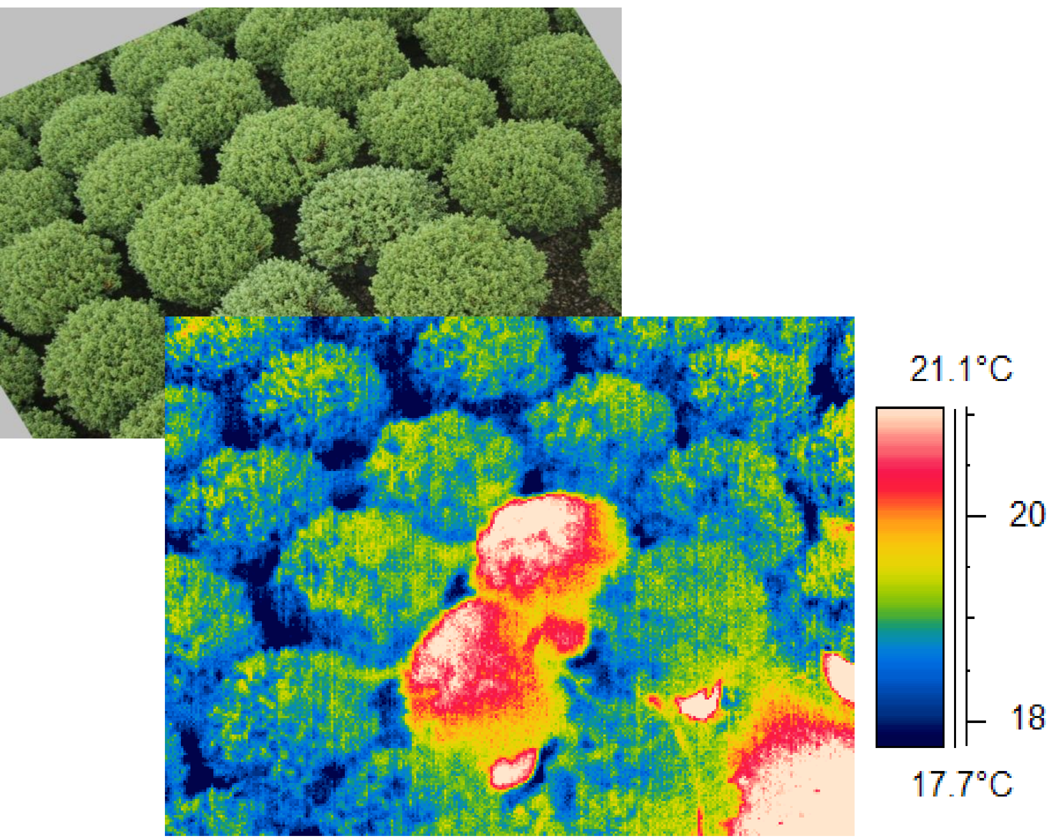
Irrigation day at LEC – 18th Mar 2010

"Plant-based irrigation scheduling"



Lyn Jones

Outline

1. Approaches to irrigation scheduling
2. Review of plant-based methods
3. Advantages/disadvantages
4. Conclusions
5. [Stress ‘diagnosis’]

Features of ideal scheduling system

- **Sensitive** to small changes in conditions
- **Rapid-response** allowing maintenance at optimum
- **Timely**, responding to changing weather
- Readily **adaptable** for different crops/stages with minimal calibration
- Capable of **automation**
- **Robust** (i.e. idiot-proof and not requiring large training or labour input)
- **Cheap** (purchase and running costs)

Let us evaluate scheduling methods against these criteria . . .

Scheduling approaches:

Uptake

'Approximate'

50%? Intuition, "Feel", Guesswork, Calendar

'Scientific'

40%? **Soil-based** - balance sheet (**=atmosphere**)

- moisture measurement

(TDR, capacitance, tensiometer, neutron-probe, etc)

Plant based

4%? moisture status - water content

- energy status (ψ)

6%? response - wilting

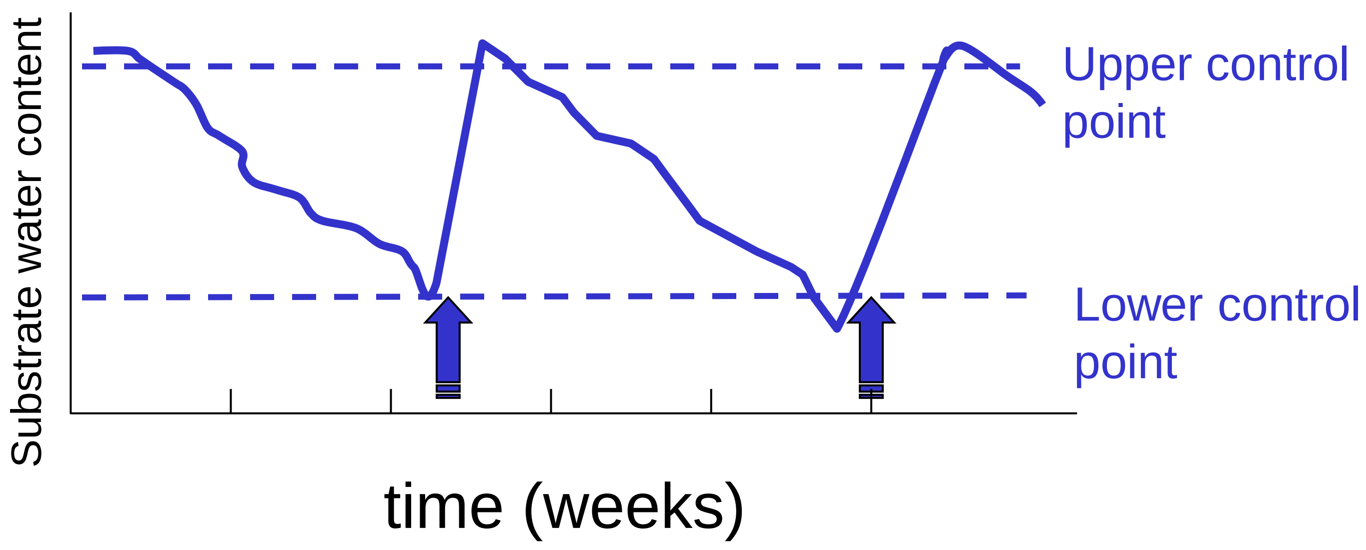
- fruit/stem/leaf shrinkage
- cavitation/embolism
- stomatal conduct./Temp

Overall trend to increased automation

Considerations determining scheduling approach. . . . . . irrigation method

- Precise control of plant growth and reduced wastage requires “little and often”

Conventional raingun/flood irrigation:



