Thermal imaging: WaterLink project

Use of thermal imaging to sense plant water status and schedule irrigation in nursery plants.

Mercè Aloy-Lleonart *

Lyn Jones's group
Division of Plant Sciences
University of Dundee

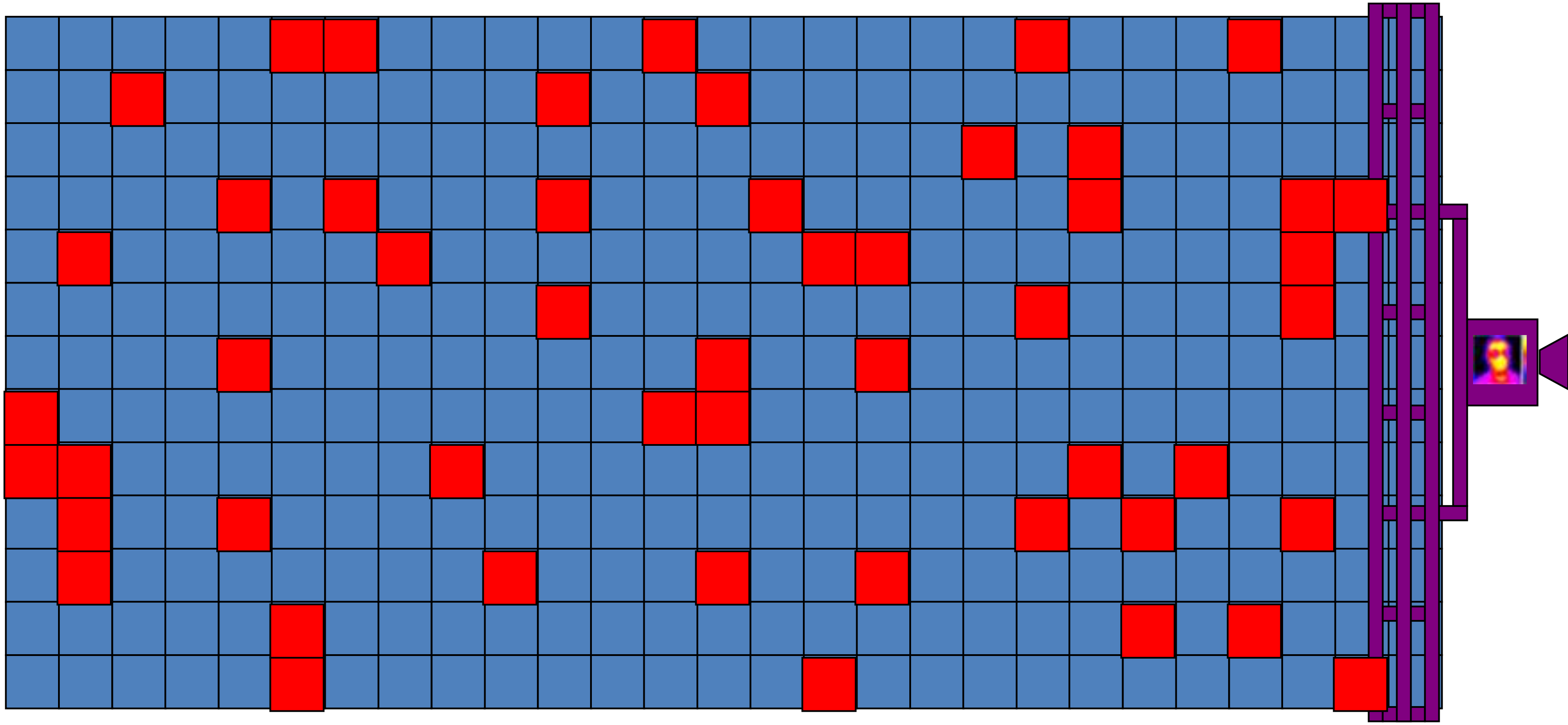
* UK-China Bridge Project
Lancaster University

