# Macquarie Valley
## canopy temperature sensor trial 2015-16

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Macquarie Cotton Growers Association
Porosity Agricultural Services
Australian Government Cotton Research and Development Corporation

# BACKGROUND

In late September 2015, the imminent cotton season was looking like a quiet one for the Macquarie Valley in central NSW, yet there was still a zest to learn amongst a few keen growers and agronomists to continue their understanding & improvement of irrigation strategies to maximise yields and water efficiency.

The previous 2014-15 season saw CottonInfo team up with CSIRO in a large research trial in the Macquarie Valley using "canopy temperature sensors" (CTS), under the theory that they could assist with irrigation timing by assessing the level of plant stress.

Temperature is one of the major environment factors affecting the growth, development and yields of crops (Luo, 2011). The cotton plant performs many vital functions throughout the day and night at any one time. Cotton has an optimum thermal kinetic window of 23 to 32°C in which metabolic activity is most efficient (Burke et al., 1988 Conaty et al., 2012).

Why do we need to know this? In a very big 'nutshell' the plant wants to keep itself cool to ensure the essential metabolic processes are maximised (eg. photosynthesis, respiration). By monitoring the canopy temperature against the air temperature and other weather conditions, we can gauge how well the plant is keeping within the optimum temperature range and thus being most productive.

Porosity Services (a sensors & telemetry provider to the district) had already been trialling a commercially available CTS for the last two seasons, integrating them with soil moisture probes and weather sensors onto the same telemetry & software platform, and was building on the research to see what the commercial benefits of the sensors were. Porosity was realising that by monitoring the crop temperature in conjunction with existing soil moisture probes and weather stations, it was building another layer of useful information for clients, by quantifying the effect that different irrigation strategies have on the crop rather than what was just going on under the ground.

An impromptu meeting between Amanda Thomas (regional extension officer for CottonInfo), and Brian Thomson (Agricultural Consultant with Porosity Services) resulted in a plan to further investigate work from the previous season, by using this technology on more of a commercial scale.

With a very pro-active MCGA president (Ryan Pratton) & committee who were willing to contribute to the trial, an unprecedented commitment from a number of growers & agronomists, and Porosity who was offering to provide the hardware and installation at a heavily discounted price, plus provide a high level of data analysis and a live website display for the MCGA members. Thus we had a solid case for a CRDC "grassroots grant".

A second meeting with all the interested parties, where the collaborative approach to the trial was agreed upon, all funding was secured, clear objectives and goals were set, and a valley-wide trial began in October 2015.

Please note this is not a scientific trial, thus this report is more of a summary of our observations from the season with anecdotal results. This is a grower led initiative and we wanted to maintain that focus rather than getting too scientific, with an objective to involve all growers & agronomists in the technology and see how it can help them make more informed decisions.

# AIMS & METHODOLOGY

**Aims**

The initial aim of the trial was to setup a 3-year project. With experiences gained from the previous season we knew we needed more information from trial sites so we devised a proposal involving the use of plant, weather and soil moisture sensors at various locations in the Macquarie Valley, for the benefit of ALL growers in the region.

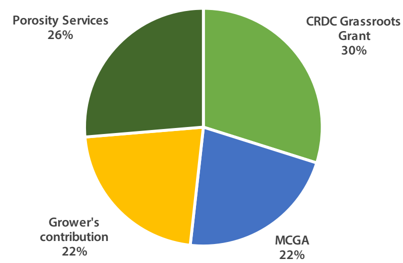
The primary objectives were to:

- Improve growers and our understanding of the relationship between different irrigation methods & strategies (ie. soil moisture content/ deficit) and how it affects the plant's canopy temperature (ie. how efficiently the cotton is cooling itself).
- Evaluate the effectiveness of different irrigation systems (drip , furrow and overhead ) to be able to utilise soil moisture to cool the canopy.
- Assess relationship between canopy temps and the resulting yields, water use efficiency.
- Improve understanding of how to irrigate during differing weather conditions (eg.hot v cool periods) by combining the info from canopy temp, weather and soil moisture sensors.
- Display the data from the sensors on a website that is easy to access and understand. This aimed to engage all current cotton growers, and also those not currently growing by enabling them to keep an eye on what crops were doing across the valley and keeping them up to date with the latest technology.
- Increase understanding of the technology by having a field day/crop walk, email updates during the season, and distribute a full report once the 1st year is completed.
- Assess how some of the new commercial varieties. (eg. BG3) would perform by applying the "accepted" irrigation scheduling practices, by monitoring the canopy temp.
- Secure funding on a year-to-year basis, resultant on the trial performance from the previous year, and the foreseeable benefits to cotton growers & agronomists by continuing.

**Methodology**

The number and spread of sensors depended upon the contributions from each party. In 2015-16, the following funds were secured:

| | |
|---|---|
| CRDC – via Grassroots Grant | $7,500 (30%) |
| MCGA | $5,500 (22%) |
| Grower's total contribution (7 participants) | $5,500 (22%) |
| Porosity Services (discounted hardware, time) | $6,611 (26%) |
| TOTAL TRIAL TRIAL AMOUNT | $25,111 |

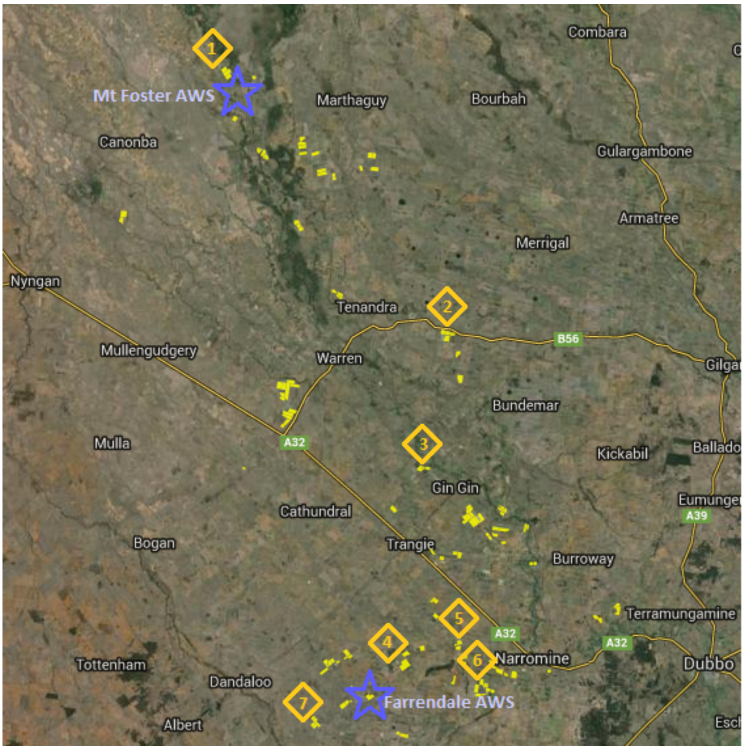



This funding allowed for the investment into the following sensors:

- 7 × Canopy Temperature Sensors (CTS), integrated with a soil moisture probe, rain gauge on an Adcon Telemetry logger (NextG).
- 4 × "in-crop" Air Temperature & Relative Humidity sensors (these were connected into the same logger as CTS). This included 1 grower-owned weather station (CTS #3 Miegunyah).
- 2 × Professional-grade Automatic Weather Stations (AWS) measuring the "out of crop" conditions of; Air Temperature, Relative Humidity, Wind Speed & Gust, Wind Direction, Solar Radiation, Rainfall, Evapotranspiration (ET), Heat models (eg. day degrees), sunlight hours, Vapour Pressure Deficit (VPD), Current Spray Conditions (eg. Delta-T)
- Website data display (www.porosity.com.au > Members Login UN: mcga PW: ctstrial )
- Communication & reports - numerous emails to the trial participants & MCGA members throughout the season, 1 × field day at the sub-surface drip irrigation trial site (9/3/16), 1 × end of season meeting with all participants to discuss yields, trial results and look at different irrigation strategies and how it affected soil moisture levels, canopy temperatures.

# MAP OF THE TRIAL SITES

*Figure 1:* map highlights (in yellow) all cotton planted in 2015-16 season (source: CottonMap).




| Icon | Site Name & description | AWS "out of crop" | Temp/RH "in crop" | CTS & Probe |
|---|---|---|---|---|
| ☆ | Mt Foster AWS (Automatic Weather Station) | ✓ | | |
| ☆ | Farrendale AWS (Automatic Weather Station) | ✓ | | |
| ◇ 1 | CTS #1 - Mt Foster (bankless, 1m beds) | | | ✓ |
| ◇ 2 | CTS #2 - Milawa (syphon, 1m beds) | | ✓ | ✓ |
| ◇ 3 | CTS #3 - Miegunyah (syphon, 1m beds) | | ✓ | ✓ |
| ◇ 4 | CTS #4 - Euroka (overhead lateral, 1m flat ground) | | ✓ | ✓ |
| ◇ 5 | CTS #5 - Bungarley (subsurface drip, 1m flat ground) | | ✓ | ✓ |
| ◇ 6 | CTS #6 - Ningawalla (syphon, 1m beds) | | | ✓ |
| ◇ 7 | CTS #7 - Waterloo (syphon on double skip, 4m beds) | | | ✓ |

# INSTRUMENTATION & PARAMETERS

The type of CTS sensors we used for the trial were an Infrared Radiometer, made by Apogee Instruments. These sensors work by measuring the amount of radiation being emitted by an object, which relates to the temperature of the target's surface. When used for measuring a cotton crop, the sensor is pointed at the crop canopy, hence gives an average temperature of the leaves that it detects within its "field of view".

*Figure 2:* photo of one of the CTS trial sites during 2015-16 season.

Picture of the CTS site #5 – Bungarley Subsurface Drip irrigation. Components of the system (from top):

- Rain gauge (with bird spikes)
- Adcon Telemetry NextG logger (with solar panel directly below)
- CTS sensor (white cylinder pointing down towards the crop)
- Air Temp/RH "in-crop" (with multi- plated radiation shield)
- Soil Moisture probe (beneath the canopy and out of view).

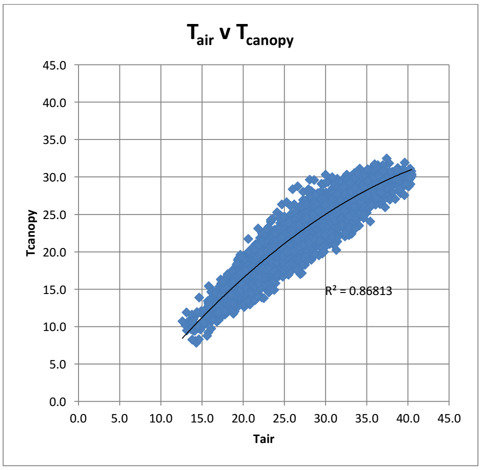
# WHAT AFFECTS CANOPY TEMPERATURE?

**Air temperature**
The leaves on any plant will be a similar temperature to the surrounding air temp, ie. the hotter the day, the hotter the canopy. The aim of the cotton plant is to stay within the optimum temp range as mentioned above (23°C–32°C).

However cotton plants have the ability to heat themselves by absorbing sunlight in the morning (enable cells to start functioning as quickly as possible each day), and when the day starts getting too hot they cool themselves by allowing moisture out of their stomates and utilise the evaporative cooling effect to lower the leaf/canopy temperature and thus minimise heat stress. See Figure 20 in the Appendix, which supports this theory.

Figure 3 (below) compares the average air temp to the average canopy temp during this year's trial from 21 Dec 2015 to 3 March 2016. This shows that they are clearly related:

*Figure 3:* Air temp verses Canopy temp from flowering period.




**Vapour Pressure Deficit (VPD)**
VPD is a measure of the humidity in the air, which affects how quickly moisture evaporates from a leaf and the resulting "evaporative cooling effect". VPD is inversely related to the Relative Humidity (RH%), eg. on a "humid" day - RH% is high and VPD is low, and vice versa on a "dry" day - RH% is low and VPD is high.

Most people involved with cotton farms would know that on a humid day two things happen – 1/ their evaporative air conditioners don't work very well, and 2/ they feel more "hot & sweaty" – in both cases it's because the water (and/or sweat on skin) is NOT evaporating quickly enough to provide a decent "cooling effect".

When measuring the canopy temperatures in cotton, its imperative to know the VPD, because this condition has a major influence on how efficiently the plant can cool itself. The higher the VPD value, the greater the potential the air has for sucking moisture out of the plant, which would result in a cooler canopy. "Canopy Cooling" can be measured by subtracting the Air Temperature from the Canopy Temperature (CC = $T_c - T_a$).

We can therefore use VPD and Canopy Cooling to determine if there is enough soil moisture available to the plant, with the assumptions: IF the VPD is high, and the canopy is NOT cooling itself, then perhaps the plant cannot access enough moisture, and by a process of elimination you could determine if it is time to apply water, or for example that water should have been applied "x" days ago (under an irrigated situation of course).

The scientific definition of VPD is: the theoretical difference between the pressure exerted by water vapor held in saturated air (100% RH at a given temperature) and the pressure exerted by the water vapor that is actually held in the air being measured at the same given temperature. In a plant, the VPD is made relevant by the difference between the vapor pressure inside the leaf compared to the vapor pressure of the air surrounding the leaf.