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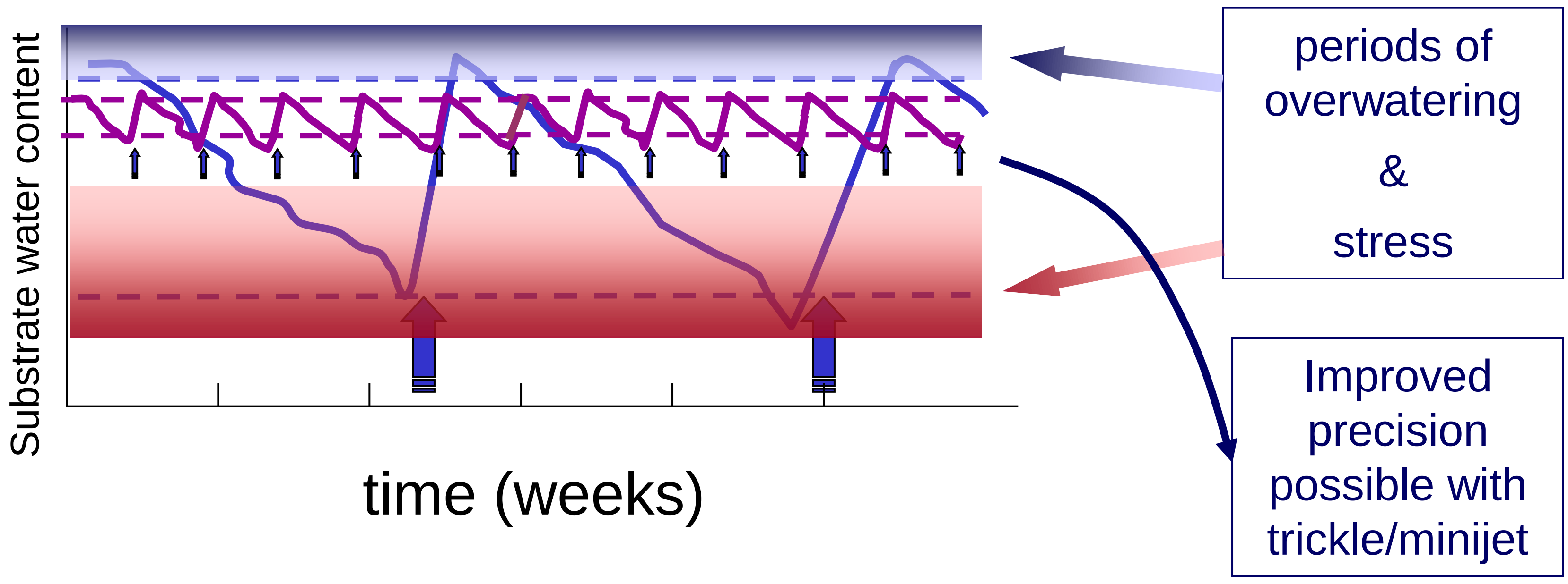


"Precision irrigation requires precision scheduling"

Considerations determining scheduling approach. . . . . . irrigation strategy

- Precise control of plant growth and reduced wastage requires “little and often”

- Other factors include - **irrigation strategy** (e.g. to maximise yield, profit, etc.), crop type and product, capital and running costs of irrigation system, etc.

Approaches available

'Approximate'

Intuition, "Feel", Guesswork, Calendar

'Scientific'

Soil-based - balance sheet (**=atmosphere**)
- moisture measurement

(TDR, capacitance, tensiometer, neutron-probe, etc)

Plant based

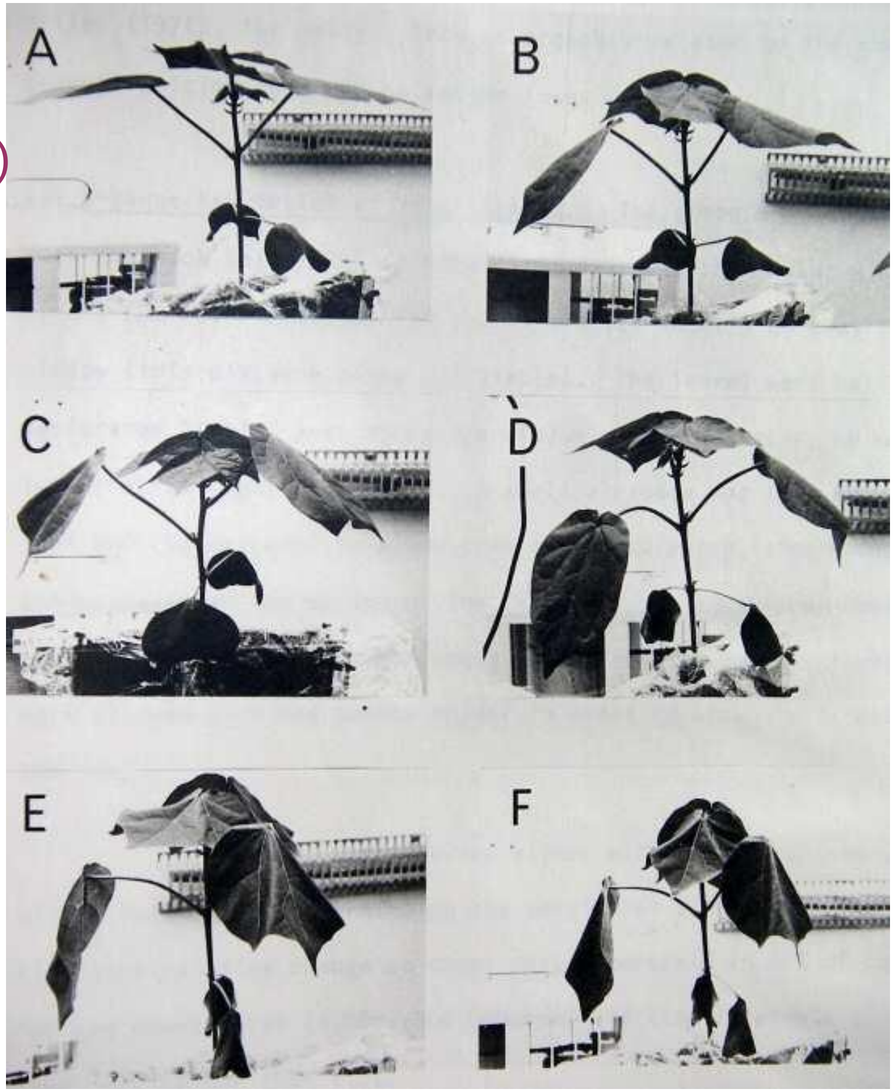
moisture status
- water content
- energy status (ψ)

response
- wilting
- fruit/stem/leaf shrinkage
- cavitation/embolism
- stomatal conduct./Temp

