Making plants do what we want

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Who I am

Plant Physiologist
35 years with ARS - spanning 3 decades, 2 centuries, 2 millennia
Plant Stress and Water Conservation Lab Lubbock TX

What I know

I have extensive experience in whole plant physiology…
particularly as it relates to water and temperature.

I work in the lab and the field…production environments are my focus.

I have developed a couple of sensor systems that have been commercialized.

I tend to think in terms of the shortest path between research and production

What I don't know

much about grapes or wine

Making plants do what we want

- Broadly
- A limited example
- Broadly

Making plants do what we want

When left alone plants do what *they* want…

• sometimes what *they* want is desirable to us and we give them resources to do it

• sometimes *we* want them to do something they don't want to do

• sometimes we want an unstressed plant … sometimes a stressed plant

A large component of agriculture is making plants do what we want. W^9

• What we want

• Where we want

• When we want

With all our technology we should be able to this more effectively than ever before.

Making plants do what we want.

Just how much smarter am I than a plant?

1_ Identify the *desired outcome*.

2_ Identify the *behavior* that results in the outcome.

3_ Identify the *observable parameter* that is indicative of the behavior.

4_ *Measure the behavior* over time to define the magnitude and timing associated with the outcome. Fingerprint

5_ *Manage* the behavior

we first define…then we can measure…then we can manage

Examples of desired outcomes and mechanisms

- **Cotton** fiber with solid cores
- **Soybeans** that are more determinate
- **Cotton** with reduced fruit drop under transient water deficits
- **Peanuts** that are preconditioned for late-season water deficits
- **Grapes** with increased concentrations of desirable metabolites

We have done all of these except grapes and inducing optimal and non-optimal water status is the key to success.

If plant water status is what we need to manage

we need to;

1_ **DEFINE** the pattern of water status over time that produces the desired outcome

2_ **MEASURE** the water status of the plant at the level that can produce the outcome

3_ **MANAGE** water status to achieve the desired outcome

Example of managing the behavior

Our goal was to interactively cycle the water status of a plant (cotton) between optimal and non-optimal states.

We want to use canopy temperature driven irrigation to manage the water status.

Our approach

1) use canopy temperature as an indicator of the plant’s water status.
2) use an automated irrigation system to alter/control the plant’s water status.

Can we drive the plant where we want using canopy temperature as the steering wheel?

Example of managing the behavior

We ran the experiment using 5 irrigation scenarios for 10 days.

1_ full irrigation…2000ml per day as per greenhouse manager

2_ canopy temperature threshold-based control with temperature thresholds

The canopy temperature control thresholds were;

- 28°C optimal
- 30°C slightly non-optimal
- 32°C more non-optimal
- 34°C significantly non-optical

Example of managing the behavior

Cotton plants in a green house
A set of infrared thermometers
A computer controlled drip irrigation system

1_ define the irrigation targets as canopy temperature (CT) thresholds.

2_ on a 5 minute interval measure the CT.

3_ if CT for the 5-minute period is < the CT threshold…withhold irrigation …let it dry.

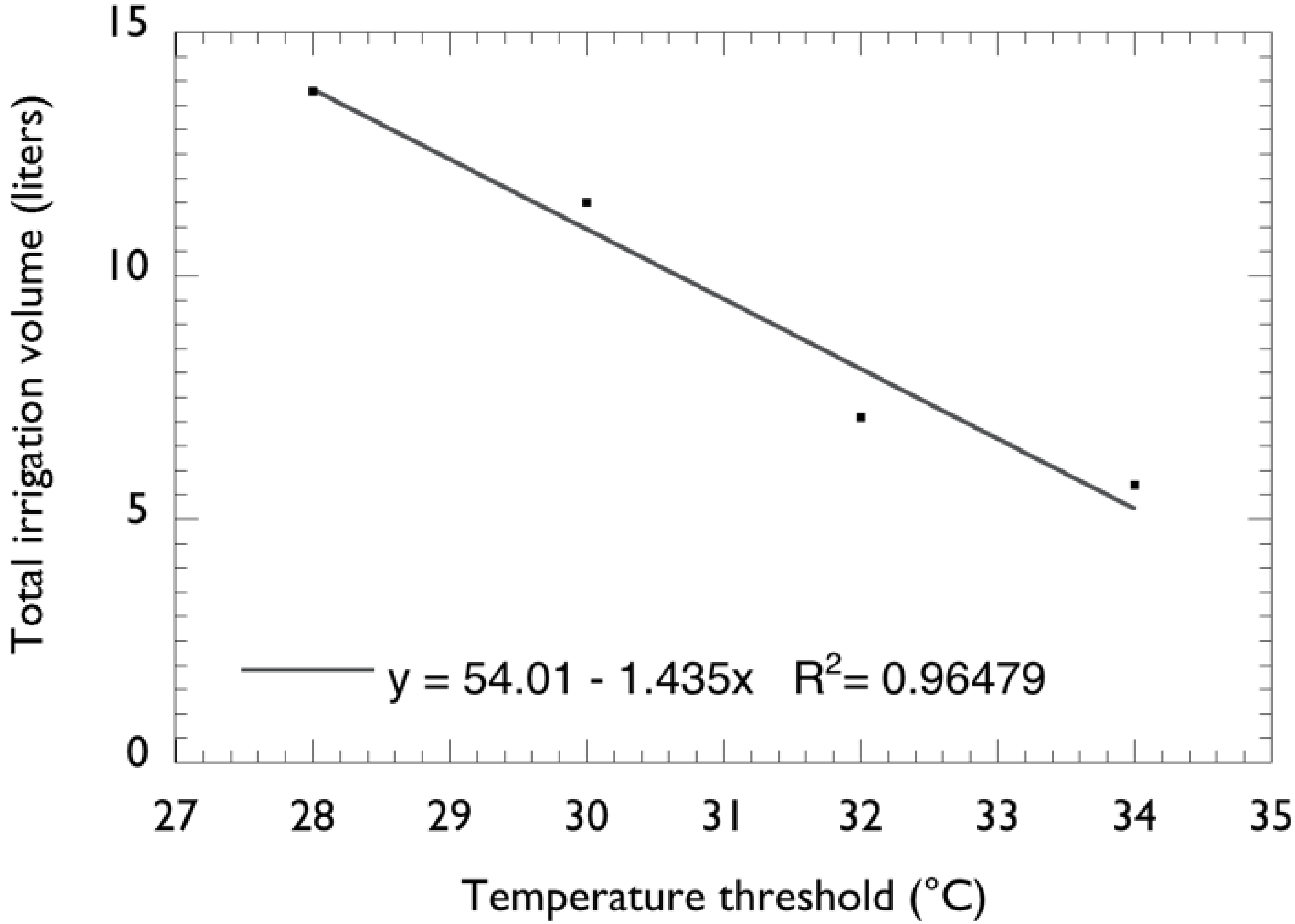
4_ if CT for the 5-minute period is > the CT threshold apply a small irrigation (30ml)… make it wetter.