# WHAT AFFECTS CANOPY TEMPERATURE? (CONT).

**Soil Moisture**

When there is plenty of moisture available to the plant, water travels up through the xylem to the stomates, where it cools the plant via the evaporative cooling effect as previously explained. When moisture is not so readily available, it can limit the ability for the plant to cool itself.

This can happen when:

- The soil is too dry and the plant cannot access enough moisture to freely travel up through the xylem, or
- The soil is waterlogged, the plant & roots cannot take up as much water due to the lack of oxygen. NOTE: Waterlogging also results in high humidity above the crop, which in turn lowers the VPD, and hence reduces the ability for the canopy to cool itself.

**Other external limiting factors**

Other factors affecting the ability for the canopy to cool itself are:

i. Pests – physical damage to the plant (roots, leaves and internal structures) from pests.
ii. Disease – Some disease can impact the plants (roots, leaves and internal structures).
iii. Herbicide chemicals – It is well documented within the cotton industry that herbicide damages such as hormone sprays can affect the plants ability to function and thus cool itself. More research is being done on the impact this can have on roots as well as surface areas to the plant.
iv. Physical damage (eg. hail) – or any other conditions that results in the roots, leaves or internal structures from functioning to their full potential.

# WHAT TEMPERATURE IS IDEAL FOR COTTON?

Although cotton is grown throughout many hot climates around the world, the plant itself will attempt to regulate its own temperature through evaporative cooling.

The ideal temperature for the cotton plant varies depending upon the function that is occurring. CSIRO has done a lot of research to establish what are the ideal temperatures for certain functions & growth stages in the plant.

For example photosynthesis is optimal at 31°C, respiration maximum is at 35°C, and optimum pollen germination and rapid tube elongation occurred between 28 and 31°C under 80% relative humidity. Decreased pollen germination occurred at temperatures above 37°C, and decreased tube elongation occurred at temperatures above 32°C (Burke .et. al 2004 ).

For this 2015-16 CTS trial in the Macquarie, we used 30°C as the "stress threshold" for the models, ie. we tracked the number of hours greater than 30°C ("Hrs>30C") to quantify the level of plants stress in the trial sites. The models could be re-calculated at a future date with a different threshold, however it would not change the relative differences between each of the CTS trial sites, ie. the coolest trial site would still have the lowest hours above the stress threshold.

# RESULTS

Side notes to be considered:

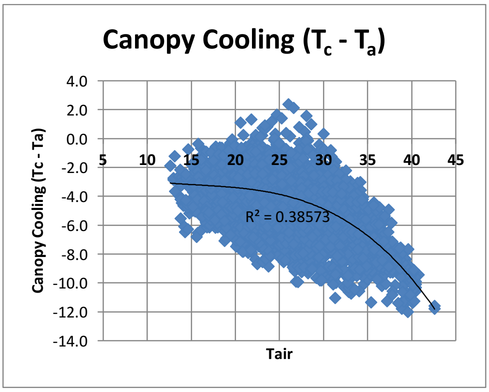
- Overall the yields were high in the 7 CTS trial sites – averaging 16.1 bales per "green Ha" (15.7 bales/Ha for the 1m solid plant fields). This is significantly higher than the Macquarie Valley average of 13.3 bales/Ha.
- One of the CTS sensors (CTS #2 Milawa) had very high readings which have been omitted from the results shown below. This is explained further in the "conclusions – methodology reviewed" below.
- One of the trial sites (CTS #7 Waterloo) was on a double skip row configuration, and so these results have been left out of the some comparisons of results because it is difficult to compare it against the other CTS trials sites, such as bales/Ha, bales/ML etc.

**Finding #1:**

The CTS sensors clearly showed that the canopy temperature cooled itself more as air temperatures increased. A scatter graph from all CTS trial sites (see Fig. 4 below), shows how much cooler the Canopy temperature (Tc) was than the Ambient Air Temp (Ta) (taken from the average of the 2 × AWS) from 21 Dec 2015 to 3 March 2016.

As an example, when the Ta was at 40°C, the canopy was approx. 10°C cooler – ie. the canopy would have been at about 30°C – notably the same temp used by our "stress threshold". However the results did vary across the CTS trial sites, for example when the air temp was 39.6°C, the canopy temps varied between 27.6°C (12°C cooler than air) and 31.9°C (7.7°C cooler than air) – the latter would have been experiencing a higher level of plant stress than the former.

*Figure 4:* "Canopy Cooling" shows how well the canopy's cooled themselves in the trial.



**Finding #2:**
All CTS trial sites reacted with similar trends on the same days. The best example of this was during a 5-day heat wave event when the daily maximum Temp was greater than 39°C (from 10 January 2016 to 14 January 16).

During this time and all CTS trial sites suffered "stress", ie. the canopy's all suffered time above the stress threshold of 30°C. The average across all sites 3.5 hours of stress per day, with one site (CTS #6) averaging 6hrs stress per day. The graph below (Fig. 5) shows the accumulated Hrs>30°C from 21 Dec 2015 to 18 Feb 2016 (the average flowering period for all the trial sites) shown as the thick coloured lines in the bottom half of graph, and the Daily $Temp_{Max}$ displayed as the red line in the top half, and the yellow circle highlighting the 5-day heat wave.

**Finding #3:**
The CTS sensors showed there was some good correlations between the amount of water being applied, and how well the canopy was cooling itself - evident as both the number hrs > 30C, and "canopy cooling" ($T_c$ - $T_a$). Fig. 6 below shows that the more water applied (both as the irrigation frequency and the amount of water applied), meant the canopy was cooler.

*Figure 6:* shows that the more water applied generally meant a cooler canopy.

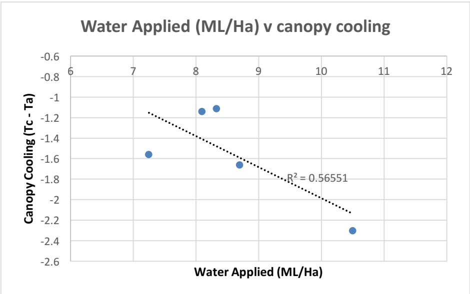
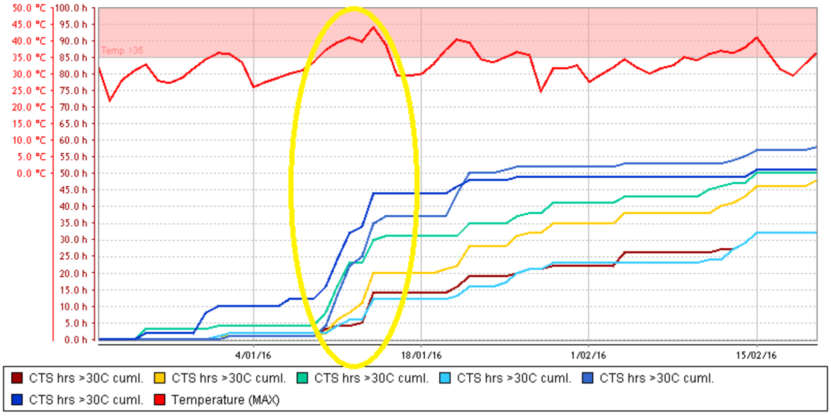


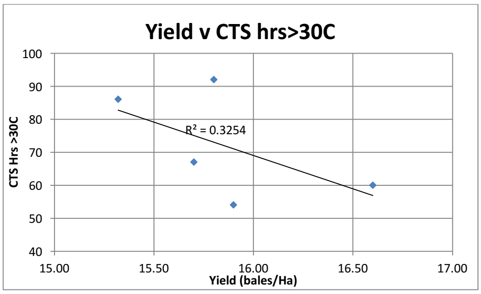

*Figure 5:* The effect of a heatwave event (10–14 January 2016) on Canopy Temperature.