Theoretical background

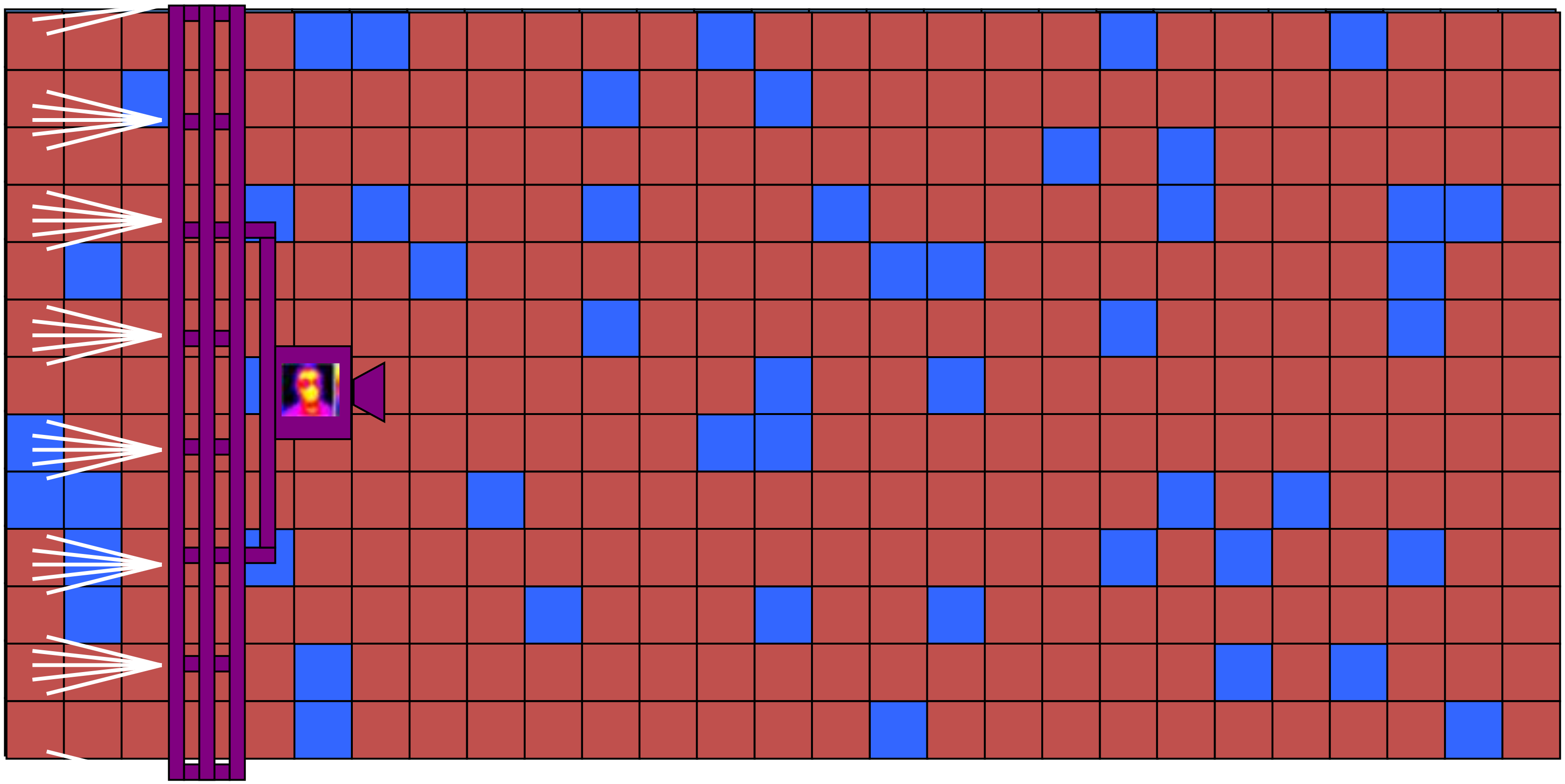
- Plant transpiration cools the leaves.
- Under drought, many plants can control the rate of water loss by closing their stomata;
- this automatically increases leaf temperature.
- Therefore, leaf temperature can be used as an indicator of water stress and the need for irrigation.

