# FINAL REPORT

Public Version

## Part 1 - Summary Details

**CRDC ID:** DAN 1701

**Project Title:** Optimising seedling emergence

**Project Start Date:** 1/7/2016 **Project Completion Date:** 30/6/2019

**Research Program:** 1 Farmers

## Part 2 – Contact Details


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**Signature of Research Provider Representative:**

**Date submitted:** approved under INT20/367481 on 22 October 2020

# Part 3 – Final Report

*(The points below are to be used as a guideline when completing your final report)*

***Background***

**1. Outline the background to the project.**

Cotton production in southern NSW has expanded over the past 10 years to a record area of 90,050 ha in the 2017/18 season. With increased cotton prices and the increased water use efficiency of cotton performing better than other summer irrigated crops, the industry is seeing more growers change over to the more profitable crop. Of the 219 growers in 2017/18, 64 were new growers with cotton pushing down into northern Victoria. There are now 4 commercial cotton gins operating in the region with plans for another to be constructed in the near future.

Growing cotton in the cooler growing regions of the south means growers face challenges around poor establishment, increased probability of seedling diseases, canopy management as well as defoliation issues. Due to the shorter growing season experienced in the south, growers are challenged with the decision of planting early and experiencing poor plant stands and delayed emergence or planting later and facing delayed maturity and wet picks at harvest time. A major issue grower's face is the decision to replant a field if the plant stand is poor.

***Objectives***

**2. List the project objectives and the extent to which these have been achieved, with reference to the Milestones and Performance indicators.**

1. What are the key factors that influence cotton plant establishment in southern production areas?

Upon starting as Cotton Researcher Officer at Yanco, Steve Buster met with many growers and agronomists to identify the key factors that influence cotton plant establishment. A Southern Cotton Panel consisting of 17 growers/consultants and extension officers was formed to deliver on this issue. Recruitment of Mr Buster occurred in late November 2017 with no reasonable time available to establish trials in this season. Tours and discussions with agronomists indicated a large variability between tactics and the skillset of growers (Appendix 2). Steve then instigated the 'Southern Field Database' (Appendix 1) where ginning and consultant's data was compiled to provide an overview of the 2016/17 season performance. Steve resigned in May 2018 and was replaced by Hayden Petty in November 2018. Hayden picked up 2 trials initiated by Steve (Chp 5 & 6).

2. What management strategies provide optimal conditions for crop establishment?

With consultation from the Southern Cotton Panel it was identified that trials examining the effect of sowing time, use of growth regulants, polymers and row orientation would all be beneficial to help improve strategies to improve crop establishment. In the 2017/18 season Mr Buster conducted three trials researching sowing dates, plant hormones and biodegradable plastic. Outcomes of these trials can be found in chapters 1, 2 and 3.

3. What are the thresholds for plant establishment in these environments that require a replant decision?

No designated experimental trials were conducted on a replant scenario during the life of this project. Grower's that replant a field do so based on poor plant stands, disease and soil/moisture interactions. A replant case study was conducted in the 2018/19 season (chapter 5) where a grower had replanted 3 of the 5 bays in a field due to black root rot resulting in poor plant establishment. The decision not to replant the other 2 bays was based on there being a sufficient plant stand.

4. What are the new technologies that can assist with optimising seedling emergence?

Biodegradable film was the only new technology trialled in this project. Chapters 1 and 4 outline the results from these trials. It appears that the biofilm has a very tight window of opportunity where it will have a benefit to the crop. Planted too early such as the trial in the 2017/18 season and other confounding factors such as cool temperatures and moisture stress during early season growth limit its effectiveness. Planted in the back end of the planting window and the benefit of increasing soil temperatures in nullified as soil temperature during this time already exceeds thresholds. Due to relying on commercial enterprises to conduct these trials it is difficult to arrange the correct timing.

5. What physiological data is required to validate the OZCOT development model for the southern areas?

Crop phenology and temperature data was supplied to Dr Mike Bange for the 2017/18 growing season.

***Methods***

3. **Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.**

Please refer to chapters.

***Results***

4. **Detail and discuss the results for each objective including the statistical analysis of results.**

Please refer to chapters.

***Outcomes***

5. **Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.**

Please refer to chapters.

6. **Please describe any:-**
   a) **Technical advances achieved (e.g. commercially significant developments, patents applied for or granted licenses, etc.);**
   b) **other information developed from research (e.g. discoveries in methodology, equipment design, etc.); and**
   c) **Required changes to the Intellectual Property register.**

***Conclusion***

7. **Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?**
   - Cotton establishment is function of temperature, moisture and seed placement
   - Temperatures in the south continue to be variable and growers need to react to these conditions to the best of their ability
   - Like Liebig's law of the minimum if one element of crop agronomy is lacking, high yields will not be achievable. For example, a potassium imbalance in the soil can lead to early senescence and therefore limit yield despite attempts to increase early season growth and development.

- Use of new technology such as Biofilm has proven to increase yields but is highly dependent on the temperature/moisture interaction at planting.
- In circumstances where cotton is planted during late September and establishes without pressure from the environment, insects or diseases it can accumulate more day degrees and yield higher than a later sown crop but is highly dependent on irrigation and nutrition.

***Extension Opportunities***

**8. Detail a plan for the activities or other steps that may be taken:**
**(a) To further develop or to exploit the project technology.**
**(a) For the future presentation and dissemination of the project outcomes.**
**(b) For future research.**

**9. A. List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s)**

- Review of Farming Practices and Opportunities for Research in the Southern Cotton Growing Region
- 2016-17 Cotton Season and physiology 101 July 17.pdf
- Rivcott 2016-17 Cotton Season.pdf
- Condobolin Farm Walk 5-3-18.docx
- CSU 4th year cotton lecture 140318.pdf
- Field day Cotton Crop Establishment 2018.pptx
- Rivcott Symposium 2018 Data Base Presentation.pptx
- Rivcott Symposium 2018 Plant Mapping 2017-18.pptx
- Southern Grower Data Base.pdf
- Yanco Cotton Research Review August 2017.pdf
- Sothern Research Review Aug 2018.pdf

**B. Have you developed any online resources and what is the website address?**

## Part 4 – Final Report Executive Summary

*Provide a one-page summary of your research that is not commercial in confidence, and that can be published on the internet. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.*


The Australian cotton industry has made considerable yield gains by improving genetics and agronomic management, which is ultimately limited by the environmental constraints in our growing regions. One of the major factors limiting yield in Southern NSW is the unpredictably cool start to the cotton growing season. This has a negative impact on grower's ability to establish a consistent plant stand within an optimum planting window that allows sufficient length of season to obtain high yields.

Germinating cotton seed is an interaction between soil temperature, moisture and seed/soil contact. Depending on the season most growers are able to achieve a uniform, consolidated seed bed for optimum seed/soil contact but must react to fluctuating temperatures and consider irrigation water temperature at the time of planting.

The results from this project suggest there is no silver bullet to improve yields. The attempts to improve crop establishment and increase early season growth returned nil significance during the seasons they were tested. The main outcome present across all experiments was that other agronomic management such as soil health, pest and disease pressure and seasonal environmental challenges limited the yield more than treatments imposed to affect establishment.

Application of plant hormones to increase early season growth and boll loads have returned mixed results from work conducted in Australia and internationally. Irrigation and nutrition management play a large role in the efficacy of such products having an influence on yield components. For example, where soil conditions resulted in the crop experiencing potassium deficiency late in the season and undergoing early senescence, a review of the treatment effects of the products used is required. This work needs further investigation targeting compensatory growth and stress alleviation.

Technologies such as biodegradable plastic applied over the seed line show promise to improve establishment but is highly dependent on planting date. Early planted crops experience an increased response to temperature/moisture dynamics when compared to late planted crops. The exercise of applying this plastic is expensive and requires a yield increase of 1 bale/ha in order for it to be worthwhile. Therefore, yield gains expected from application of the plastic should be done so on fields where there is no expected yield constraints from other factors such as disease or nutrition.

Evaluation of factors limiting yield potential should be considered from a whole farm perspective and not just one facet of crop agronomy. While achieving a consistent plant stand is crucial to achieving high yields; other factors like nutrition, irrigation management, pest and disease control and seasonal conditions have a considerable influence on yield. Tackling all of this to improve yield is a massive task but over time with the skill set of the Australian cotton industry it can be done.

## *Chapter 1 - Biofilm Trial 2017-18*

### Introduction and Aim

The southern cotton growing region is typified by a cool start and finish with a warm to hot growing season during flowering and early boll fill with high solar radiation compared to the established northern cotton growing regions.  Southern growers have found significant delays in germination time (greater than 14 days and up to 21 days) and slow early growth.  Studies undertaken in the 1960's and 1970's by Christiansen and others, document the effect of temperature on germination (Christiansen, 1963, 1964, 1968; Christiansen & Thomas, 1969). Film/plastic has been used in many horticultural crops for weed control and early planting (Lament, 1993).  A clear slotted bio-film that can be placed over a cotton row has been developed by One-Crop P/L and Norseman planters.

The aim of the trial was to compare cotton planted under bio-film with cotton planted direct into bare soil in terms of germination, growth and yield.

### Material and Methods

The experiment was located west of Griffith with cracking grey clay soil with cotton rows on 1 metre spacing in bay irrigation system.  Field experiment design is shown in Figure 1.  Plot sizes were 12 metres wide (planter width) approximately 450 metres long.  Cotton variety Sicot 748B3F was planted with 12 row planter and slotted film was laid over the top of the plant line. The field was then irrigated up.

East Side

| **Rep** | **Rep 1** | | **Rep 2** | | **Rep 3** | |
|---|---|---|---|---|---|---|
| **Variety** | Film | Control | Film | Control | Film | Control |
| **Rows 450m** | 12 | 12 | 12 | 12 | 12 | 12 |
| **Tractor pass** | 1 | 1 | 1 | 1 | 1 | 1 |
| **Picker pass** | 2 | 2 | 2 | 2 | 2 | 2 |

**Figure 1.  Trial design of biofilm 2017-18**

**Results**
**Germination**
Germinating temperatures are shown in figure 2.

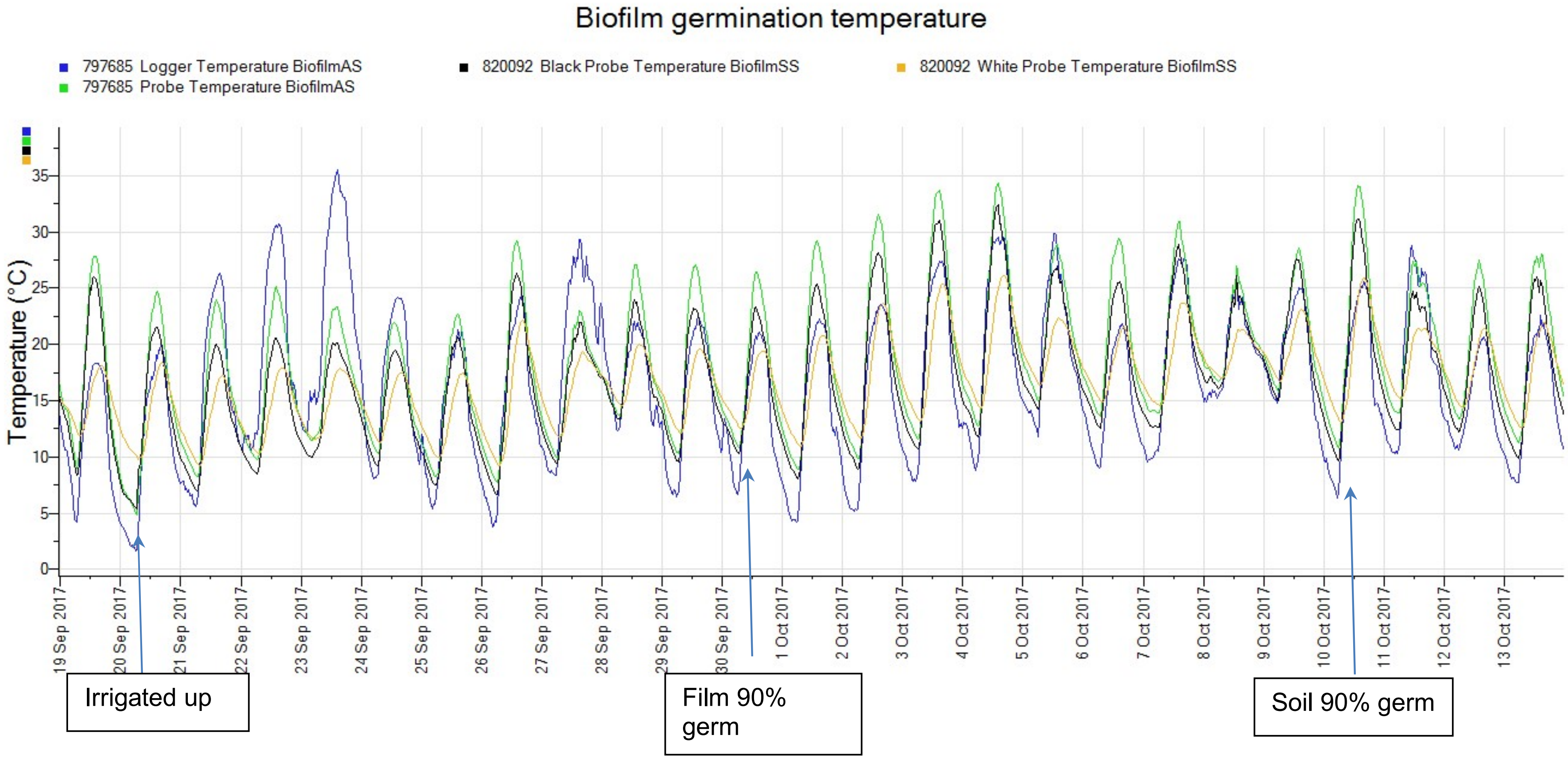



**Figure 2. Biofilm air and soil temperatures, blue trace is logger air temperature, green trace is film@25mm probe temperature, black trace is soil@25mm probe temperature and orange trace is bare soil @100mm probe temperature**

The impact of film on germination and radical growth is shown in figure 3. Seed was randomly dug up from two rows on the 25th September, 5 days after sowing (photo says six but is incorrect). Film averaged 20mm long and soil average 8.5mm long


**Figure 3. Photo showing radical length 5 days after field was irrigated up.**

Seed was planted shallow and under the soil treatment some seed probably dried out faster than they could develop the radical to stay in moisture. This resulted in a patchy stand in different parts of the field depending upon soil type. Some rows were better than others. From a commercial viewpoint it is questionable whether the soil treatments should have been replanted.. Slow germination is a function of both cool temperature, cold water and marginal moisture (moisture was not measured just observed).

Photos of germination/emergence under film and soil treatments are in figure 4a and 4b. Moisture accumulation under the film is apparent as is the much greater plant population that emerged.

Germination counts were measured over 5 metres. Seed under film had 90% emergence 10 days after sowing acquiring 70 day degrees base 12 (DD12) and 53 day degrees base 15/32 (DD15). Seed planted direct to soil had 90% emergence in 20 days and acquired 141 (DD12) and 108 (DD15). Germination rate and total plants are shown in figure 5. Full temperature records are contained in the spreadsheet.

Figure 4a. Emergence under film and 4b emergence under bare soil treatments.

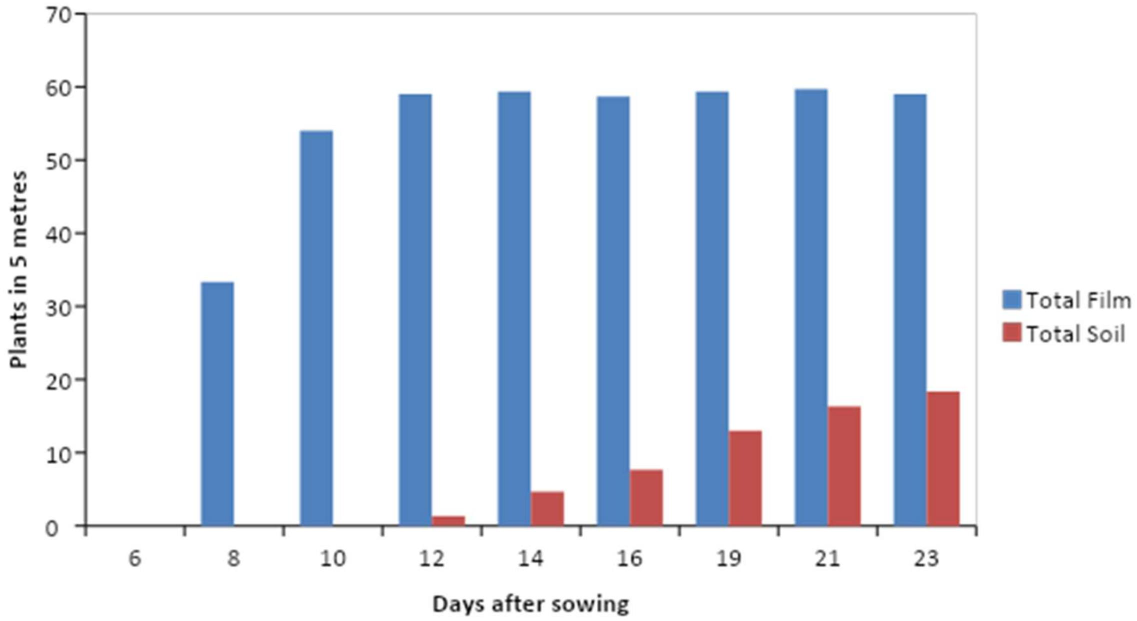



**Figure 5. Total emerged seedlings for film and soil in 5 metres of row.**

**Node Growth**

Node growth, Nodes above white flower (NAWF) and Nodes above cracked boll (NACB) are plotted against days after sowing (figure 8). The first flower appeared around 10 NAWF and this indicates balance between vegetative growth and reproductive growth is in favour of the vegetative potential of the crop. Total node growth is 29-30 nodes which is 6 to 8 nodes above other trials this year. The vegetative nature of the crop is also demonstrated by the slow rate of decrease of NAWF (normally 1 node per week), and the defoliation when the NACB is still 8.5 for the soil treatment. The film treatment is slightly better at 5.5 NACB at defoliation is considered safe for quality issues at 4 NACB.