**Legend:** Red = Air Temp Daily Max, Crimson = CTS1 Mt Foster, Gold = CTS3 Miegunyah, Aqua = CTS4 Euroka lateral, Pale Blue = CTS5 Bungrley drip, Blue = Ningawlla, Dark Blue = Waterloo

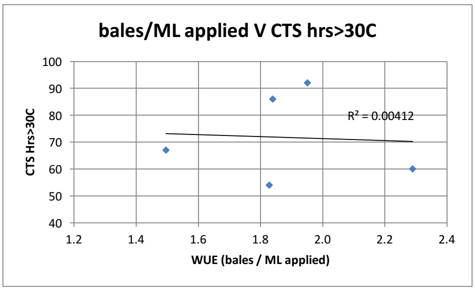
**Finding #4:**
There was only a very weak correlation between Canopy Temperature and yield – ie. the canopy's that were kept coolest, generally resulted in higher yields, as per Fig 7 below:

*Figure 7:* Yield in bales/ha and hours above 30°C.




**Finding #5:**
There was no correlation between the canopy cooling and WUE (Water Use Efficiency) across all sites in the trial, ie. a cooler canopy did not result in more bales / ML applied (see Fig 8 below).

*Figure 8:* Relationship between WUE and cumulative hours above 30°C.




**Finding #6:**
There was a very interesting trend when comparing just the 3 furrow irrigated trials on 1.0m beds, which displayed a very clear inverse relationship that canopy's with higher temperatures (CTS Hrs>30°C) had an increased water use efficiency( WUE) .

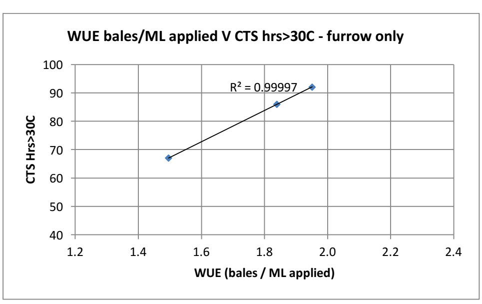
This is shown in Fig 9 below, and can be explained here:

- The fields that were "pushed harder" with longer irrigation intervals (eg. one trial had an average interval of 14 days) was hotter (total 92 Hrs>30°C), than fields that were irrigated most frequently (eg. one trial had an average interval of 9 days) – total of 67 Hrs > 30°C.
- The fields that had longer interval applied less water (8.1ML/Ha) than the field with the shorter interval (10.5ML/Ha).
- Interestingly, the longer interval did have a hotter canopy but without any yield penalty; 15.8bales/Ha on long interval, versus 15.7bales/Ha on long interval.
- Hence WUE was higher on the longer interval (1.95 bales/ML applied) than the short interval field (1.5 bales/ML applied).

NOTE: this may not be a typical result, as the season was notably "long and kind" as put by one of the agronomist involved with the trial. In a hotter and shorter season, some of the stress events seen on the CTS sensor in the longer interval crop may not have been compensated by the later finishing bolls in a more difficult season, and the resulting yields and WUE may have been reduced significantly.

However this begs to ask the questions – "how much stress can a cotton crop handle before it start impacting on yield?", or "how much can growers improve their WUE by stretching out irrigations longer, to allow enough stress that increases its root water extraction without it impacting on yield?".

*Figure 9:* Cumulative CTS hours above 30°C v's WUE on the 3 furrow irrigated fields only.




By comparing the CTS data on the shortest irrigation interval to the longest interval – see Figures 10 & 11 below, it is clear to see the effect it has on the canopy temperature, and the accumulation of hours >30°C (67Hrs versus 92Hrs respectively).

It is worth noting that the Fig 10 is located north of Warren with an accumulative air temp hrs above 36°C of 246hrs. Fig 11 is located in the southern end of the valley with an accumulation of 210hrs above 36°C (based from the 12 Nov 2015 until 15 March 2016 – see Fig.19 in Appendix).

*Figure 10:* CTS & Soil Moisture graph at "Mt Foster", Warren (shorter deficit).

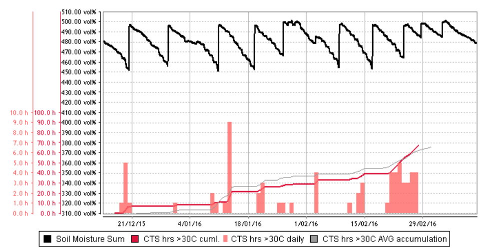
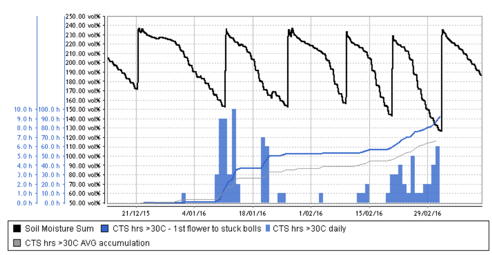


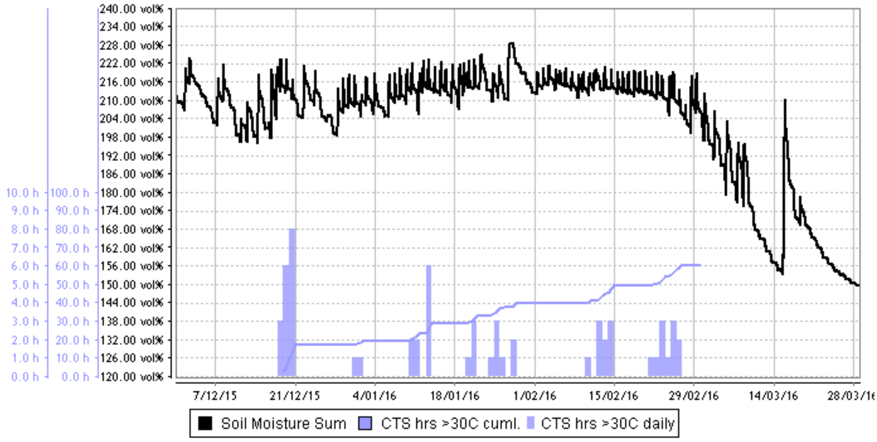

*Figure 11:* CTS & Soil Moisture graph at "Ningawalla", Narromine (larger deficit)