Plant-based methods . . . turgor

- **Plant water status**
  - **wilting**

RWC	ψ (Mpa)
93%	-0.45
86%	-1.05
75%	-1.70



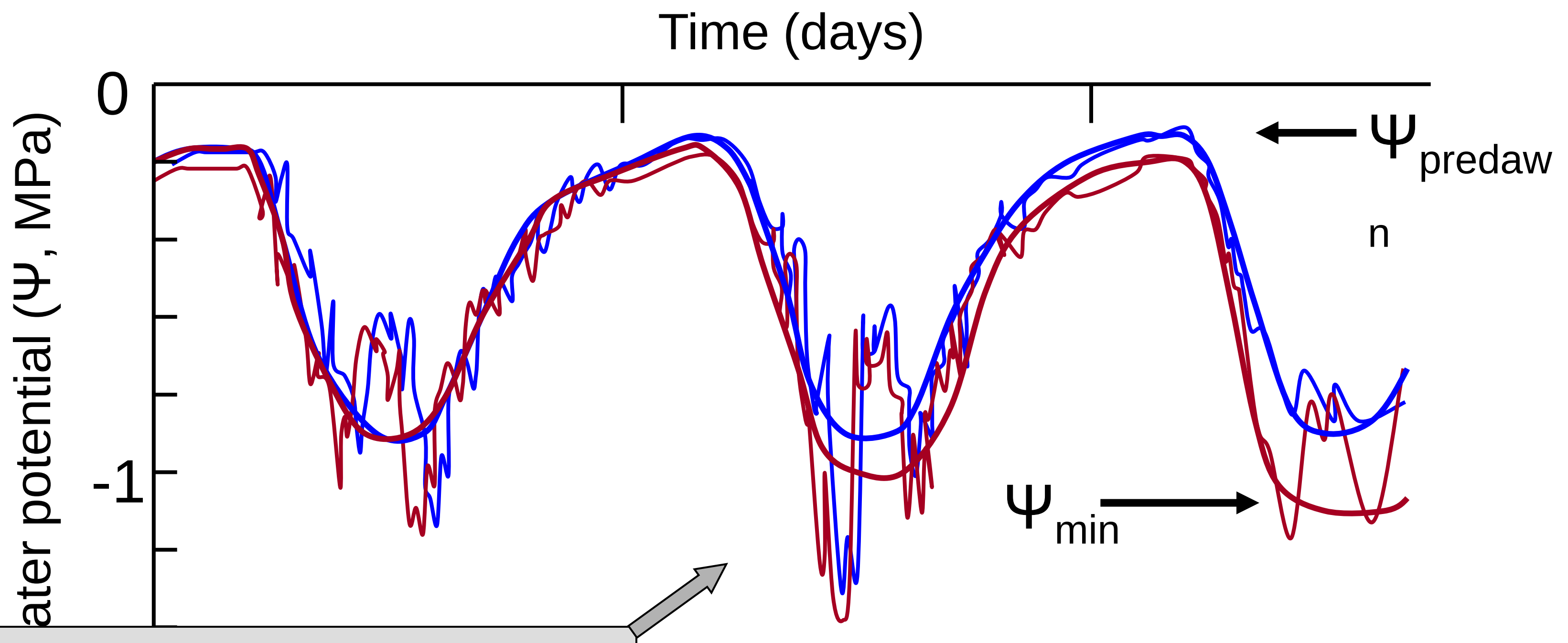
Widely used for visual monitoring, but not very quantitative nor capable of automation. Many spp. not this demonstrative

Plant-based methods . . . Water potential

Plant water status

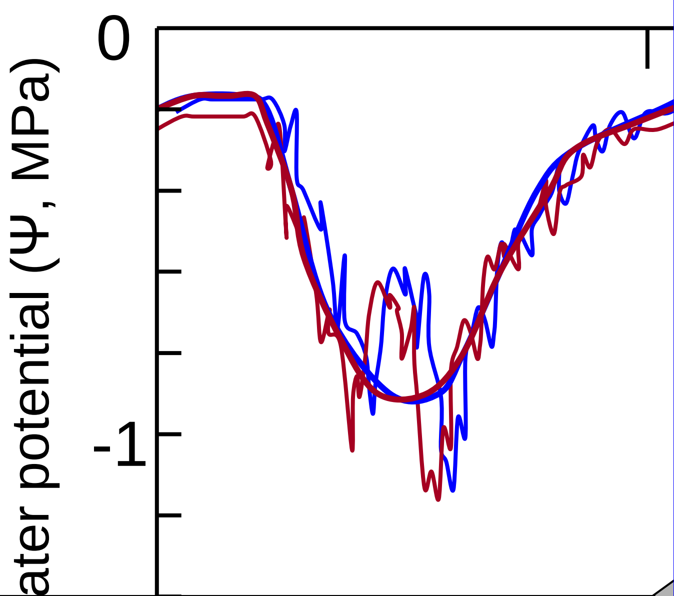
- wilting
- leaf water potential (widely used for research, less so for practical irrigation)

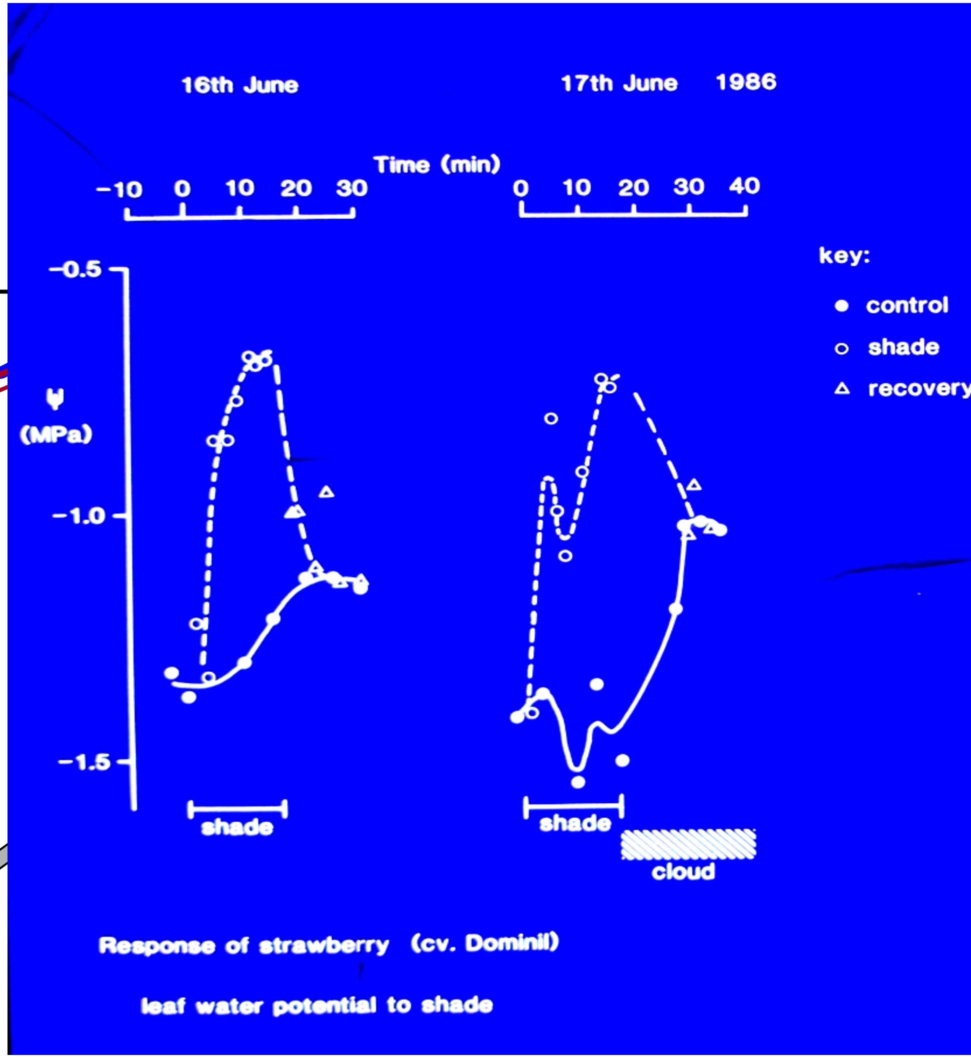
Plant-based methods . . . Water potential



But – short-term fluctuation greater than treatment differences

Plant-based methods . . . Water potential





But – short-term fluctuation greater than treatment differences

Plant-based methods . . . Water potential

- Leaf Ψ is **too sensitive** (!) to water status - and does **not discriminate** treatments.