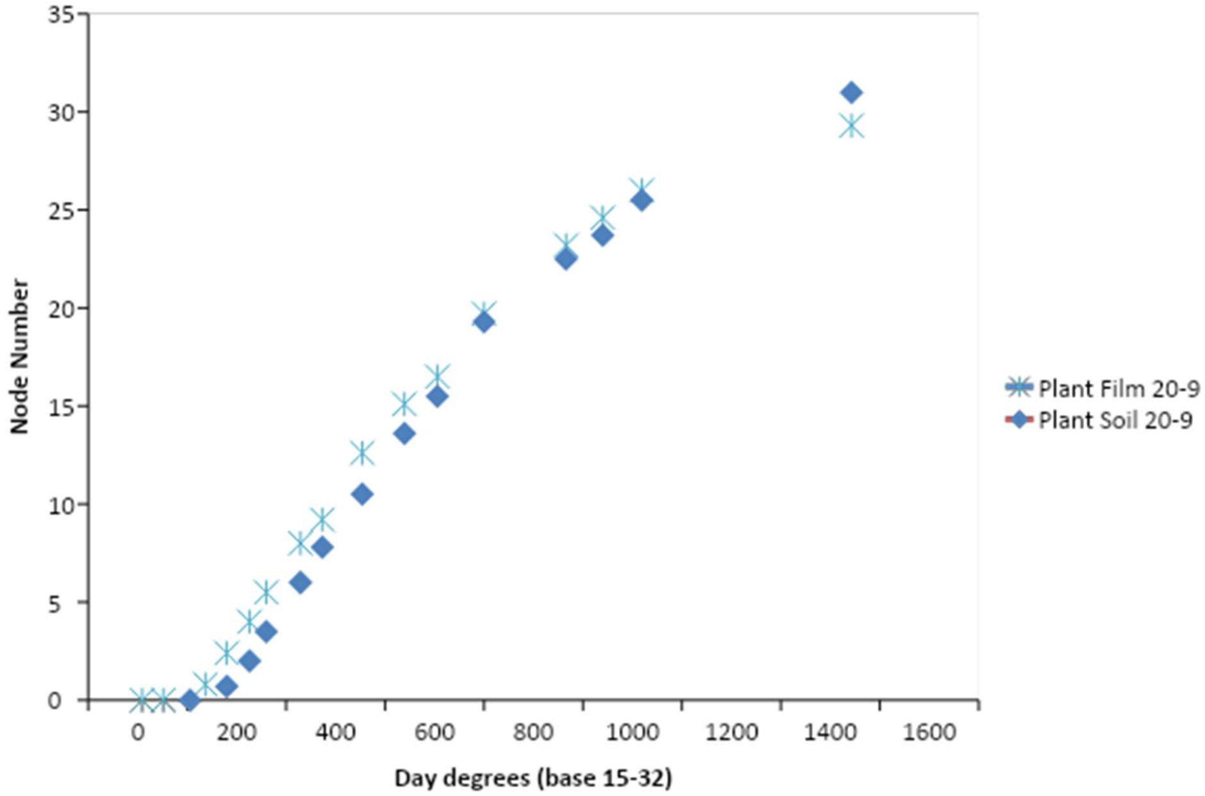



**Figure 6. Node growth for plants in film and soil treatments as a function of day degrees base 15-32**

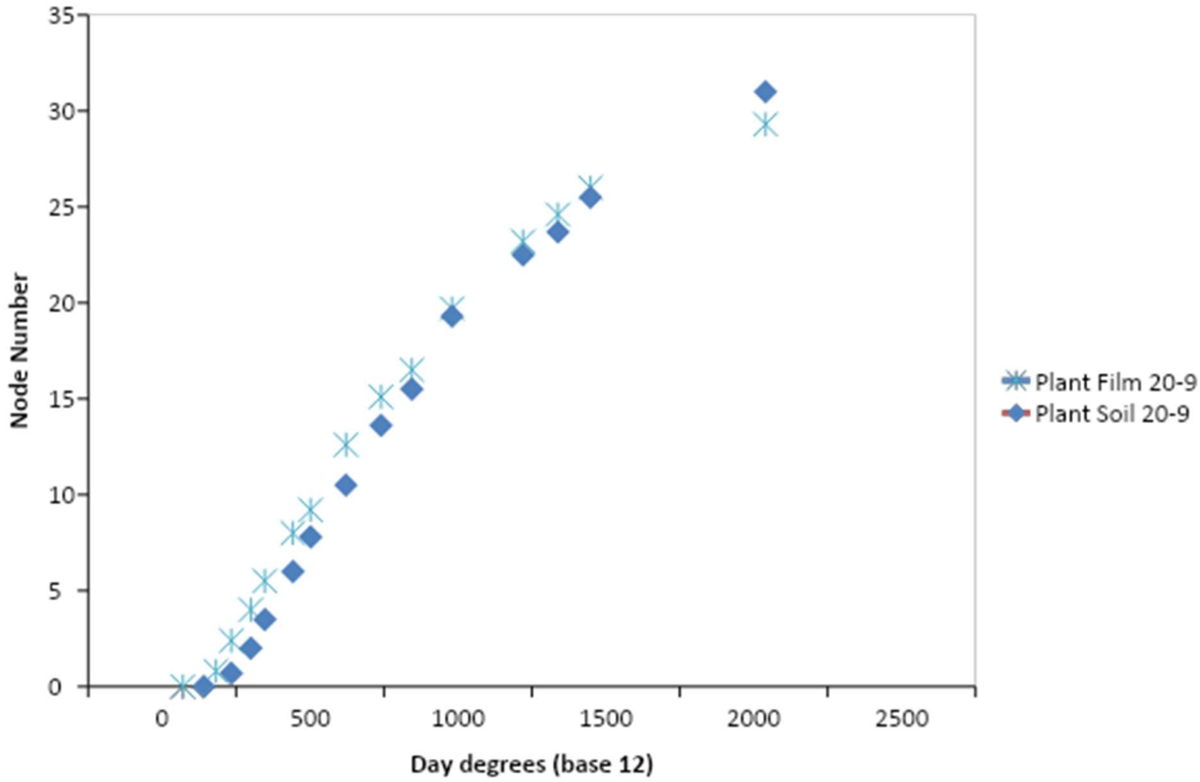



**Figure 7. Node growth for plants in film and soil treatments as a function of day degrees base 12**

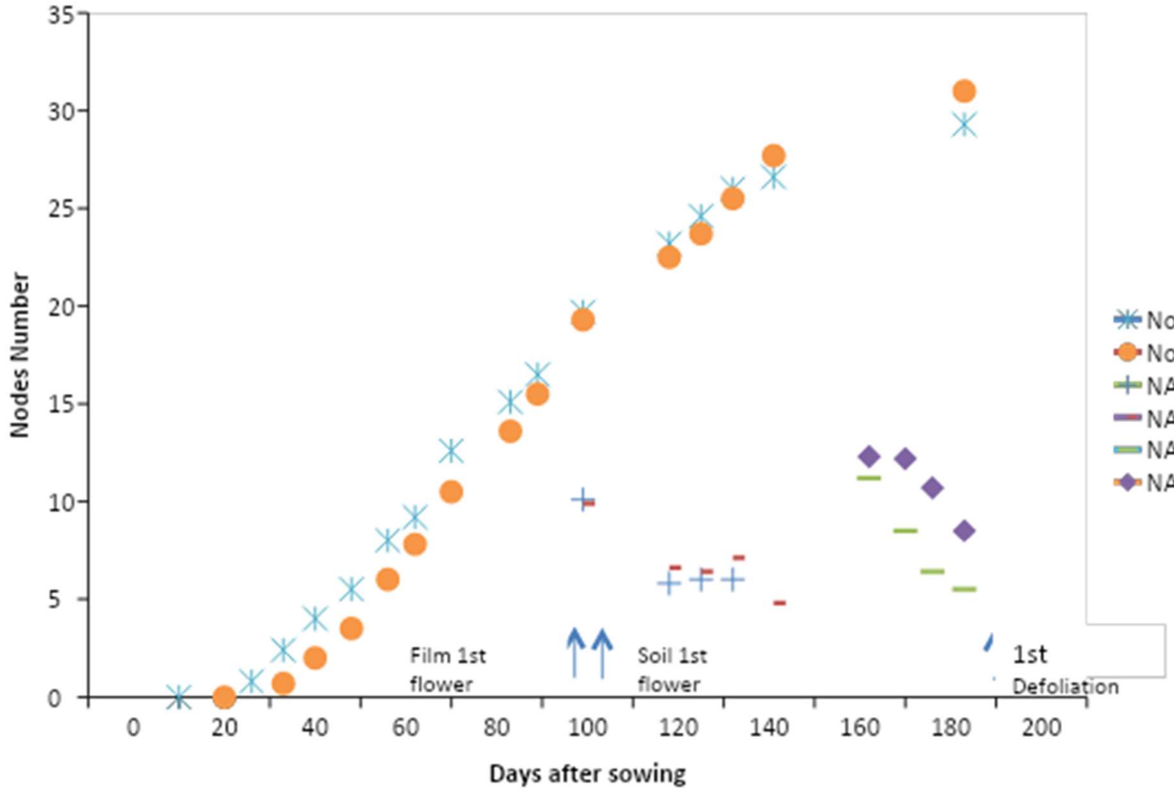



Figure 8. Node growth, NAWF and NACB for plants in film and soil treatments, as a function of days after sowing.

**First fruiting node**
The appearance of the first square was averaged 10.0 in the film and 9.9 in the soil treatments respectively. This is one to two nodes higher than other trials planted later in warmer temperatures. The other trials were of variety CS 74-6 compared to CS 74-8. This may explain the difference in first fruiting node, however the literature suggest that temperature stress can raise the first fruiting branch up to three nodes (Edmisten, 1993).

**NDVI**
A Greenseeker was used to measure NDVI from late November to late December. No significant (P<5%) result was recorded between treatments (table 1). However, NDVI recorded around first flower on the 29th December was significant at 7.5% level (P=7.3%). Recorded data is in trial spreadsheet. Data is mixed and somewhat unreliable due to the many gaps in the soil treatment (however this is a reflection of crop growth). Rows in the soil treatment had to be selected that had the least amount of gaps in them so data needs to be interpreted carefully.

**Dry Matter Cuts and Final Yield**
Dry matter cuts were taken around first flower (28th Dec) and before defoliation (22nd March). Dry matter production at first flower was significant at 5.7% level with film having about twice the production as the soil treatment. This did not carry through to final dry matter production (table1).

Cotton was harvested by a 6 row cotton picker making two round modules per plot. Cotton was ginned, and yields calculated to bales per ha from an average turnout of 38.6% (total lint weight from gin/total seed cotton weight form modules weights). Estimated yield resulted in the film treatment yielding 1.3 bales/ha greater than the soil treatment. This was significant at the 6% level.

| | Film | Soil | F prob | LSD (P<0.05) |
|---|---|---|---|---|
| B/ha | 10 | 8.7 | 0.06 | 1.48 |
| DM 1st flower | 2100 | 1017 | 0.057 | 1162.6 |
| DM cut-out | 13630 | 14496 | 0.524 | Ns |
| NDVI 29_11 | 0.395 | 0.344 | 0.471 | Ns |
| NDVI 18_12 | 0.651 | 0.4171 | 0.073 | 0.288 |
| NDVI 28_12 | 0.855 | 0.6966 | 0.225 | Ns |

**Table 1. Yield as estimated from seed cotton weights and dry matter production measured at first flower and before defoliation and NDVI results for film and soil treatments.**

**Discussion and Conclusions**

The use of planting cotton with biofilm as opposed to bare soil resulted in faster germination (10 days compared to 20 days), initially faster node production up to node 19. Increased dry matter production at $1^{st}$ flower which is reflected in NDVI readings and ultimately increased yield by approximately 1.5 bales per hectare. The seed depth/soil temperature is higher under film compared to bare soil. It is interesting to note that the minimum temperatures for film averaged 1°C warmer than the minimum soil and 2.7°C warmer than the maximum of soil over the 20 days of germination. While these temperature differences are not great in magnitude they have significant impact on cotton that is germinating.

Figure 2 also records ambient air temperature.During germination the minimum temperature on some days was below 5°C. This cool temperature is reflected in the minimum soil temperature at 10cm rarely getting above 14°C (let alone for three days) which is the recommendation for optimum planting conditions. Thus the use of biofilm overcame the cool ambient temperature effect but it still exposed seedling to cold temperatures once the crop established.

Upon germinating both treatments were exposed to cool conditions resulting in slow node growth and possibly raising the first fruiting branch position.

Both treatments were not pixed until cutout at the end of January. The plants struggled to stop growth and stop producing nodes and flowers as a consequence of variety (Sicot 746B3F), low boll load (with higher fruit set) and a gappy plant stand in the soil treatments. The gappy stand can be seen in the soil treatment harvest photo (figure 9). As discussed above the crop became vegetative as a result of variety, delayed first fruiting branch and gappy stands. This vegetative growth required three defoliations before harvest (other crops planted two weeks later only required two) and delayed maturity as can be seen in the harvest treatment photo (figure 10). Yield was enhanced by allowing the crop to grow out but this would not normally be the case and defeated the purpose of planting early to try and achieve an early crop.

The yield increase of 1.3 bales/ha of film over soil treatments could result in a gross margin income of $650 per hectare (cotton at $500 per bale). The cost of the film is roughly $300/ha which would imply a profit of $300 per hectare. There are issues of planting capacity with the film that need to be addressed but the results do mean the concept should continue to be investigated.

**Figure 9. Open cotton in the soil treatment showing the gappy plant stand as a result of poor establishment at planting**

**Figure 10. Open cotton of the treatments of soil (left and far right) and film (right) showing the delayed maturity of the soil treatment with less open cotton at the top of the bush.**

The trial should be repeated but sown in the more suitable sowing window of late September-early October so seedlings are not exposed to cool temperatures. Care needs to be taken with seed depth as some seed in the soil treatments dried out before emerging causing a gappy plant stand. Four replicates would also reduce variability in the data if unplanned events happen (like gappy plant stands).

**References**


Christiansen, M. N. (1963). Influence of Chilling upon Seedling Development of Cotton. *Plant Physiology, 38*(5), 520-522.

Christiansen, M. N. (1964). Influence of Chilling Upon Subsequent Growth and Morphology of Cotton Seedlings. *Crop Science, 4*(6), 584-586.

Christiansen, M. N. (1968). Induction and Prevention of Chilling Injury to Radicle Tips of Imbibing Cottonseed. *Plant Physiology, 43*(5), 743-746. doi:10.1104/pp.43.5.743

Christiansen, M. N., & Thomas, R. O. (1969). Season-Long Effects of Chilling Treatments Applied to Germinating Cottonseed. *Crop Science, 9*(5), 672-673. doi:10.2135/cropsci1969.0011183X000900050052x

Edmisten, K. (1993) Plant Monitoring: The Onset of Fruiting to Bloom. In*: Vol. CCN-93-6a June, 1993. Carolina Cotton Notes*: North Carolina State University.

Lament, W. J. (1993). Plastic Mulches for the Production of Vegetable Crops. *HortTechnology, 3*(1), 35-39.

## *Chapter 2 – Irrigation Research and Extension Committee (IREC) Hormone Trial 2017/18*

**Introduction and Aim**

Southern growers have found significant delays in germination time (greater than 14 days) and slow early growth due to the typical cool start to the season. In addition, fruiting cotton plants can respond to stress events by shedding fruit. These stress events can include cloudy cool weather, extreme temperatures and water logging to name a few. Fruit is shed as either young squares (less than 5mm) or young bolls (10mm diameter). The aim of the IREC hormone experiment was to investigate ways to influence germination time, increase early plant growth and retain fruit after a shedding event by using and or manipulating plant hormones.

The first question this experiment tried to answer was whether we can influence germination time, early growth and yield by the use of a composite of plant growth hormones. The literature has shown that a PGR-IV used in the 1980's and 90's enhanced seedling growth and yield (Oosterhuis, 1994). PGR-IV produced by Micro Flow, Lakeland, Florida USA consisted mainly of 0.003% (w/v) gibberellic acid (GA), 0.0028% (w/v) indolebutyric acid (IAA) and a proprietary fermentation broth (*ibed*). PGR-IV is no longer available but Biozyme TF produced by Arista Life Sciences in Mexico was found. It consists of GA (0.0031% w/v), IAA (0.0031% (w/v) and Cytokinin (0.0083% w/v) in addition to a number of micronutrients. One litre of Biozyme TF was provided by Arisata Life Sciences for this experiment.

Ethylene is known to affect plant processes as fruit maturation, ripening and fruit drop. It is thought it is involved in shedding of young fruit caused by stress events. The second question this experiment looked at was whether applications of Aviglycine (AVG) which inhibits the production of ethylene could reduce the shedding of fruit caused by a stress event. AVG is produced by Sumitomo under the label of ReTain and was provided by Sumitomo for this experiment.

**Material and Methods**

The experiment was located at the Irrigation Research and Extension Committee (IREC) research farm located at Whitton NSW. Coordinates of the field are Latitude -34.541340° Longitude 146.181137°. Soil is a transitional red brown earth and is described by (Blackwell et al., 1991).

The experimental design was a split plot with two main plots of Control versus Biozyme TF and three sub plots of AVG consisting of nil, early square and mid flowering applications of AVG, replicated three times. Plot sizes were 12 rows (metres) wide by 310 metres long. Cotton variety Sicot 746B3F was planted on a bed (camel hump) configuration and irrigated in bay irrigation design from both ends.

Trial Design

| Buffer | Rep 3 | | | | | | Rep 2 | | | | | | Rep 1 | | | | | | Buffer |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Buffer | Control | AVG 2 | AVG | Biozyme | AVG | AVG 2 | Biozyme | AVG | AVG 2 | AVG | AVG 2 | Control | AVG 2 | AVG | Control | Biozyme | AVG | AVG 2 | Buffer |
| 32 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Results**
Recorded temperature at sowing and emergence is shown in figure 1.