**Other interesting findings:**

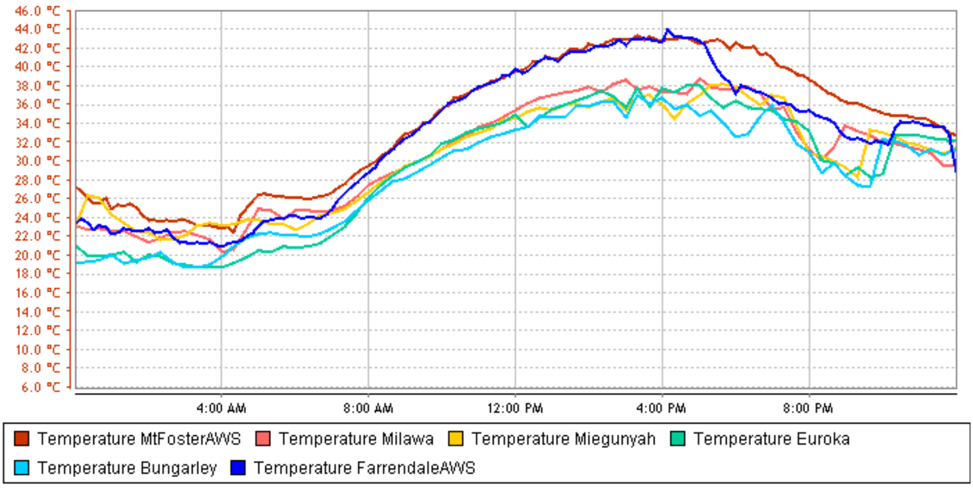
- The subsurface drip block was the "benchmark" for the CTS trial, as it was irrigated daily, and soil moisture was not a limiting factor to the canopy temperature and canopy cooling effect – see Fig 12 below. It had the lowest water applied of the "solid plant" trials @ 7.25ML/Ha, the highest yield @ 16.6bales/Ha, and hence the highest WUE @ 2.3 bales/ML applied.

*Figure 12:* CTS & Soil Moisture graph at "Bungarley", Narromine on subsurface drip



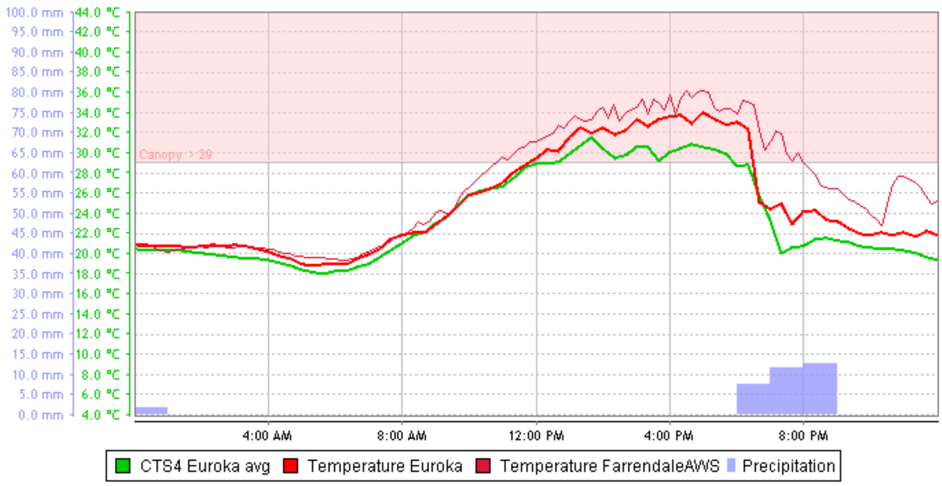

- How significantly different the apparent weather conditions can be on an AWS that is "out of crop" (as per the BOM standards for measuring local weather conditions), versus the same parameters "in-crop" where the Air Temp/RH sensor was located at the CTS trial sites in middle of an irrigated field:
  - Temperature - as an example, on 13 January 2016, the average Air Temp from the 2 AWS (Mt Foster & Farrendale) in the heat of the day (between 2pm & 5pm) was 42.8°C, which was 6°C hotter than the same time for the "in-crop" Air Temp readings of 36.8°C – see Fig 13 below.
  - Humidity – The average RH% during the 5-day heat wave event (10-14 Jan 2016) was 17% higher "in-crop" than it was "out of crop (49.8% in crop V 32.5% out of crop). This just goes to show how much an irrigated crop affects its own climate, and the importance of monitoring both the out of crop and in crop conditions.

*Figure 13:* Temperature "Out of Crop" (AWS as per legend) versus "in crop".



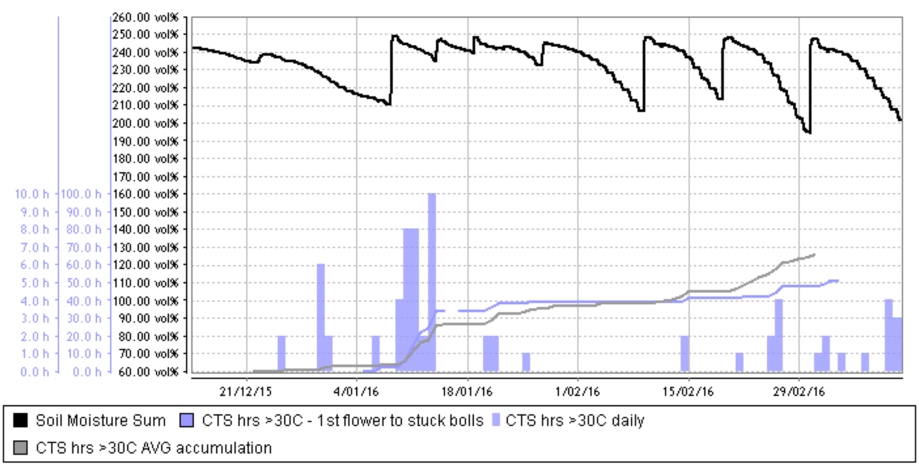
- Overhead irrigation – it's often claimed that by applying overhead irrigation (via lateral or centre pivot) can cool the canopy down significantly. On 9 January 2016 at 6:20pm, the CTS trial # 4 confirmed the theory during an overhead irrigation event (via Lateral irrigation), when both air temp "in crop" dropped 7.4°C, and canopy temp dropped 8.8°C, while at the same time the nearby Farrendale "out-of-crop" AWS Air temp only dropped 3.2°C. That's one way to cool the canopy down!