5_ if CT for the 5-minute period is > the CT threshold apply a small irrigation (30ml) … make it still wetter.

just like the instructions on a shampoo bottle…LATHER, RINSE, REPEAT

Example of managing the behavior

Irrigation by temperature thresholds altered the 10-day irrigation volume in a linear manner with CT threshold indicating potential for active management of water status.



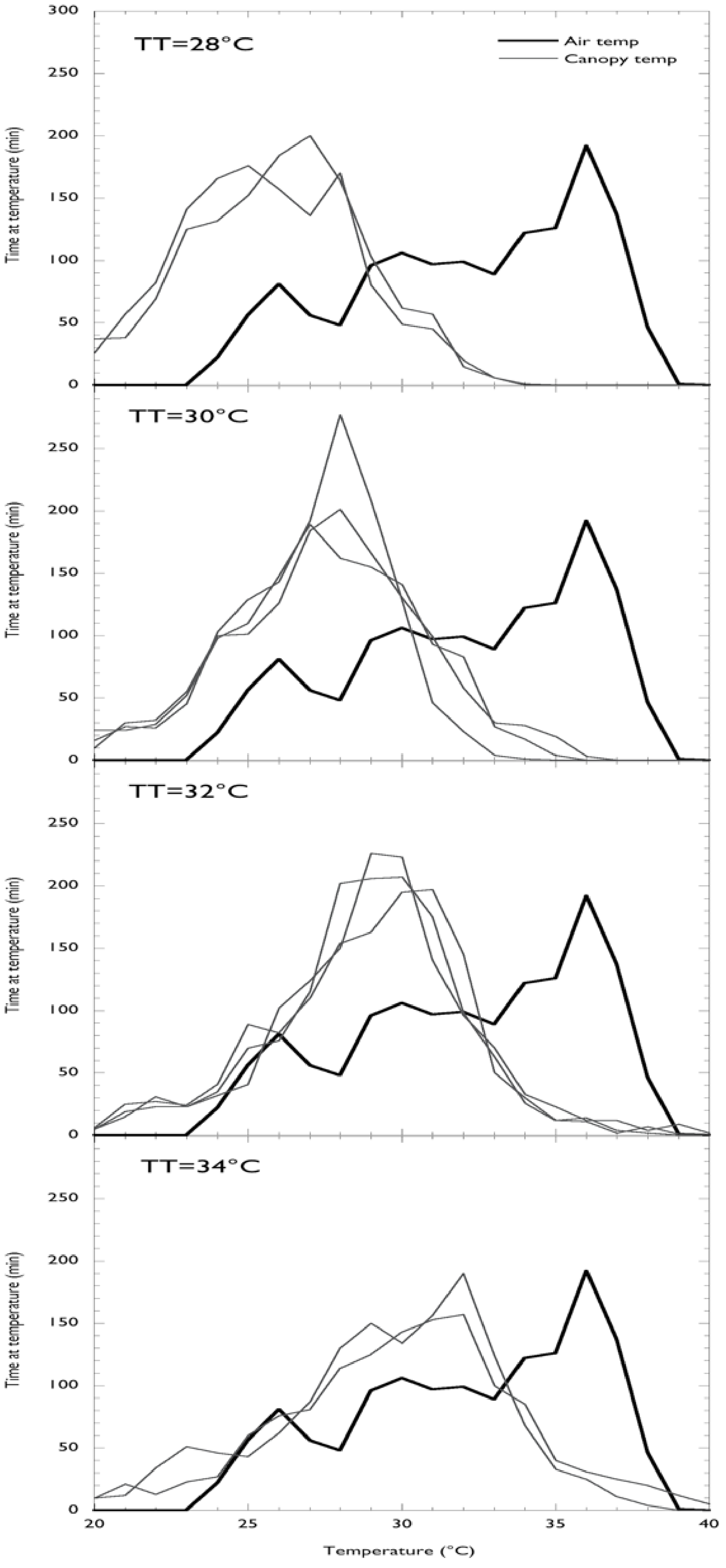
Example of managing the behavior

The distribution of canopy temperatures was altered over the 10-day interval.