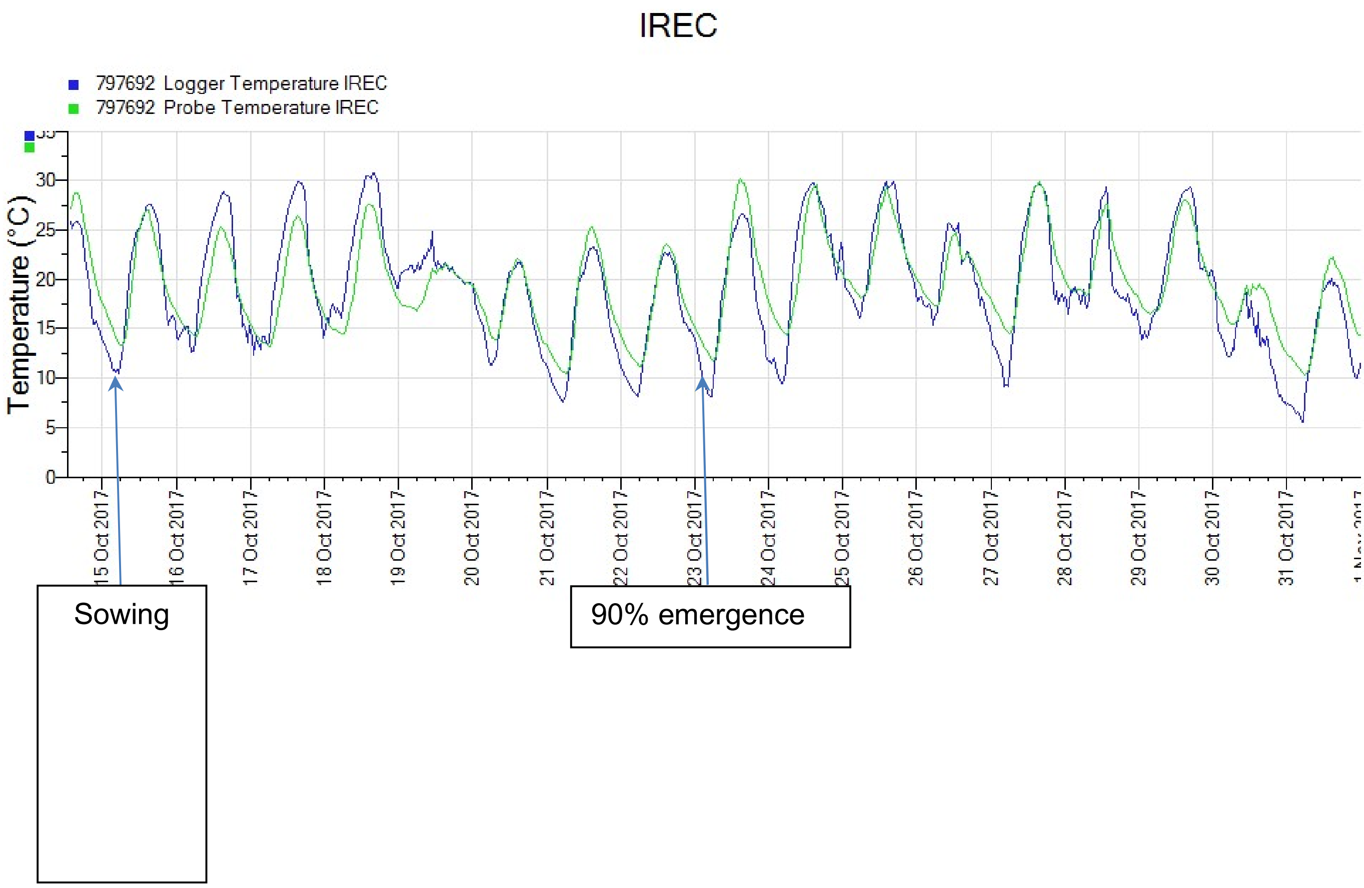



**Figure 1. Air and seed/soil @25mm temperature for sowing germination at IREC October 2017. Blue trace line is air temperature, green trace line is soil probe temperature at 25mm in seed line.**

**Germination**
Germination counts were measured over 5 metres. Only Biozyme and Control treatments were counted. Eight days after sowing the germination results are shown in Table 1. Germination took only 65 day degrees base 12 (DD12) or 47 day degrees base 15/32 (DD15). Full temperature records are contained in the spreadsheet.

**Table 1. Germination percentage and plants per meter eight days after sowing for Control and Biozyme treatments.**

| | | % Germ | Plants/m |
|---|---|---|---|
| **Rep 1** | **Biozyme** | 95% | 11.6 |
| | **Control** | 87% | 13.2 |
| **Rep 2** | **Biozyme** | 100% | 13.8 |
| | **Control** | 93% | 14 |
| **Rep 3** | **Biozyme** | 96% | 14.6 |
| | **Control** | 92% | 11.6 |
| **Average** | **Biozyme** | 97% | 13.3 |
| | **Control** | 91% | 12.9 |

**Node Growth**
Weekly node counts were taken on Biozyme and Control treatments. The data set is contained in the spreadsheet. There is no difference between treatments. The control treatment node growth as a function of DD12 is shown in figure 2. Figure 3 shows node growth of control treatment along with nodes above white flower (NAWF) and nodes above cracked boll (NACB) as a function of days after sowing. The combined average treatment data has been included in the Combined Trials 17-18 DD and Phenology.xlsx

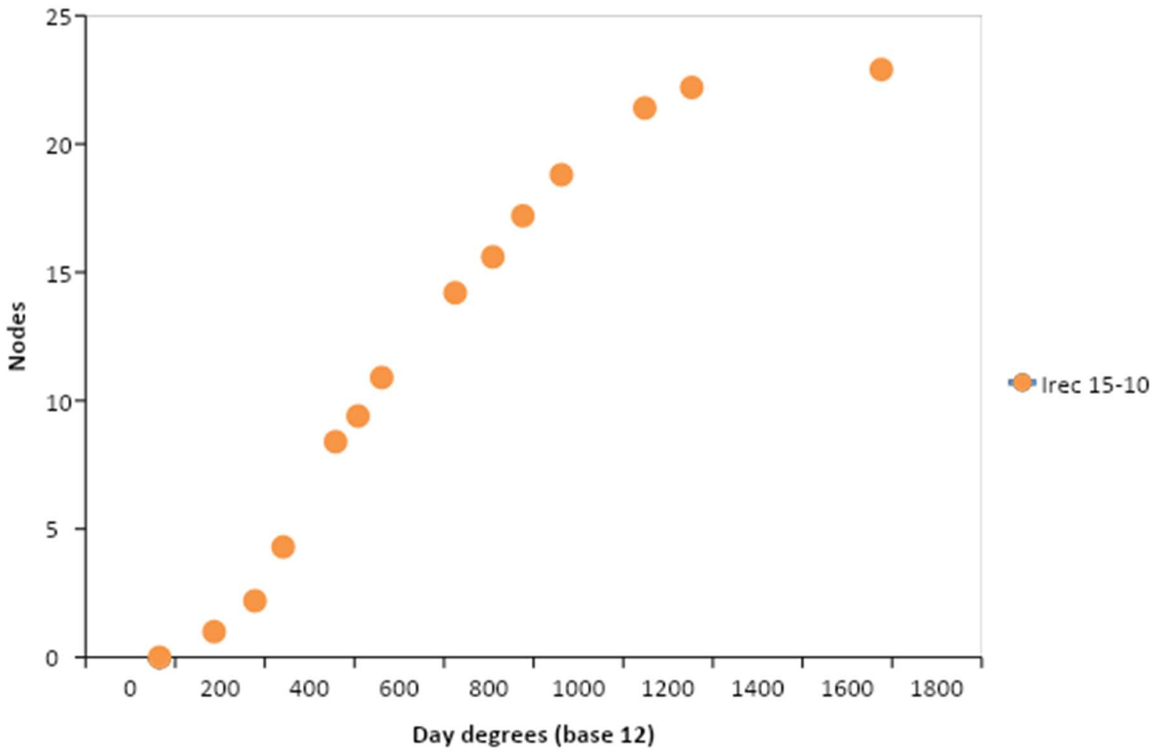



Figure 2. Nodes growth of the control treatment as a function of day degrees base 12.

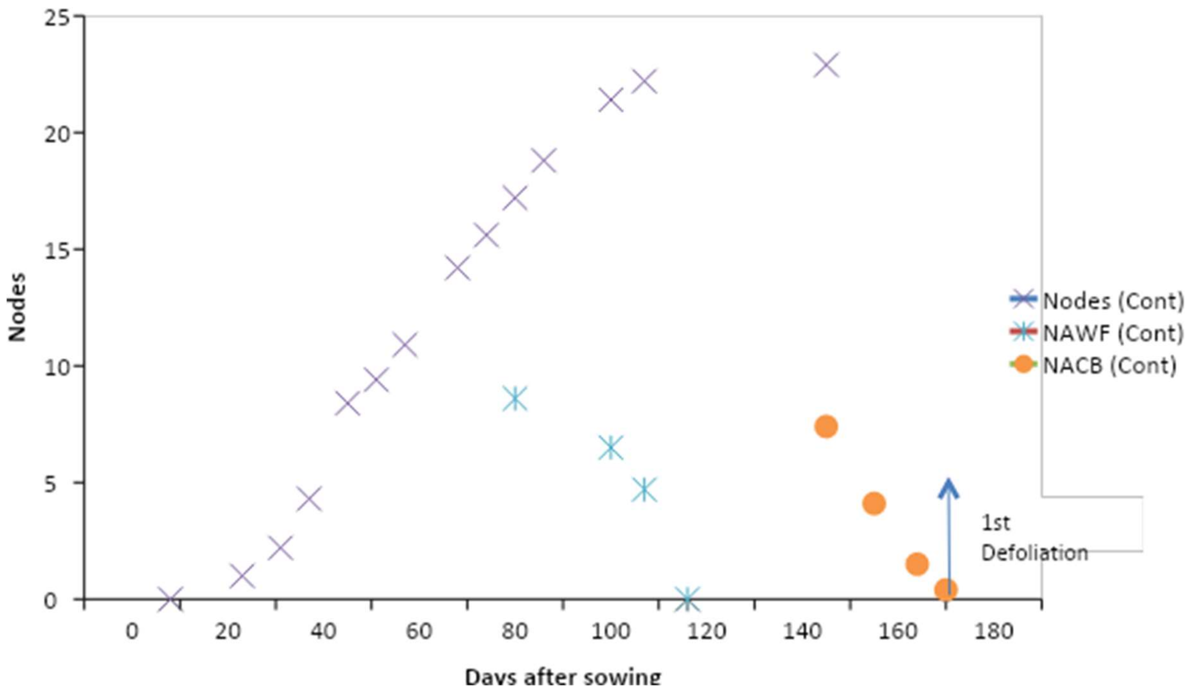



Figure 3.  Node production, NAWF and NACB for the control treatment as a function of days after sowing.

**NDVI**
A Greenseeker was used to measure NDVI from late November to early January.  No significant result was recorded between the Biozyme and Control treatments.  Recorded data is in the trial spreadsheet.  On a practical note this instrument needs to have a consistent operator and be held at a consistent height above the crop as it grows to reduce the error of measurement.

**Fruit Retention**
Fruit retention was taken from the Control, Biozyme and AVG2 treatments on the 9th March (after crop was cut-out).  While not statistically analysed the summary of plots is shown in Table 2.

Table 2.  Total fruit retention, number, nodes above cracked boll, plant nodes and height for Control, Biozyme and AVG2 treatments measured on 9th March 2018

| Treatment | Fruiting sites | Fruit/m | % Retention | NACB | Nodes | Height |
|---|---|---|---|---|---|---|
| **Control** | 417 | 140 | 34.3% | 7.4 | 22.9 | 77.8 |
| **Biozyme** | 403 | 141 | 34.5% | 8.5 | 23.8 | 80.2 |
| **AVG2** | 382 | 125 | 32.0% | 7.6 | 23.3 | 78.4 |

**Dry Matter Cuts and Final Yield**
Dry matter cuts were taken on around first square (5th Dec), first flower (3th Jan), one week post flower included leaf area measurements (9th Jan), peak flower (24th Jan) and before defoliation (28th March).  No significant differences were found between treatments with respect to dry matter cuts or leaf area.

Cotton was harvested by a 6 row cotton picker making one round module per plot. An average turnout of 45% was calculated from the total lint weight recorded by the gin and the raw module weight recorded by the bale trailer. No significant differences were detected between treatments. Results for yield and final dry matter are shown in Table 3.

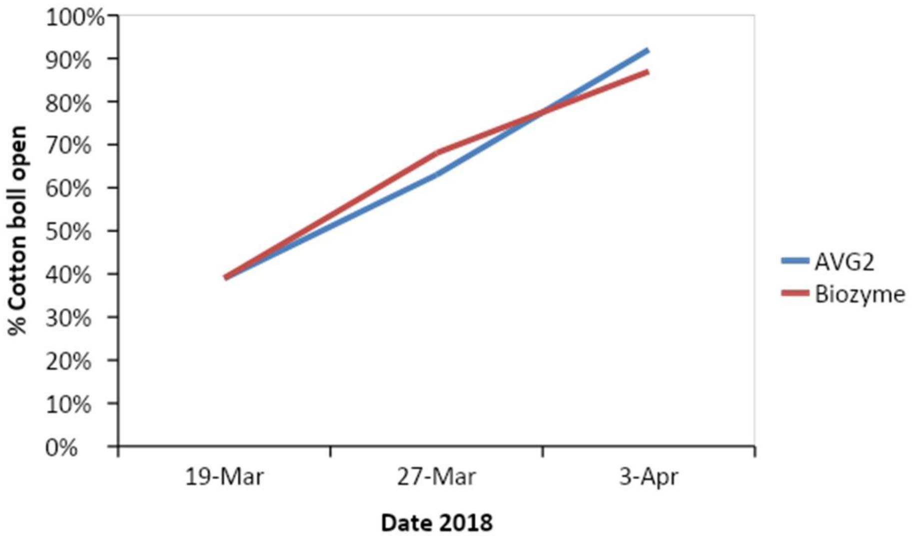
**Table 3. Yield and dry matter production measured before defoliation for all treatments.**

| Main Plot | Sub Plot | Yield (bales/ha) | Defoliation DM (kg/ha) |
|---|---|---|---|
| Biozyme | Nil | 11.51 | 12496 |
| | AVG | 11.35 | 11330 |
| | AVG2 | 11.7 | 11530 |
| Control | Nil | 11.12 | 11530 |
| | AVG | 11.4 | 10263 |
| | AVG2 | 11.4 | 10496 |

### Hand Picked Cotton

Cotton was hand-picked as it opened comparing Biozyme and Bio-AVG2 treatments. Figure 4 shows the linearity of the crop opening for Biozyme and AVG treatments. Boll number averaged 115/meter for Biozyme and 113/meter for Bio-AVG2

**Figure 4. Boll opening over time for Biozyme and AVG treatments.**




### Discussion and Conclusions

Germination was ideal and the crop had emerged when visited 8 days after sowing. There was no apparent differences in germination or seedling growth. Subsequent measurements of node growth, dry matter, NDVI, leaf area, fruit retention and yield showed no difference between any of the treatments. It is postulated that any differences may have been masked by heavy thrip pressure and cool weather in late October-early November when the crop was 0-1 leaf emerged, however this does not explain the lack of result from Biozyme in subsequent applications. In hindsight, thrips should have been controlled going into the cool wet period but the decision was made not to control them as the crop was growing strongly and considered to be able to grow out of any potential damage.

No moisture probes were available for the IREC trial site. Irrigations were made by educated guess. In discussing irrigation timing with the grower it is thought the crop may have been stressed in the 3rd and 4th irrigations, particularly in early January. This may explain why the crop terminated itself early and struggled to hold fruit higher than 5 nodes above the white flower. The crop appeared to senesce early due to stress (Figure 5) with leaves becoming lighter green with purple blotches. Nitrogen uptake was not measured but it is thought that the application of 280kg N/ha should have been adequate for the boll load the crop was holding. The lack of vegetative growth is also shown by the space down the plant row where the plant failed to fill in the available space (Figure 6). There may be issues with this site and the high magnesium content in the soil profile. Calcium to magnesium ratios are in a 1:1 ratio. It is questioned whether there is an imbalance of potassium caused by too much magnesium thereby causing premature senescence. Further work to test this hypothesis could be undertaken.

