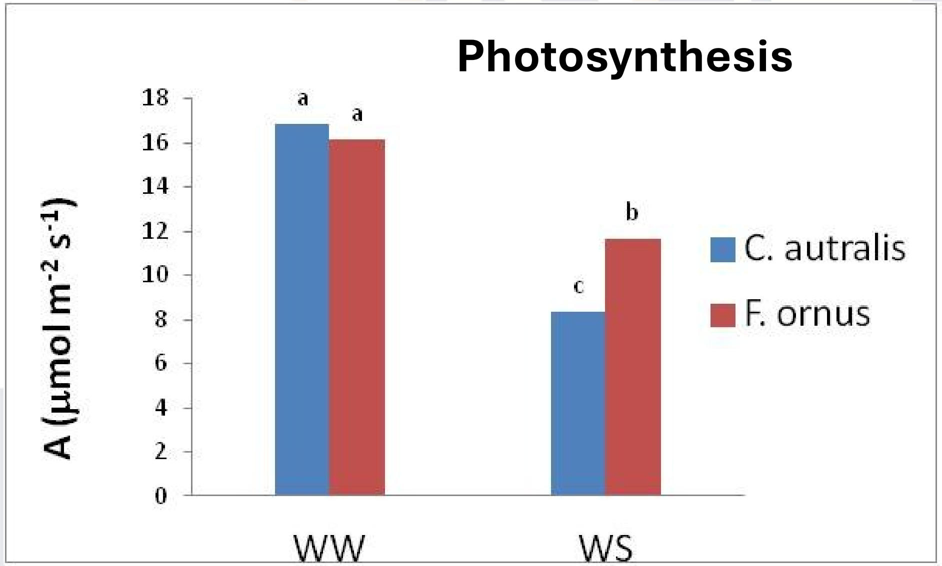
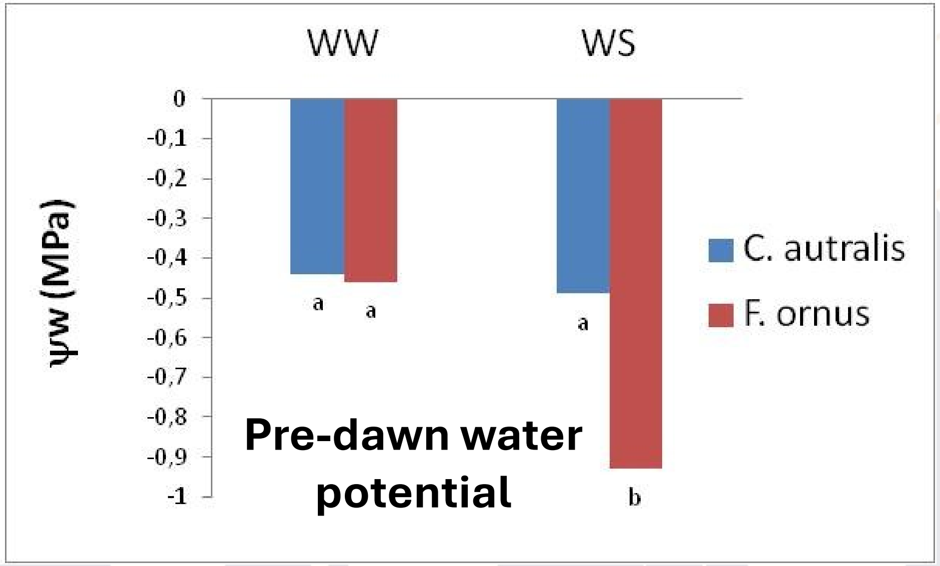
Tree factors

- In the absence of proper post-planting irrigation, large differences in mortality rate were observed among woody species (*Elmes et al., 2018; Wattenhofer and Johnson, 2021*).
- **Some of genera that better tolerate transplanting**, such as *Acer, Platanus, Tilia*, and *Ulmus*, display an **isohydric** response to drought stress.
- Conversely, **some hard-to-transplant species**, such as *Quercus* spp. and *Fagus* spp., typically display an **anisohydric** response (*Tattini et al., 2015; Hesse et al., 2022; Cregg et al., 2023; Waite et al., 2024*).

ISOHYDRIC SPECIES:
Early stomatal regulation to preserve plant hydration during drought, at expenses of carbon gain

ANISOHYDRIC SPECIES:
Sustained stomatal opening during drought to maintain positive carbon gain, at expenses of hydration





Management factors

- **Irrigation** is crucial to promote establishment
- Two irrigation events per week for 6 months; then 1 per week for additional 6 months; finally 1 every second week until full establishment

- **How long will it take the tree to establish? How long should we irrigate?**

PRACTICAL REPLY: 3-12 months per each 2.5 cm DBH

SCIENTIFIC REPLY: there is still no widely-accepted method to assess whether the tree is established or not. Several indicators were tested

Resumption of nursery growth rate

Biased by soil fertility and management (*Harris and Day, 2017*)

Crown dieback, shoot extension, trunk movement

Not really working if used as individual indicators (*Leers et al., 2018*)

Hydraulic connection with the hydrological cycle of the planting site restored *(Yin et al., 2014; Levinsson et al., 2017)*

How to assess?

Can pruning mitigate post-planting stress?

Pruning at planting is an intuitive approach to reduce leaf area and restore root:shoot in newly planted B&B stock

Pruning at planting may also improve tree structure (*Gilman, 2015*).

Nonetheless, pruning is now not recommended as a sound technique to mitigate post-planting stress (*Koeser, 2017*).

Such notion is based on very old science, where often pruning was not conducted according to the actual BMP (*Evans and Klett, 1984; Wood et al., 1990*).

It was hypothesized that pruning may be more effective in isohydric than in anisohydric species, because of the higher capacity of the former species to modulate leaf area (Hoffman et al., 2011).

Pruning improved plant hydration in near-isohydric *Picea abies*, but not in near-anisohydric *Quercus petraea* (Arsic et al., 2025).

Aim

Under the umbrella of an extensive tree planting initiative (**10000 trees for Padova**), we conducted a research to test the hypotheses that:

1) Species' differences in tolerance to PPS are related to their isohydric/anisohydric behaviour

2) pruning can mitigate the severity of PPS

3) The duration of PPS is species specific and pruning can reduce it

To test these hypotheses, in March 2022, an experimental field was established in a derelict area of Padova (Italy) according to a randomized complete block design with 8 blocks. 128 plants were used in total (4.9-5.9 cm circumference at planting).

The soil of the experimental site **was a silt loam with a sub-alkaline pH, a high total lime content and a phosphorus-deficiency.**

Treatments

4 species:

1) *Acer campestre AC* (transplants well)

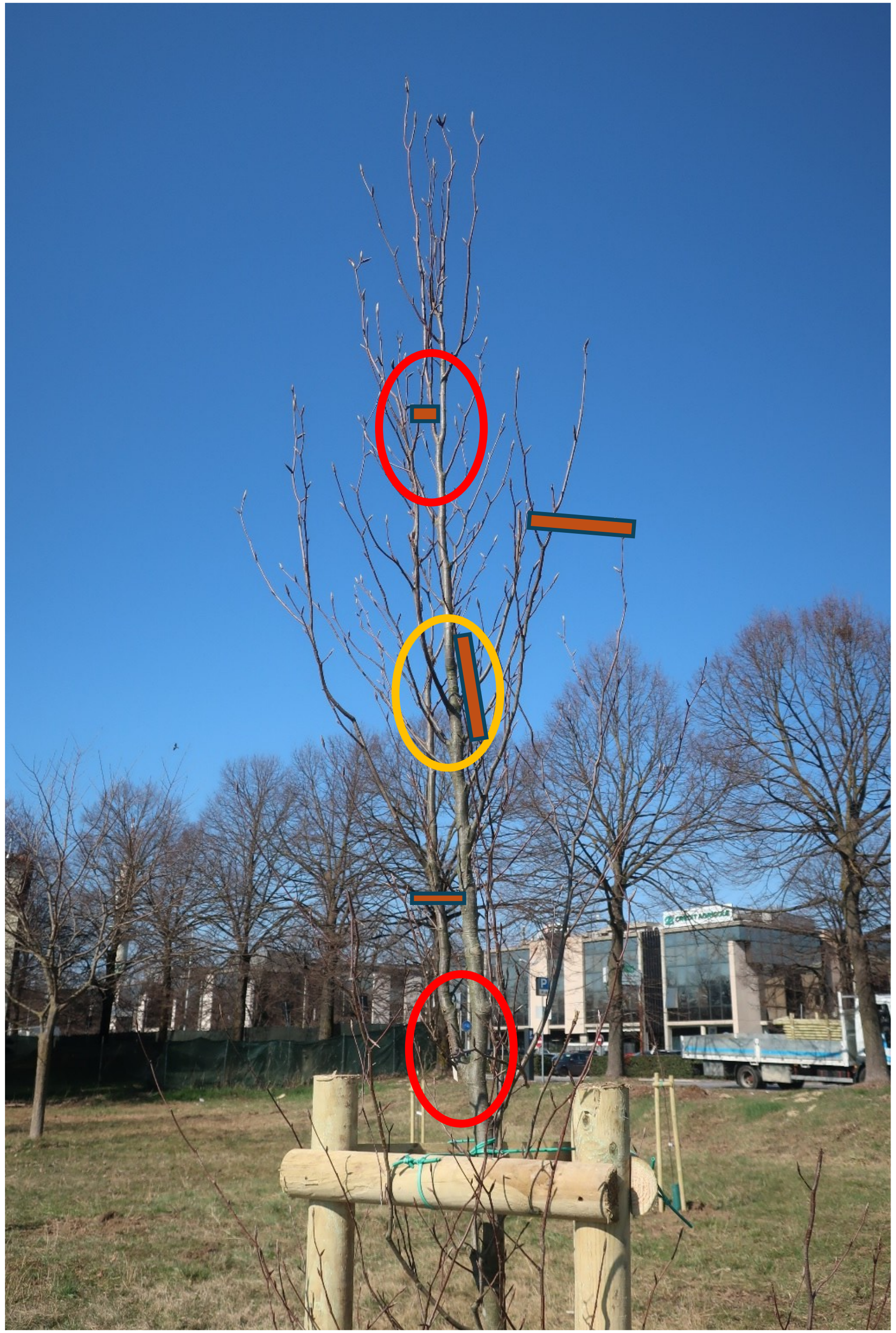
2) *Carpinus betulus CB* (medium tolerance)

3) *Fraxinus angustifolia FA* (medium tolerance)