The 10-day distribution of canopy temperatures was a function of the CT threshold value.

Enrichment for desired canopy temperature was associated with each of the canopy temperature control thresholds.

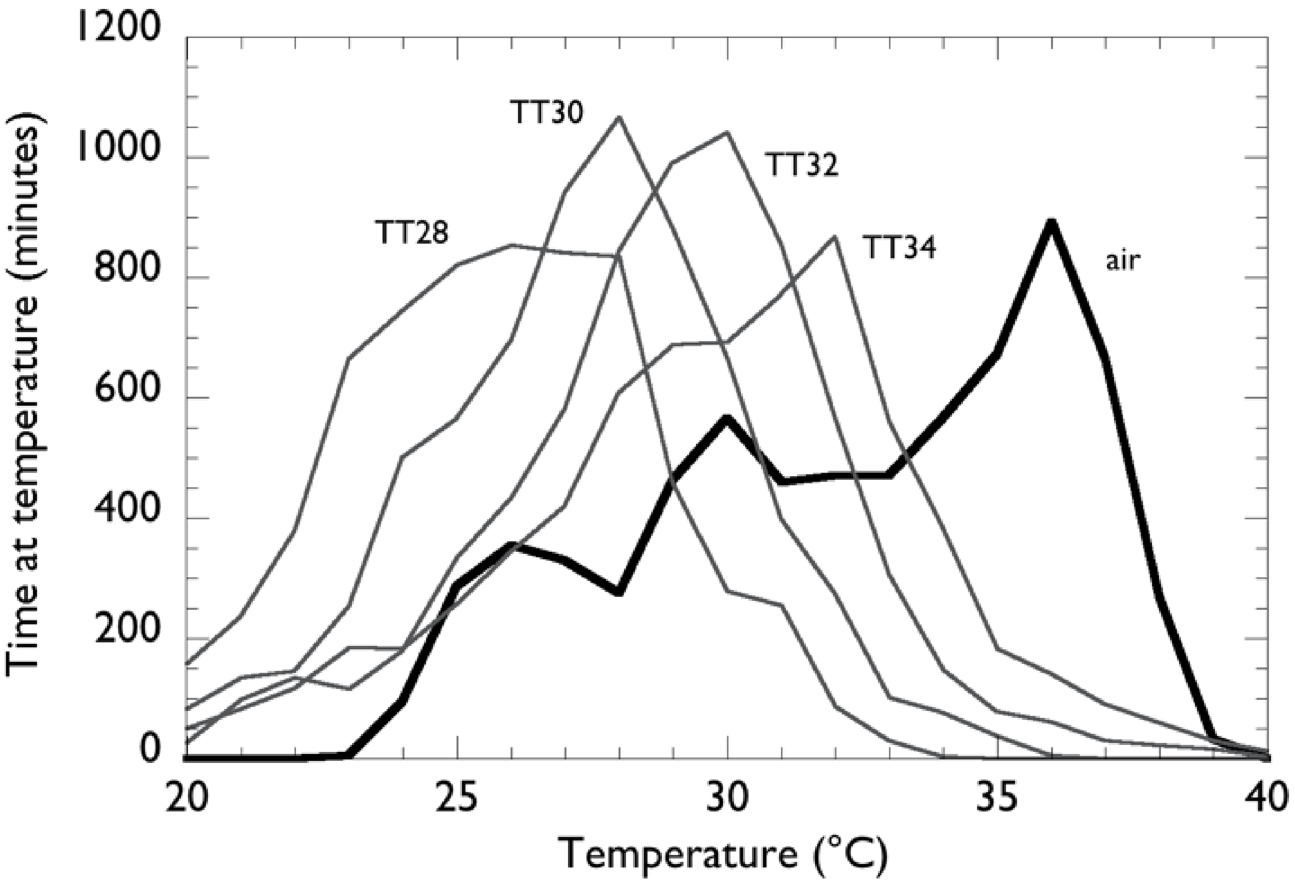
The CT-based irrigation altered the thermal behavior of the plant and its water status in the desired manner.