Objective: automated irrigation control

1. Identify stressed plants - thermal imaging



2. Apply water where necessary



Develop test rig for automated irrigation

- Commercial partners (Pera Innovation Ltd, Denton Automation) to develop test rig and prototypes;
- University of Dundee to derive algorithms for estimation of canopy cover and plant temperature. Algorithms need to be robust for:
  - a wide range of plants;
  - a wide range of background materials;
  - different lighting conditions.

Automated irrigation: steps involved

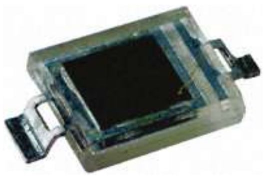
1. Take images and temperatures.
2. Identify plant from background.
3. Estimate plant temperature (removing effect from background).
4. Assess plant water stress level – environmental calibration required (stress index) .
5. Calculate amount of water needed / where.
6. Apply irrigation.

1. Take images and temperatures

- Easy!
- Visible and thermal cameras

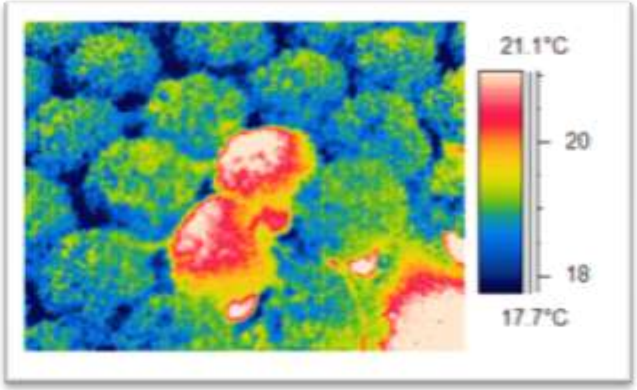
- Infrared thermometers

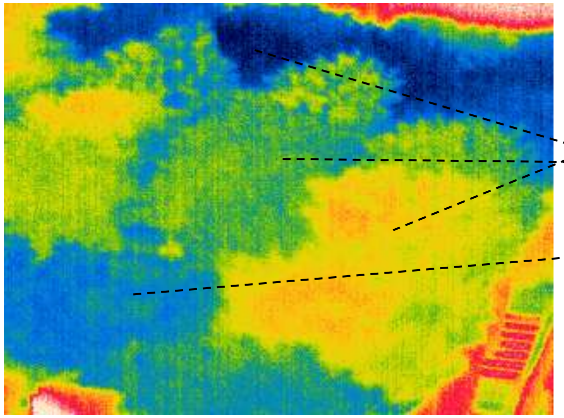
- Thermal sensors

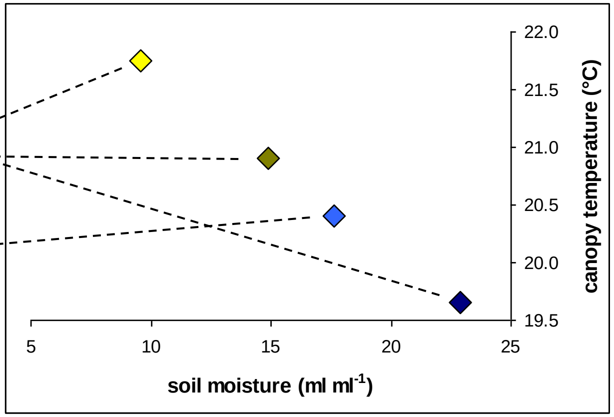


Actual performance of thermal sensing

Is it good enough?   Yes.







2. Identify plant from background

Need a way to distinguish between plant and background:

- to allow us to detect empty areas (stop irrigation);
- to estimate plant temperature if not all the area covered by the field of view of the sensor is plant.

Difficulty of recognising plant and background from thermal images – Use Vegetation Indices.

Identifying plant: Vegetation Indices (VI)

VI methods work on ratios of Red (R) and near-Infrared (NIR) reflectances.