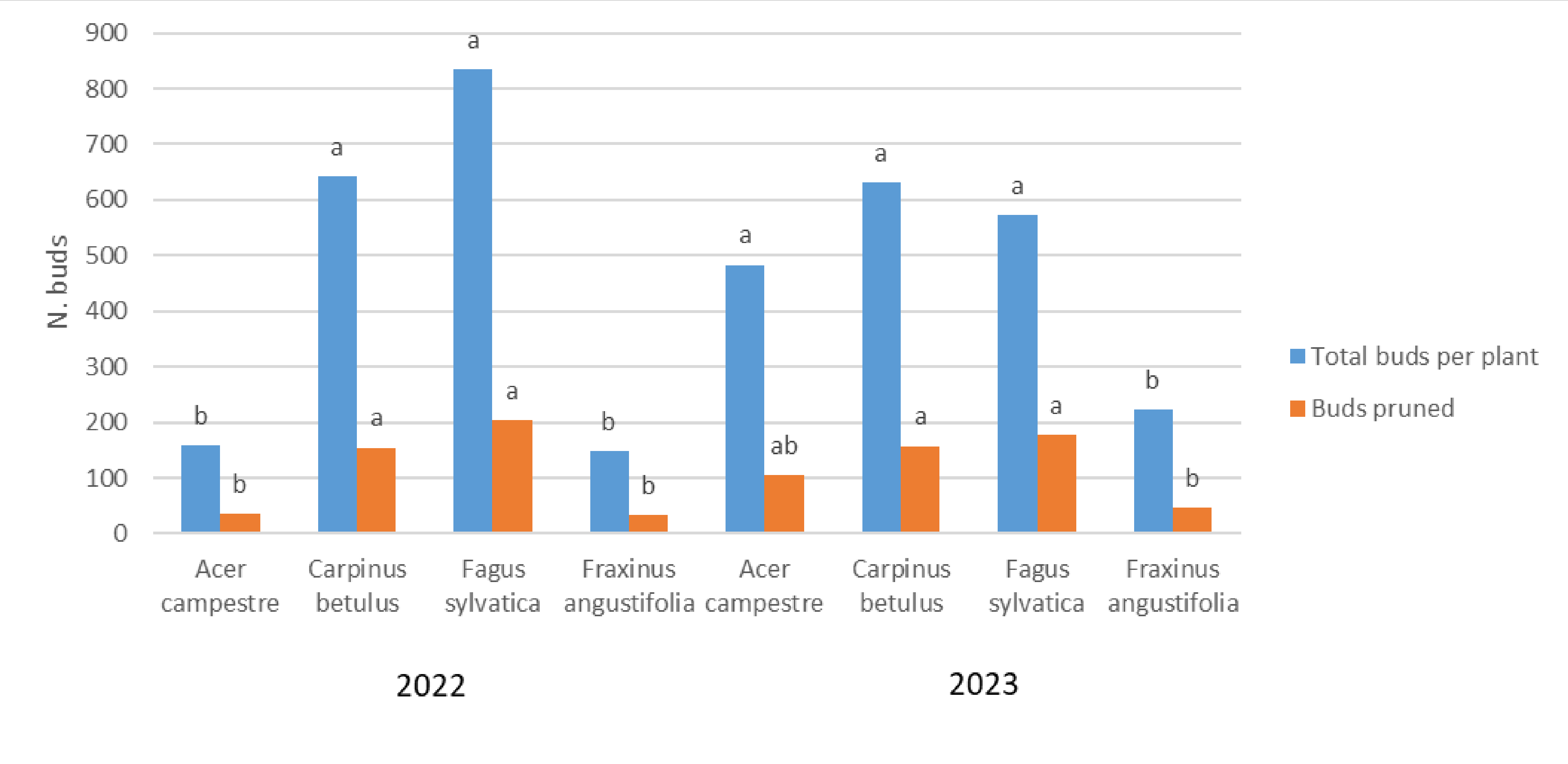
4) *Fagus sylvatica FS* (transplants poorly)

2 pruning treatments:

1) Unpruned (control)
2) Structural pruning according to BMP



Pruning intensity



Pruning was done in March 2022 and February 2023.

Pruning dose was set by:

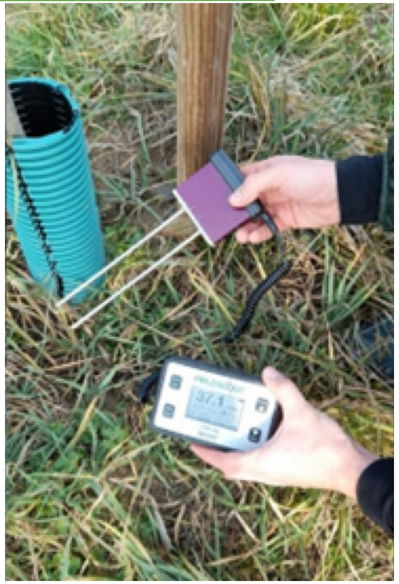
1) Counting total bud number per plant
2) Pruning was targeted to remove about 25% of buds

Post-planting Management

Trees were manually watered by distributing 40-50 dm^3 water around each tree every 13-18 days for 2 years after planting.

Mowing was carried out 4-6 time per year both on the rows and between the rows.

Measurements (2022-2024)



Environmental traits

1- Soil physico-chemical and hydraulic properties

2- Soil moisture (0-20 cm), measured using a TDR-probe (Fieldscout) inside the rootball and in the native soil

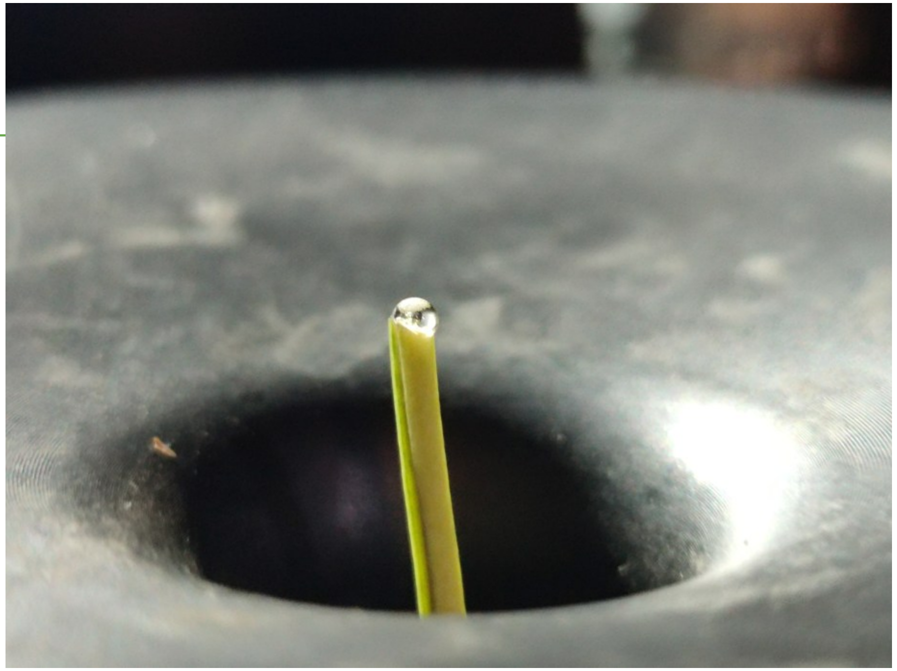
3- Air temperature and rainfall, measured using a nearby weather station

Plant growth

1- Stem DBH
2- Plant height, measured using a graduated rod
3- Canopy radius, measured according to Rotzer et al. (2020)
4- Number of codominant branches: n. of structural branches with aspect ratio > 0,7

Stem (RGRstem) and crown projection area (RGRcpa) growth rates were calculated as:
RGR = $(\ln X_{t1} - \ln X_{t0})$/n of active growth days

Measurements (2023-2025)



Physiology:

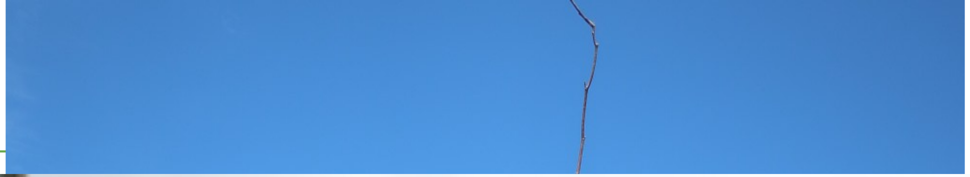
1- **Pre-dawn water potential**, measured using a pressure bomb between 01:00 and 03:00

2- **Leaf gas exchange and electron transport rate**(ETR), measured using an IRGA (Ciras-2) equipped with a fluorometer (CFM)

3- **A/Cc curves** and quantitative analysis of **stomatal, mesophyll and biochemical contributions to photosynthesis**, measured according to Buckley e Espejo-Diaz (2015)

4- **Leaf Greenness Index**, measured using a SPAD-meter (Minolta)

Measurements (2023-2025)



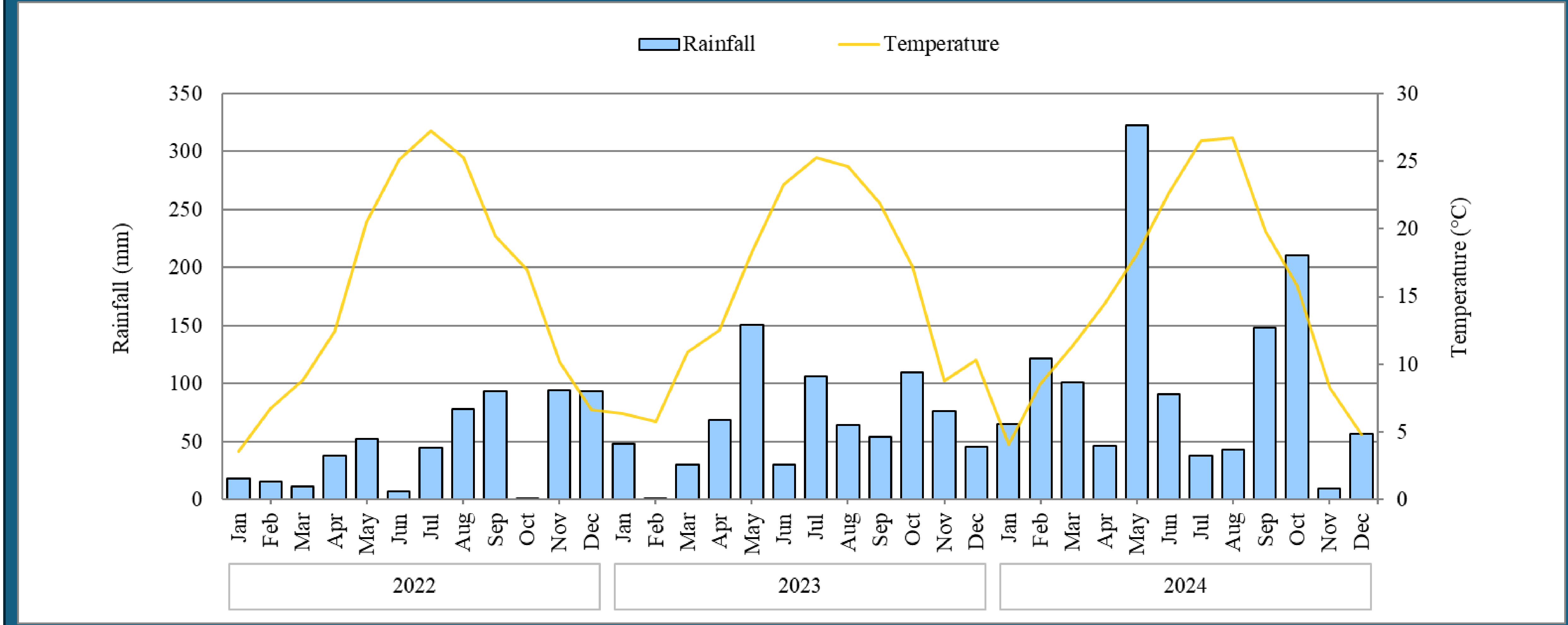
Wilting and mortality
Visually estimated according to Engelbrecht and Kursar (2003):

0- **healthy**
1- **Slightly wilted** (change in leaf angle)
2- **Wilted** (loss of turgor, no necrosis)
3- **Severely wilted** (necrosis on >25% of leaves)
4- **Nearly dead** (all leaves dead but stems alive)
5- **Dead** (all above-ground organs dead)

Let’s see what happened!