Example of managing the behavior

Distribution of canopy temperatures
was a function of the CT threshold value.

temp threshold	temp peak
AIR	36°C
TT28	26°C
TT30	28°C
TT32	30°C
TT34	32°C

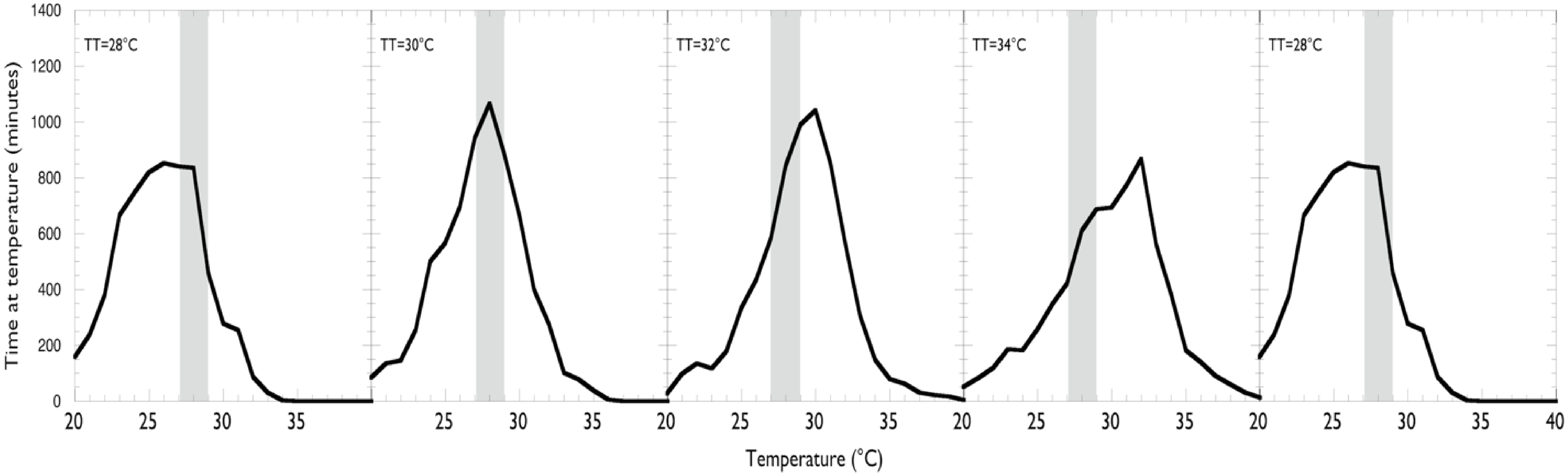


The CT-based irrigation altered the thermal behavior of the plant in a predictable manner. Some plants optimal and some non-optimal.

Not perfect but functional.

Example of managing the behavior

By varying the canopy temperature threshold over time it is possible to alter the plant water status from optimal to non-optical over a period of days.



Example of managing the behavior

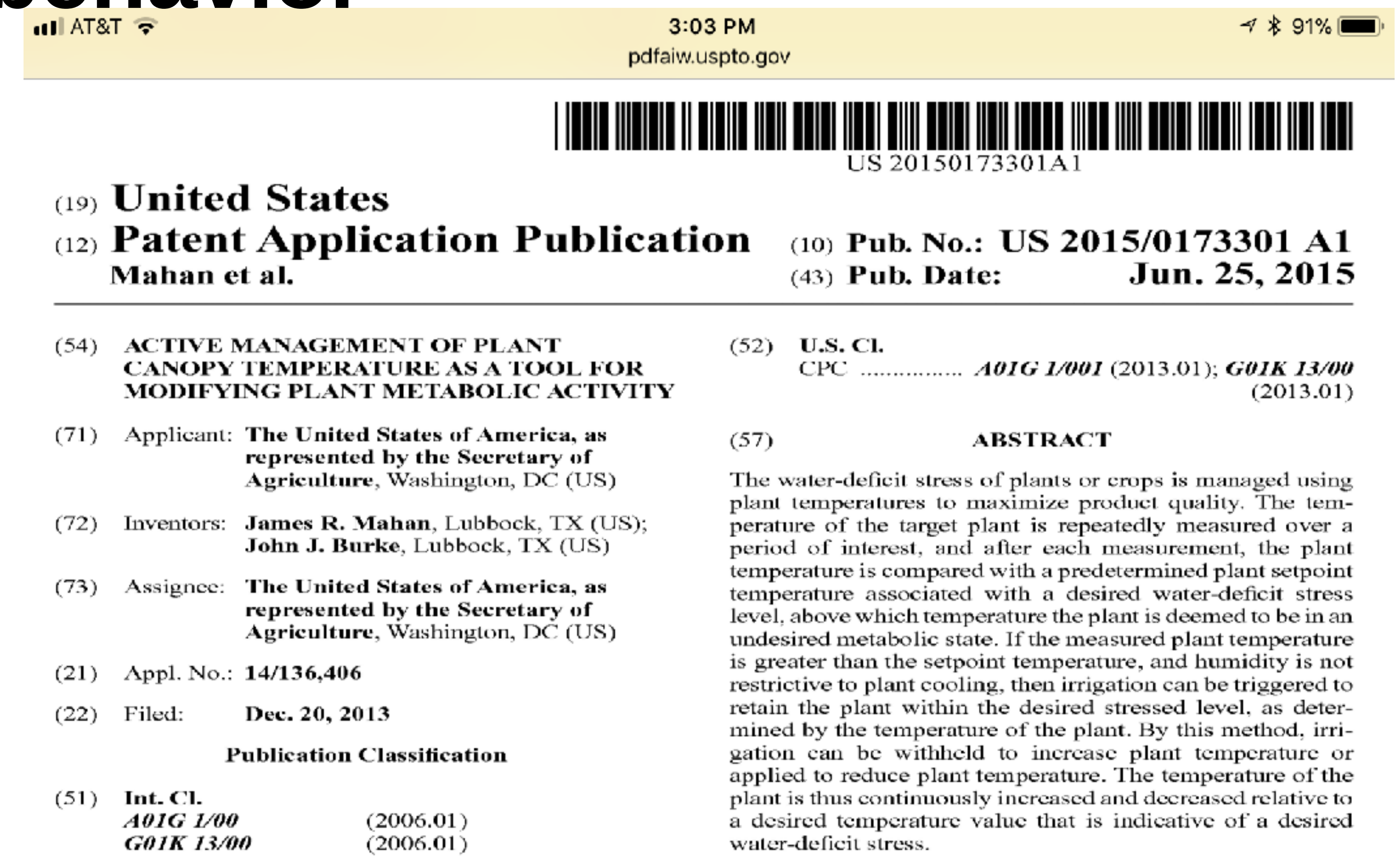
We have a patent on this approach.