Based on the property of plant material to reflect NIR light more efficiently than most other materials.

$$Reflectance = \frac{Reflected\ light}{Incident\ light}$$

Identifying plants: high resolution

- Two-camera system to estimate canopy cover:
  - IR-blocking filter (>700nm) – measures visible (R)
  - Visible-blocking filter (<700nm) – measures NIR
- NDVI calculated at pixel level (high resolution)

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}$$

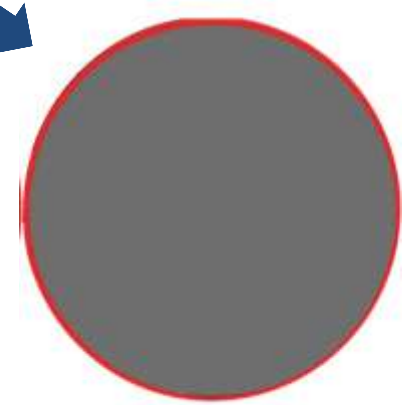
- Problem: too large and expensive to mount on a gantry

Identifying plants: low resolution

- Alternative: use cheaper and more robust point sensors (R and NIR)
- Problem: low resolution:

actual plant cover

NDVI-thresholded image (from camera)



average plant cover (as “seen” by sensor)

From high to low resolution

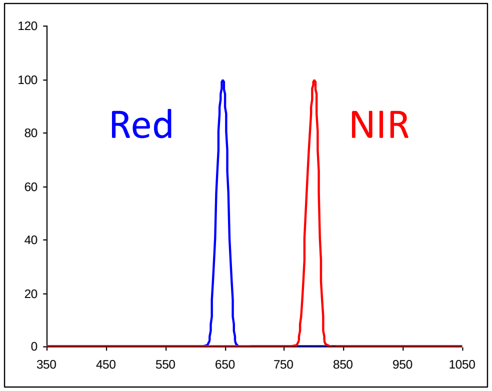
Use the high-resolution camera system to calibrate the low-resolution sensor system.

– This is done using Vegetation Indices;

– and by testing against different backgrounds and light conditions.

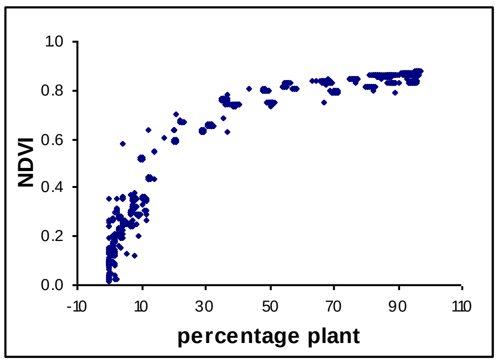
R/NIR sensors for VI determination

- Two single-channel downward-pointing sensors (reflected light):
  - Red (650 nm) and NIR (800 nm) Skye sensors
- One upward-pointing sensor (incident light):
  - Two-channel (650 and 800 nm) Skye sensor