*Figure 14:* How an overhead irrigation event drops the air and canopy temp




- The double skip irrigation trial was very interesting. Early in the season the CTS readings were much higher than the other trial sites – due to the amount of ground radiation affecting the canopy temperature readings (this was also not helped by it being the last of all the trial sites to be planted). However later in the season it was cooling itself more efficiently than even the sub-surface drip trial site – presumably due to the much larger volume of soil moisture that the crop had access to, which obviously contributed to the water coming up through the leaves and cool itself better. See Figure 15 below showing the graph of the soil moisture Sum (top), CTS Hrs >30°C light blue daily (blue bar) & cumulative (blue line), V AVG cumulative Hrs>30°C for all sites.

*Figure 15:* CTS #7 Double Skip at "Waterloo" – shows how much cooler than canopy was toward the end of flowering.



# METHODOLOGY REVIEWED

Assessment of how the trial went in 2015-16 season:

Of the 7 CTS sensors that were installed and 2 AWS:

- All data transfer (telemetry) and display (software) worked without any glitches.
- All soil moisture probes worked without fault for the season
- All weather sensors worked without fault, including the rain gauges. One rain gauge has reportedly been reading below that of a nearby manual rain gauge, which will be assessed prior to any further trial works.

Problems noted:

- One CTS (at Milawa) had high readings all season. This field also happened to have suffered severe hormone spray drift early in the season, hence we watched the high readings all season assuming that the canopy was not cooling itself efficiently due to stomatal damage evident in the deformed leaves. However upon inspection at the end of the season a black spider was found in the lense part of the CTS sensor, and we are not certain as to how long it had been residing here. This could have been the reason for such high readings all season, and hence we have had to disregard these results. Testing after removal of the spider showed it was reading within 1% of all the other CTS sensor in the trial, so the sensor itself was not faulty.
- On another monitoring site, the grower decided to lift the solar panel up so as to avoid it being shaded by a larger than usual canopy. In doing so, they inadvertently positioned it right below the telemetry unit, hence it was being shaded for most of the day, and as a result the battery dropped below critical voltage for approx. 3 days. As soon as we noticed the battery issue, the problem was fixed within 2 days. Lesson learned – to position the telemetry units slightly higher, and advise growers / consultants to discuss any changes to hardware configuration prior to any in-field adjustments.
- One of the major limitations of using the technology is the lifting of the CTS sensor so that it is a reasonable distance above the canopy (eg. 30cm), and hence taking a good sample size of the "canopy temperature". Although the process takes less than 1 minute at each site, it still requires a concerted effort for someone to remember to perform the task – drive to the site etc. Unfortunately, at this stage there is no way around this, except to allow 3-4 visits to each site to lift the sensor. At this point in time the person could also check for spiders and/or other insects (as noted in the first point above) to ensure the sensor is clean and reading accurately, and potential take a photo as a visual record of the crop development for future reports anyway.

# SUGGESTIONS FOR FUTURE TRIALS

- Increase the number of CTS trial sites to 10 sensors, with in-crop Air Temp & RH to be included at every site. This will increase the anecdotal evidence and support any findings with a greater level of confidence.
- Keep the 2 out-of-crop AWS going, as they tell us what the weather conditions are in the region as per BOM measuring standards, and enable us to compare to what is happening to the "in-crop" measurements. The extra level of data collected allows the calculation of daily Evapotranspiration potential, how many sunlight hours, what the wind speed & gusts were, the Humidity in the atmosphere (as opposed to what the humidity is in an irrigated crop), increased amount of information for spray operators in the hope that it assists with reducing the likelihood of spray drift events. From December 2015 through until March 2016, the data on the AWS sites alone was viewed over 100 times per month, on both AWS, so obviously the data was being watched by many farmers and/or agronomists.
- Although there are a number of other AWS in the Macquarie Valley as well, the software that we used for the CTS sensors (Adcon AddVANTAGE Pro6) only supports data from Adcon Telemetry hardware, hence it would be very difficult to have any live display of weather information "out of crop" such as VPD to the soil moisture and CTS data, without a significant amount of software integration, which would be significantly higher than the relatively low cost of the AWS themselves.
- Our suggestion would be for a 3rd AWS to be located in a central location to the CTS trial sites. This could be in the form of a "mini-AWS" which still has BOM standard sensors, however only collects the basic parameters of Temperature, Humidity, Wind Speed & Gust, Wind Direction and Rainfall, and would add a significant amount of extra data to the CTS trial information being collected.
- Funding to be sought from the same parties as the 2015-16 season; Cotton Info, MCGA, Porosity Services & the individual growers involved with the trial.
- Improved assessment of phenological development at each site, to ensure that the crucial period of recording CTS Hrs > 30°C is quantified during the "flowering" phase, in order to compare each trial site better.

# SUGGESTIONS FOR FUTURE TRIALS (CONT).

- Visit the prospect of having 2 CTS in the same fields (ie. have 2 separate treatment zones), in an attempt to find some answers to or to test some theories:
  - 1 field could be used to try to find out the question posed earlier; "how much can growers improve their WUE by stretching out irrigations longer, to allow enough stress that increases its root water extraction without it impacting on yield". For example, have 1 CTS in short irrigation interval & small deficit, and 1 CTS in longer interval & larger deficit. The CTS in the larger deficit area could be used to monitor ONLY the differences between the 2 treatments, or alternatively be used proactively during the season to assist with the timing of irrigations. The goal would be to find the trigger point where the canopy stops cooling itself efficiently, in the hope that it stretches out the irrigation interval to minimise the total water applied and increase the WUE (bales / ML applied). If such a trial were to take place on a flood irrigation field, then we would also need to take into account soil and bed cracking, and what effect this has on irrigation performance; notably some soils that crack heavily may have issues with water crossing into a skip furrow, and/or the soil could absorb much large volumes of water that make timely irrigations for following fields difficult. A drip irrigation field may also be considered here.
  - 1 field to test another burning question: Is it OK to irrigate during a heat wave, or alternatively (IF your irrigation infrastructure allows it), are you better off to:
    - Irrigate early so as to avoid irrigating during the hot days, or
    - Try to delay irrigations as long as possible, and push the irrigation until after the worst of the hot days.
  - One train of thought is that irrigating during a heat wave can do more damage due to the possible waterlogging event that ensues, which reduces water uptake, combined with higher humidity & low VPD means the canopy can cook itself worse than having taken another course.
- Should either of these suggestions get up, then a number of other things need to be considered, such as how much extra monitoring would be required to quantify the differences (namely water use & yield), plus if the grower is happy to potentially sacrifice a small area of their fields in case it has severe negative impacts on their yield.
- Along with comparing WUE to CTS, it would also be beneficial to then analyse the gross margins (GM) respectively to each irrigation strategy, versus the risk profile eg. if irrigation is pushed one day too far, could this severely affect the yield.