**Figure 5. Photos sowing lighter green leaves and purple blotches taken on the 6th March 2018, 142 days after sowing, correlating to approximately 1% open bolls.**

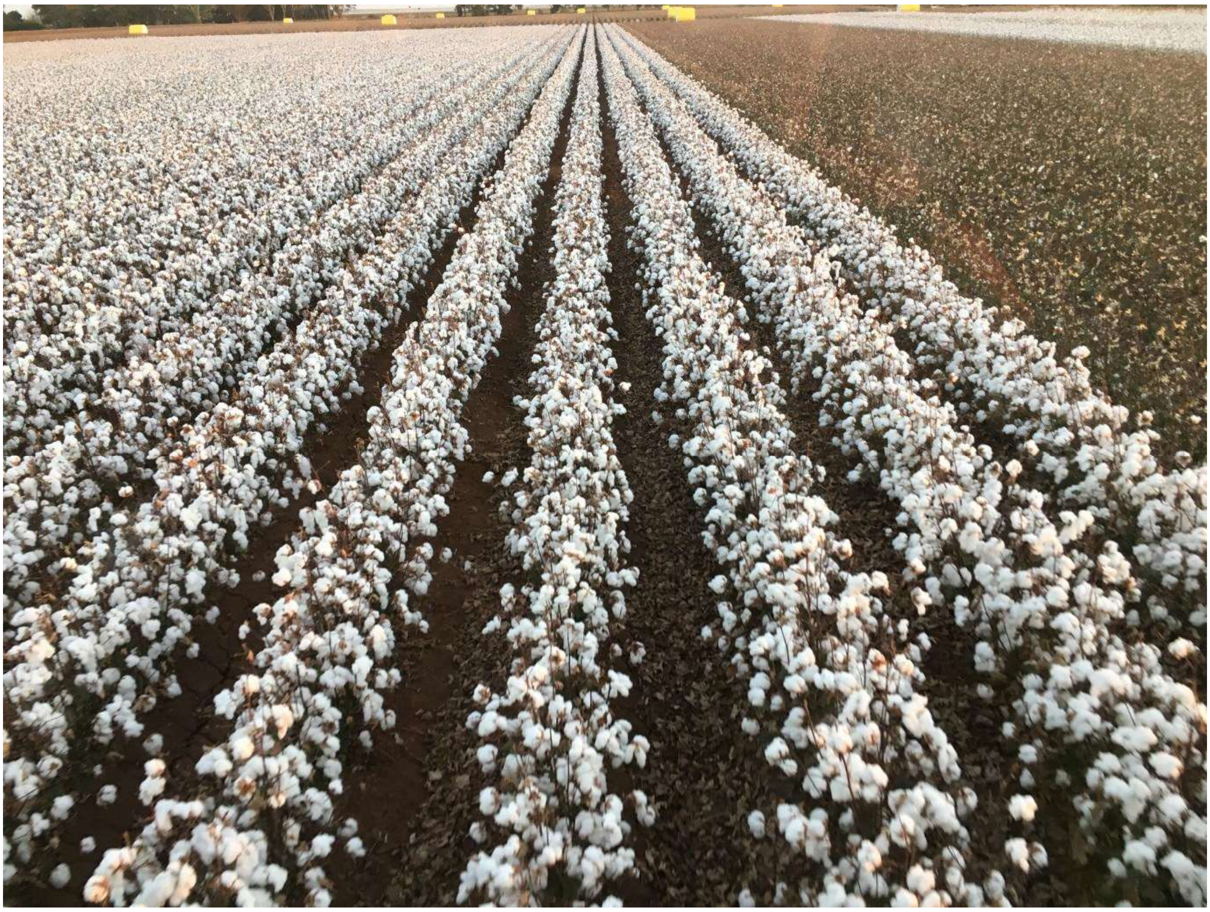


**Figure 6. Open cotton showing where cotton plants have not filled in the available space between the planted rows.**

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## *Chapter 3 - Sowing Date Trial 2017-18*

**Introduction and Aim**

, January and February in the southern growing season experience higher solar radiation relative to the established northern cotton growing regions. The recommended sowing time for the southern region by the CSIRO OZCOTT model is around the 13$^{th}$ October (Australian Cotton Production Manual, 2017 p89). Many growers plant much earlier than this period and some try to be finished planting by this date. This means some farms are planting as early as the 3$^{rd}$ week of September and through to early November.

The aim of this trial was to compare the emergence, growth and yield of cotton planted in the same field at different planting dates.

**Material and Methods**

The trial was located south west of Griffith, on the southern side of the Murrumbidgee River. Soil is a self-mulching grey clay Vertisol. Plot widths were 24 rows (metres) wide with a furrow length of 584 metres. Trial design is shown in Figure 1.

Three sowing (irrigated up) dates were selected, late-September, mid-October and late-October. Due to the difficulty of planting in a field that has had parts irrigated, the whole field was planted, with the strategy to irrigate respective plots at the correct time of 'sowing'. This strategy worked for the first planting on the 28$^{th}$ September. Rain (18mm) occurred on the 9$^{th}$ October which was enough to germinate all remaining treatments, so the remaining plots were irrigated (in order to provide subsoil and consistent moisture) on the 10$^{th}$ October. This prevented the last sowing date treatment being utilised. There was some water subbing across the rows from the early planting to the other treatments so all measurements were taken from the middle of plots approximately 50 metres from the tail drain. Sampling was taken from row 6 and 7 within the set of 8 planter rows to avoid any guess row or wheel compaction impacting the sample row.

Crop phenology measurements were taken approximately weekly. Air and soil temperatures were recorded with Tiny Tag data loggers

Flag on Head Ditch

Head Ditch- East

| Rep | Buffer 48 rows | Rep4 | | | Rep3 | | | Rep 2 | | | Rep 1 | | | Buffer 24 rows |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | | 24-Oct | 9-Oct | 28-Sep | 28-Sep | 9-Oct | 24-Oct | 9-Oct | 28-Sep | 24-Oct | 24-Oct | 9-Oct | 28-Sep | |
| Variety | | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | 74-6 | |
| Rows, 584m | | | 24-3rows | | | | | 24-3rows | | 24-3rows | | | | |
| Width (m) | | 24 | 21 | 24 | 24 | 24 | 24 | 21 | 30 | 21 | 24 | 24 | 24 | |
| Tractor pass | | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | |
| Picker pass | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |

Air and Soil Temp

Figure 1. Trial design and dimension of 'Kulki' sowing Date trial.

## Results

### Germination Temperature

Air and soil temperatures are shown in figure 2.

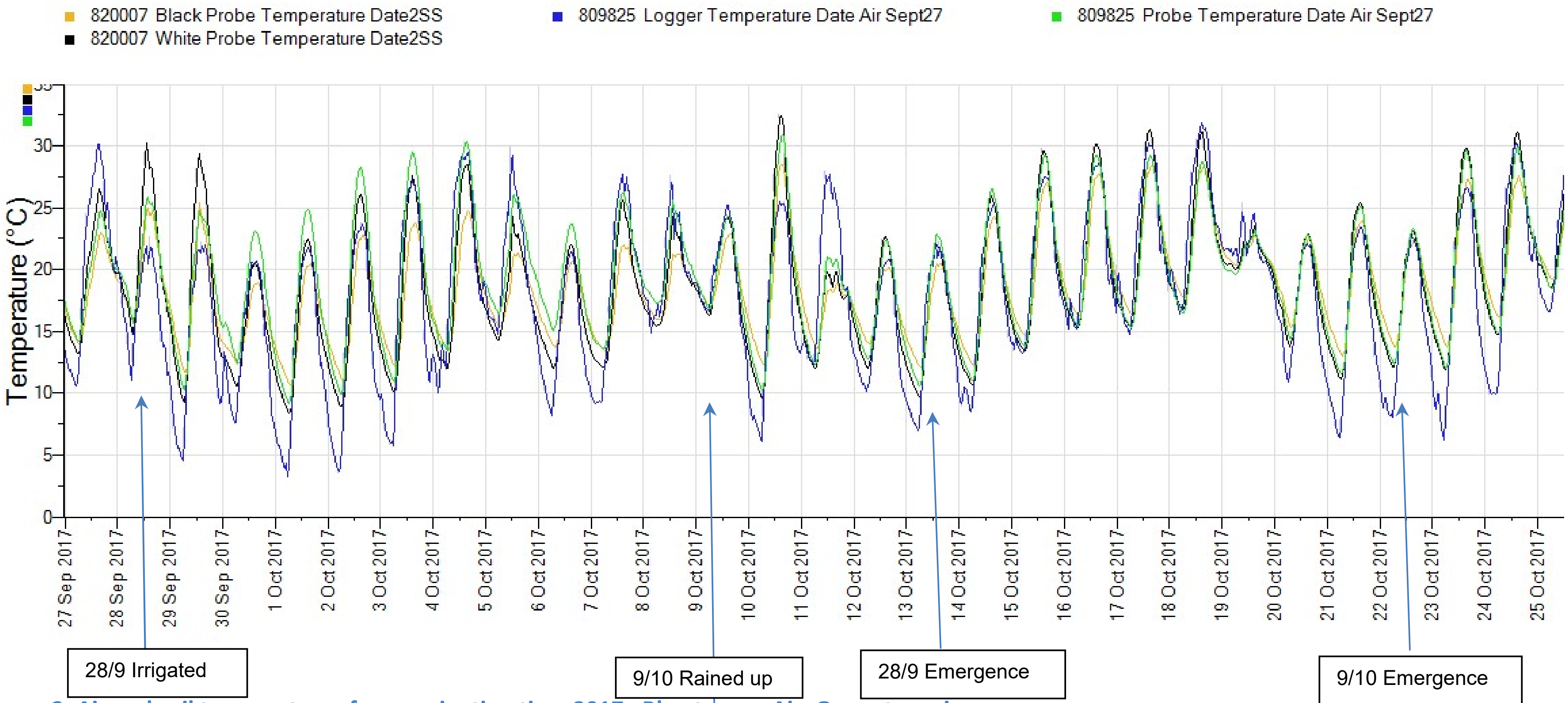


**Figure 2. Air and soil temperatures for germination time 2017. Blue trace = Air; Green trace is seed/soil temp 28/9@35mm; Black trace is seed/soil temp 9/10@35mm; Orange trace is soil temp 28/9@100mm**

The treatment irrigated up on the 28th September took 15 days to emerge after being planted at 35-40mm deep. Emergence for the treatment that received rain on the 9th October took 13 days to emerge even though planted at the same depth. Days and day degrees base 12 and 15-32 are in table 1.

**Table 1. Sowing date trial, 90% emergence time and day degrees base 12 and base 15-32.**

| **Phenological Events** | **Sow Date** | **Actual** 90% Germ | DAS | DD12 | DD15 |
|---|---|---|---|---|---|
| | 28-Sep | 13-Oct | 15 | 101 | 75 |
| | 9-Oct | 22-Oct | 13 | 98 | 72 |

Both sowing dates had a mixture of warm and cool temperature conditions over the germination period. The trial was sown on the deeper side than normal (35/40mm compared to 25/30mm) which may have contributed to a slightly slower germination time. As shown by the results there is only two days difference in emergence time and this correlates to slightly less accumulation of day degrees using either base (DD12 or DD15) between treatments. More analytical work could be carried out comparing ideal seed/soil temperature and depth.

**Node Growth and NDVI**

The plant production of successive nodes and crop growth measured by NDVI was monitored approximately each week. It is graphed against the accumulated heat units using both DD12 and DD15 as shown in figures 3 and 4.

Both, node production and vegetative index show a similar linear increase with accumulated day degrees regardless of which calculation base is used. Visually it appears the DD15 base shows a better fit but this needs to be verified statistically. Regardless of which base is used there appears to be very little difference in growth as a function of day degrees as measured by node production or NDVI.

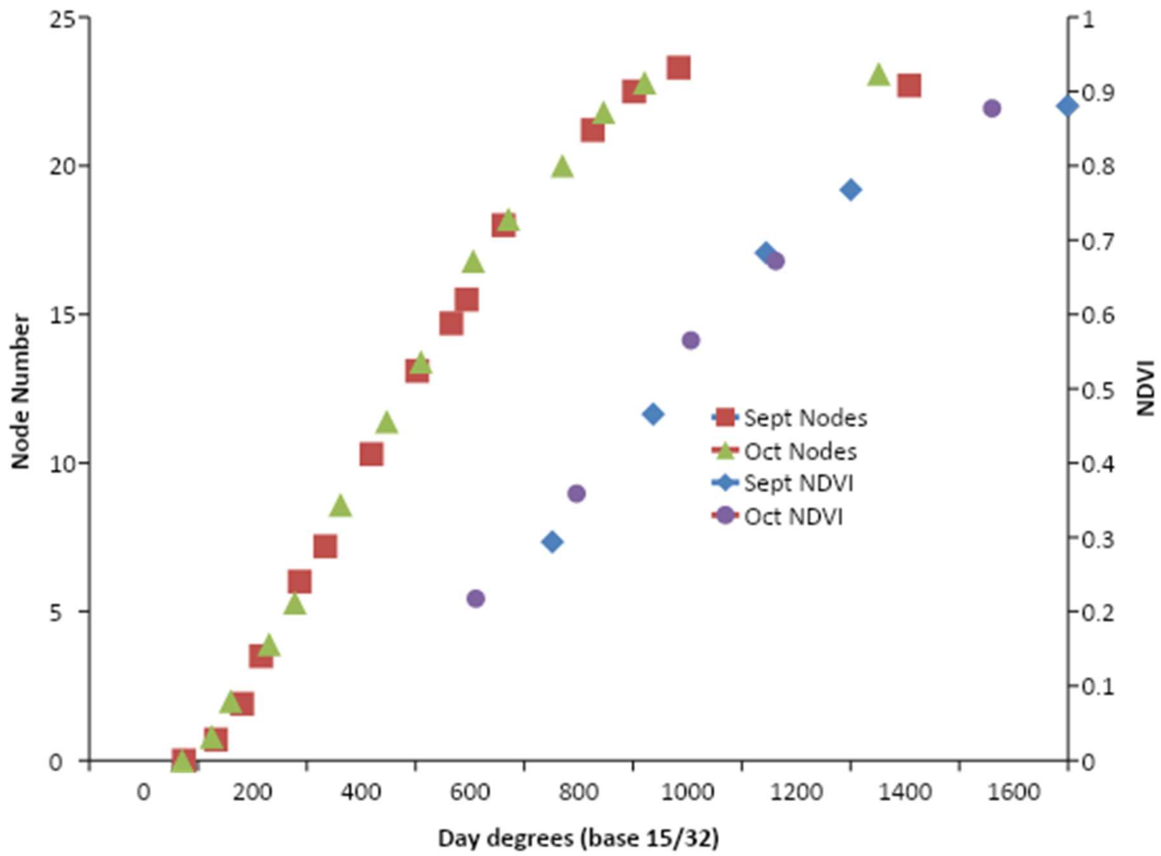


**Figure 3. Node growth and NDVI readings for sowing date 28th September and 9th October a function of day degrees base 15-32.**

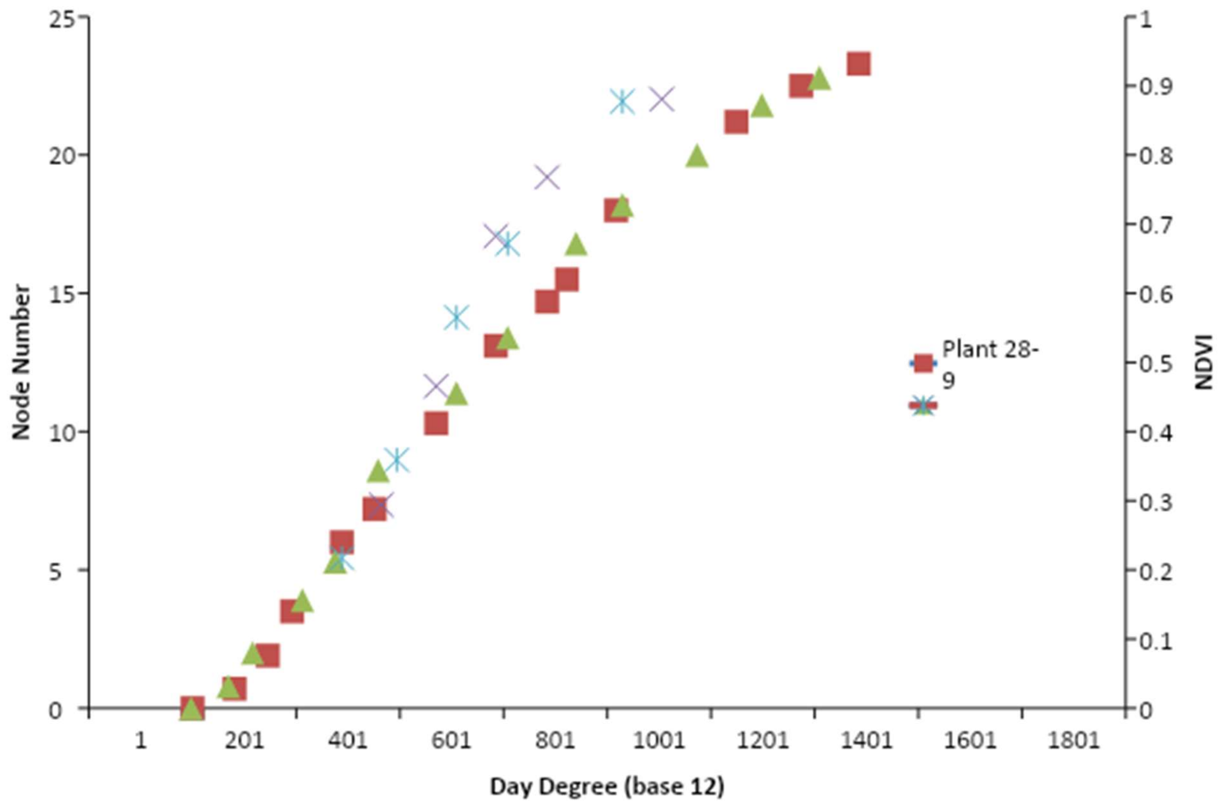


**Figure 4. Node growth for sowing date 28th September and 9th October a function of day degrees base 12.**

## Fruiting Phenology

There is very little difference between treatments with respect to first fruiting branch, day degrees to first square and first flower and time to crop maturity as measured by nodes above cracked boll. The data shows the similarity of crop growth between the two treatments regardless of how it is measured.

**Table 2. Fruiting phenology of sowing date treatments as measured by days after sowing (DAS), day degrees base 12 (DD12), day degrees base 12 with cold shock function (DD12c) and day degrees base 15/32 (DD15).**

| Phenological Events | Sowing Date | |
|---|---|---|
| | **28-Sep** | **9-Oct** |
| **Emergence** | | |
| 90% Emerged | 13-Oct | 22-Oct |
| DAS | 15 | 13 |
| DD12 | 101 | 98 |
| DD15 | 75 | 72 |
| **First Square 50%** | | |
| 3mm Sq | 27-Nov | 5-Dec |
| 1st Sq No | 7.9 | 8.0 |
| DAS | 60 | 57 |
| DD12 | 541 | 543 |
| DD12c | 400 | 434 |
| DD15 | 398 | 397 |
| **First Flower 50%** | | |
| Date | 25-Dec | 1-Jan |
| DAS | 88 | 84 |
| DD12 | 872 | 886 |
| DD12c | 706 | 762 |
| DD15 | 630 | 641 |
| **4 NACB** | | |
| Date | 19-Mar | 27-Mar |
| DAS | 172 | 169 |
| DD12 | 2015 | 2012 |
| DD12c | 1786 | 1810 |
| DD15 | 1413 | 1406 |
| **60% Open** | | |
| Date | 23-Mar | 28-Mar |
| DAS | 176 | 170 |
| DD12 | 2054 | 2023 |
| DD12c | 1834 | 1815 |
| DD15 | 1438 | 1415 |

**Yield and Dry Matter Production**

Dry matter production was measured at both first flower and at four nodes above cracked boll 4NACB. The measurements taken at first flower are not reliable for comparison between treatments as the timing of first flower prevented accurate timing of dry matter cuts.