“Active management of plant canopy temperature for modifying plant metabolic activity.”

This approach has been successfully implemented on a small field scale using drip irrigation and in greenhouse operations.

Using canopy temperature to steer the plant where we want it…optimal and non-optimal.

The approach alters both the water status and metabolic activity of the plant.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US 20150173301A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2015/0173301 A1**
Mahan et al. (43) **Pub. Date: Jun. 25, 2015**

(54) ACTIVE MANAGEMENT OF PLANT CANOPY TEMPERATURE AS A TOOL FOR MODIFYING PLANT METABOLIC ACTIVITY

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(21) Appl. No.: **14/136,406**

(22) Filed: **Dec. 20, 2013**

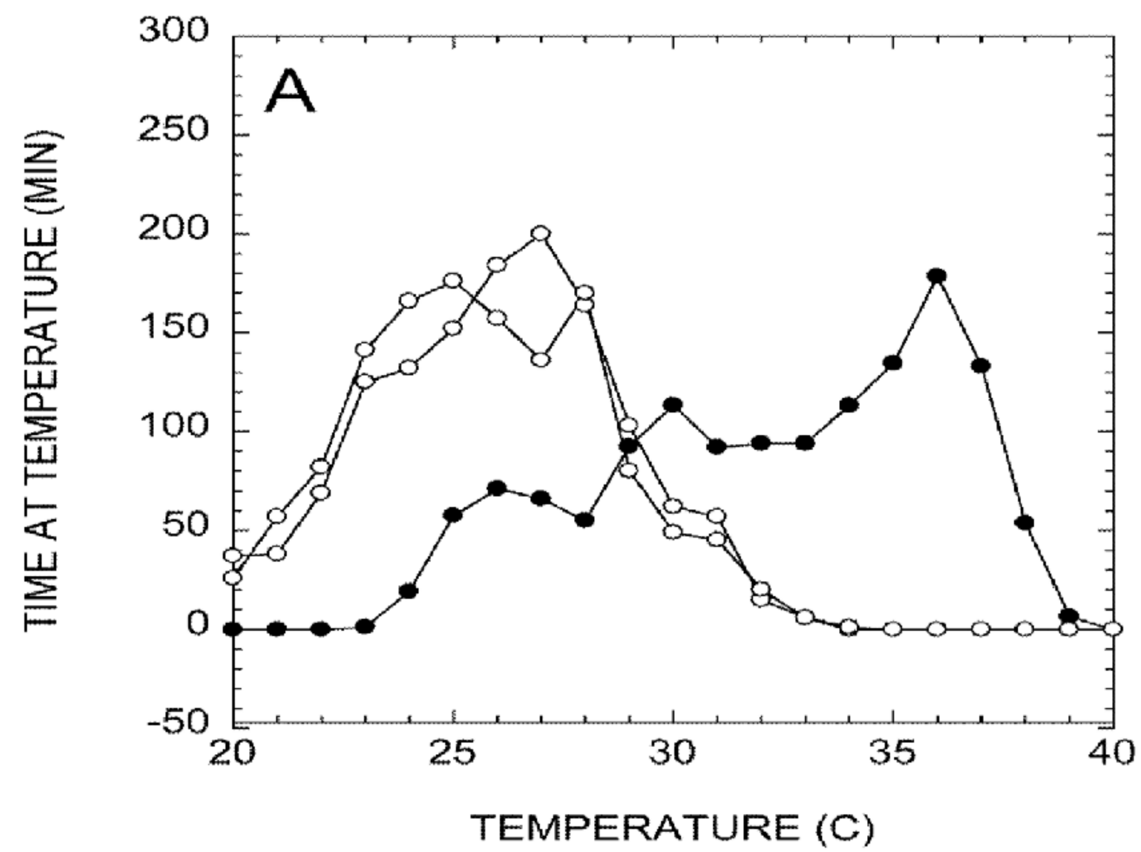
Publication Classification

(51) **Int. Cl.**
A01G 1/00 (2006.01)
G01K 13/00 (2006.01)

(52) **U.S. Cl.**
CPC *A01G 1/001* (2013.01); *G01K 13/00* (2013.01)

(57) **ABSTRACT**

The water-deficit stress of plants or crops is managed using plant temperatures to maximize product quality. The temperature of the target plant is repeatedly measured over a period of interest, and after each measurement, the plant temperature is compared with a predetermined plant setpoint temperature associated with a desired water-deficit stress level, above which temperature the plant is deemed to be in an undesired metabolic state. If the measured plant temperature is greater than the setpoint temperature, and humidity is not restrictive to plant cooling, then irrigation can be triggered to retain the plant within the desired stressed level, as determined by the temperature of the plant. By this method, irrigation can be withheld to increase plant temperature or applied to reduce plant temperature. The temperature of the plant is thus continuously increased and decreased relative to a desired temperature value that is indicative of a desired water-deficit stress.