# CONCLUSION & ACKNOWLEDGEMENTS

**Conclusion:**
The CTS trial conducted in the Macquarie Valley was a success, especially when you put a value on the amount of information gained by those people involved in the project. It showed how a collaborative approach by willing parties can help to pool resources, with each party benefitting more than if each party had tried to perform the same trial work individually; typical of the old adage "the whole is greater than the sum of its parts".

Some of the key lessons learned were:

- how the technology works, including some its limitations of the sensors.
- what the CTS data from the sensors means in relation to how the crop is performing.
- that canopy's are kept coolest when irrigated with more water and / or more frequently, and although a weak correlation to higher yields it does not equate to higher WUE.

There would be significant value to keep learning from continuing the trial, and put some theories to the test for future seasons, such as how far can an interval be stretched before the stress affects the yield.

**Acknowledgments:**
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- Stewart Denston (grower – Miegunyah)
- Matt Gainsford (grower – Euroka)
- Stuart & Jock Crawford (growers – Bungarley)
- Brad Anderson (grower – Ningawalla)
- Andrew Gill (grower – Waterloo)
- Tom Quigley (advisory panel)
- All other family members and work colleagues of the above-mentioned people.

Photographs in this report have kindly been provided by: Stuart Doyle (cover, page 8), Brian Thomson (page 7, 15 and 21), and Amanda Thomas (page 11).

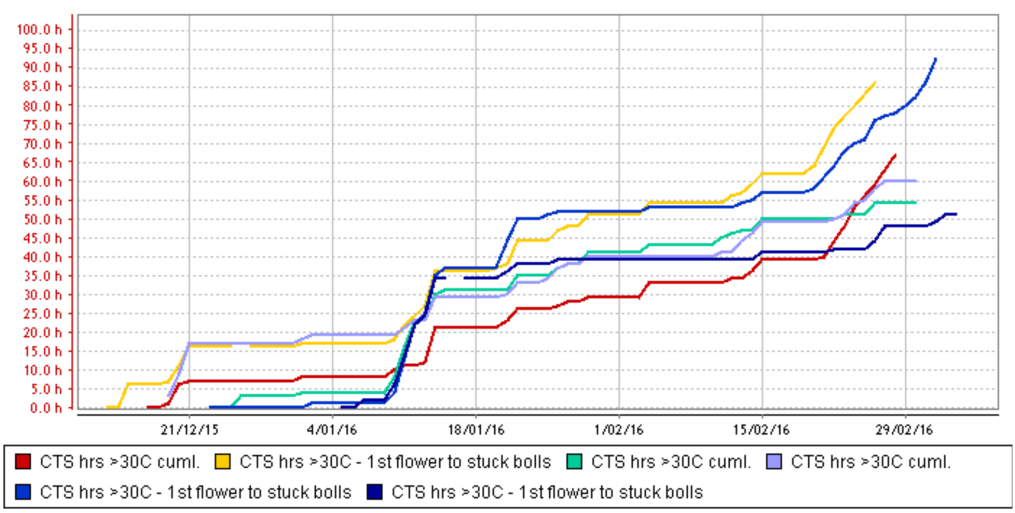
# APPENDIX

**Additional results:**

*Figure 16:* ALL trials sites and the vital information (crop dates, water applied, yield etc.)

| **MCGA – CTS Trial Site Information** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| **CTS Site #** | **CTS #1** | **CTS #2** | **CTS #3** | **CTS #4** | **CTS #5** | **CTS #6** | **CTS #7** |
| **Property & Field Name** | Mt Foster F60 | Milawa F2 | Miegunyah F8 sth | Euroka - Lateral | Bungarley F16 | Ningawalla F2 | Waterloo F1 Dskip |
| **Soil Type / Description** | Grey Vertisol to Red | Red alluvial loam | Grey Clay | Red loam into black | Sandy Loan (red) | Black Clay / Heavy W | Grey Silty Clay |
| **Cotton Variety** | 74BRF | 74BRF | 74BRF | 74BRF | 846 | 74BRF | BG3 |
| **Planting & bed configuration** | 1m rows, 1m beds | 1m rows, 1m beds | 1m rows, 1m beds | 1m rows, on the flat | 1m rows, on the flat | 1m rows, 1m beds | DBL skip, 4m beds |
| **Planting date** | 6/10/2015 | 21/10/2016 | 30/09/2015 | 14/10/2015 | 12/10/2015 | 7/10/2015 | 30/10/2015 |
| **Probe installed** | 11/11/2015 | 18/11/2015 | 11/11/2015 | 4/12/2015 | 23/11/2015 | 12/11/2015 | 5/12/2015 |
| **1st flower** | **16/12/2015** | **22/12/2015** | **12/12/2015** | **24/12/2015** | **18/12/2015** | **22/12/2015** | **4/01/2016** |
| **last effect. Flower** | 14/02/2016 | 28/02/2016 | 12/02/2016 | 16/02/2016 | 16/02/2016 | **18/02/2016** | 20/02/2016 |
| **Est. stuck bolls** | **28/02/2016** | **13/03/2016** | **26/02/2016** | **1/03/2016** | **1/03/2016** | **3/03/2016** | **5/03/2016** |
| **Probe removed** | 24/03/2016 | 24/03/2016 | 24/03/2016 | 30/03/2016 | 7/04/2016 | 30/03/2016 | 7/04/2016 |
| **Defoliation date (s)** | | | | | | | 12/04/2016 |
| **Harvest date** | 14/04/2016 | 19/04/2016 | 5/04/2016 | 28/04/2016 | 20/04/2016 | 15/04/2016 | 15/05/2016 |
| **Irrigation water source / quality** | Riparian | river | River | Bore | Bore | Bore | Bore |
| **Irrigation method** | bankless furrow | head ditch & syphon | head ditch & syphon | Overhead via Lateral | Sub-surface drip | head ditch & syphon | head ditch & syphon |
| **Irrigation notes from growers** | | When required, did | 63mm Siphon | Believed we had en | drip | Apply when needed | Dbl skip |
| **No. irrigations applied (& amounts)** | 10.5 | 8 in-crop | 9 in-crop on clay, 12 | Water up 3x15 ml...h | daily application | 7 incrop Irrigations T | 6 irrigations |
| **Water applied (ML/Ha) - A** | 10.5 | 7.6 | 8.33 | 8.7 | 7.25 | 8.1 | 4.15 |
| **In-crop rainfall (mm) - B** | 240 | 272 | 277 | 257 | 276 | 257 | 240 |
| **Starting minus Finishing moisture - C** | 80 | 100 | 100 | 90 | 100 | 110 | 240 |
| **Rainfall runoff - D** | | | | | | | |
| **Total water used (ML/Ha) = A+B+C** | 13.7 | 11.3 | 12.1 | 12.2 | 11.0 | 11.8 | 9.0 |
| **Yield (bales/Ha)** | 15.7 | 14.78 | 15.32 | 15.9 | 16.6 | 15.8 | 9.38 |
| **Yield (bales/Green Ha)** | 15.7 | 14.78 | 15.32 | 15.9 | 16.6 | 15.8 | 18.76 |
| **Yield (bales/ML)** | 1.15 | 1.31 | 1.27 | 1.31 | 1.51 | 1.34 | 1.05 |
| **Yield (bales/ML applied ONLY)** | 1.50 | 1.94 | 1.84 | 1.83 | 2.29 | 1.95 | 2.26 |

*Figure 17:* The cumulative hours above 30°C at all trial sites (from first flower till last effective flower).