Yield was calculated from a turnout percentage of 43% which was taken from total lint weight of ginned cotton by weighed seed cotton modules harvested off the middle 12 rows of each plot (Table 3). Cotton was handpicked (Figure 5) and ginned from one metre sections of rows from each treatment over successive weeks. Total yield and bolls per metre are presented in table 3 along with final node count. Results as predicted by all phenological events show no significant difference between treatments for all measured parameters.

Table 3. Sowing date trial yields as measured by seed cotton weights using 43% turnout, handpicked yield and bolls and dry matter cuts and yield taken at four nodes above cracked boll.

| | Sowing Date | | |
|---|---|---|---|
| | **28-Sep** | **9-Oct** | P level |
| Germination Days to 90% | 15 | 13 | |
| Yield (bales/ha) | 14.8 | 14.7 | 0.942 |
| Hand pick Boll/mtr | 130.8 | 140 | 0.163 |
| Hand pick Lint/boll | 2.49 | 2.39 | 0.278 |
| Hand Pick Yield B/ha | 14.36 | 14.73 | 0.478 |
| Dry matter Cut-out kg/ha | 13888 | 14113 | 0.844 |
| DM Boll/meter | 145 | 148.5 | 0.642 |
| DM cut-out yield B/ha | 14.5 | 14.5 | 0.998 |
| Final Nodes | 22.7 | 23.1 | 0.279 |

The photo above shows the well grown crop with no visible difference before cotton harvest.

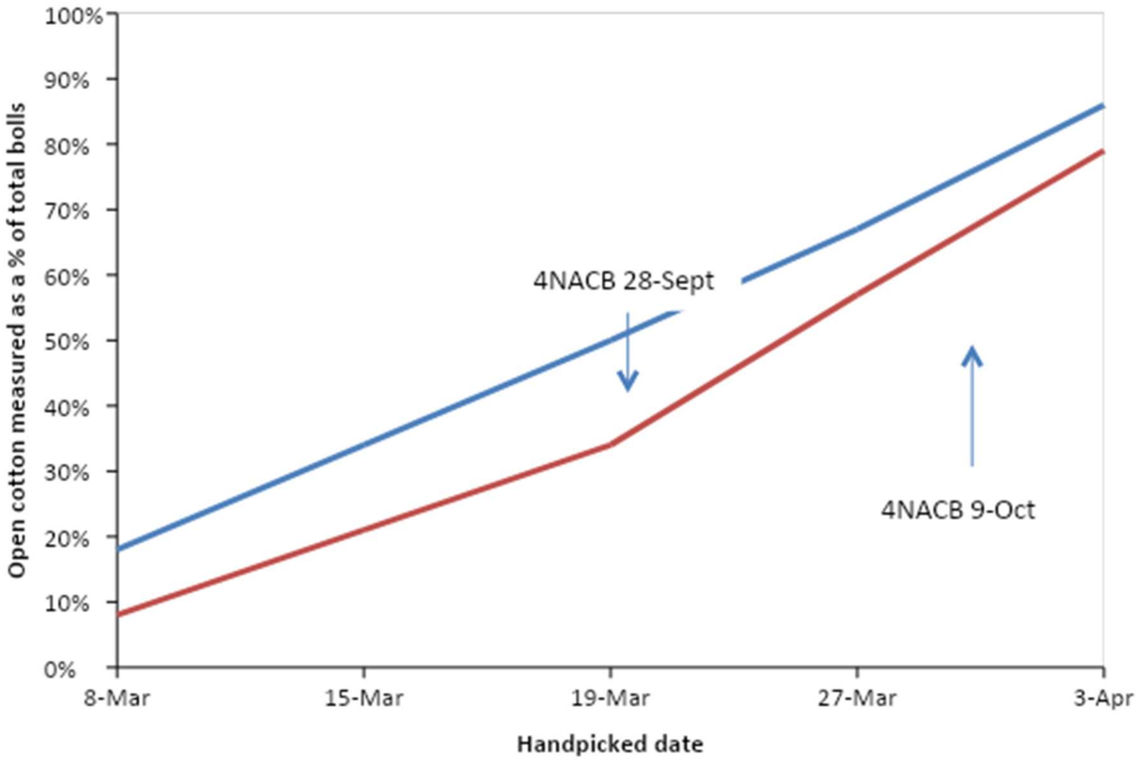


**Figure 5 shows the rate of cotton bolls opening and 4 NACB for both treatments. As can be seen in this trial 4 NACB corresponds to 50% and 57% open for the two treatments. The rate of crop opening is a function of crop moisture and nutrition and will vary around the 60% level considered the optimum time for the crop to be defoliated.**

### Discussion and Conclusions

While the initial design of the trial was to have a wide spread in planting dates from late September to late October, this was not possible due to rain effectively removing the last planting date. It would appear that in this season 2017-18, there is no discount for planting earlier as predicted by the OZCOT modelling and as experienced in the 2016-17 season. The field sowing date analysis of the 2016 planting year predicted a possible yield decline of up to 9% for planting two weeks either side of the optimum of the 10$^{th}$-17$^{th}$ October (Steve Buster, NSW DPI 2018 Report on the Southern Field Database – Growing Season 2016-17). This was not evident in this trial.

## *Chapter 4 – 30” vs 40” Row Spacing*

A trial was initiated near Darlington Point in the 2017/18 season. Treatments were 30 inch and 40 inch row spacings. Planting in early October saw complications and as a result the 30 inch treatment had to be replanted. This compromised the experiment and it had to be abandoned.

## *Chapter 5 – Biofilm Trial 2018/19*

Poor crop establishment in the south is a major factor reducing cotton yields. The growing season is limited by cool, wet conditions in autumn that can compromise crop yields and fibre quality. Therefore, it is preferable to plant as early as possible to allow the crop to accumulate enough day degrees to achieve high yields before the season hits a harsh finish. Cool temperatures around planting in September/October result in sub-optimal soil temperatures for germination. Research suggests planting should occur when soil temperatures are >14°C at 8am for 3 consecutive days and plant on a rising temperature forecast.
Biodegradable film that can be applied to the soil at planting is a method of increasing soil temperature and moisture available to the germinating seed. Seedlings germinate through perforated slots in the plastic and reportedly benefit from a 'microclimate' created by the film.


Figure 1. An example of the planting rig used to apply the biofilm at planting.

The film costs approximately $300 per ha on top of planting costs and hence growers need to produce an extra bale per ha out of the film in order for the operation to be worthwhile.

*Methods*

The trial was conducted south-west of Griffith in a newly developed field and soil type is a red brown earth. The bay configuration was metre hills with 1m row spacing and irrigated via a bankless system on zero grade. Cotton variety Sicot 746B3F was planted dry on 26 October 2018 using a Norseman planting rig configured to apply the Onecrop biofilm in the single pass. The field was then flushed up on 31 October 2018. (Figure 1)

*Measurements taken*

- Phenology
- Biomass (flowering and defoliation)
- Yield
- Temperature (Figure 2)

*Trial Design*

**Table 1. An overview of the trial design**

| Buffer | Rep 1 | | Rep 2 | | Rep 3 | | Rep 4 | | Buffer | |
|---|---|---|---|---|---|---|---|---|---|---|
| Buffer | Soil | Film | Film | Soil | Film | Soil | Soil | Film | Buffer | 500 |
| 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 240 |

*Weather Data*

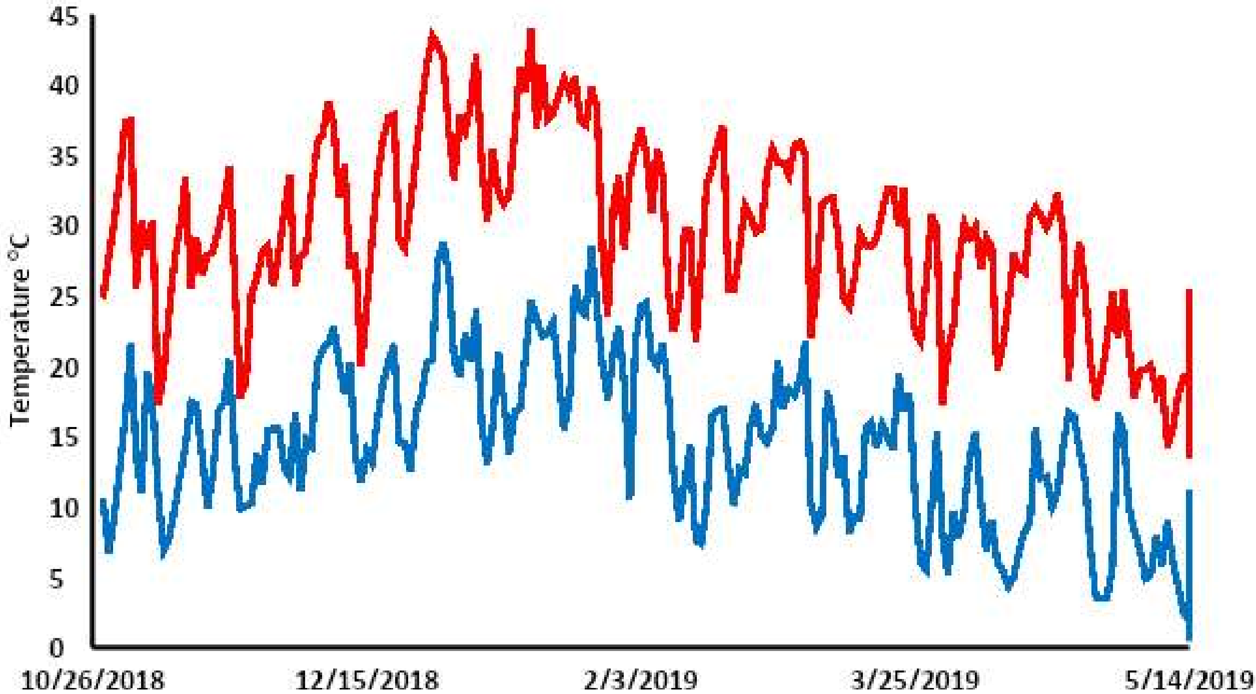


**Figure 2. Maximum and minimum temperatures recorded over the growing season at Benerembah NSW.**

*Results & Discussion*

The planting date chosen by the grower was one that showed no benefit from soil temperature by applying the film but rather to conserve moisture under the film. From Figure 3 the temperature probes all recorded 8am temperatures exceeding the 14 °C minimum for safe planting. While the film temperatures were greater than bare soil by approximately 1 °C after flushing up occurred on 31 October neither treatment was cooled significantly to have an influence on germination. The flush up timing coincided with a rising temperature plane which saw mid to high 30 °C days following the irrigation. As a result first emergence occurred on 2 November with 90% emergence occurring on 3 November. There was no significant difference between treatments for final plant numbers averaging 9.2 plants/m.

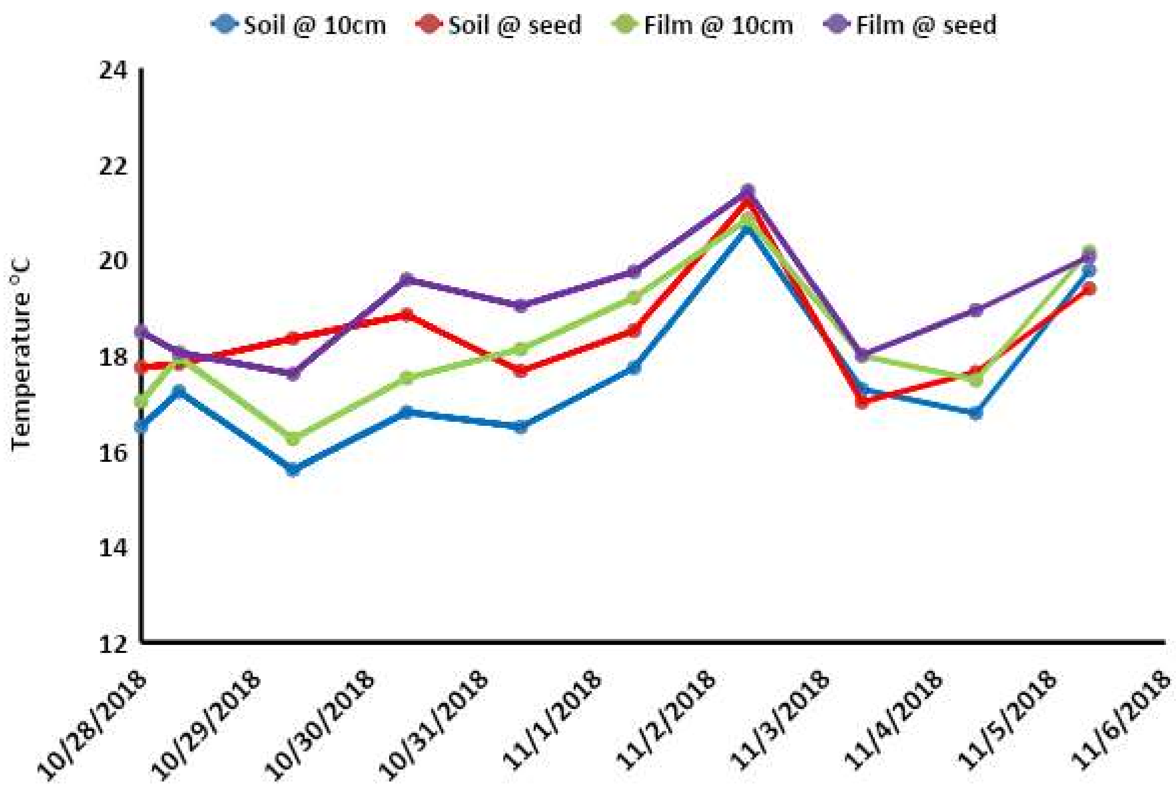


**Figure 3. Soil temperature recorded at seed depth and 10cm at 8am following planting until 90% germination.**

With no difference in emergence date the two treatments showed no significant differences in phenological development. Node number increased linearly at 3-4 days per node until reaching a max node number of 23. First flower occurred on 11 January 2019 and biomass was collected at this time. There were no significant differences in flowering biomass between the film and bare soil treatments with an average of 1269 kg DM/ha. Nodes above white flower declined steadily until reaching physiological cut out on 18 February (4NAWF). The boll opening period lasted for just 38 days from sighting of first open boll until first pass defoliation. Biomass taken at defoliation was also not significant between treatments and averaged 12634 kg DM/ha.

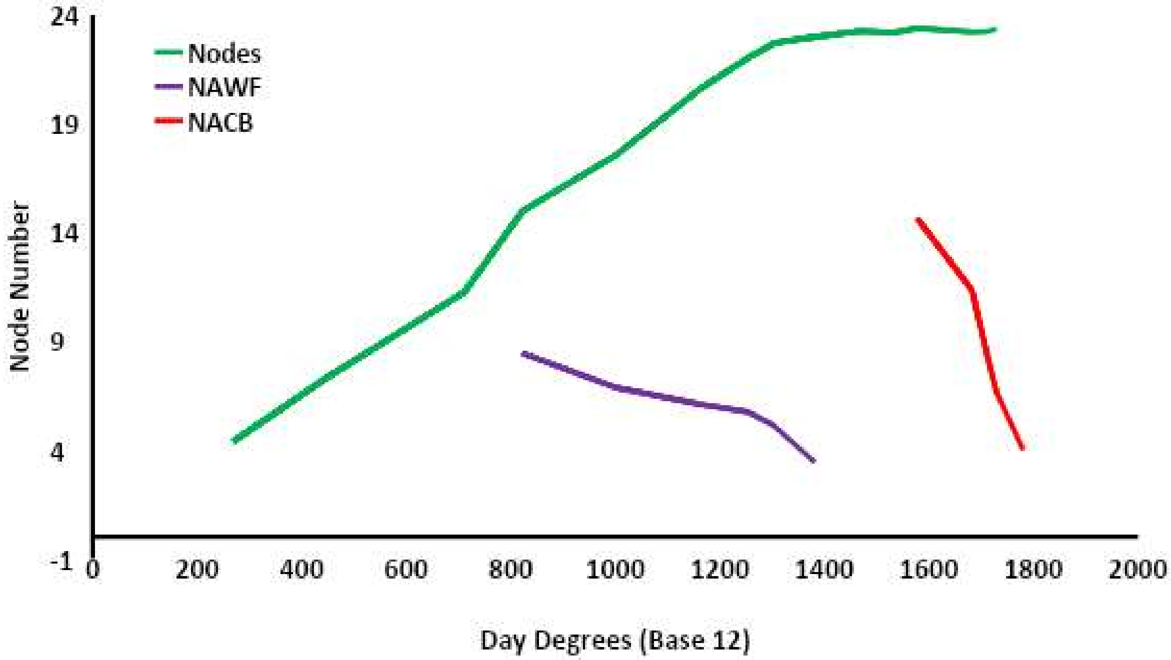


**Figure 4. Phenological development averaged across all treatments plotted against day degrees (base 12) including node development, nodes above white flower (NAWF) and nodes above cracked boll (NACB).**

The trial was picked on 15 June 2019 and 2 modules were produced per plot. Each module was weighed on a bale trailer. Seed cotton weights were converted and averaged 5457 kg/ha. No significance was detected between the yields of each treatment. An average turnout of 37% was applied taking the yields to 8.9 bales/ha. Due to there being no significance across any of the measures taken on this trial it was decided to not gin the modules separately to obtain quality as this would have been an unnecessary waste of transport and ginning time for the grower.


**Figure 5. Picking of the trial on 15 June 2019.**

*Conclusion*

The target of achieving an extra bale by applying biofilm was not an outcome for the grower in this season. The complete lack of significant difference between any measure taken through the season was an indication that the grower could have saved $300 per ha and not applied the film and still maintained the 8.9 bale/ha yield across the field.

When compared to the biofilm trial conducted in the 2017/18 season this trial was planted too late to have an effect on establishment. Whilst the earlier trial approached significance ($P<0.1$) it was planted too early and had other confounding effects. A trial planted in early October would be ideal to make more representative inferences but due to conducting trials with commercial growers timeliness is very hard to achieve.