All statistics were performed using SPSS software

Weather conditions during the research



2022
Tavg = 15,15°C
Rainfall = **548 mm**

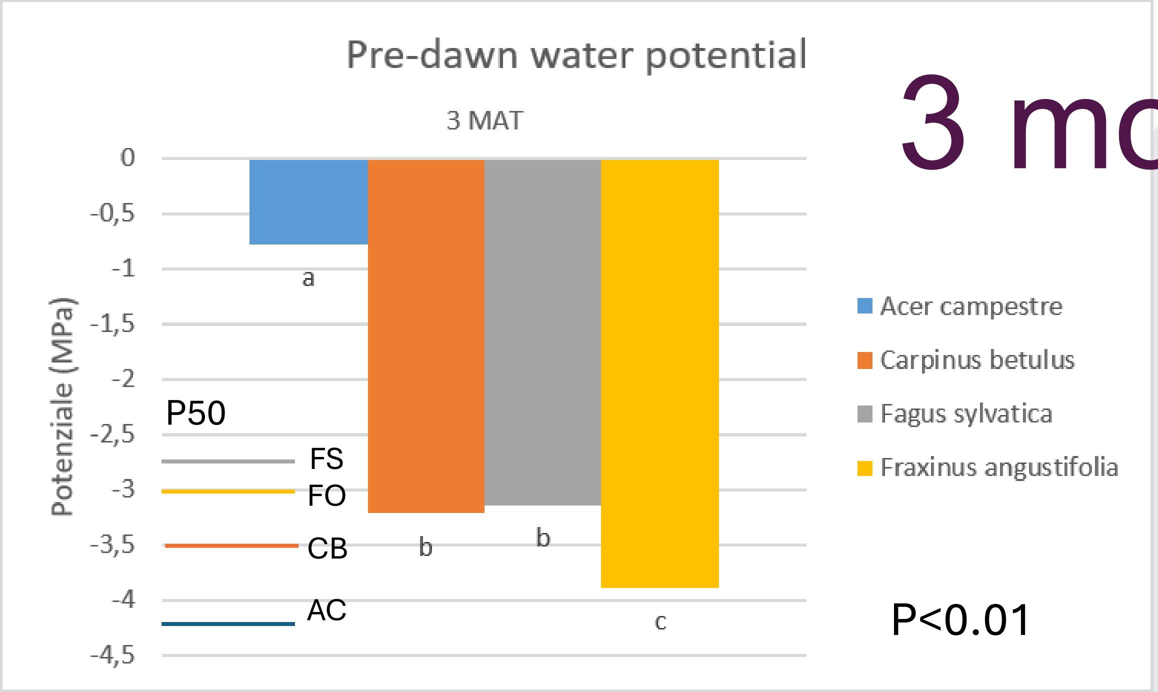
2023
Tavg = 15,10°C
Rainfall = 787 mm

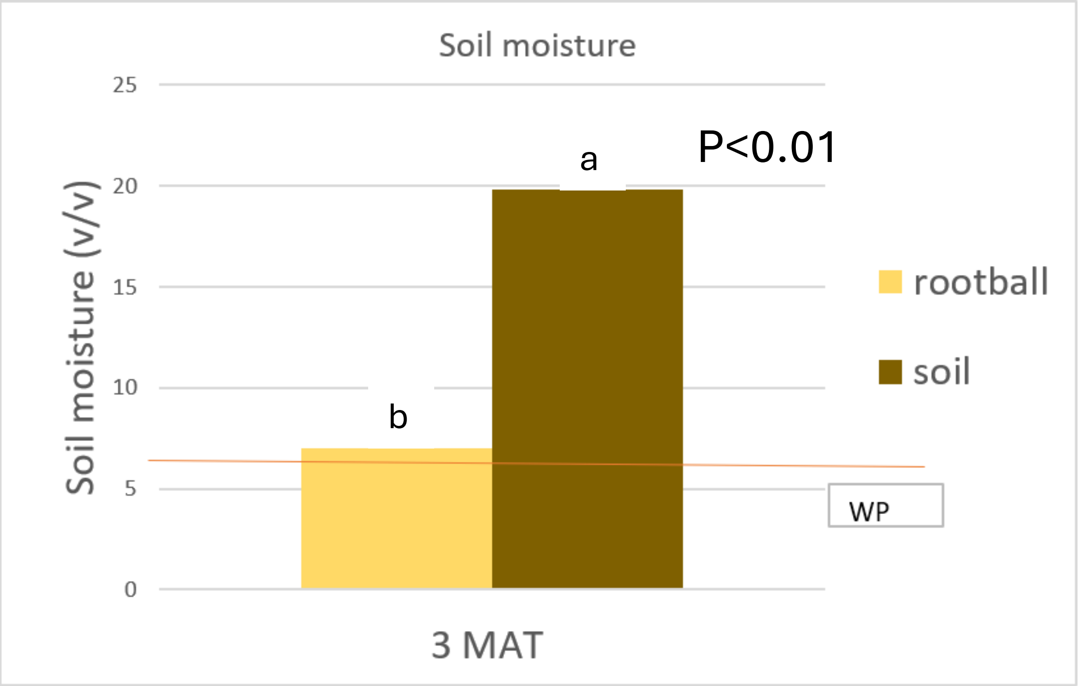
2024
Tavg = 15,13°C
Rainfall = 1254 mm

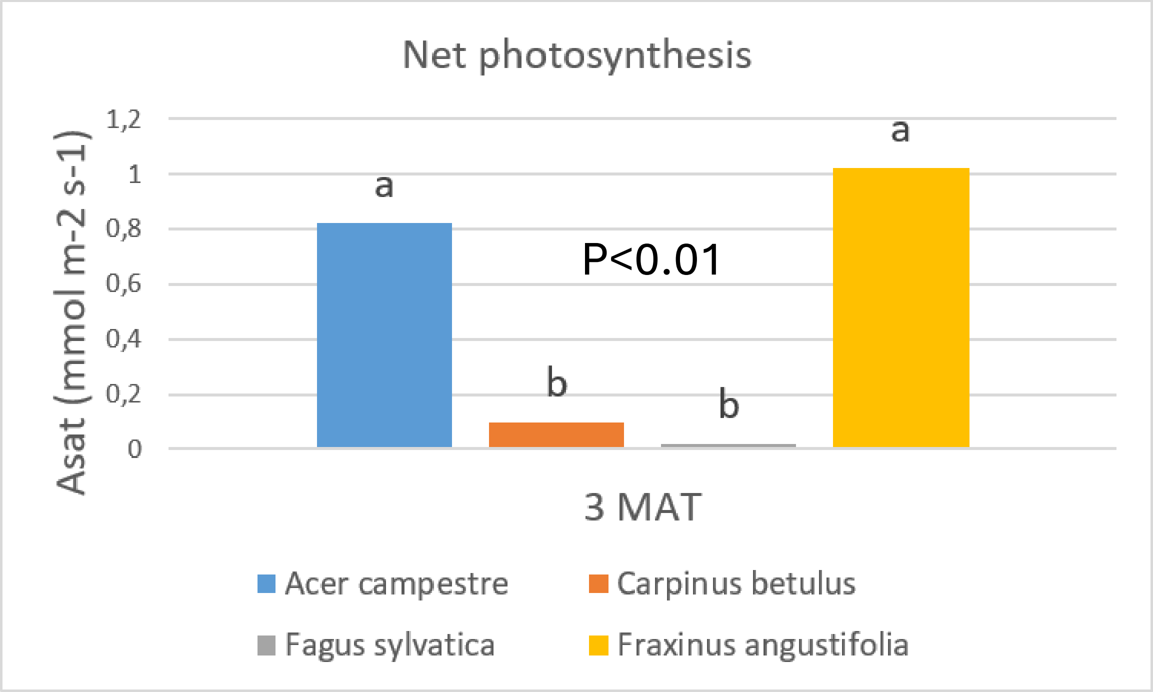
30-year avg
Tavg = 13,90°C
Rainfall = 994 mm


3 months

3 months







- Rootball dried up quickly
- Pre-dawn water potential approached P50 (potential at which 50% of xylem conductivity is lost) in all species except *Acer*
- Very low photosynthetic rate for the species

Very severe drought experienced early after transplanting

Methods to estimate species isohydry

The isohydric/anisohydric behaviour of the species was estimated using two methods:

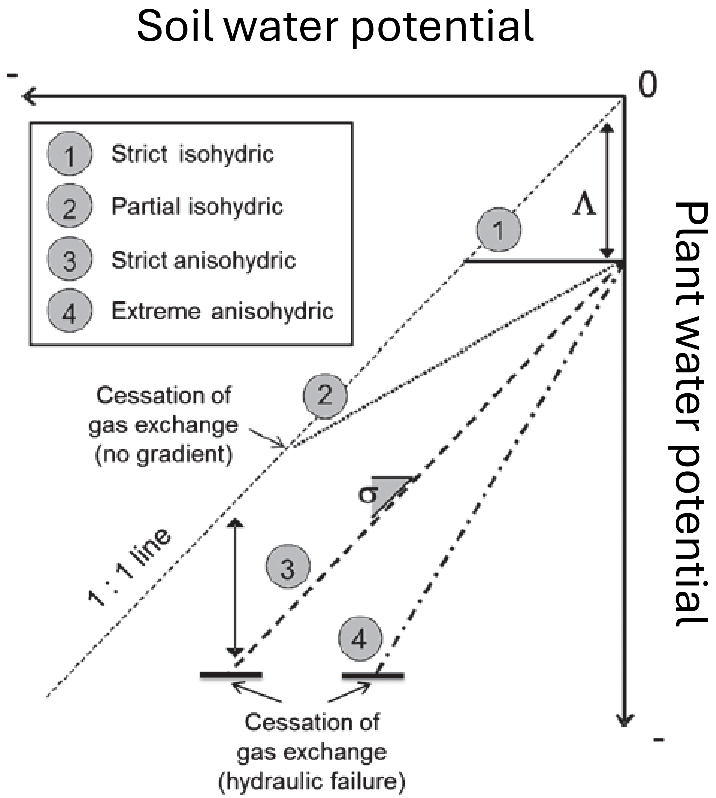


Fig. 1 Relationship between predawn and midday leaf water potentials according to our theoretical model, which assumes a linear relationship. Four different behaviours are depicted, all sharing the same intercept (Λ): strict isohydric ($\sigma = 0$), partial isohydric ($0 < \sigma < 1$), strict anisohydric ($\sigma = 1$) and extreme anisohydric ($\sigma > 1$). The point of cessation of gas exchange is also represented: for isohydric behaviours; it occurs when $\Psi_{PD} = \Psi_{MD}$; for anisohydric relationships, it occurs when Ψ_{MD} reaches the water potential inducing complete loss of plant hydraulic conductance. The 1 : 1 line is also depicted.

1) Martinez-Vilalta et al., 2014

$\psi w = \Lambda + \sigma\, \psi s$

where ψs is soil water potential (MPa), σ is the slope of the ψw- ψs relationship, and Λ is the y-intercept.

ψs was calculated from volumetric soil moisture as described by Saxton and Rawls (2006)

2) **NIV method**

$NIV = (X_{stressed} - X_{healthy})/(X_{stressed} + X_{healthy})$,

Where X indicates photosynthesis (NIV_A) or pre-dawn water potential (NIVpd)

High NIV_A/NIVpd → isohydric

Low NIV_A/NIVpd → anisoisohydric

How did the species cope with drought?

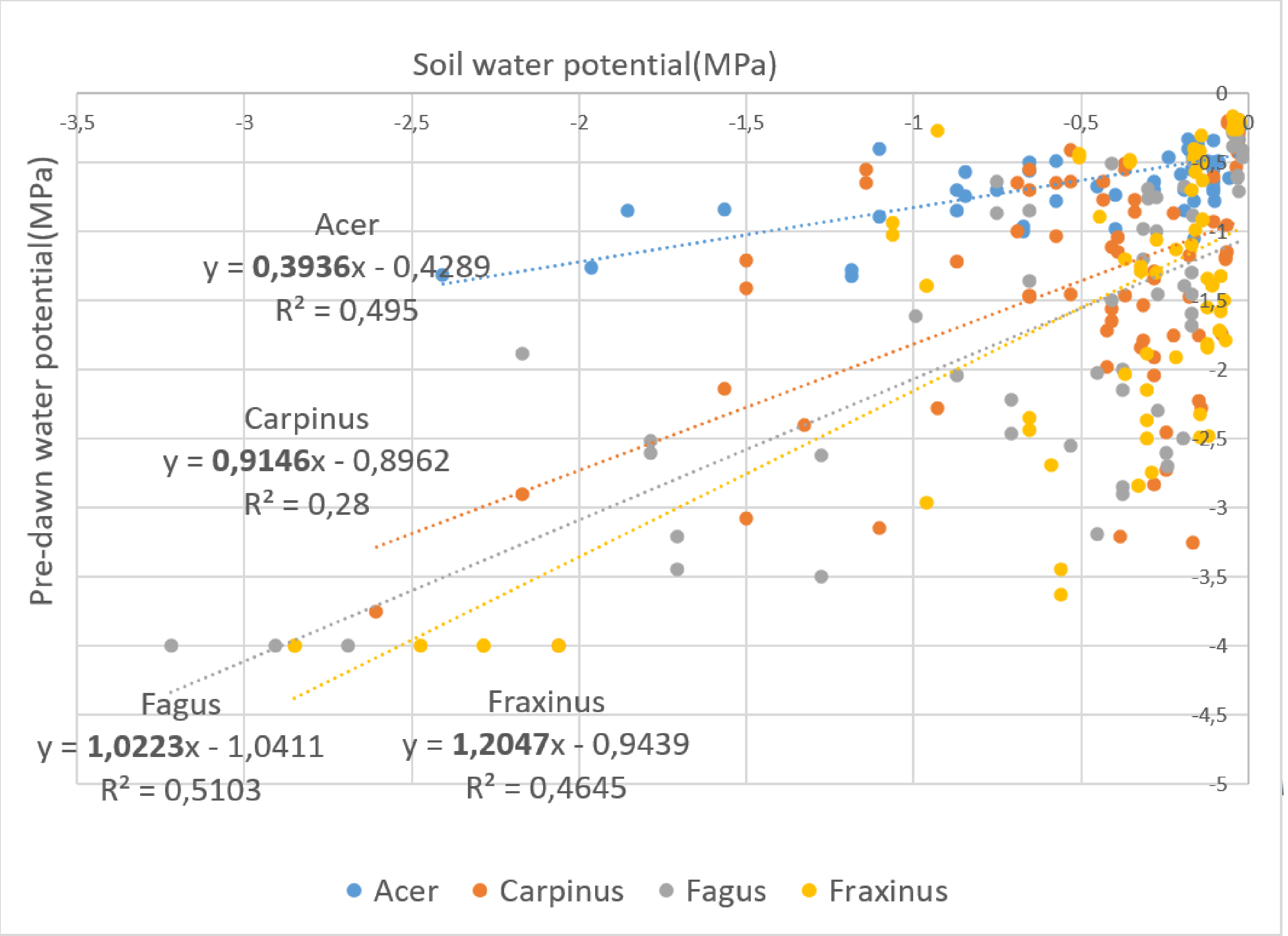
1- Martinez-Vilalta method

Change in leaf potential per unit change in soil potential

Acer had a slope around 0.4, and can be classified as partial isohydric

Carpinus and *Fagus* had a slope near 1, and can be classified as anisohydric

Fraxinus had a slope > 1 and can be classified as extreme anisohydric



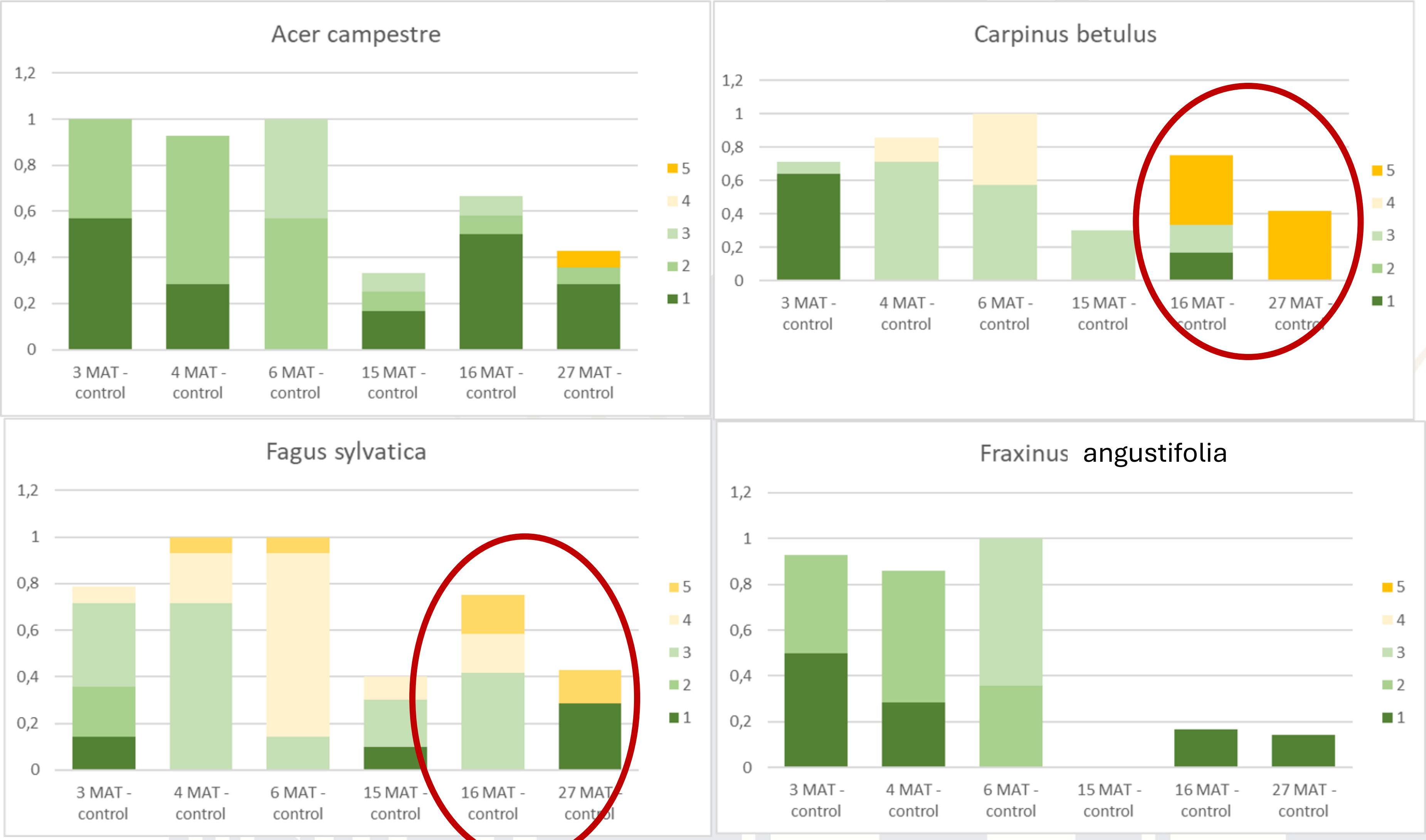
What happened next?

or

?

Is the severity of PPS is affected by the species mechanism to withstand drought, under sub-optimal irrigation regime?