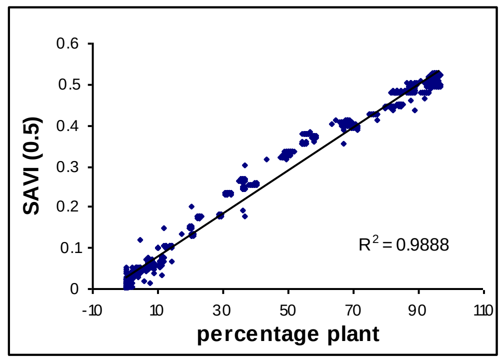
Comparison of Vegetation Indices

Relationship between different VIs and % plant



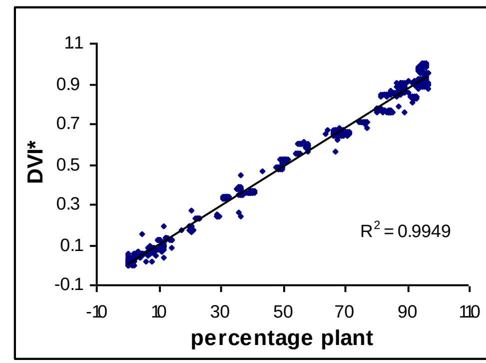
NDVI

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}$$



SAVI

$$SAVI = \frac{(1+L)*(R_{NIR} - R_{RED})}{R_{NIR} + R_{RED} + L}$$

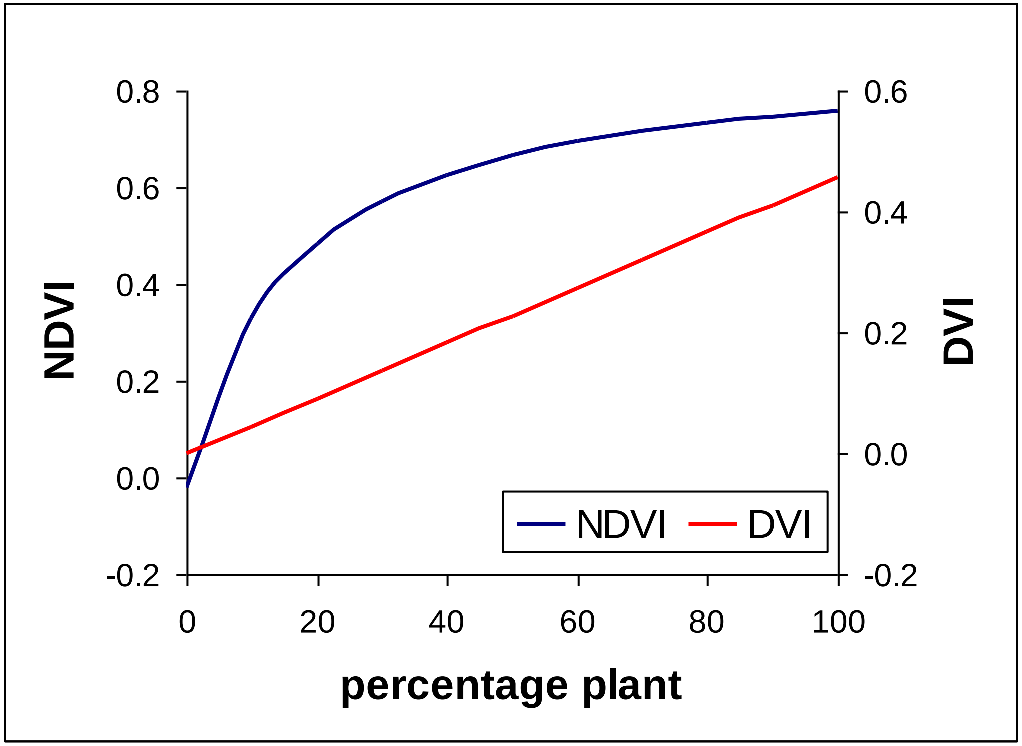


DVI*

$$DVI* = \frac{(R_{NIR} - R_{RED}) - (R_{NIR} - R_{RED})_{\min}}{(R_{NIR} + R_{RED})_{\max} - (R_{NIR} + R_{RED})_{\min}}$$

Comparison of Vegetation Indices

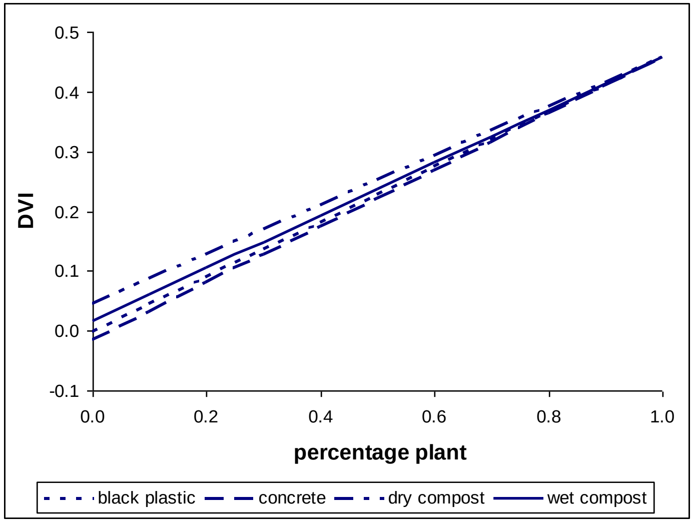
For simplicity we decided to use the DVI, which is a linear function of % plant:



Calculation of % plant from DVI

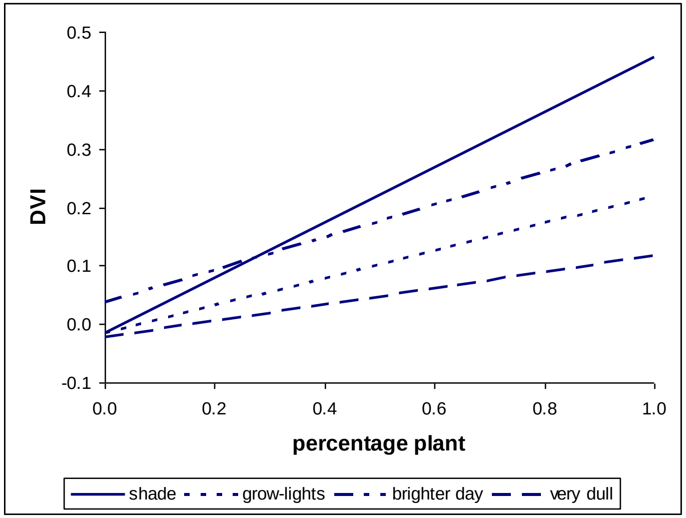
DVI is normalised for the actual range of DVIs observed, from 0% to 100% plant cover.

DVI at 0% plant (all background) will depend on the background material:



Calculation of % plant from DVI

Reflectances in the different wavelengths also change with the quality and intensity of the incident light:



- So, need to calibrate for different green-house conditions.

3. Estimate plant temperature

If not all the area viewed by the sensor is plant, the temperature recorded by the sensor (T_s) will be an average of plant temperature (T_p) and background temperature (T_b):

$$T_s = T_p * N_p + T_b * (1-N_p)$$

where N_p is the proportion of plant

- So, need to know temperature of background.

4. Environmental calibration

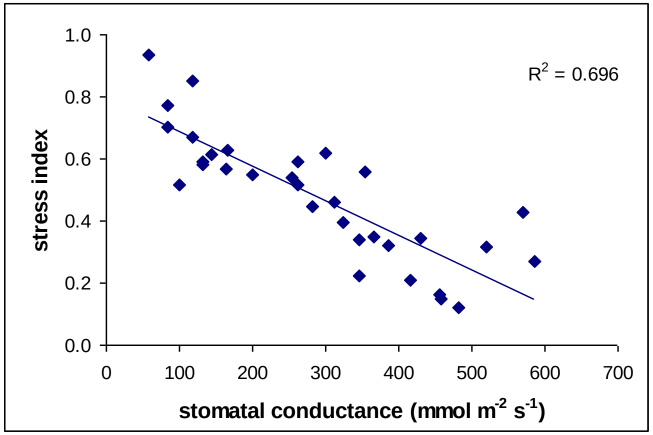
- Transpiration (and hence temperature) also affected by other environmental conditions (radiation, air temperature, RH, wind)
- Normalise using wet and dry temperatures, (from reference surfaces), to simulate non-transpiring and fully-transpiring plants
- Calculate a Crop Water Stress Index:

$$CWSI = \frac{(T_l - T_w)}{(T_d - T_w)} \qquad T_i = \frac{(T_d - T_l)}{(T_l - T_w)}$$

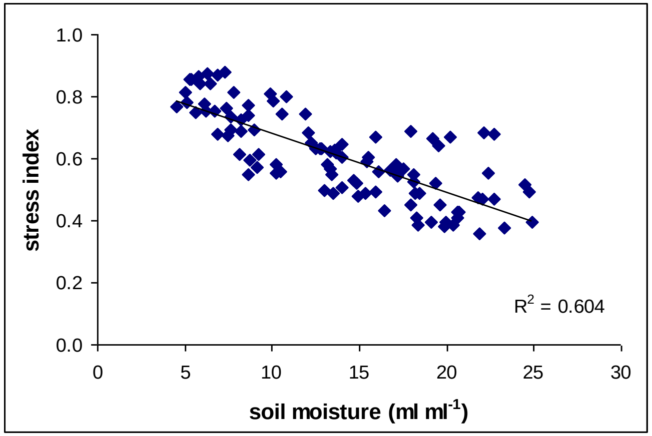
Reference surfaces and stress indices

Wet and dry filter paper used to obtain the reference temperatures (T_{dry} and T_{wet})