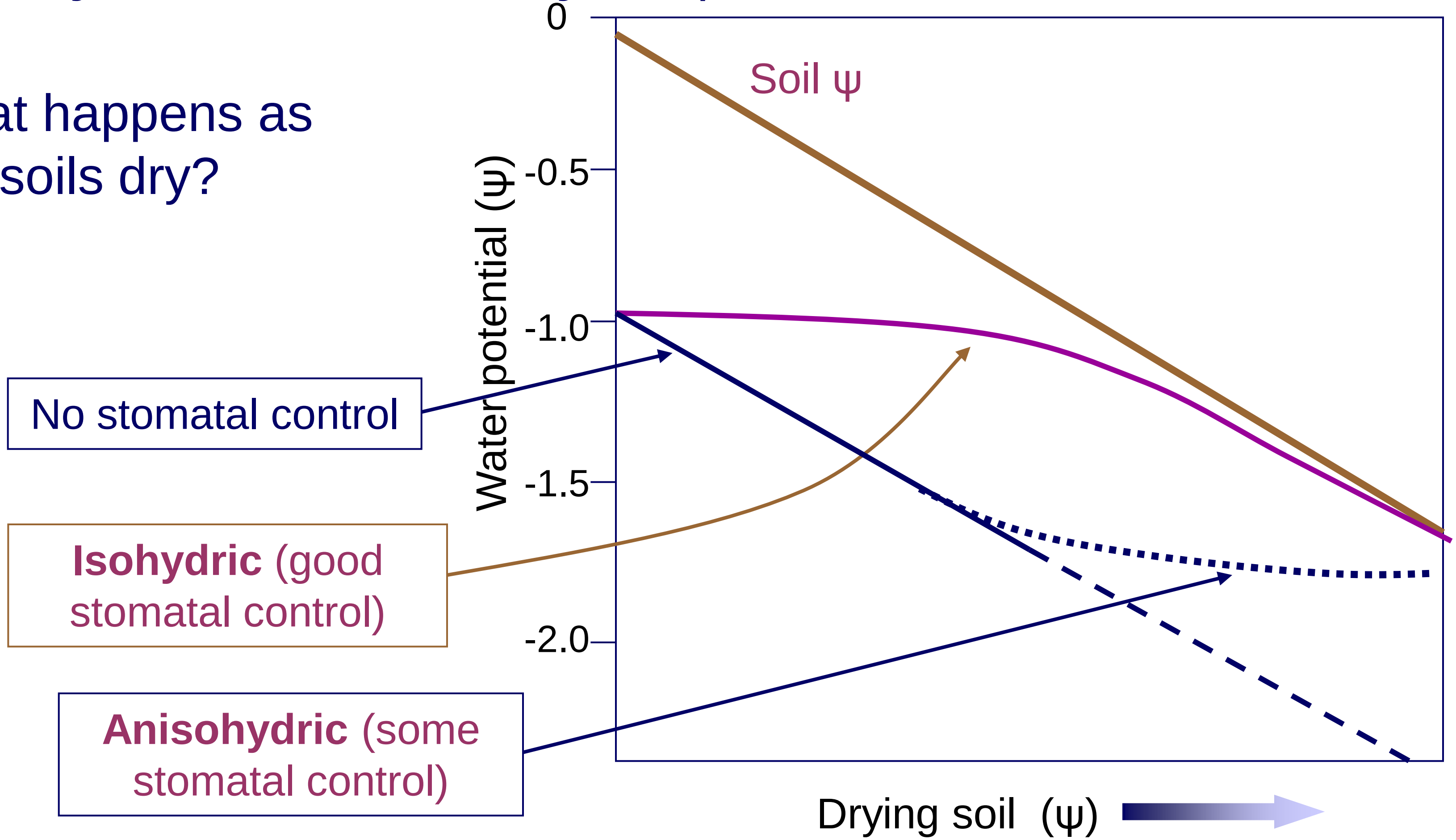
- To overcome this variability:
  - Shackel and co-workers have proposed the use of Ψ_{stem}
  - others have favoured $\Psi_{predawn}$ or even Ψ_{sucker}
  - yet others to go back to measuring soil directly!!

- But all $\boldsymbol{\Psi}_{\mathbf{plant}}$ methods suffer from the problem that Ψ is regulated by the plant, minimising change

Plant-based methods

Consequences depend on characteristic responses:
Isohydric versus **Anisohydric** plants

What happens as soils dry?



Plant-based methods

Isohydric versus **Anisohydric** plants

Isohydric		Anisohydric
Grenache	*vs.*	*Syrah*
Maize		*Sunflower*
most temp. woody spp.		*many crops*

	Isohydric	Anisohydric
Leaf water status	✗	✓
Stomatal conductance	✓	✗

(e.g. Tardieu & Simmoneau 1998
Schultz 2003)

Plant-based methods

- **Plant water status**
  - wilting
  - leaf water potential
  - (and tissue water content)

Subject to homoeostatic control – therefore insensitive (**isohydric)**

Susceptible to environmental variation

Difficult to automate – Psychrometers unreliable

Plant-based methods . . . indirect

Plant water status

- wilting
- leaf water potential
- (and tissue water content)

Other indirect measures of water status

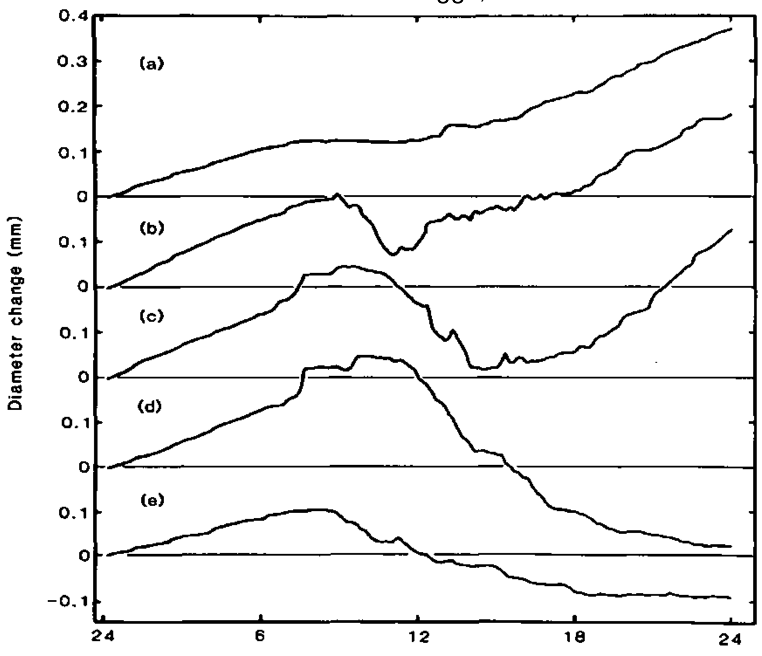
- **fruit or stem diameter**
- **leaf thickness**