Mortality and wilting

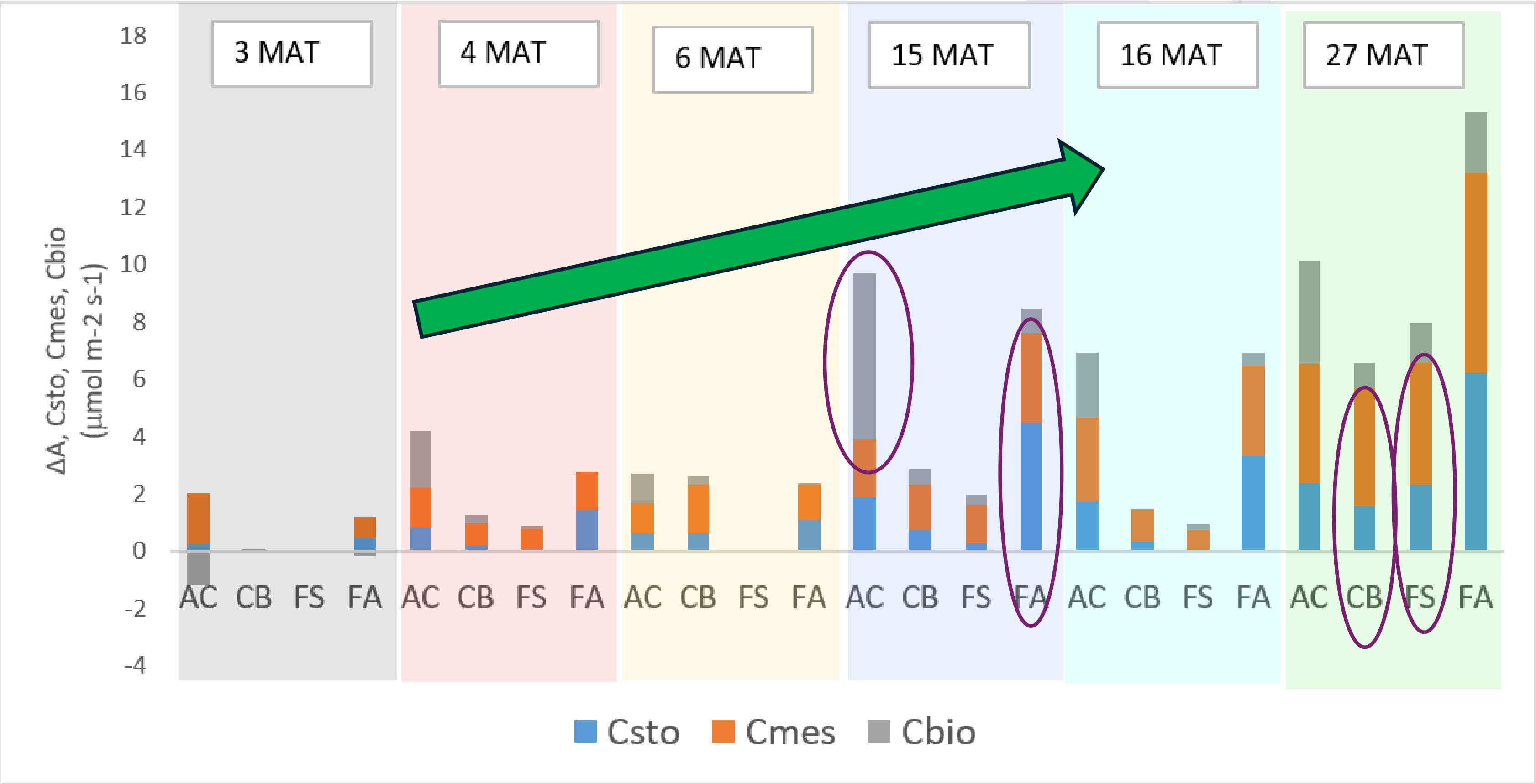


5- Dead (aboveground)
4- Nearly dead
3- Severely wilted
2- Wilted
1- Slightly wilted

Mortality was higher in anisohydric CB and FS than in both anisohydric FA and isohydric AC

MAT = months after transplanting

Diffusive and biochemical contributions affect the **recovery of photosynthesis**



AC = Acer; CB = Carpinus; FS = Fagus; FA = Fraxinus

MAT = months after transplanting
Csto = stomatal contributions;
Cmes = mesophyll conductance contribution;
Cbio = biochemical contributions

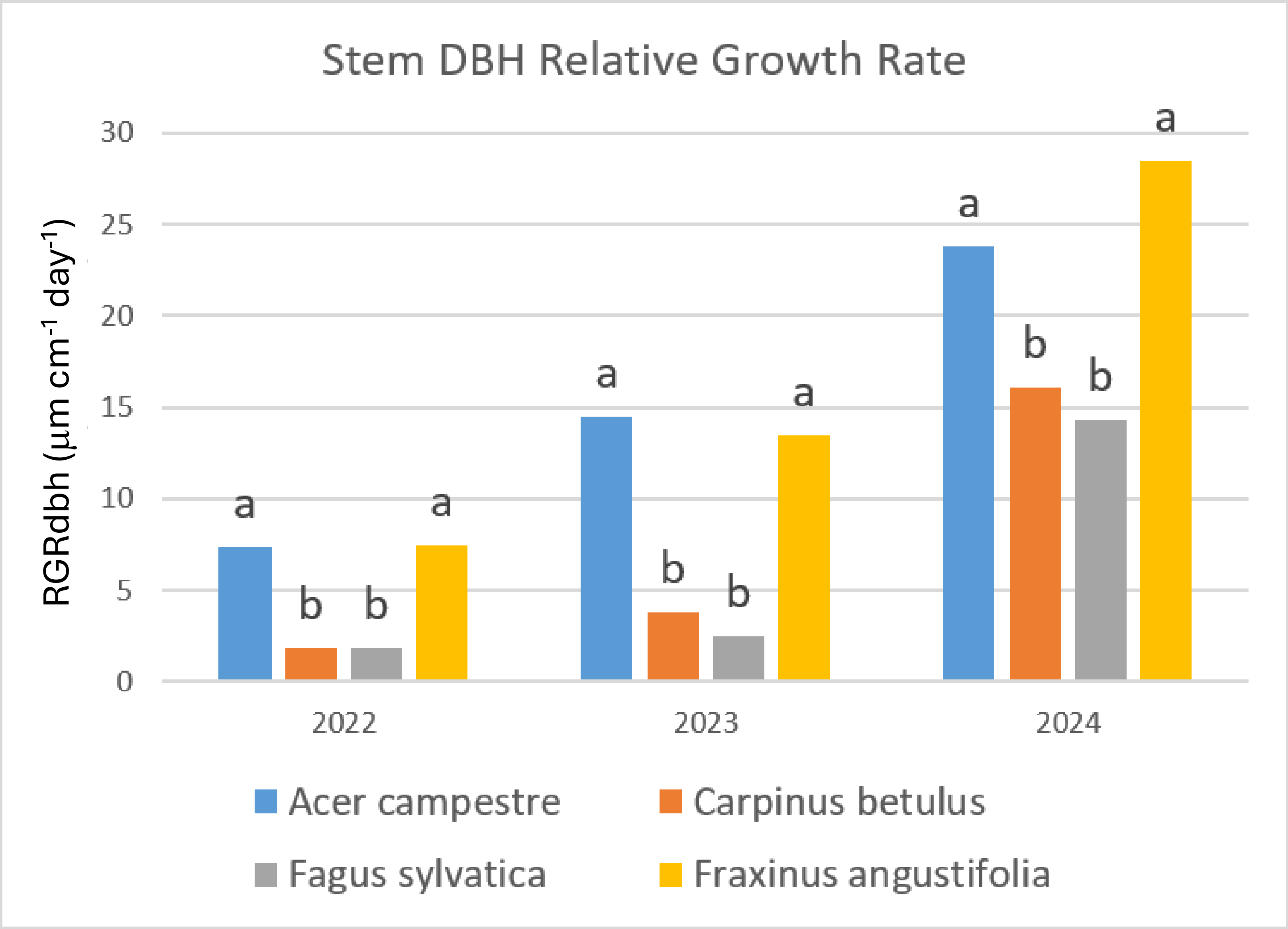
In AC, C_{bio} (grey bar) accounted for 42.7% of the total change in A observed between 3 and 27 MAT

Efficient Rubisco is key to isohydric species, where tight stomatal regulation may constrain CO_2 availability for photosynthesis (*Guo et al., 2022*)

In other species, C_{sto} (blue bar) and C_{mes} (orange bar) accounted, on average, for 87.6% of the increase in A

This is consistent with their near-anisohydric behaviour, which is based on maintaining CO_2 flux into the leaf at decreasing water potential (*Tarin et al., 2024*).

Growth rate



Acer and *Fraxinus* showed higher RGRdbh compared to other species

Carpinus and *Fagus* showed almost no DBH increase for 2 years after transplanting

Do species isohydry affect transplant tolerance?

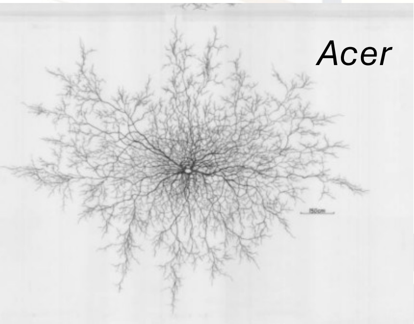
Not necessarily,

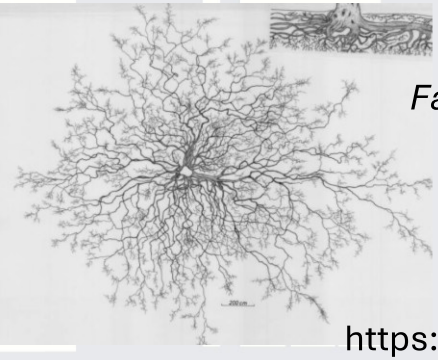
- Isohydric species avoided cavitation, but the flushing of new leaves with active Rubisco is required for recovery of photosynthesis
- Anisohydric species likely experienced cavitation, and their tolerance to PPS is related to the capacity to restore plant hydraulic conductivity
- Anisohydric can transplant well as isohydric species if they can sustain stem DBH growth to compensate for cavitation and restore xylem conductivity

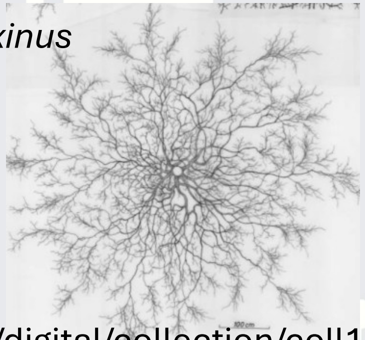
Other traits rather than the iso-/anisohydry gradient, may have contributed, including:

1) differences in root anatomy. *Carpinus betulus*, *Fagus sylvatica*, and *Fraxinus oxycarpa* are not reported to possess pre-formed roots, whereas species of *Acer* may have (Fink, 1982);

2) differences in root morphology. Species with fibrous root system, such as AC, retain more intact roots tips at transplanting, thus can regenerate roots faster, compared to coarse rooted species (Watson and Hewitt, 2020).