Two possible approaches to implementation in grapes.

1_ biochemical/physiological definition of desired CT thresholds and the seasonal timing of desired conditions.

- This would be physiologically-based and mechanistic but perhaps time consuming to develop.

2_ monitoring of CT in vineyards under various irrigation regimes and environments to identify the CT patterns that are associated with desirable outcomes. Perhaps an “Environmental Vintage Characterization”.

- This would be empirical and would require an organized campaign to collect sufficient data to describe the operating envelope of a management system.

Either approach might be useful in the management of quality factors.

Potential obstacles

1_ Defining the desired outcome

This is often pretty straightforward

2_ Figuring out how to measure/observe the behavior.

This can be challenging

3_ Managing the behavior

This is often a matter of engineering/design…generally achievable

Figuring out how to measure the behavior can be difficult.

- we can’t manage what we can’t measure
- defining the temporal phenotype of the behavior… the path to the outcome
- we can only manage to to the level that we measure

Sensors will be the key to success…some new some old

Sensor performance windows in terms of spatial and temporal resolution will be a major factor in sensor selection.

The correct sensor is ideally suited to the data needed for decisions. More data at finer resolution is not necessarily better.

Incorporating the correct combination of sensors may be important and correctly defining the problem to be solved will be essential to success.

Figuring out how to measure the behavior can be difficult.

Sensors require:

- Well-framed questions… appropriate questions lead to appropriate sensors.
- The lack of basic physiological insight into plant physiology must be overcome.
- Understanding of data density requirements…avoid big data as soon as possible.

Water is often the important variable to measure.
Generally difficult to measure accurately over time.

There are a handful of water measurement tools available.

- leaf wp
- soil moisture
- stem flow
- ET models
- canopy temperature

All have their strong and weak points that can be debated endlessly.

I work primarily with canopy temperature as a tool. Major weaknesses:

how often to make the measurement?
how much of a field needs to be measured?
how accurate does the measurement need to be?

These questions apply to almost all sensor data.

As Dr Seuss might put it…

Green Truck…

Black Truck…

Black Truck…

Green…

Two colors <u>same</u> truck…what does it mean?

When and where you take a measurement can be important!

How we measure temperature

in-field wireless IRT system

Fast (15min) and small footprint (0.5m)

~ 1 X 10^6 measurements/season

Seasonal thermal patterns represent water status phenotypes.

Pattern recognition
Data decimation
All in light of the plant and its function

A season of canopy temperature data

How we measure temperature

UAV

Slow (day) and large footprint (ha)

~ 100 measurements/season

UAV data covers large areas

Limited in terms of a single instantaneous image per flight and perhaps a flight per day.

It is so cheap ($1500) and easy it has to be valuable.

How we measure temperature

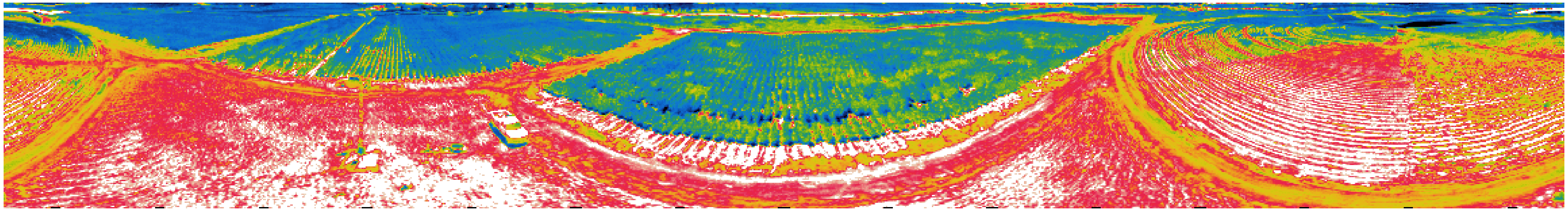
<u>Smartfield Sentinel system</u>

Fast (15min) and large footprint (ha)

~ 4 X 10^{12} measurements/season

Sentinel can scan the field at sub-hour intervals for unlimited periods.

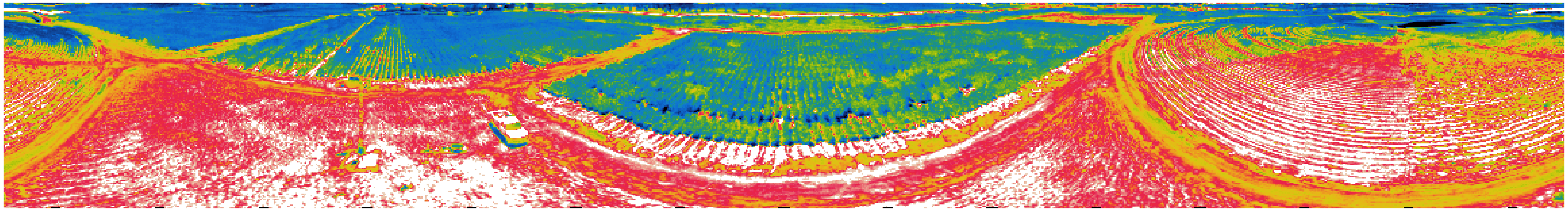
Data reduction is challenging



I used to think I needed more data.