## *Chapter 6 – Replant Case Study*

Cotton production in southern growing regions face issues surrounding emergence and early season growth. In many instances where conditions are unfavourable, up to 40% of seeds planted do not establish leading to resource inefficiencies and poor yields as a result of poor plant stands and or replants. To better understand the phenological impact on subsequent cotton yields under a replant scenario a field was monitored that had 3 out of 5 bays replanted due to poor establishment from the disease Black Root Rot. The remaining 2 bays were not replanted as they had a plant stands greater than 4 plants/m which is currently the threshold for replant decisions. These fields did however have hotspots that could be measured and compared to the surrounding plant stand and replanted bays.

*Field Details*

**Original Plant**
Germination Date: 5 October 2018
Variety: Sicot 746B3F
**Replant**
Germination Date: 31 October 2018
Variety: Sicot 714B3F

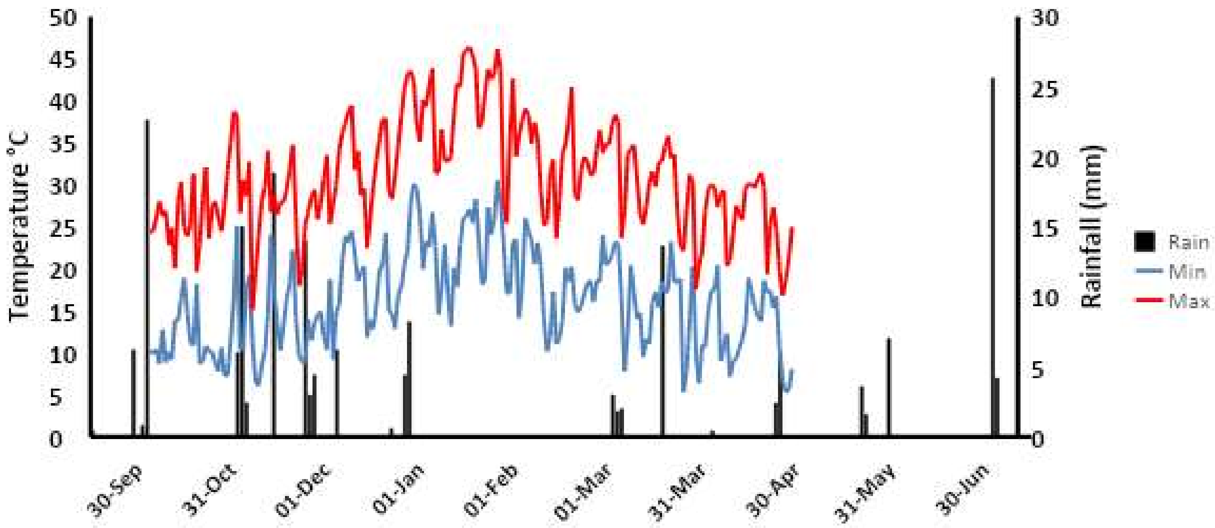


**Figure 1. Weather data for the 2018/19 growing season. BOM Griffith**

Measurements taken:

- Nodes
- NAWF
- Flowering biomass
- NACB
- Hand pick yields

*Early Season NDVI*

Satellite imagery from Data Farming (figure 2) indicated the poor biomass within the replant bays compared to the original plant stand. Hotspots in the original plant stand returned a similar NDVI reading to the replant bays.


**Figure 2. NDVI Satellite imagery of the replant fields observed 12 Nov 2018. Source: Data Farming**

NDVI imagery (Figure 3) taken closer to the first flower date (actual 8/1/19) of the original plant stand shows a reading closer to 0.82 indicating that the plant stand close to canopy closure. Replanted bays are still lagging behind but are quite uniform across the field.


**Figure 3. NDVI Satellite imagery of the replant fields observed 6 Jan 2019. Source: Data Farming**

*Nodes*

Originally the planted crop reached 22.5 total nodes on average which amounted to 1.4 nodes taller than hotspot sections of the crop that suffered from delayed emergence from black root rot. The bays that were replanted reached 19.7 nodes on average.

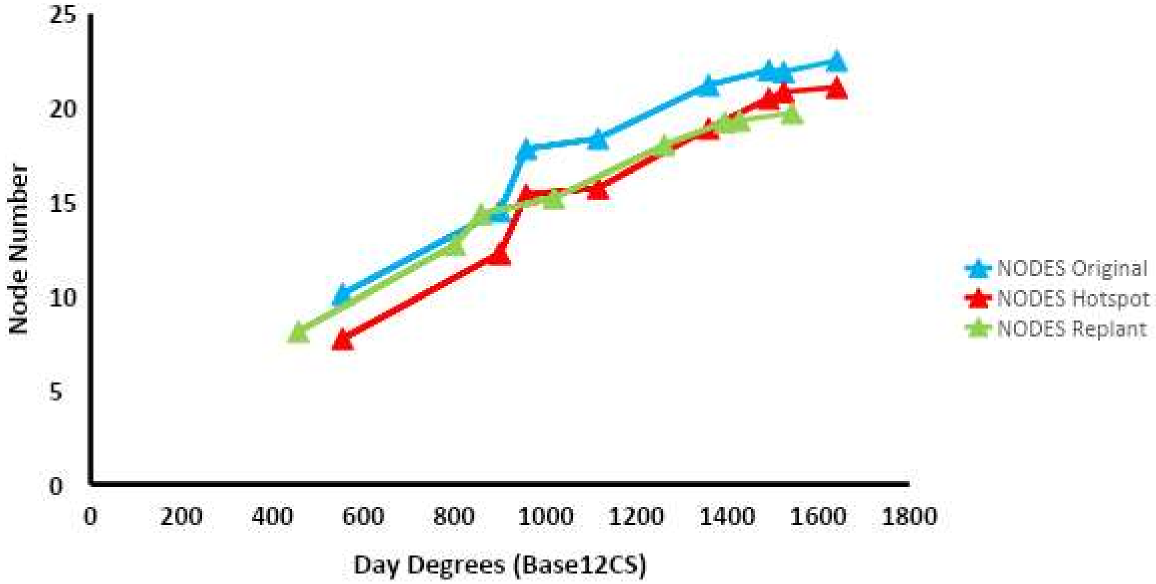


**Figure 4. Node development plotted against accumulated day degrees from date of germination calculated from a base temperature of 12 with cold shock factor included.**

*Nodes Above White Flower (NAWF)*

The original plant stand reached first flower (50% of plants with one white flower) on 8 Jan 2019. Both the plant type in the hotspots of the original plant stand and the replant first flowered on 18 Jan 2019. Nodes above white flower (NAWF) were recorded across 1 m of plant row on the same plants each date. Both the original plant stand and the replant tracked along similarly declining nodes at a rate of 1 node every 6 days leading up to physiological cut out (4NAWF).

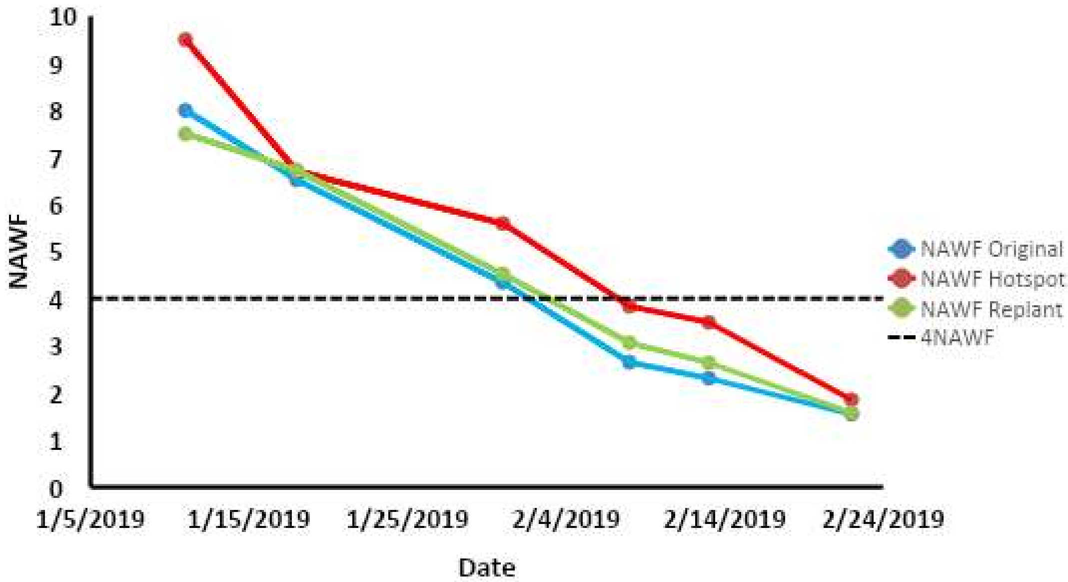


**Figure 5. Nodes above white flower (NAWF) plotted against time with a line indicating physiological cut-out at 4 NAWF.**

*Flowering Biomass*

Biomass taken at first flower (figure 6) indicated that the original plant stand was approximately 400 kg/ha higher yielding than the hotspots within the same bays. This is a direct function of sub-optimal conditions (BRR, cold etc.) reducing the plant stand and delaying early season growth and development. Interestingly, the replant bays yielded almost 4000 kg/ha of biomass at first flower, considerably more than the original plant stand. This is due to the replant accumulating 1018 DD up until first flower, 103 DD ahead of the original plant stand. This could also be a function of Sicot 714B3F being quicker maturing than 746.

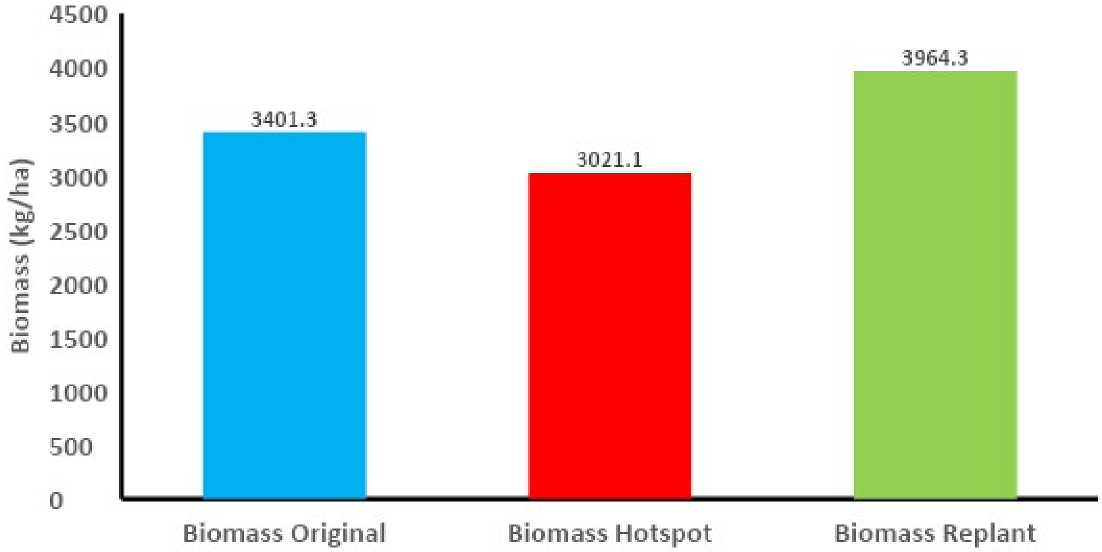


Figure 6. Biomass at first flower in kg/ha

*Nodes Above Cracked Boll (NACB)*

The first cracked boll appeared on the replant crop at 9.4 NACB, less than the 11.4 NACB on the original plant stand. This is understandable as the replant bays had less nodes. The original plant stand declined NACB at a linear rate whereas the replant tapered off quickly due to natural senescence compared to the original plant stand which stayed greener for longer.

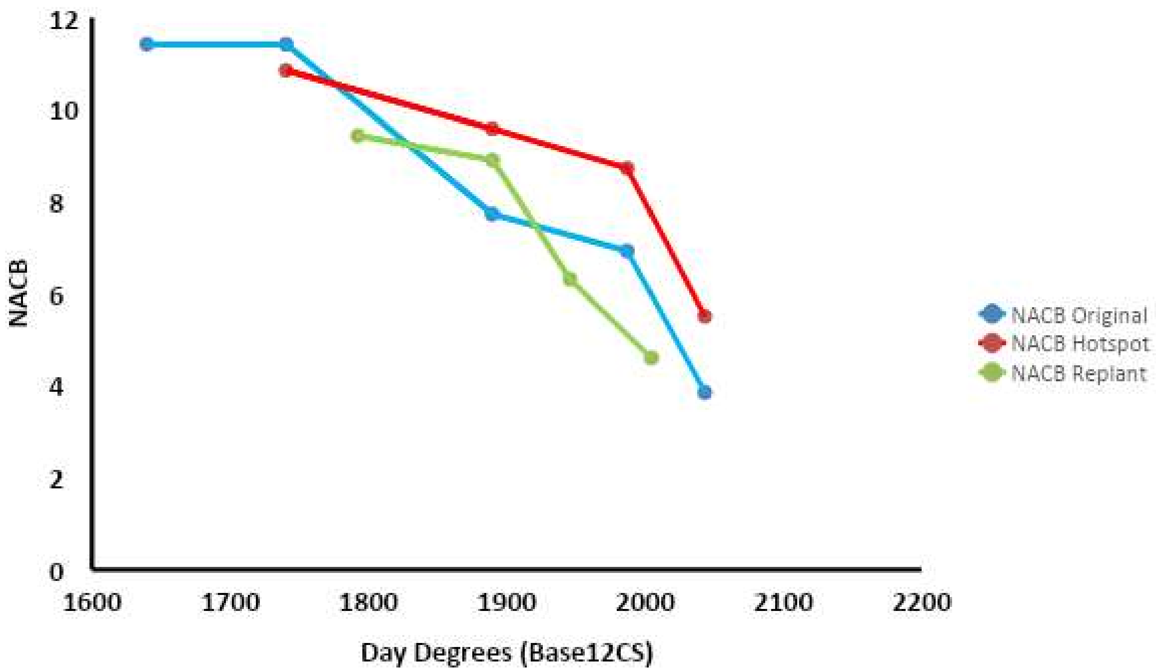


Figure 7. The decline in nodes above cracked boll (NACB) for each of the 3 plant types monitored

*Hand Picked Yields*

Lint collected from monitored sites in the respective bays were ginned using a 20-saw hand gin to obtain a lint yield in bales/ha. The original sown plant stand achieved 13.2 bales/ha, an increase of 2.4 bales over the hot spots located in the same bays. The bays replanted in late October yielded 11 bales/ha.

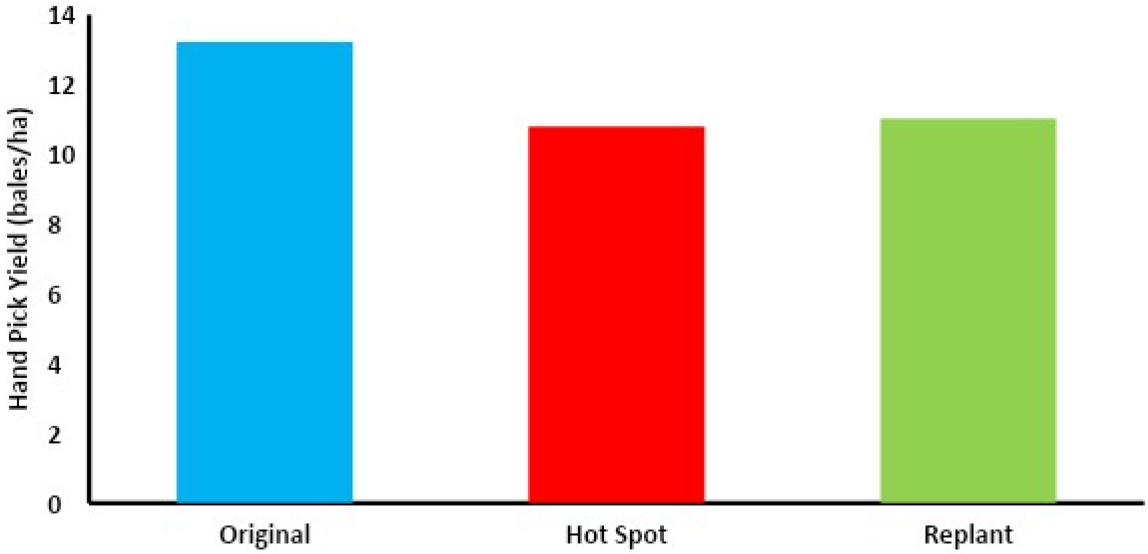


**Figure 8. Handpicked yields taken from respective bays to gauge an understanding of phenological differences from poor/delayed establishment.**

The raw pick data taken from the picker shows dark green sections of the crop yielding up to 16 bales/ha. The bay on the lower left of Figure 9 is an original plant stand with a large number of hotspots visible yielding less than 10 bales/ha. Interesting, the bulk of the replant bays yielded approximately 12 bales/ha but the more southern bay yielded less than 10 bales/ha, hence averaging out the hand pick yields to 11 bales/ha.


**Figure 9. Raw yield data taken from John Deere picker to see variation across the bays.**

*Conclusion*

The grower's decision to replant was based solely on there not being enough plants per m to obtain their desired yield in the bays. Replanting when they did allowed the crop to escape damage from black root rot and achieve a more uniform plant stand and crop thereafter. The phenology of the three different plant types, not surprisingly, saw the original plant stand grow more nodes and as a result more fruit attributing to yield. Sicot 714B3F in the replant bays due

to its more determinate nature, cut itself out and underwent premature senescence which potentially limited its yield.
The replant issue needs further work and dedicated experiments need to be conducted on the interaction between plant number and phenology as drivers of yield.

# Appendix 1

Southern Cropping Systems

# Report on the Southern Field Database – Growing Season 2016–17

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Australian Government
Cotton Research and Development Corporation

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# Introduction

The southern region includes the river valleys of the Lachlan, Murrumbidgee and Murray River systems. While cotton has been grown in the areas of the Lachlan (Hillston) for many years, cotton production in the Murrumbidgee and Murray systems in any significant land area is relatively new. The Murrumbidgee Irrigation Area is more renowned for its production of rice, maize and horticultural crops. Being a relatively new cotton production area, combined with a cooler start and finish to the crop compared with northern cotton growing regions, the question of whether the basic production drivers are similar to the north is a point of discussion.