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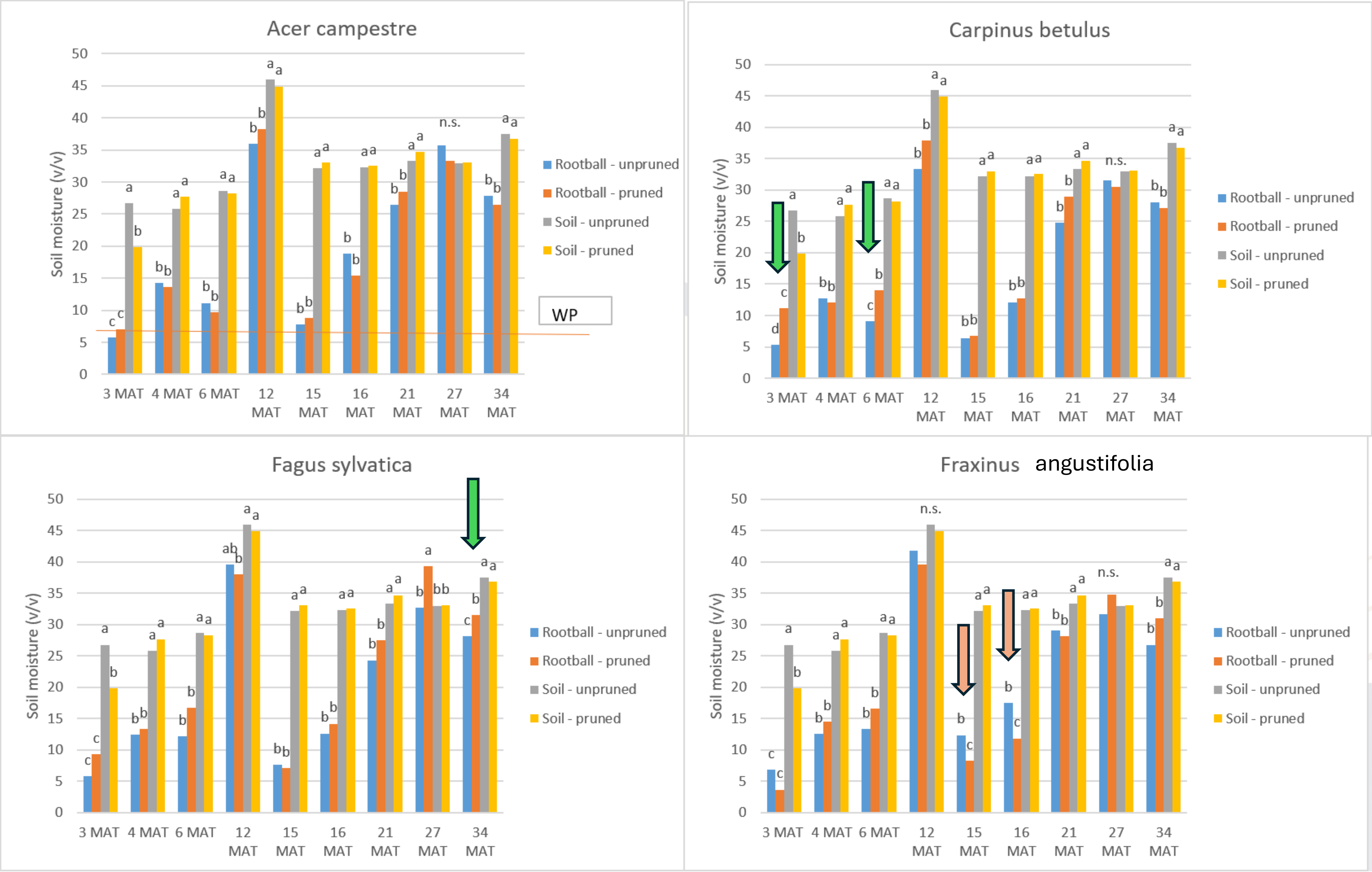
What about pruning?

What about pruning?

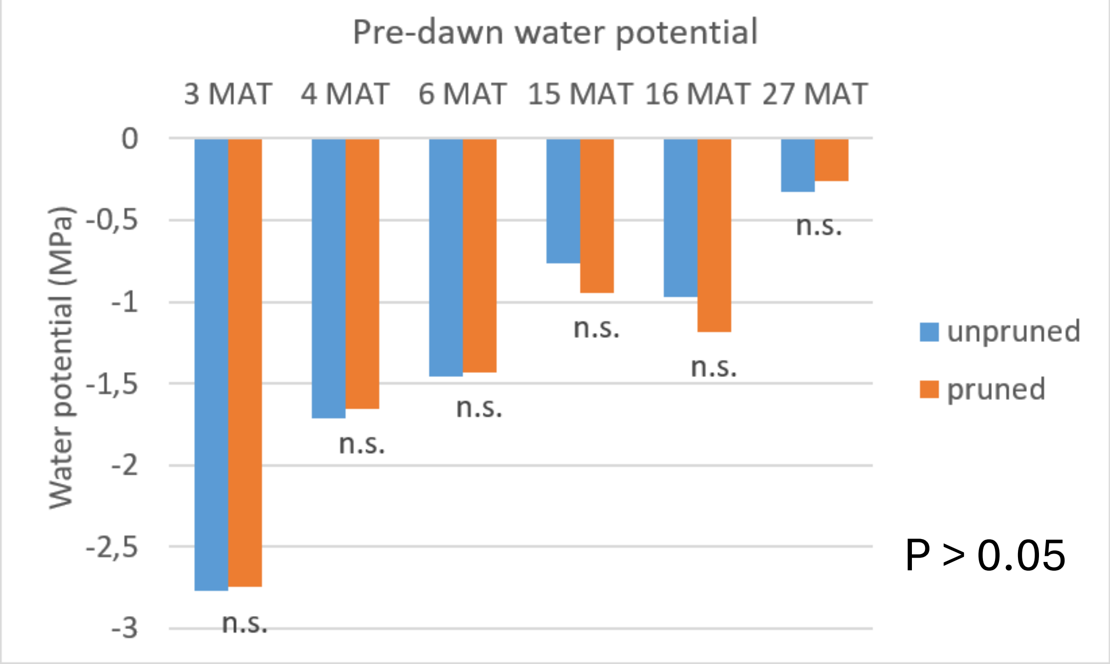
1- Soil moisture

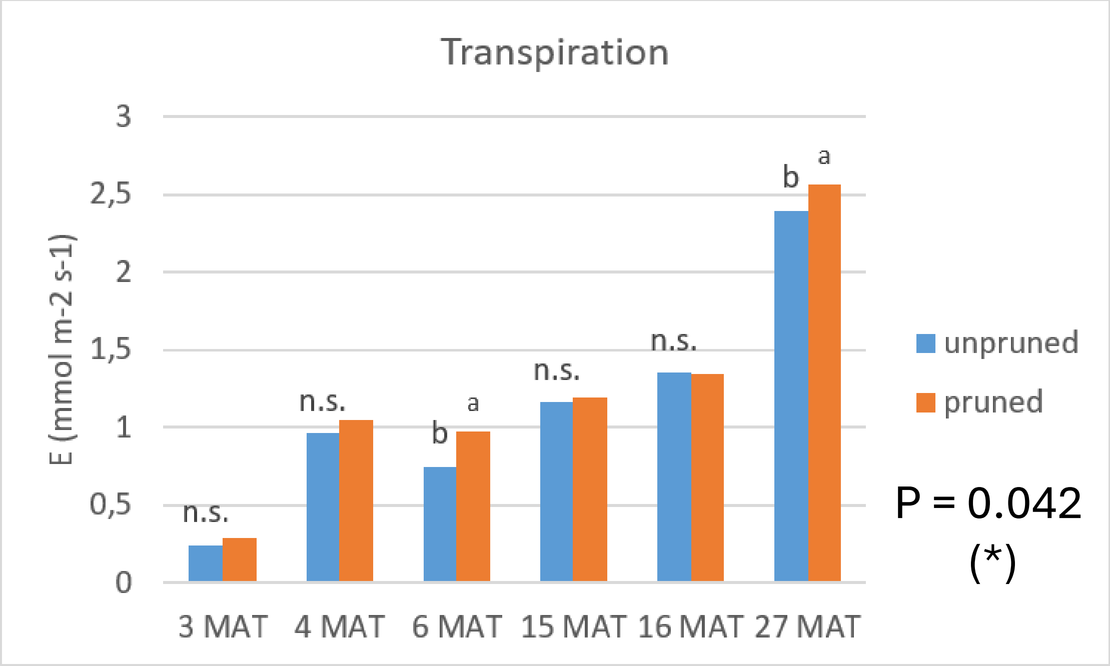


With few exceptions (e.g. *Carpinus*) it failed to improve water availability in the rootball

Arsic et al. (2025) showed that pruned trees (50% canopy reduction increased root-ball moisture up to 67% compared to unpruned trees

What about pruning?
2 - water potential and transpiration





- Pruned plants did not display more favourable water potential throughout the research
- Pruned plants displayed higher transpiration in 2 of the 6 sampling dates (i.e. higher water use per unit leaf area)
- Evidence for compensatory increase in stomatal conductance in pruned plants?

What about pruning? 3 - net photosynthesis

The effects of pruning on net photosynthesis were species-specific

Pruning only increased photosynthesis in anisohydric CB, FS, and FO,

This contradicts the hypothesis that pruning may be more beneficial to isohydric than to anisohydric species (Arsic et al., 2025).