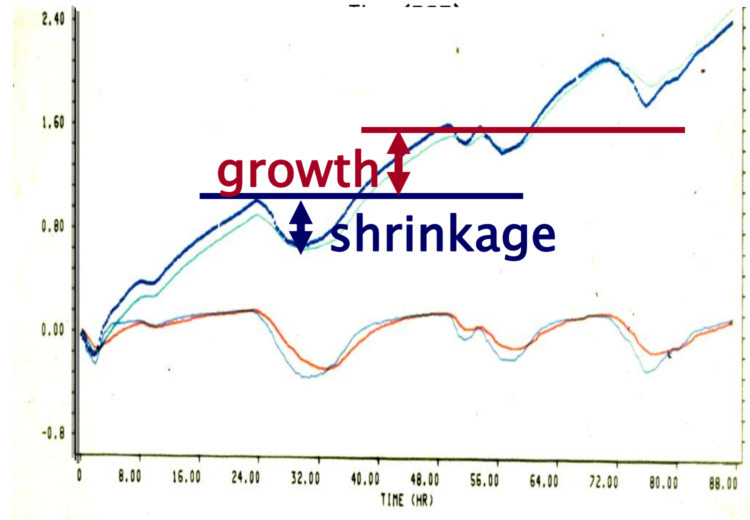
Jones and Higgs 1983

Agristore online

Plant-based methods . . . indirect

Jones & Higgs, 1984





Plant water status

- wilting
- leaf water potential
- (and tissue water content)

Other indirect measures of water status

- fruit or stem diameter
- leaf thickness

Analysis of these curves can provide much more information

Plant-based methods . . . indirect

Plant water status

- wilting
- leaf water potential
- (and tissue water content)

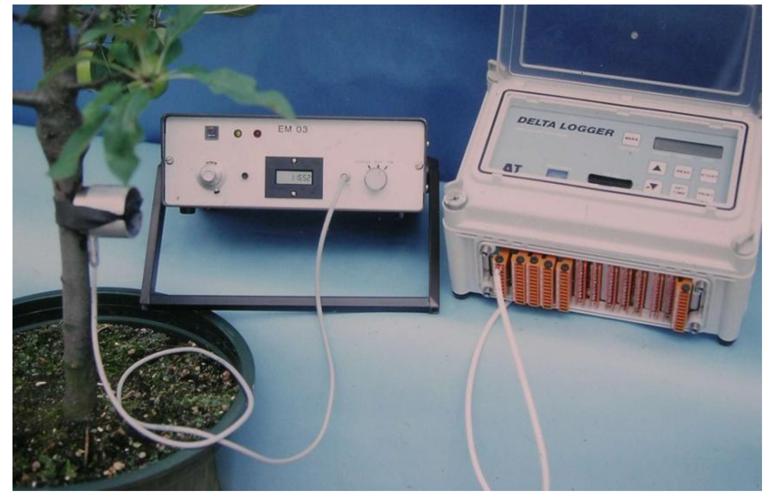
Other indirect measures of water status

- fruit or stem diameter
- leaf thickness

Subject to some of the same problems as water status - but provide much more information.

Growth, especially, may be more sensitive

Plant-based methods . . . indirect



Plant water status

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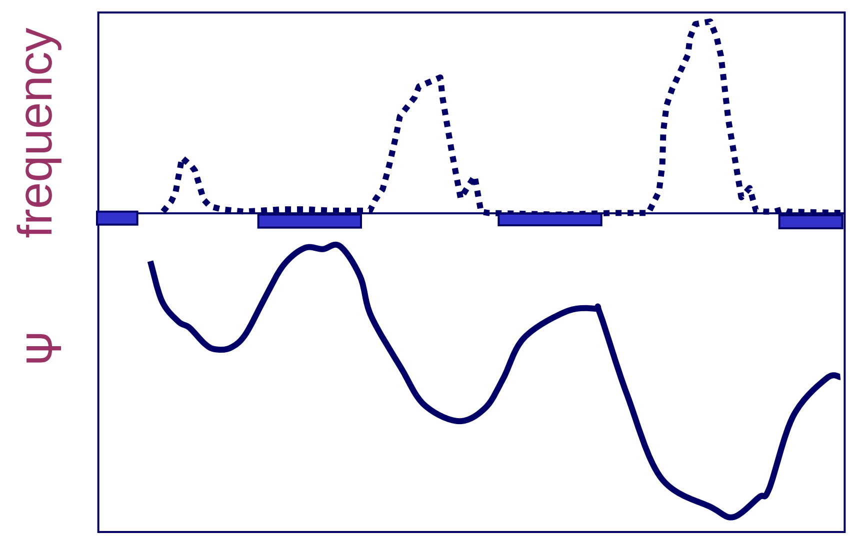
Other indirect measures of water status

- fruit or stem diameter
- leaf thickness
- **xylem cavitation**



Plant-based methods . . . indirect

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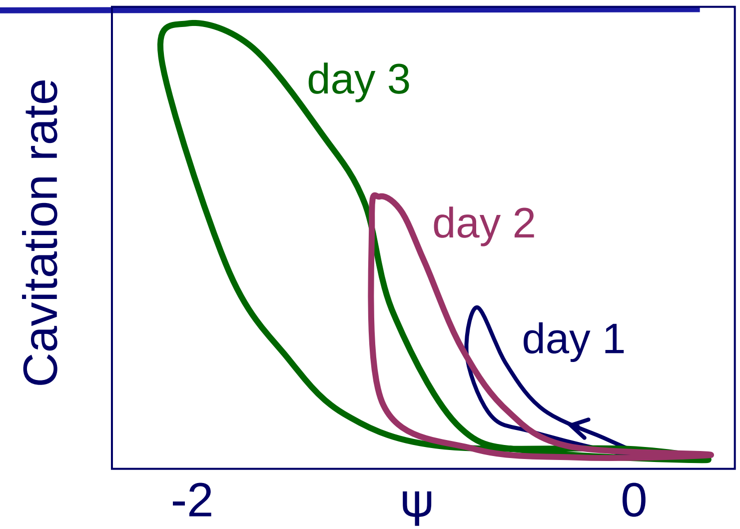