Now I have more than enough.

My limitation now is seeing the data in agronomic terms and getting it into the production world.



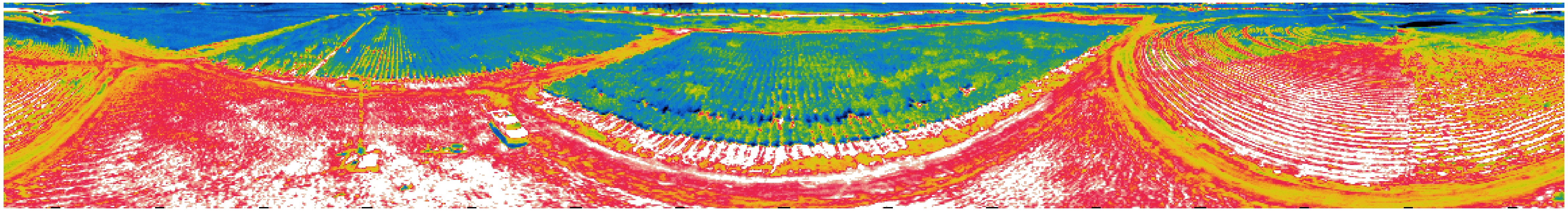
Mixing the data from multiple sensors types…
“sensor interleaving” may be very productive.

How do we mix and match to get the right information?

Fast small ~$500

Slow big ~$1500

Fast big ~$15k



“Phenomenal cosmic power…ity bity living space”

Perhaps we can begin to let the genie out of the lamp.

Do we need infinite power?

Maybe sufficient power?

We need a “living space” that encompasses production settings.

Production gains that offset costs

- cheaper
- simpler
- reliable and robust
- multiple uses of sensors and data

Be like David and kill the giant with a small smooth round stone.

Making plants do what we want

Improved sensing technology will allow us to better define the temporal pathways to desired outcomes and thus better control of the plant.

It is possible that new sensing technology, combined with the appropriate questions, will allow us to “make plants do what we want” on a scale that was not possible 5 years ago (= to 1 RPES panel)

Making plants do what we want

- define what we want
- identify measurable parameters associated with the desired outcome
- figure out how to measure at the appropriate scale
  develop seasonal phenotypes
  data density…spatial and temporal
  appropriate sensors with adequate performance
- look for fast paths to commercialization
- ask the physiological questions
- avoid over-dependence on big data to tell us how it works