**Legend: Red = CTS1 Mt Foster, Gold = CTS3 Miegunyah, Green = CTS4 Euroka lateral, Pale Blue = CTS5 Bungrley drip, Blue = Ningawlla, Dark Blue = Waterloo**

# APPENDIX

*Figure 18:* 2015-16 season Day Degree comparison to previous years.

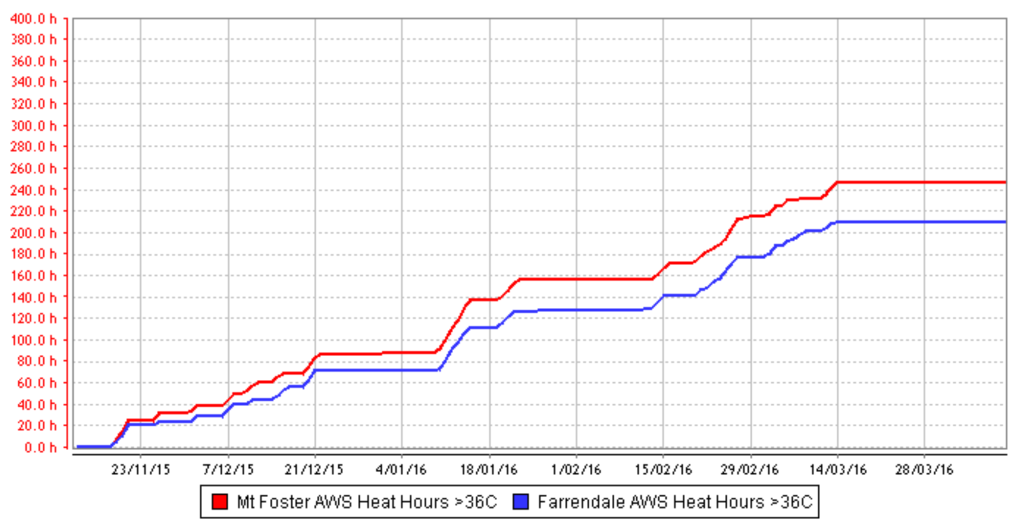
**Table of Day Degree Details for Warren (Mumblebone) (51034)**
Day Degree Accumulations for the period 1 October to 20 March in the years 1957 to 2016.
Note: Hot Days have Max Temp >= 36°. Cold Shock Days have Min Temp <= 11° and are shown with *.

| Date | 2015 | 2014 | 2013 | 2012 | 2011 | 2010 | Hi 2005 | Lo 2011 | Average |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **20-Mar** | **2,375.5** | **2,333.3** | **2,231.3** | **2,274.5** | **1,808.0** | **2,033.3** | **2,390.8** | **1,808.0** | **2,082.4** |
| 19-Mar | 2,367.3 | 2,317.0 | 2,217.8 | 2,263.0 | 1,797.3 | 2,021.0 | 2,376.0 | 1,797.3 | 2,070.7 |
| 18-Mar | 2,361.3 | 2,303.3 | 2,205.5 | 2,253.0 | 1,789.0 | 2,010.8 | 2,362.8 | 1,789.0 | 2,058.8 |
| 17-Mar | 2,346.0 | 2,285.5 | 2,196.3 * | 2,245.3 | 1,779.3 | 2,000.5 | 2,350.3 | 1,779.3 | 2,047.2 |
| 16-Mar | 2,332.0 | 2,272.3 | 2,189.0 | 2,236.5 | 1,769.3 | 1,986.3 | 2,341.0 | 1,769.3 | 2,036.0 |

**Table of Day Degree Details for Narromine Airport (51115)**
Day Degree Accumulations for the period 1 October to 20 March in the years 1957 to 2016.
Note: Hot Days have Max Temp >= 36°. Cold Shock Days have Min Temp <= 11° and are shown with *.

| Date | 2015 | 2014 | 2013 | 2012 | 2011 | 2010 | Hi 1982 | Lo 1971 | Average |
|---|---|---|---|---|---|---|---|---|---|
| Hot Days | 45.0 | 34.0 | 39.0 | 45.0 | 7.0 | 18.0 | 48.0 | 2.0 | 23.0 |
| Cold Shock | 14.0 | 26.0 | 40.0 | 31.0 | 30.0 | 20.0 | 25.0 | 43.0 | 30.8 |
| | | | | | | | | | |
| **20-Mar** | **2,187.3 *** | **2,150.5** | **2,054.8** | **2,125.3** | **1,685.5** | **1,879.0** | **2,232.8** | **1,624.6** | **1,906.2** |
| 19-Mar | 2,179.5 * | 2,135.8 | 2,042.8 | 2,115.0 | 1,675.3 | 1,866.5 | 2,224.3 | 1,613.3 | 1,895.5 |
| 18-Mar | 2,174.0 | 2,123.0 | 2,032.0 * | 2,105.8 * | 1,667.3 | 1,855.8 | 2,212.8 | 1,601.2 | 1,884.5 |
| 17-Mar | 2,161.5 | 2,107.3 | 2,023.3 * | 2,098.5 | 1,658.0 | 1,845.8 | 2,200.5 | 1,590.8 | 1,873.7 |
| 16-Mar | 2,149.8 | 2,095.5 | 2,016.3 | 2,090.8 | 1,648.0 | 1,832.5 | 2,187.5 | 1,581.3 | 1,863.3 |

*Figure 19:* Heat Stress Hours (>36°C) comparison of Mt Foster AWS( north) v Farrendale AWS (south).



# APPENDIX

*Figure 20:* Compares the average Air Temp "in-crop" to the Canopy Temperature by time of day. Canopy warms up with the air temp in the morning then starts cooling itself after midday. This data is an average of the 3 × CTS trial sites that had both the CTS sensors and the Air Temp "in-crop" sensors, for the period from 21 Dec 2015 to 18 Feb 2016.