In 2016, NSW DPI and the CRDC created a new Cotton Researcher position for the southern growing region based at Yanco. The position was created to not only research establishment and early growth of cotton, but to also develop future industry research relevant to production in the south. Upon starting, the new researcher interviewed and toured with many agronomists and farmers to benchmark industry practice and current needs with respect to cotton production and future research.

The cotton industry in the south has some particular attributes:

- New growers − while some growers have been producing cotton for a decade, most have been producing cotton for less than five years.
- Agronomists − the industry appears to source most of its information from agronomists/consultants due to the somewhat specialist knowledge required to grow a successful crop. Many of the agronomists have varying opinions on key aspects of successful cotton production (as would be expected) with many having only been involved with cotton for as long as their cliental.
- Few cotton gins − the region is serviced by three main cotton gins in the Murrumbidgee, two of which only started ginning in 2015.
- Diverse soils − the southern area appears to have a much wider range of soil types than the north and this can often be within one field. Farms in the north are primarily on uniform grey clay soils with a smattering of red−brown earth.
- Irrigation techniques − since many farms have come out of rice or vegetable production, there is a much greater diversity of irrigation techniques with bay and siphon being the two main water delivery systems. Similarly row configuration varies with ranges of 1.0, 1.5,
  1.8 and 2.0 metres for rows/beds and row spacings of 0.75, 0.9, and 1.0 metre.
- Limited machinery − many farmers new to the industry have utilised existing farm machinery to 'try cotton' before undertaking significant capital expenditure on specific cotton row crop machinery.

## Identifying factors influencing yield and quality – industry database analysis

In light of the above diversity of farming backgrounds, techniques and machinery and in order to not 're-invent the wheel', a database was created to try and identify key attributes required for successful cotton production in the southern region. Data was provided on an individual field basis by the three cotton gins in the Murrumbidgee Valley and many agronomists as authorised by the growers. Of the approximately 42,000 hectares (ha) of cotton produced in 2016–17, growers agreed to provide data for 31,384 ha. Agronomists provided basic field data totalling 23,797 ha, of which 692 ha was screened out of the analysis due to significantly low yield (less than 6 bales/ha). Thus, 23,105 ha of the district total or 55% of the southern cotton region was included in this analysis.

## 2016–17 Season

The 2015–16 cotton growing season in the south was the most successful of all the seasons in the districts short lifetime (Rivcott Gin: 11.3 bales/ha in 2015; 12.6 bales/ha in 2016; 8.6 bales/ha in 2017). However, the peculiarities of the region were highlighted when over 525 mm of rain fell during May to October 2016 compared with the average of 230 mm for the same time period in previous years (Griffith Airport, Bureau of Meteorology). It was under these wet conditions that growers were trying to prepare fields for the 2016–17 cotton growing season. The daily maximum, minimum temperatures and rainfall are shown in Figure 1. Extreme temperatures (hot and cold) were experienced in early to mid-December and hot temperatures in mid-January to mid-February.

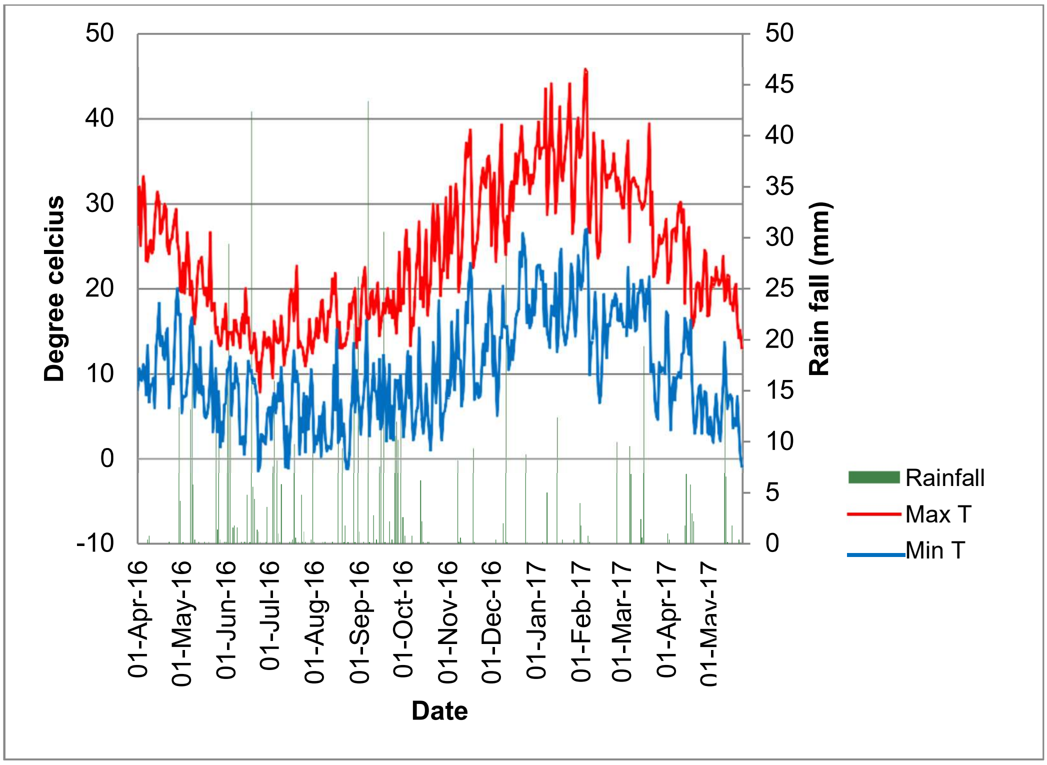


Figure 1. Griffith airport daily maximum, minimum and rainfall for the 2016–17 season (Source: Bureau of Meteorology).

The main yield drivers for the 2016−17 season identified by this data set were location, rotation, bed geometry, variety, nitrogen (N) rate and sowing date, with interactions between some drivers. Table 1 shows the significance levels and percentage contribution to yield variance for each driver. Data was analysed using the Genstat 18 statistical package and R.

Table 1. The significance levels and percentage contribution of drivers to variance of yield in the southern cotton region for the 2016-17 season.

| | Location | Rotation | Nitrogen | Sowing date | Variety | Bed shape |
|---|---|---|---|---|---|---|
| Individual drivers | *** 23.6% | *** 11.9% | *** 9.8% | *** 3.2% | *** 6.4% | *** 4.3% |
| Combination of drivers | | | | | | |
| Rotation | *** 28.9% | – | – | – | – | *** 13.1% |
| Nitrogen | * 24.2% | *** 17.2% | – | – | – | – |
| Sowing date | ** 24.4% | – | – | – | – | – |
| Variety | *** 25.9% | – | – | – | – | – |
| Bed shape | * 24.3% | – | – | – | – | – |
| Interacting drivers | | | | | | |
| Location × Rotation | ** 30.9% | – | – | – | – | – |
| Location × Nitrogen | *** 27.9% | – | – | – | – | – |
| Location × Sowing date | *** 32.0% | – | – | – | – | – |
| Location × Variety | * 28.2% | – | – | – | – | – |

Significance: (*) is significant at 5% level, (**) is significant at 1% level and (***) is significant at 0.1% level. A (−) means contribution to variance was not significant

### *Location (district) and yields*

Season and soils vary considerably within the southern growing region. Contributing growers had fields from south of Jerilderie to as far west as Balranald and north of Griffith. Farms were grouped into their geographic districts or locations. Location grouping had the most significant effect on yield accounting for 23.6% of yield variation within the data. Average yield for each location is shown in Figure 2.

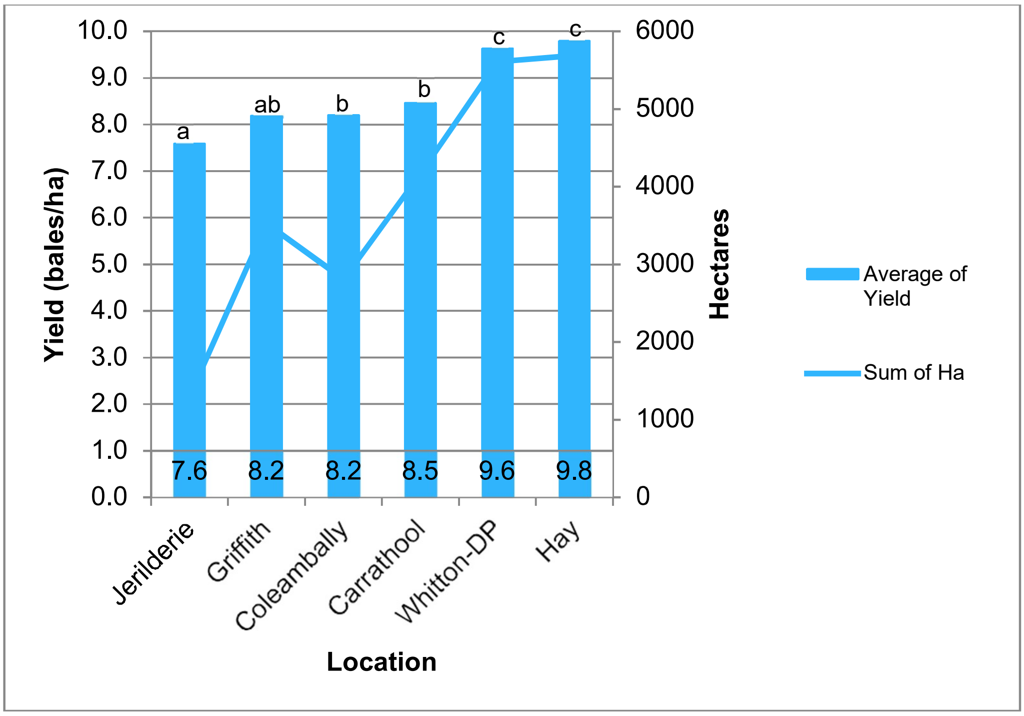


Figure 2. Average yield (bales/hectare) and area grown (ha) for various locations in the southern cotton growing region for the 2016-17 season. Columns with different letters are significantly different at the 5% least significant difference (l.s.d.) level using Fishers protected l.s.d.test.

The factors behind regional differences are numerous. These include, but are not limited to, differences in:

- climatic variation
- predominant soil type
- irrigation layout and design
- farm size
- cotton management experience
- available machinery.

There were significant interactions between location and other yield drivers and this might reflect differences in farming practice, experience, farm infrastructure and design. As cotton is a tropical plant it could be assumed that yield would be associated with warmer districts, however in the 2016–17 season this did not hold absolutely true as many other factors had an influence on variability between districts.

### *Sowing date*

The average sowing date was much later in the 2016–17 season compared with previous years. This was a result of a very wet, cool winter which delayed picking of the previous crop and didn't allow time for adequate ground preparation by delaying some field operations. Some fields were able to be planted in late September to early October but these were minimal. The yield relationship to sowing date is very significant and is best described by a quadratic relationship, accounting for 9.6% of yield variation compared with 3.2% using a linear relationship (Figure 3). Based upon this sowing year and in spite of a delayed start to the season the optimum sowing time was the second week of October.

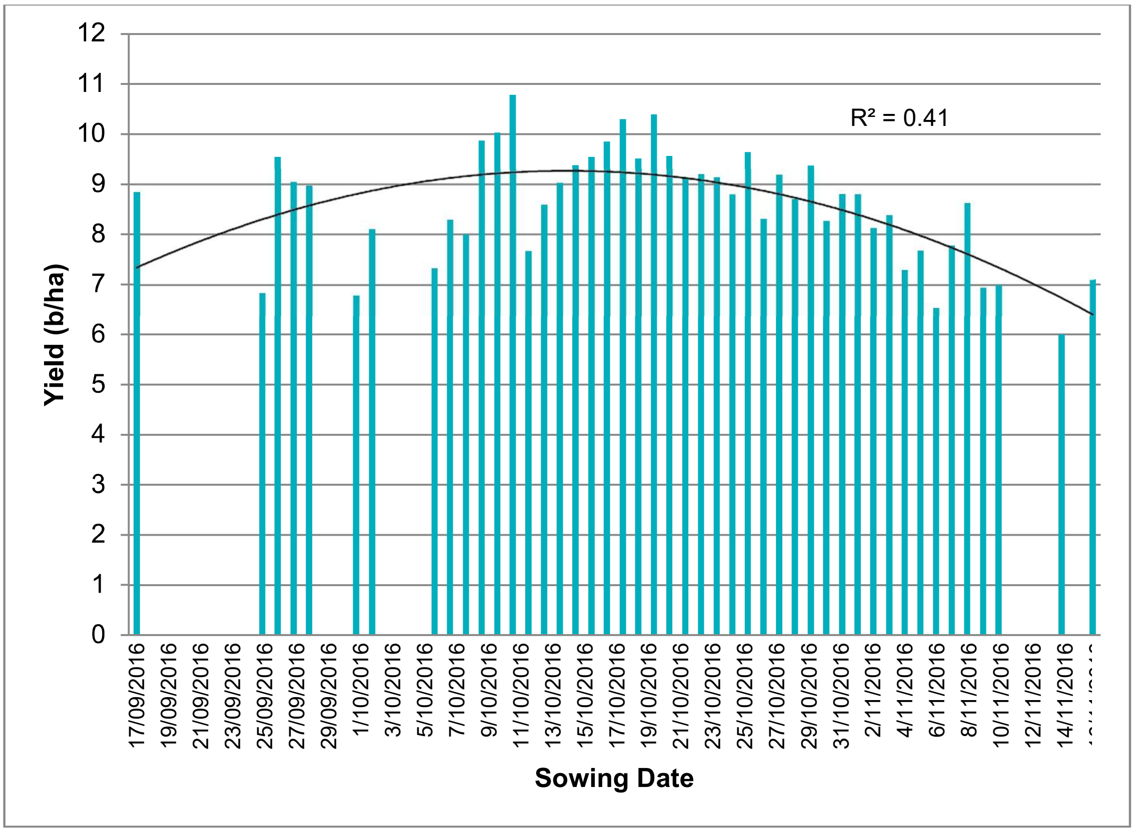


Figure 3. Average cotton yield as function of sowing date in the southern cotton growing region for the 2016-17 cotton season.

The predicted optimum sowing date for this season was from 10 October to 17 October. There was a 3% yield decline for the each week either side of this optimum. The predicted yield decline for the second week either side of the optimum was 9% and the third week was 18%. Many other factors affected yield this season, however it is interesting to note that the predicted optimum time of sowing by CSIRO, using the OZCOTT model was the week around 13 October (Australian Cotton Production manual, 2017 p. 87).

When the interaction with location is included in the analysis, 35.3% of yield variation is explained by these two factors. The various locations' average sowing date/yield trend lines are shown in Figure 4. Figure 4 uses the number of days from 1 September, which means 15 October would be planting day 45. Planting in some locations was delayed by weather. Other locations were able to start planting a bit earlier by either having fields ready to plant or missing the rain event. The scatter in the yield plot shows the high variability in the data. Data for subsequent years is needed to confirm this season's optimum sowing time.

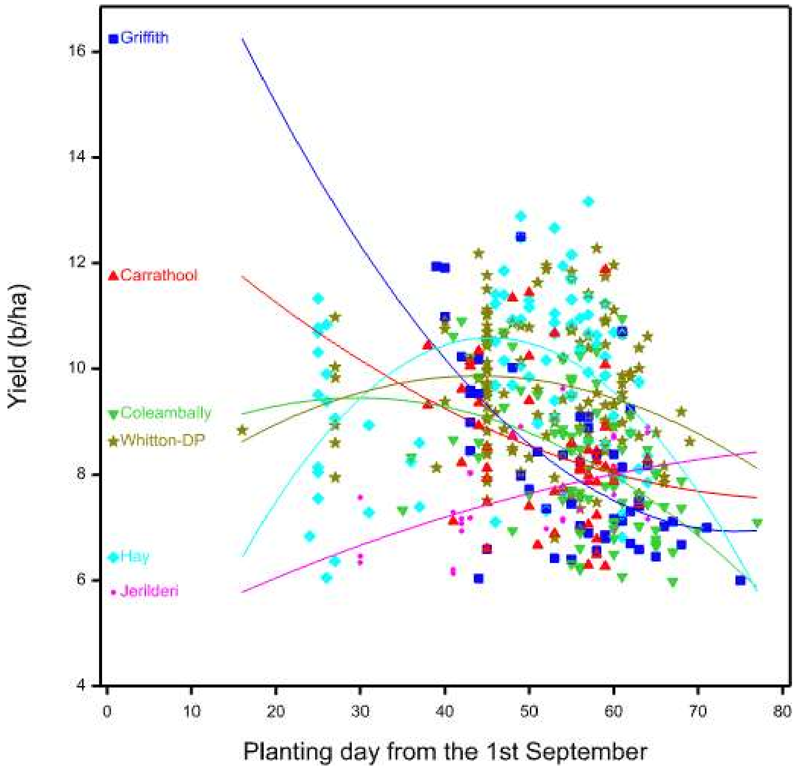


Figure 4. Average cotton yield quadratic trend lines for various district locations within the southern cotton growing region for the 2016–17 season.

## *Sowing date and micronaire*

While temperatures for sowing are better later in the season there is a danger for sowing crops after 7 November. The data suggest that planting after this date, the lint quality of micronaire (a measure of fibre maturity) is predicted to be in the discount range of less than 3.5. Thus growers sowing after this date would have a possible yield penalty of at least 18% but also a discounted quality due to micronaire caused by lack of time to mature at the end of the season (Figure 5). No other lint measurement was affected by sowing date.