Stress index generally well related to stomatal conductance and soil moisture:



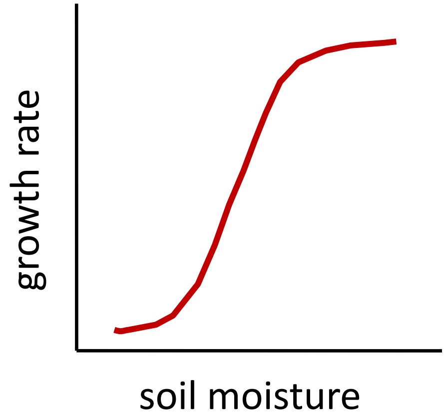
Forsythia intermedia

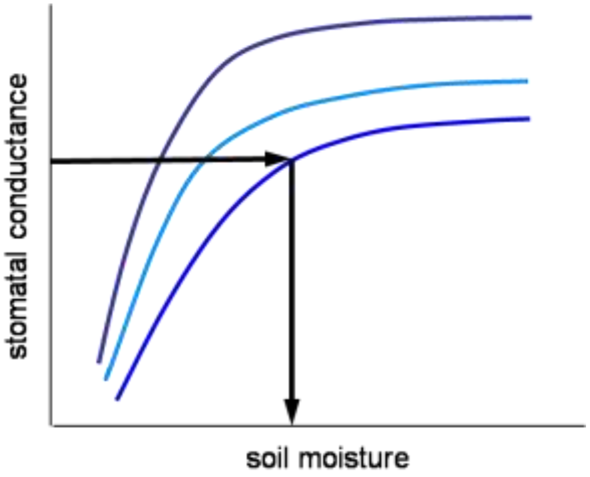


Hebe ping "sutherlandii"

5. Calculate amount of water required

Need to identify a soil moisture threshold for irrigation for each species.





Then relate temperature measurements to the stomatal conductance at the threshold level.

Identify thresholds for different species

Results:

- Qualitative differences between treatments are clear; however, relationship not so clear when studied quantitatively.
- Difficult to define threshold level, particularly in terms of ‘plant performance’ (estimation of growth by non-destructive methods).

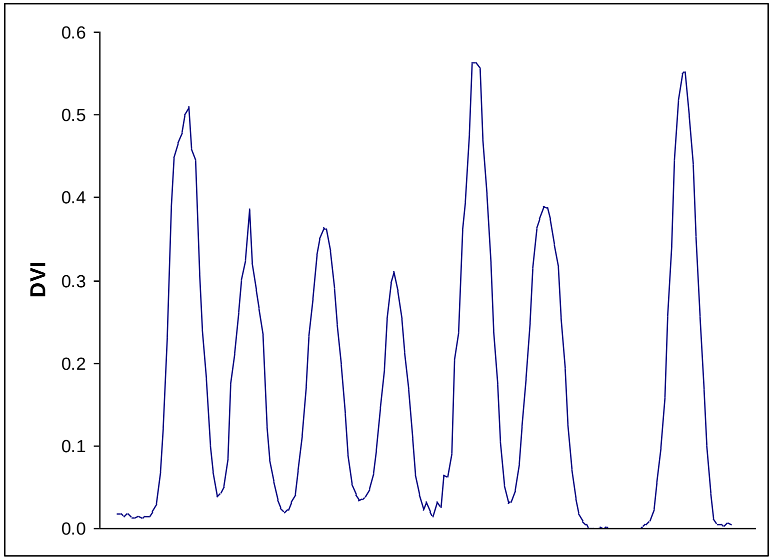
6. Apply irrigation

Irrigation gantry (Denton Automation) fitted with:

- thermal and light sensors on front arms;
- irrigation sprinklers on rear arms;
- algorithm to control watering (Dundee);
- wireless communication system (Pera).