People who help

Paxton Payton…ARS colleague

John Burke…ARS Co-inventor patent

Mick Bange…CSIRO cooperator

Julia Brown…my technician

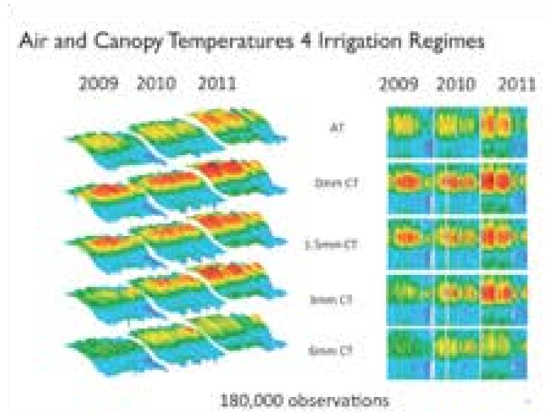
Cotton Incorporated…ongoing support

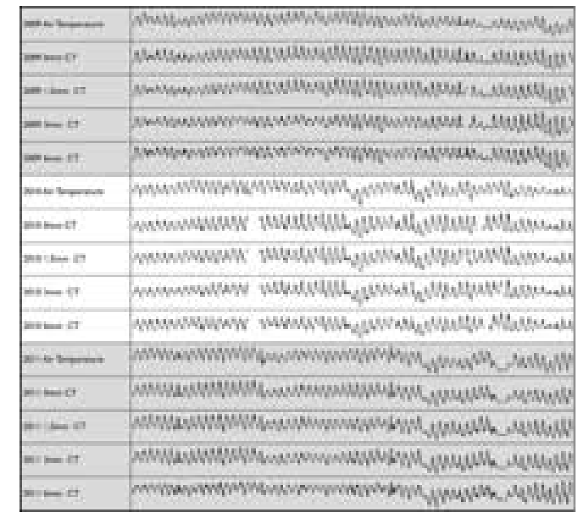
ARS Ogallala Aquifer Program…support

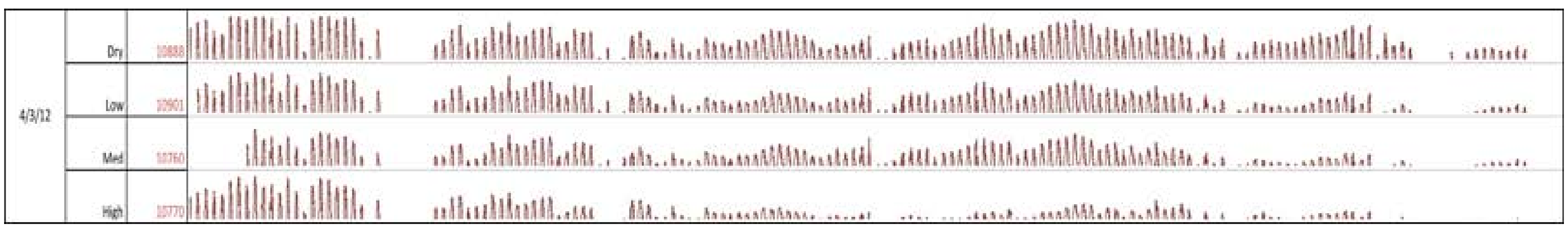
Rosetta Stone

Created 196 BC
Re-found 1799

Parallel texts provided basis for translation of Egyptian hieroglyphs into greek.







We want to develop a Rosetta Stone that allows use to translate these seasonal patterns of canopy temperature into the plant's stress story.

Translation of canopy temperature into;

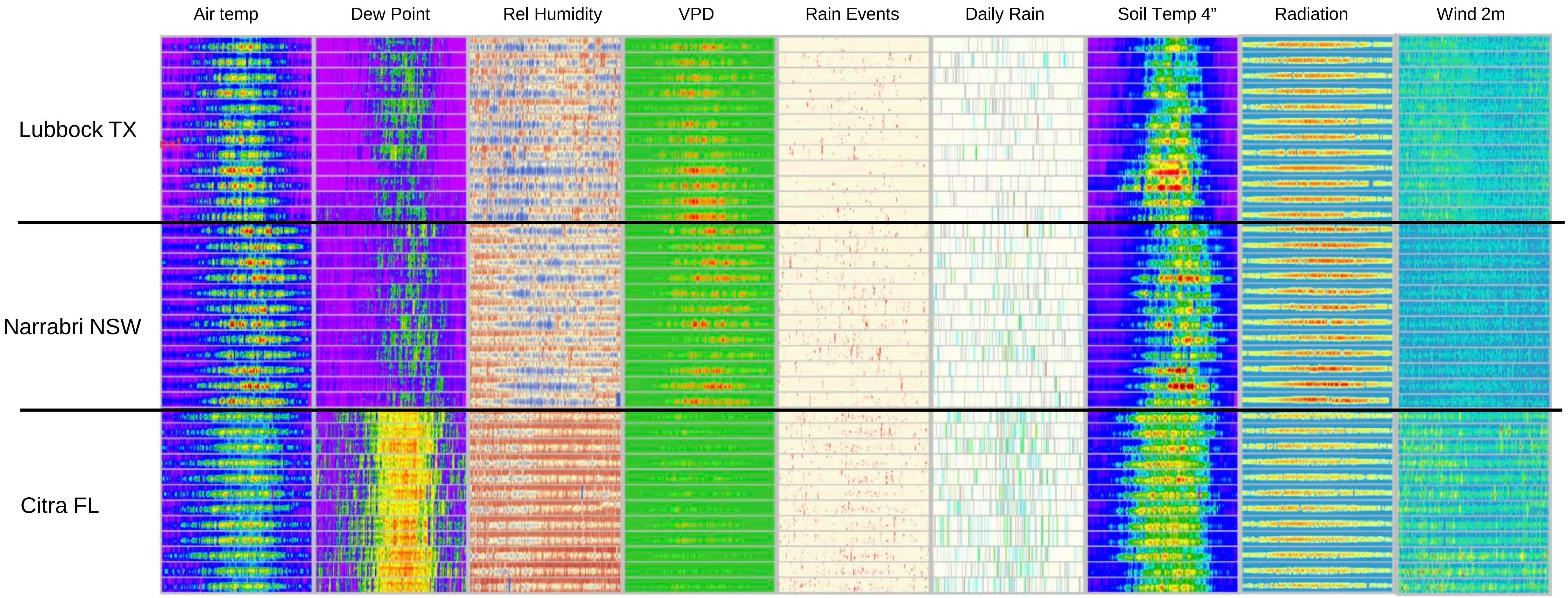
- root patterns
- fiber quality
- metabolites
- gene expression
- photosynthesis
- water status
- acclimation

Weather is one thing we can measure continuously and reliably.

Interpretation of data from a cropping perspective can be a challenge

comparison of 10 years of weather data for 9 variables at 3 locations on 1 hour intervals

~2 X 10^6 measurements



We have an example of how we might make grapes do what we want.

What are some obstacles to doing this routinely?

1_ Defining the desired outcome

2_ Figuring out how to measure/observe the behavior.

defining the temporal phenotype of the behavior..path to outcome

- we can’t manage what we can’t measure

3_ Managing the behavior
is the behavior subject to management?
is the system sensitive enough?

can we alter the behavior often enough to alter the final outcome?

no… not at all
yes… but not much/enough to matter
yes… and it looks promising

Plant water status is what we need to manage.

To manage we need to identify the seasonal pattern of plant water status that:

- optimizes fiber characteristics in cotton
- increases determinacy in soybeans
- reduces fruit drop in cotton
- enhances root proliferation in peanut
- enhances the content of desirable metabolites in grapes