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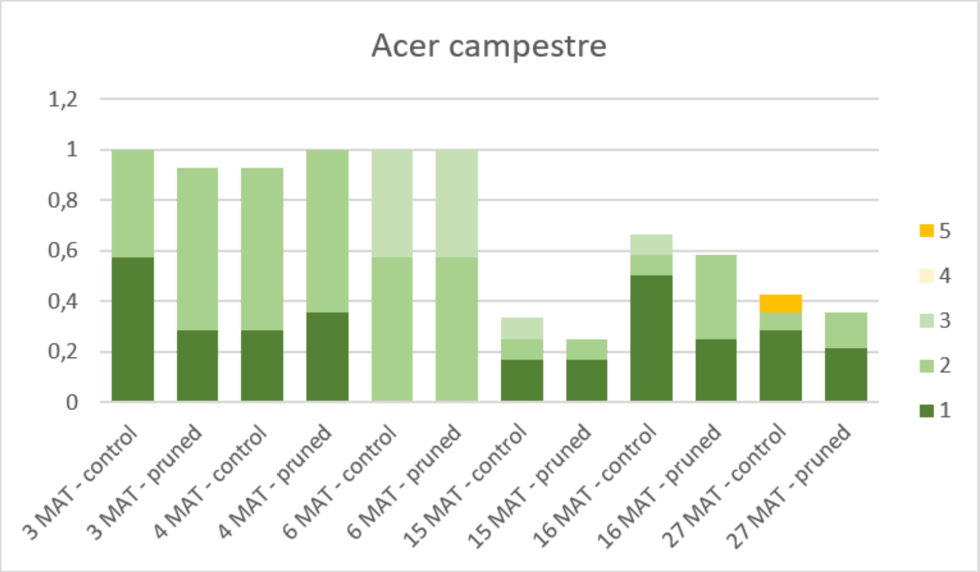
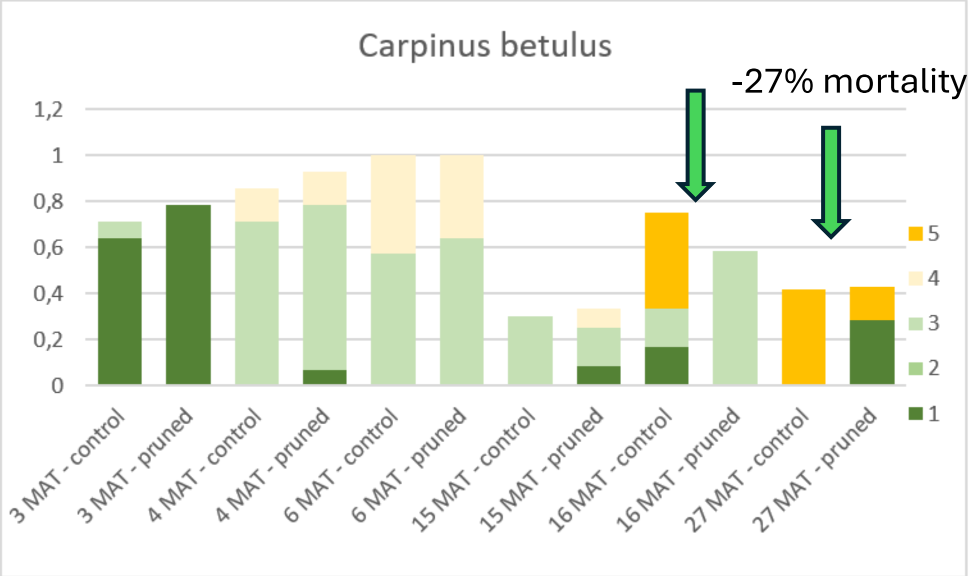
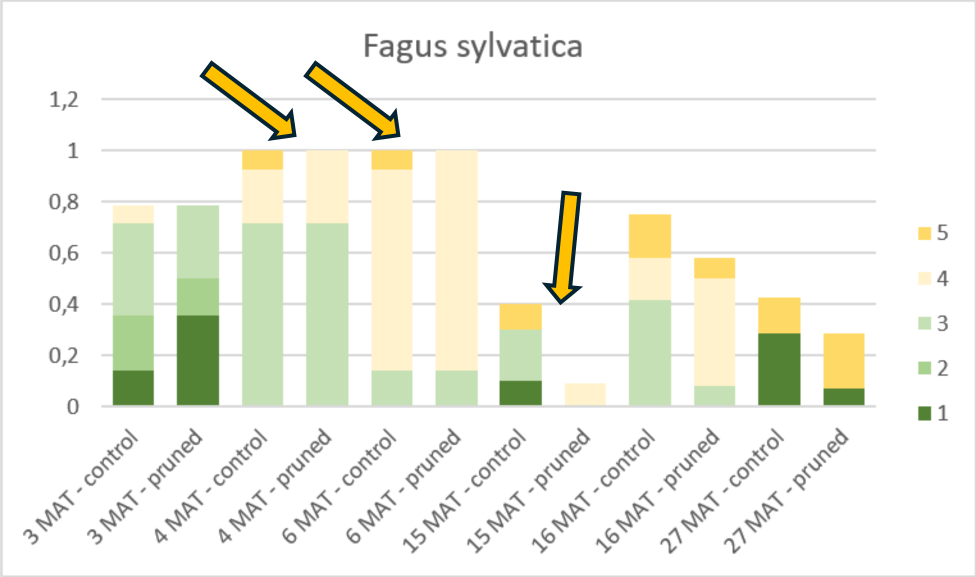
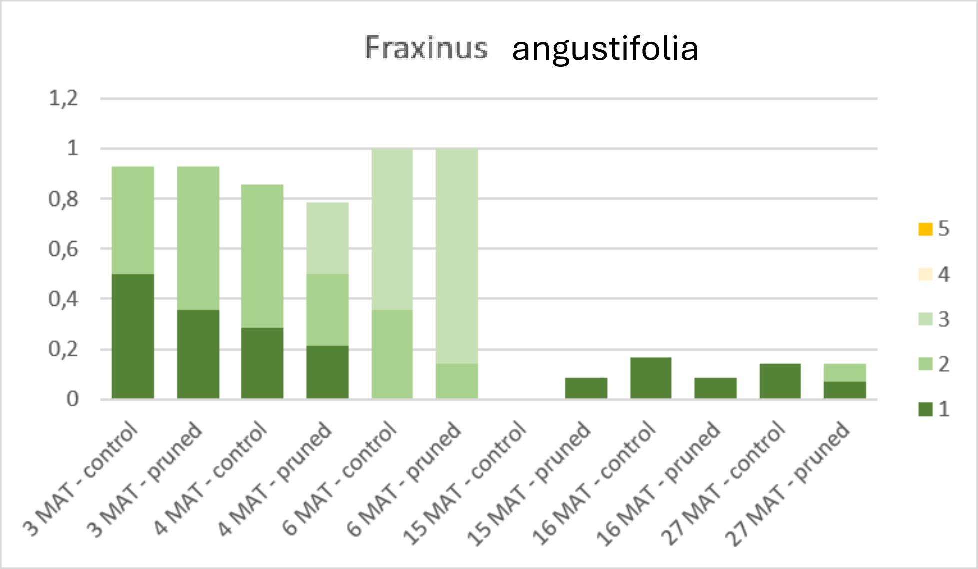
What about pruning? 4 - wilting and mortality









Small changes can make a big difference

Biologically relevant effects found only in one species

Can pruning mitigate the severity of PPS?

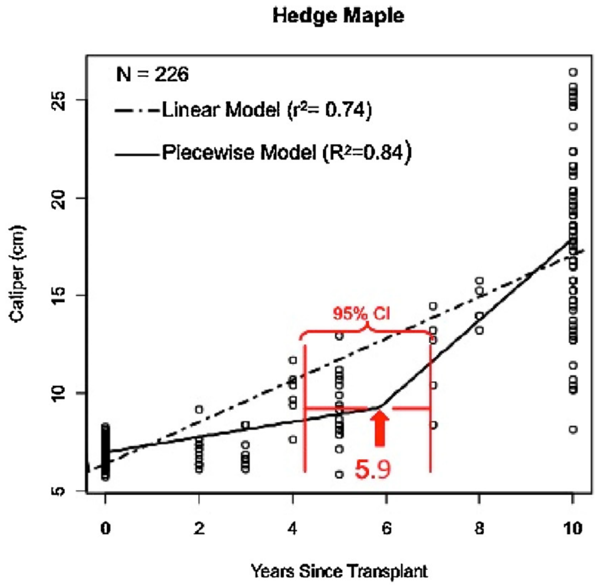
It depends on species.
Pruning had little effects in species that transplant well.
Some positive effects of pruning were observed in anisohydric species which poorly tolerated transplanting, *Carpinus betulus* in particular.

Before pruning

After pruning

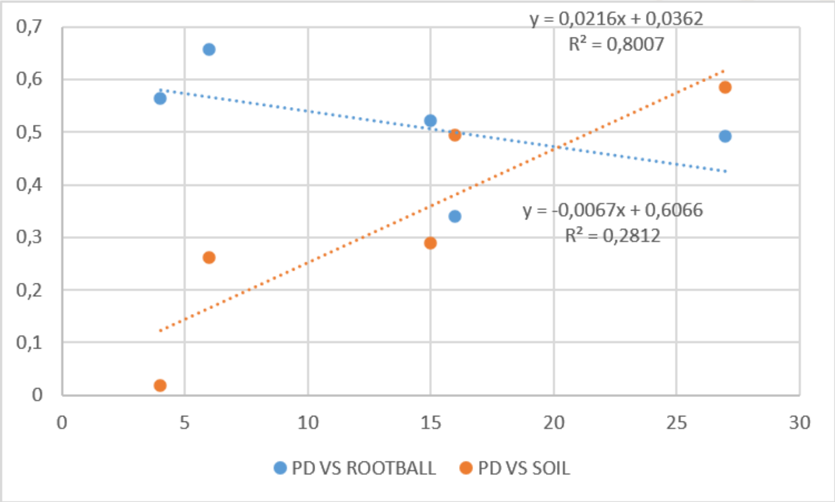
How long did it take to establish?

The durantion of post-planting stress was estimated using three methods:



1) Sherman et al., 2016

Establishment occurs when trees show a change of slope in DBH growth, assessed using a segmented regression approach

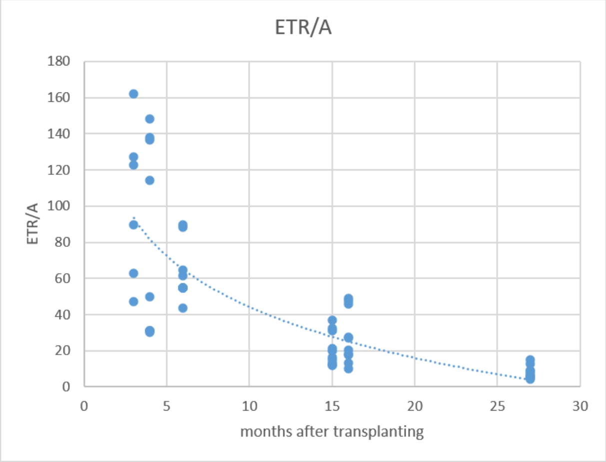


2) Water potential method

Based on the idea that plant hydration (ψpd) of newly-planted trees is affected by rootball moisture, rather than moisture of soil outside the planting pit. *Vice versa*, established trees will rely more on soil moisture.