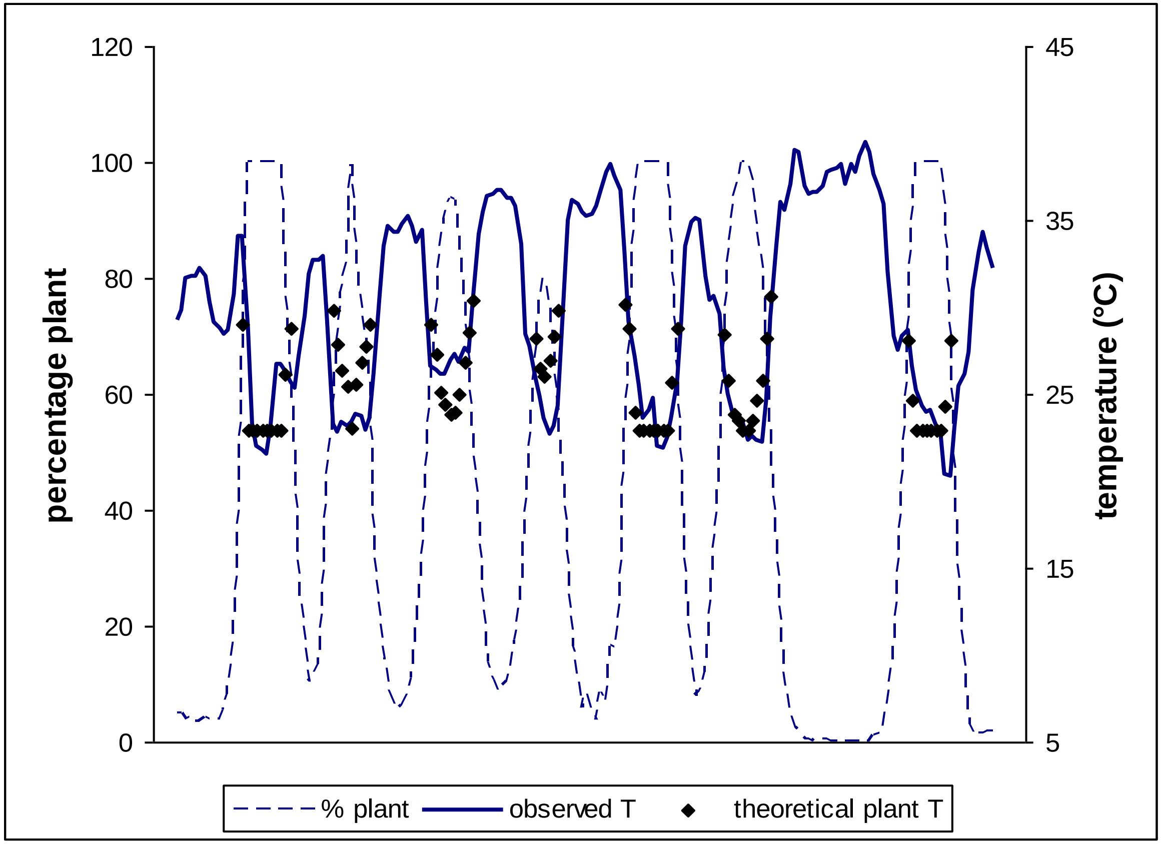
Sensor-controlled irrigation

Does it work? – identify plant



calculated DVI after running sensors over plants

Does it work? – calculate temperature



Limitations

- System developed and tested using high-quality Skye light sensors and Calex infrared thermal sensor – expensive!
- Cheaper light sensor alternatives used by the commercial partner were not accurate enough (unstable readings)

Where are we? Further developments

- *Take images, temperatures and identify plant*

  Need to be able to repeat the work using cheap light sensors.

- *Estimate plant temperature*

  Test more thoroughly cheap temperature sensors.

- *Environmental calibration*

  Refine algorithm to estimate water stress.

- *Calculate amount of water required*

  Further study required to identify threshold levels.

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