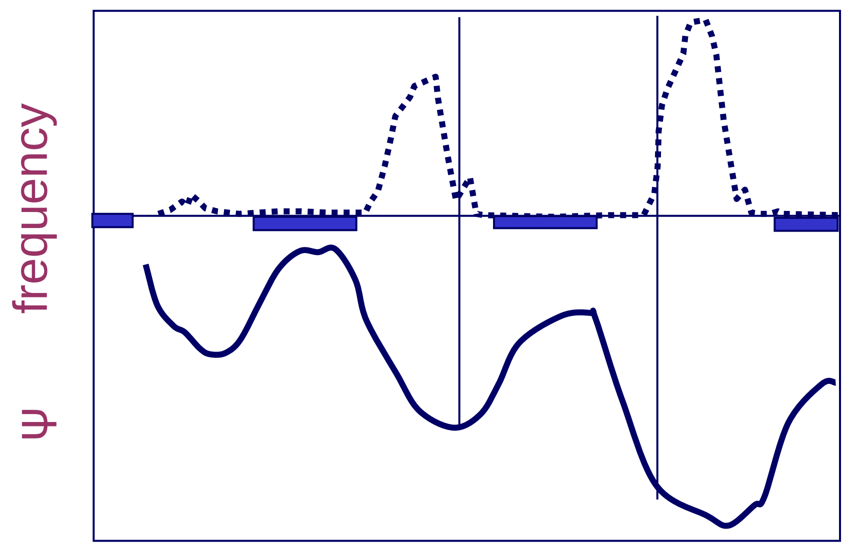

Plant-based methods . . . indirect

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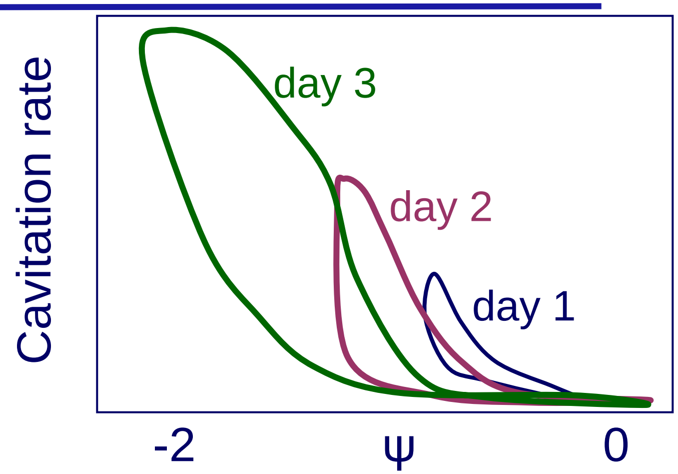


Again subject to some of the same problems as water status

The main problem, however, is **hysteresis,** so cavitation rate is not proportional to stress - so not v. good for control

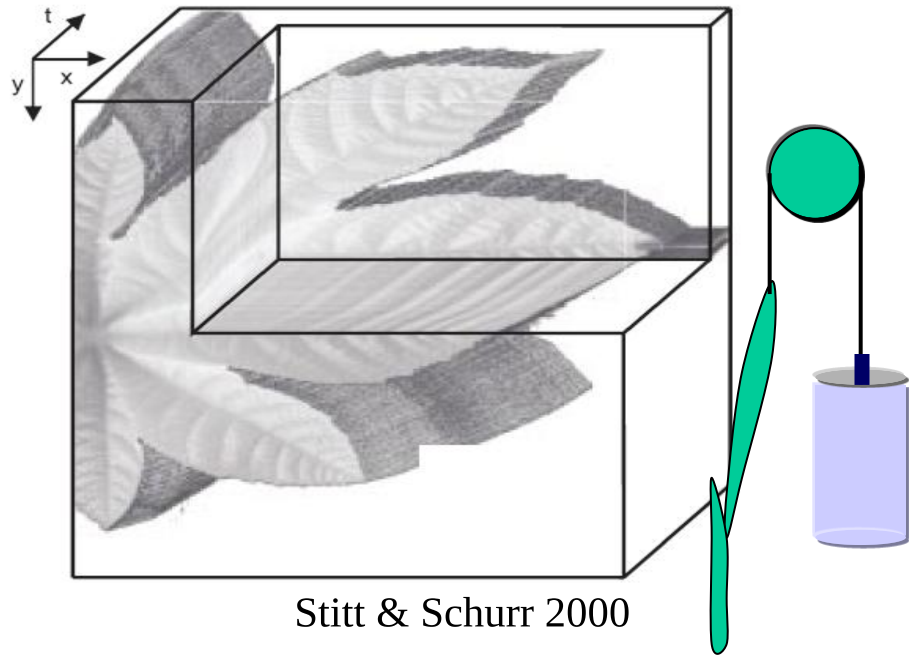
Plant-based methods . . . responses

Water status related

- wilting
- leaf water potential
- (and tissue water content)
- fruit or stem diameter
- leaf thickness
- xylem cavitation

Physiological responses

- leaf growth



Stitt & Schurr 2000

Sensitive – but **difficult to apply** (fruit or stem easier to monitor)

Difficult to define control thresholds

Plant-based methods . . . responses

Water status related

- wilting
- leaf water potential
- (and tissue water content)
- fruit or stem diameter
- leaf thickness
- xylem cavitation

Physiological responses

- leaf growth
- **sap flow**

But perhaps most useful as a measure of **water use** for use in water balance method

Granier

Agristore online

Sensitive – but dominated by evaporative demand not stress/stomata - therefore needs supplementary data

Plant-based methods . . . stomata

Water status related

- wilting
- leaf water potential
- (and tissue water content)
- fruit or stem diameter
- leaf thickness
- xylem cavitation

Physiological responses

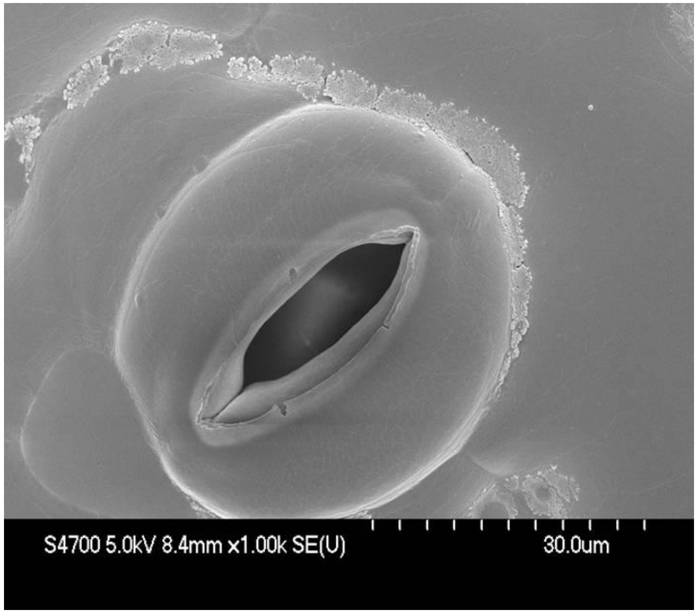
- leaf growth
- sap flow
- **stomatal conductance**