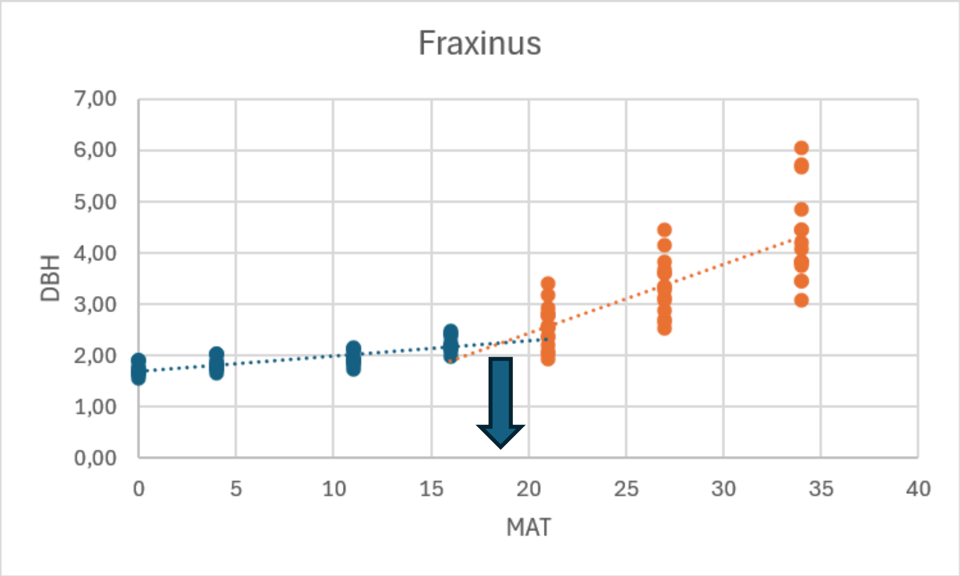
3) ETR/A method

Based on the concept that the ratio between electron transport rate and CO_2 fixation is < 10.5 in healthy plants.

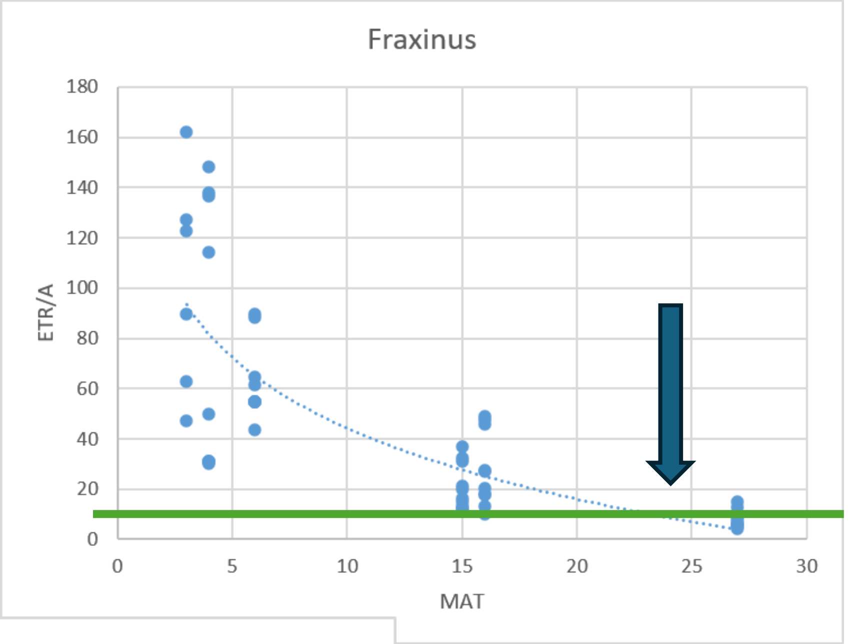


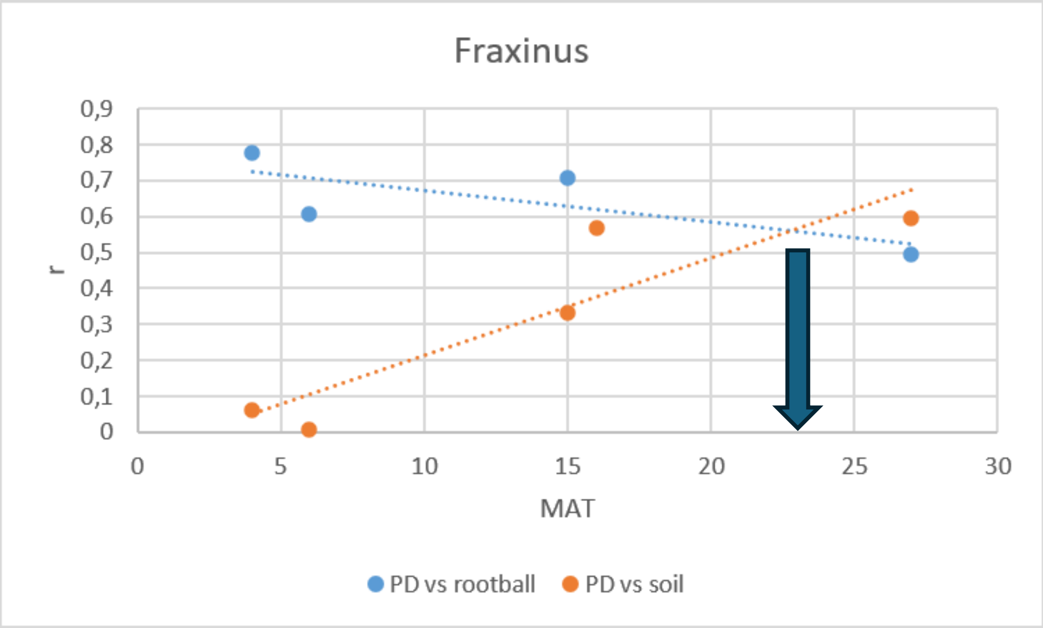
How long did it take to establish?

DBH method



ETR/A method





Water potential method

How long did it take to establish?

Number of months required to overcome post-planting stress

Species	ψw	ETR/A	DBH
Acer campestre	24	24	18
Carpinus betulus	depends on pruning	> 27	23
Fagus sylvatica	> 27	> 27	22
Fraxinus angustifolia	21	22	19

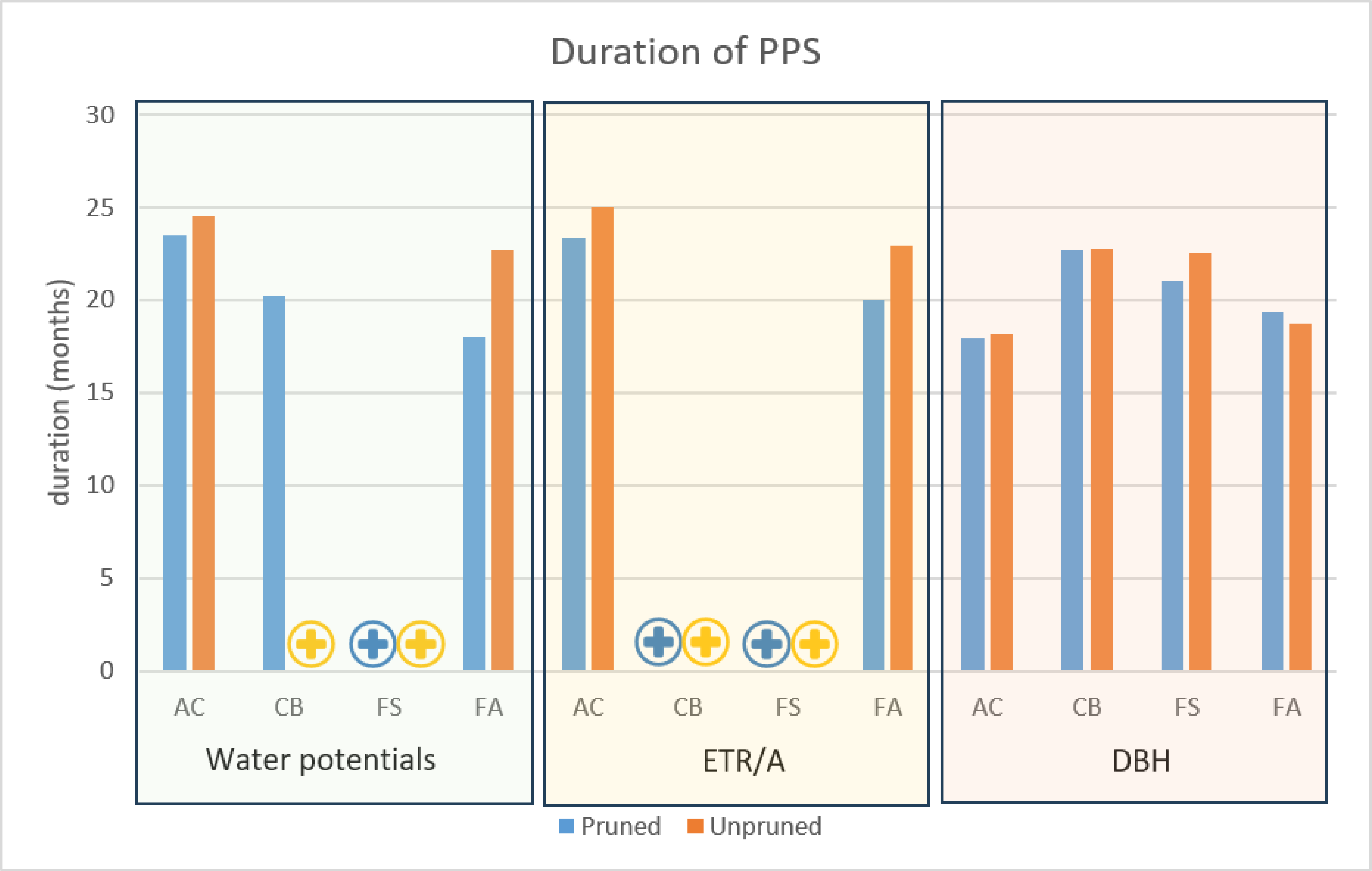
Acer and *Fraxinus* established within 2 years according to all methods

Establishment of *Carpinus* and *Fagus* was slower, and affected by pruning regime.

Drought-sensitive anisohydric species may require longer to establish, because they can't sustain high stem radial growth during stress to restore hydraulic conductivity after cavitation (Peters et al., 2023).

Establishment time of all species exceeded that expected using the "12-months per each 2.5 cm DBH" rule proposed for temperate climates (Pryor and Watson, 2016).

How long did it take to establish – Effects of pruning



and

Denote no establishment for pruned and control trees, respectively

Pruning fastened establishment in *Carpinus* (1 method). Some minor effects also observed in *Fraxinus* (2 methods)

Why wasn't pruning that effective to reduce the duration of PPS?

1- pruning remove apical meristems, which produce auxin, the rooting hormone

2- pruning reduces leaf area and, by consequence overall carbohydrate production

3- compensatory transpiration occur in pruned trees and reduce the overall impact on pruning

4- canopy dieback may have reduced the impact of pruning

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Thank you for your attention

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