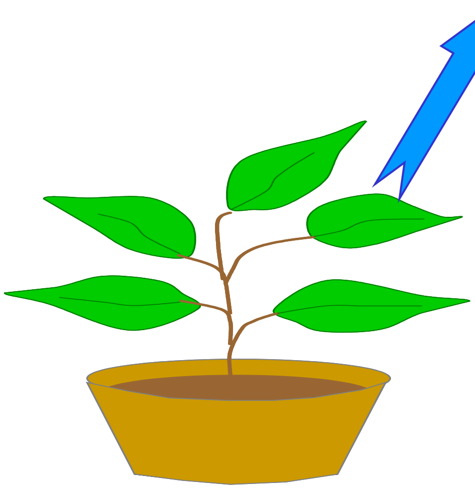
Potentially v. Sensitive – esp. in isohydric spp. - but porometer **very labour intensive** and requires some expertise so impractical for routine scheduling

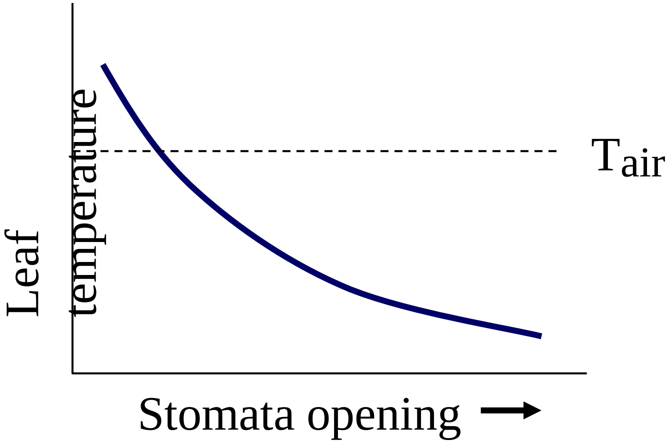
→ **Infrared Thermometry/thermography**

Why thermal sensing?

- Leaves are cooled by evaporation - therefore as stomata open the temperature falls.
- Temperature is therefore a primarily a measure of **evaporation rate** and hence of **stomatal opening**







Why thermal sensing?

Hot, non-transpiring

Cool, rapid transpiration, open stomata

Why thermal sensing?

- Thermal sensing measures water loss and its control by stomata.
- It assumes that **stomatal closure** is a good surrogate for **water deficit stress**
- **but** stomata can close in response to other stresses – and responds to many diseases which affect water relations

Plant-based methods . . .IR thermography

Available sensors range from ‘point sensors’ to ‘thermal cameras’ to airborne and ‘cherry-picker’ imagery

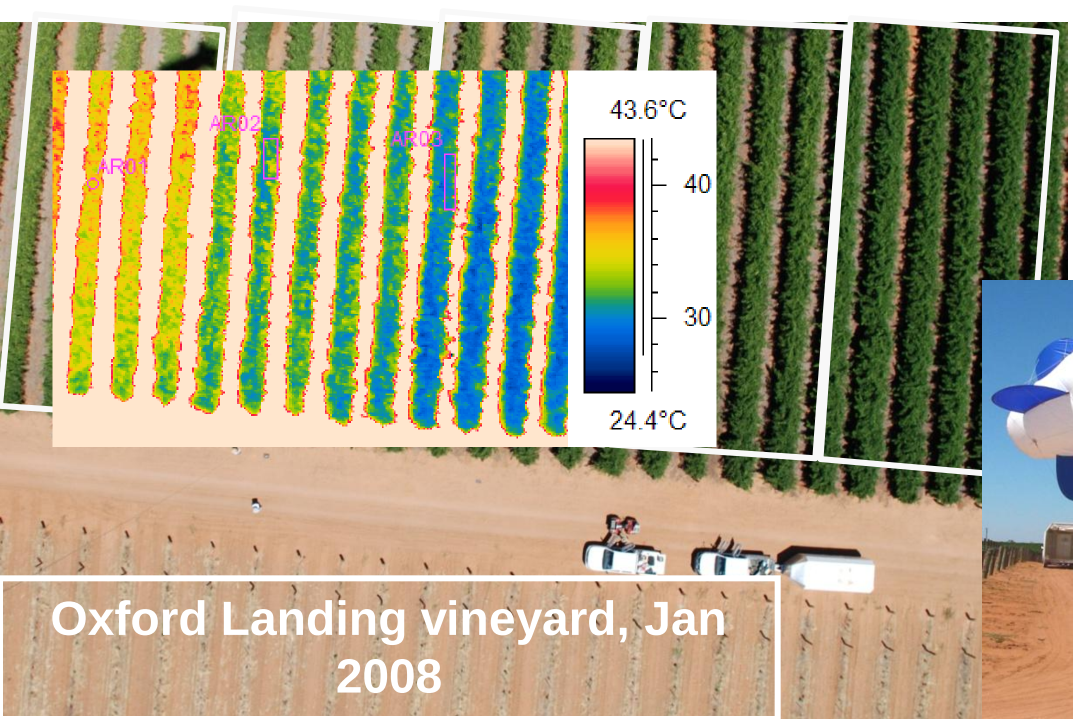
‘Imagers’

‘Point sensors’

IR thermography

Available sensors range from ‘point sensors’ to ‘thermal cameras’ to airborne and ‘cherry-picker’ imagery

photo by Victor Alcanatis

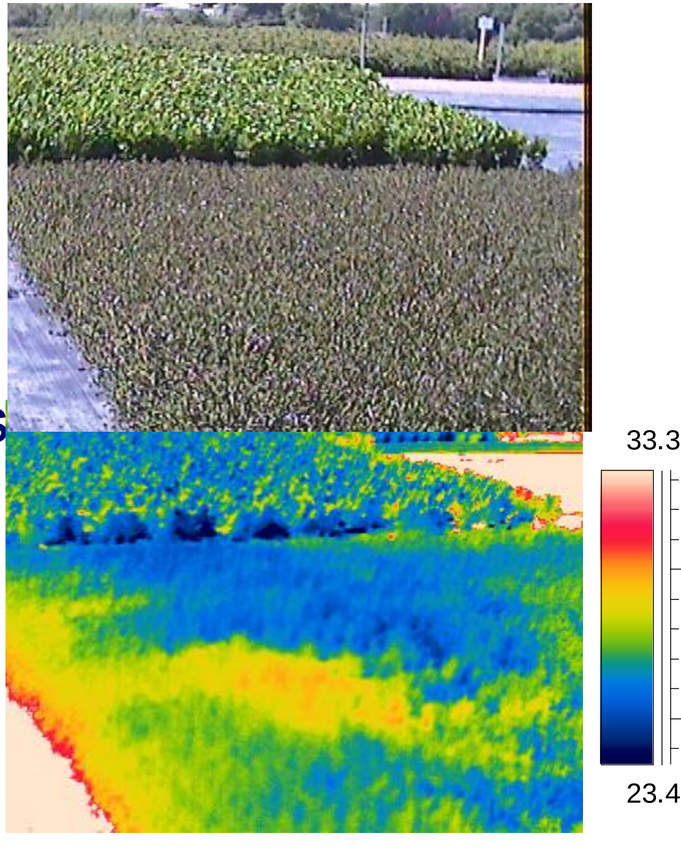


Oxford Landing vineyard, Jan 2008

Why thermal sensing?

Advantages of thermal sensing:

- Can be very sensitive to plant response
- Non-contact
- Non-destructive
- Rapid, much replication
- Suitable for automation
- Best for ‘relative’ uncalibrated values
- Useful for check monitoring
- Readily scaled up



Some conclusions

– General advantages/disadvantages

Soil water measurement:
"easy" to measure; can indicate amount of water needed

But - soil heterogeneity, representative position? Does not allow for Evaporative demand

Water balance calculation
minimal data requirement; indicates amount

Hard to determine crop coefficients, Subject to large cumulative errors

Plant-based methods:
potentially measure actual stress/response experienced by plant; integrates environmental effects; potentially sensitive

Often require sophisticated instrumentation; may be hard to determine control thresholds; may not indicate "how much"; require "sophisticated" users

Some conclusions

Thermal imaging specifically

Advantages

- large areas of crop
- can avoid background (cf. IRT)
- as good as porometry
- best for isohydric spp.
- best in hot/dry conds
- very suited for check monitoring

Disadvantages

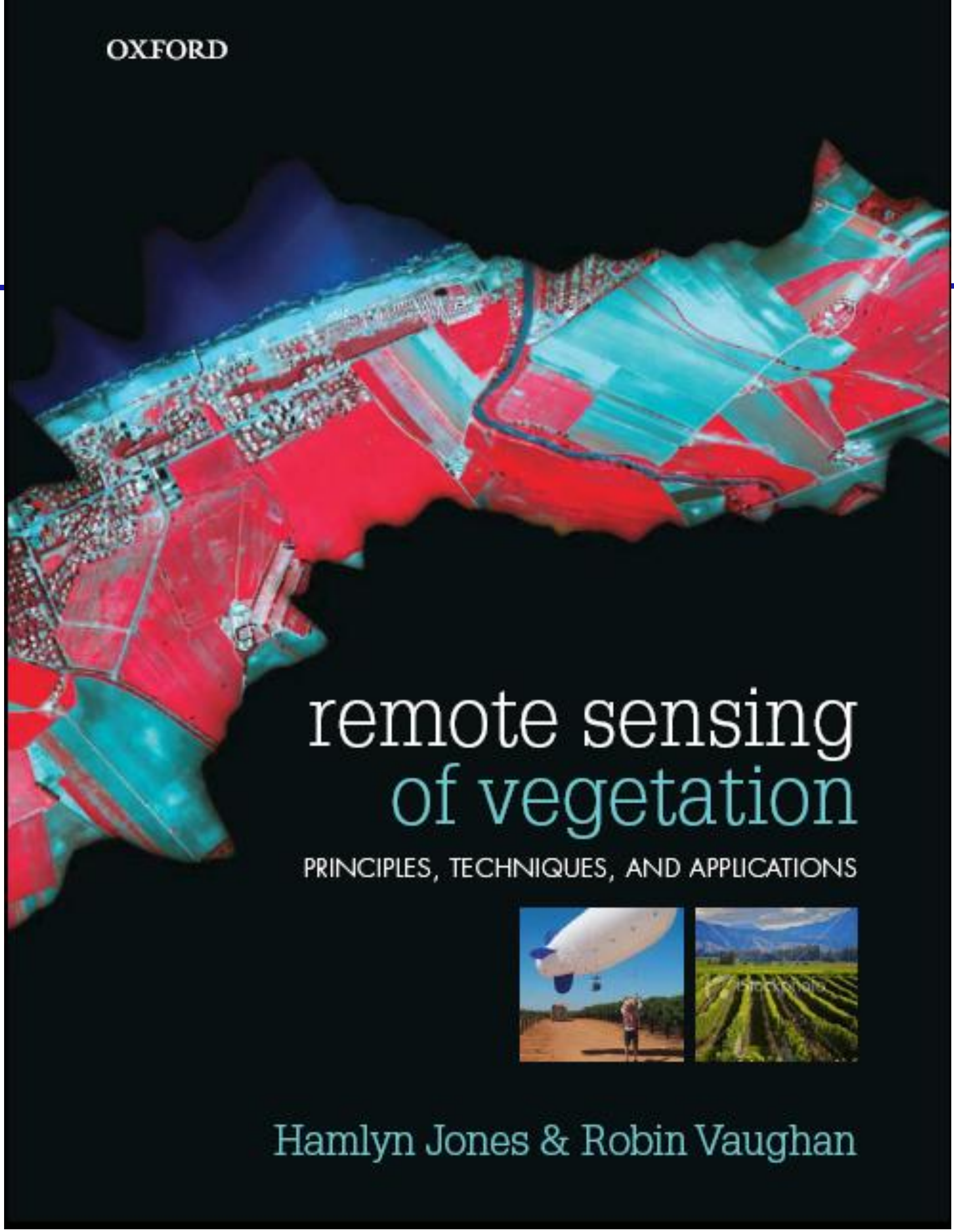
- Does not indicate **amount** of water
- Need to determine appropriate referencing strategy
- Equipment expensive
- Less sensitive for anisohydric spp.
- Image analysis requires sophisticated software (not user friendly)

Some conclusions

Final comment on the suitability of plant-based methods:

In general they do not provide information on the **amount** of water required - therefore need **feedback irrigation control** where irrigation **“threshold”** is feasible - ideally requires frequent/continuous irrigation

Where lag is substantial can lead to control problems



To be published by Oxford University Press, May (?) 2010

Remote "stress" diagnosis and monitoring

- **Abiotic stresses**
  - drought/water stress
  - salinity/flooding
  - UV/high light
  - frost/heat/pollutant
  - mineral deficiency/toxicity
- **Biotic stresses**
  - disease
  - insects

Common Intermediate Responses

e.g.
- stomatal closure
- yellowing/sensescence
- poor growth
- 'oxidative stress'

Remote "stress" diagnosis and monitoring

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Common Intermediate Responses

Sensing technique

- **Thermal**
  - Temperature
  - Indices (CWSI, etc.)
  - dynamics
- **Spectral reflectance**
  - Visual patterning
  - Indices (NDVI, etc.)
- **Fluorescence**
  - Chlorophyll
  - Other fluorescence
- **Multiangular**
- **Other (MRI, TL, etc.)**

Remote "stress" diagnosis and monitoring

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- **Biotic stresses**
  - disease
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Evaporation /stomata

Pigments

Biochemistry

Canopy structure

Sensing technique

- **Thermal**
  - Temperature
  - normalised (CWSI, etc.)
  - dynamics
- **Spectral reflectance**
  - Visual patterning
  - Indices (NDVI, etc.)
- **Fluorescence**
  - Chlorophyll
  - Other fluorescence
- **Multiangular**
- **Other (MRI, TL, etc.)**

Summary of remote stress diagnosis

- Do not image stress directly (image **responses**)
- Any **signal** observed can have **multiple causes** (e.g. stomatal closure/high Temp results from drought, salinity, disease, flooding, toxicity, etc.)
- Any **stress** can have **multiple effects** (e.g. water stress increases Temp, decreases PS, increases oxidative stress, wilting, leaf colour, etc.)
- Many stresses have **common intermediate signals** – stomatal closure, Ca signalling, pigment changes, decreased photosynthesis, oxidative stress, etc.
- Therefore stress diagnosis and quantification ideally requires a **"multi-sensor approach"**