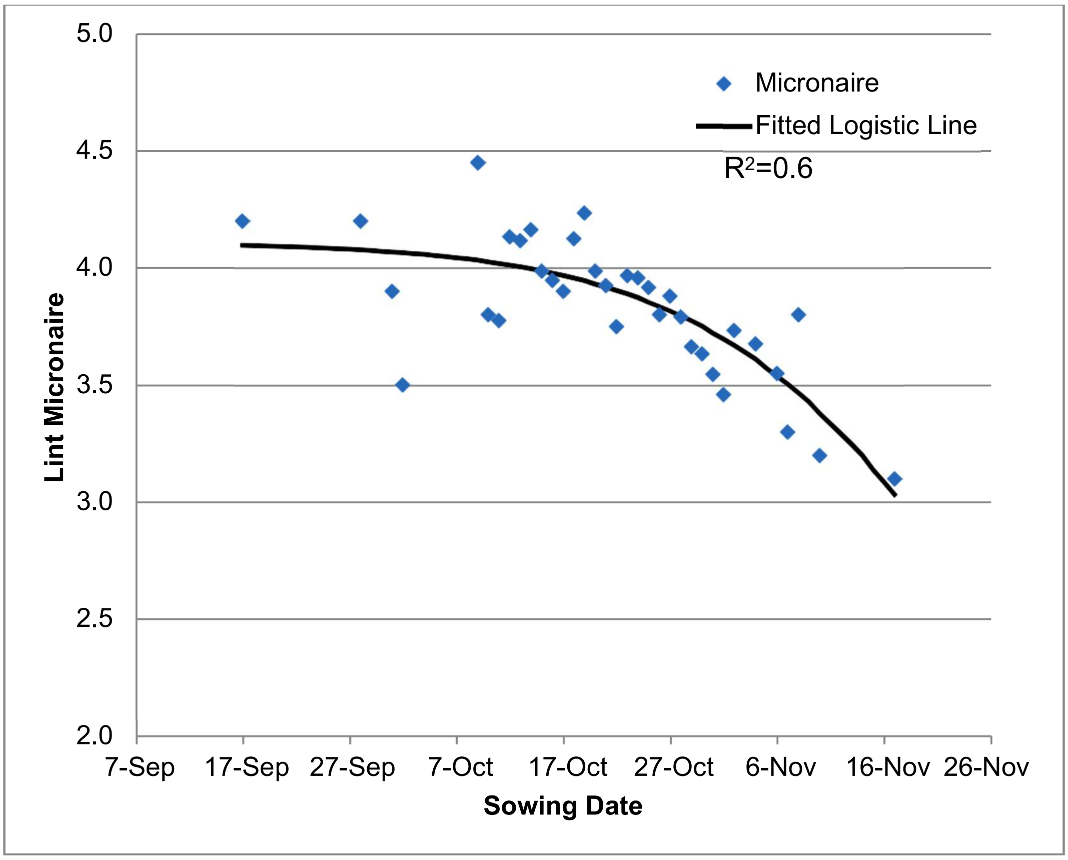


Figure 5. Average cotton lint micronaire as function of sowing date in the southern cotton growing region for the 2016-17 cotton season.

### *Field history and rotation*

Fields were grouped by previous crop field history. Fields cropped in the previous summer (e.g. corn, cotton, soybean) were classified as 'back-to-back' (B/B) in the analysis. Fields left fallow over the summer regardless of the previous winter crop were considered 'fallow'. All summer crops were grouped as it was assumed that ground preparation may have been compromised with the wet winter compared with a dry bed preparation in the summer. Cotton grown after a fallow summer yielded 1.28 bales/ha or 13.8% more than cotton grown after a crop (predominantly cotton) the previous summer (Figure 6). Some locations were better able to manage back-to-back cotton and reduce the yield differential between back-to-back and fallow. Whether this difference between locations and rotation is because of management or other factors is not clear from the data and warrants further investigation.

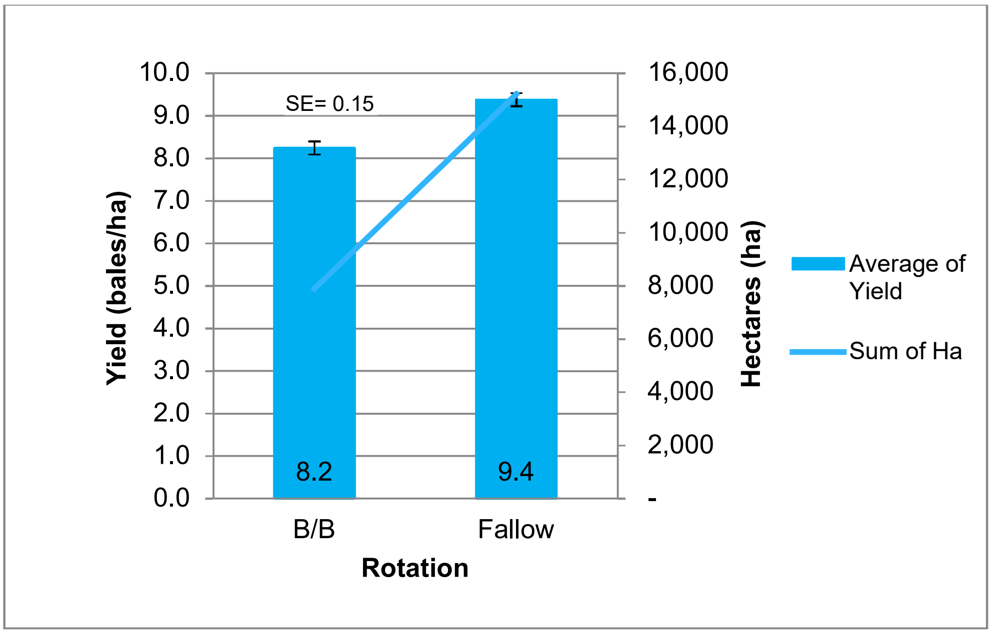


Figure 6. The effects on yield of summer fallow compared to back-to-back summer crops within the southern cotton growing region in the 2016–17 cotton season.

### *Bed geometry*

Growing cotton on wide beds as opposed to one metre spaced hills has long been a point of discussion around the cotton industry. The results from this season show no significant difference between bed and hill configurations under fallow conditions. However there was a significant difference 0.6 bales/ha (7.5% yield increase) in favour of hills compared to beds when the crop was back-to-back (Figure 7). When all rotations are grouped together the yield increase of hills over beds was 0.8 bales/ha or 8% in favour of the one metre hill.

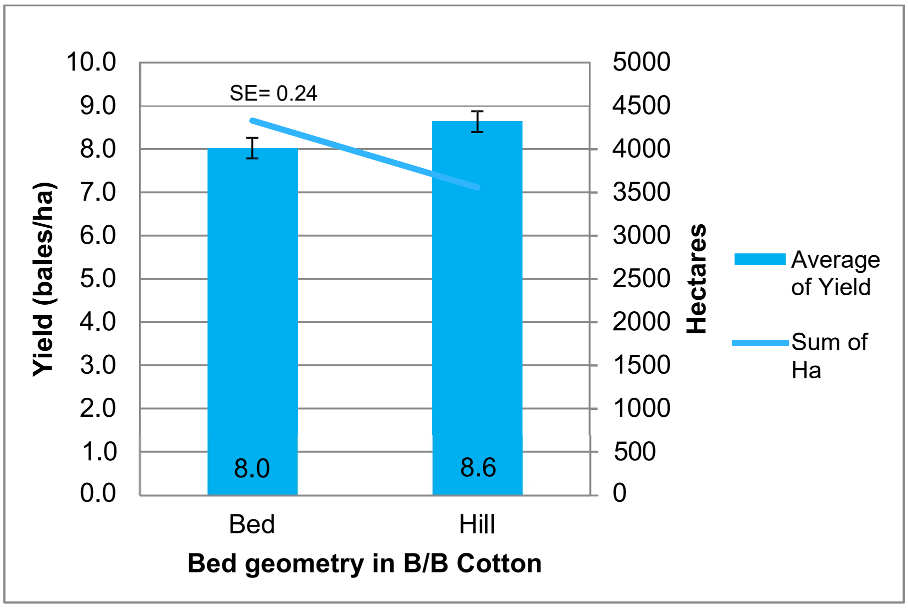


Figure 7. The effects on cotton yield of back-to-back cotton fields compared to fallow cotton fields within the southern cotton growing region for the 2016-17 season.

It is not clear from the data which type of irrigation system was predominant within each row configuration. Another variable might be compaction caused by wet picking and the dual wheel of the picker causing more compaction on the top of the bed in the back-to-back system compared to the fallow system. This might have resulted in water infiltration issues, fertiliser recovery and consequently lower yield. These issues and the management of back-to-back cotton fields is an area requiring further research.

## Variety

The data indicated that Sicot 74-6B3F was the predominant variety sown in the region last year accounting for 64% of the area. This was followed by Sicot 71-4B3F with 21%. The remaining area was sown to Sicot 74-8B3F and Sicot 707B3F. As this season saw a change from the Bollguard 2 (BG2) technology to the Bollguard 3 (BG3) technology, similar breeding lines of BG2 were grouped with BG3 lines in the analysis. The results show that the most popular variety (74-6) was the highest yielding variety with 0.72 bales/ha (8%) higher yield than the second most popular variety 71-4 (Figure 8). The data also showed some differences between varieties between locations, however due to the small sample size of some varieties (one or two fields per location) few conclusions can be drawn from these mixed results.

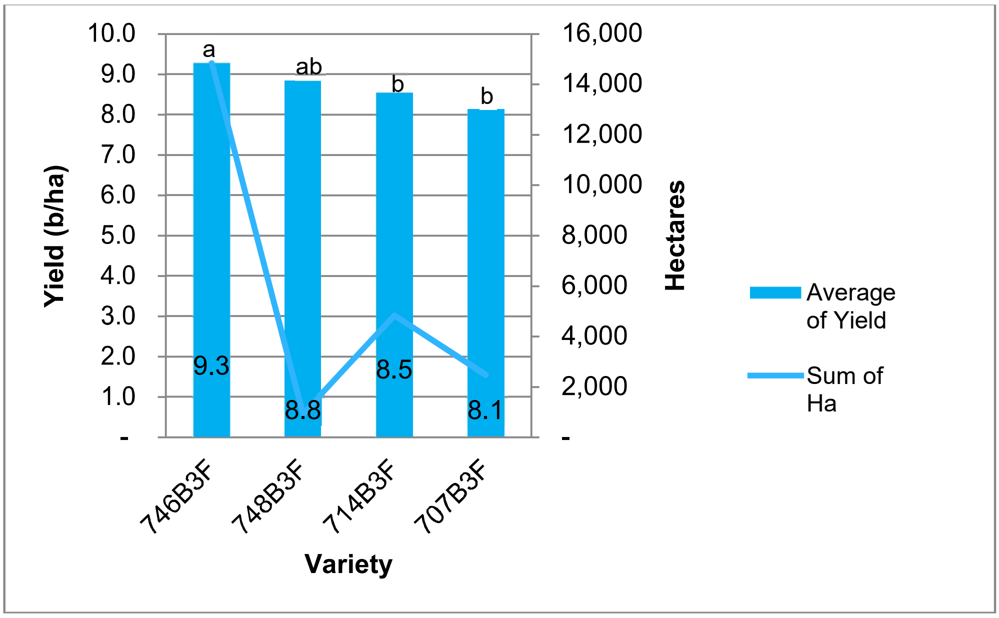


Figure 8. The average cotton yield and area grown for various varieties in the southern cotton growing region for the 2016-17 season. Columns with different letters are significantly different at the 5% l.s.d. level using Fishers protected l.s.d. test.

### *Nitrogen application*

Nitrogen use has been increasing over time across the industry and in the 2016–17 season there was a wide range of application rates and techniques. Rates varied between 170 kg N/ha to 456 kg N/ha. Application timing ranged from 100% applied pre-crop to 100% applied post planting. Similarly, application methods ranged from deep banding with either urea or anhydrous ammonia, or spreading urea and incorporating with a cultivation or with water using irrigation or rain. Banding of urea/anhydrous ammonia was either placed under plant line or beside the plant line. While applied N accounted for 9.8% of yield variation using general linear modelling, there were significant interactions with location as shown in Figure 9.

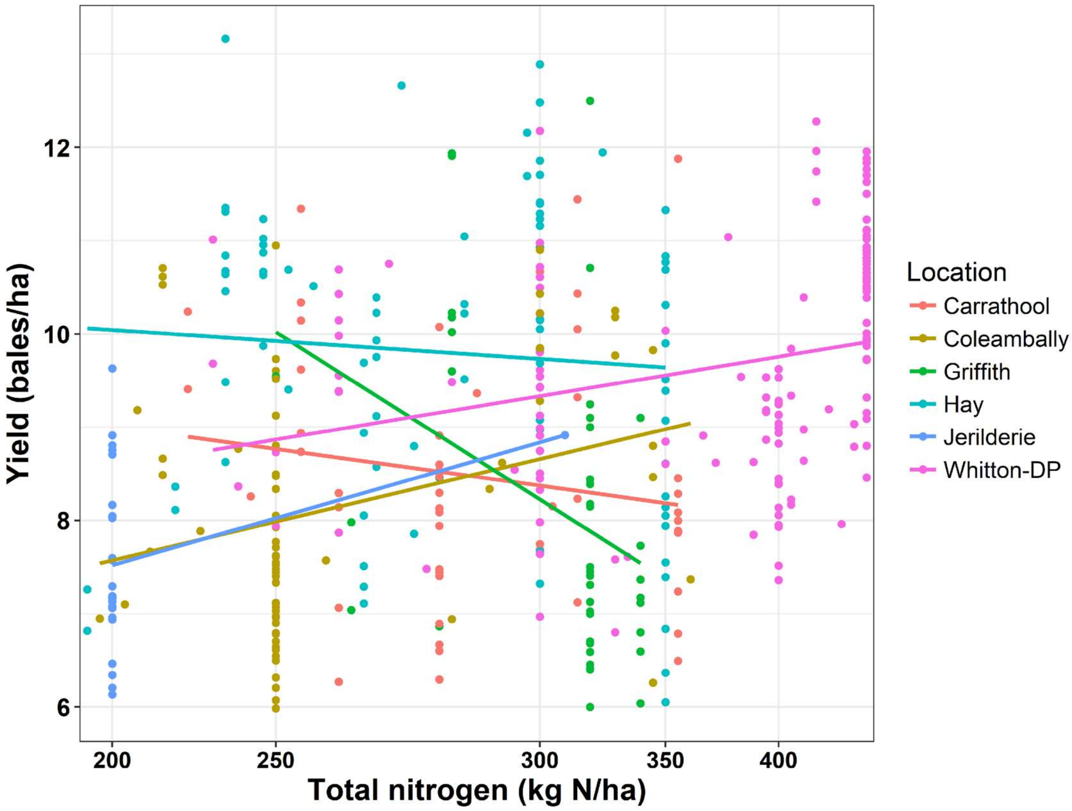


Figure 9. Cotton yield as a function of total N applied (kg N/ha) for various cotton farm locations in the southern cotton growing region for the 2016-17 season.

When applied N and its effect on yield is examined separate to location, the relationship is best shown by a logarithmic function (Figure 10). Regardless of whether a log function or linear function is used the data show there is no significant difference between applied N rate from 250 to 450 kg N/ha. This raises the question of whether applying N at rates over 250 kg N/ha is economical. Whether this holds true for other seasons is yet to be determined. The trend lines show the variability within the data set. The data implies that nitrogen should be managed within the respective crop and season and with realistic seasonal yield potential.

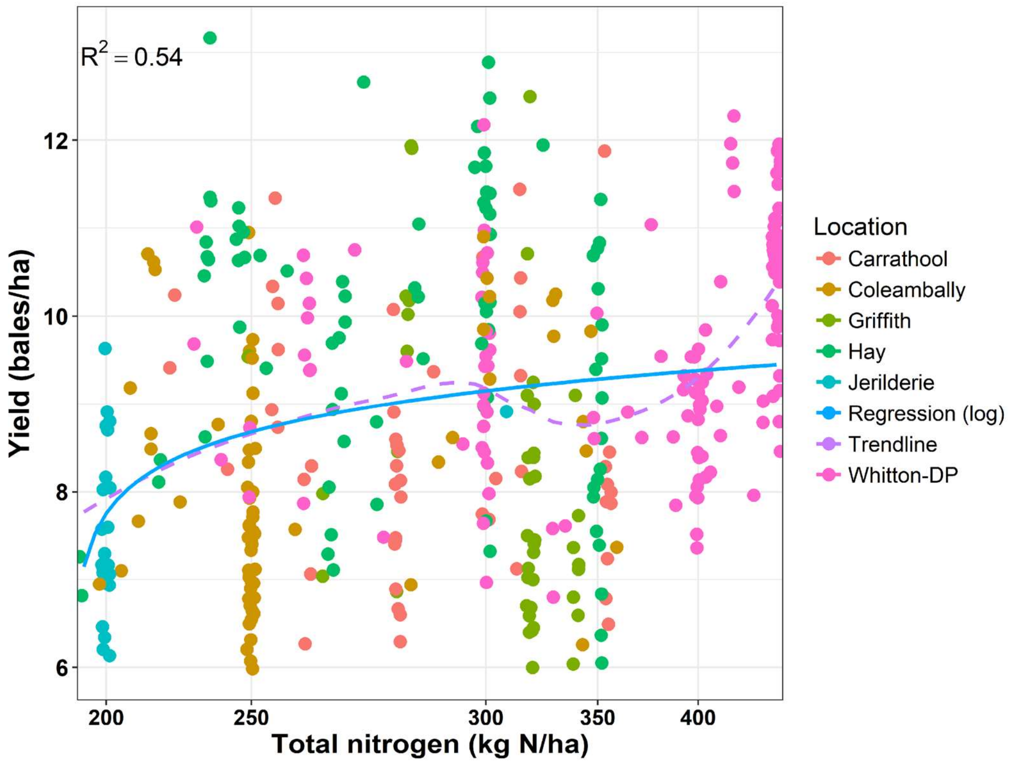


Figure 10. Cotton yield as a function of total N applied (kg N/ha) in the 2016-17 season.

Nitrogen application rates in both fallow and back-to-back fields were also highly variable (Figure 11). The interaction between rotation and N rate had a significance level of 6.6%. This indicates that back-to-back cotton benefits from higher rates of applied nitrogen compared with fallow fields, however this still needs to be considered within the context of N use efficiency and utilisation. The loudest message from the nitrogen analysis is the spread in the data. This implies that many other factors affect yield other than applied nitrogen. Therefore consideration needs to be given to the farm system as a whole and not just assume more nitrogen will improve yield.

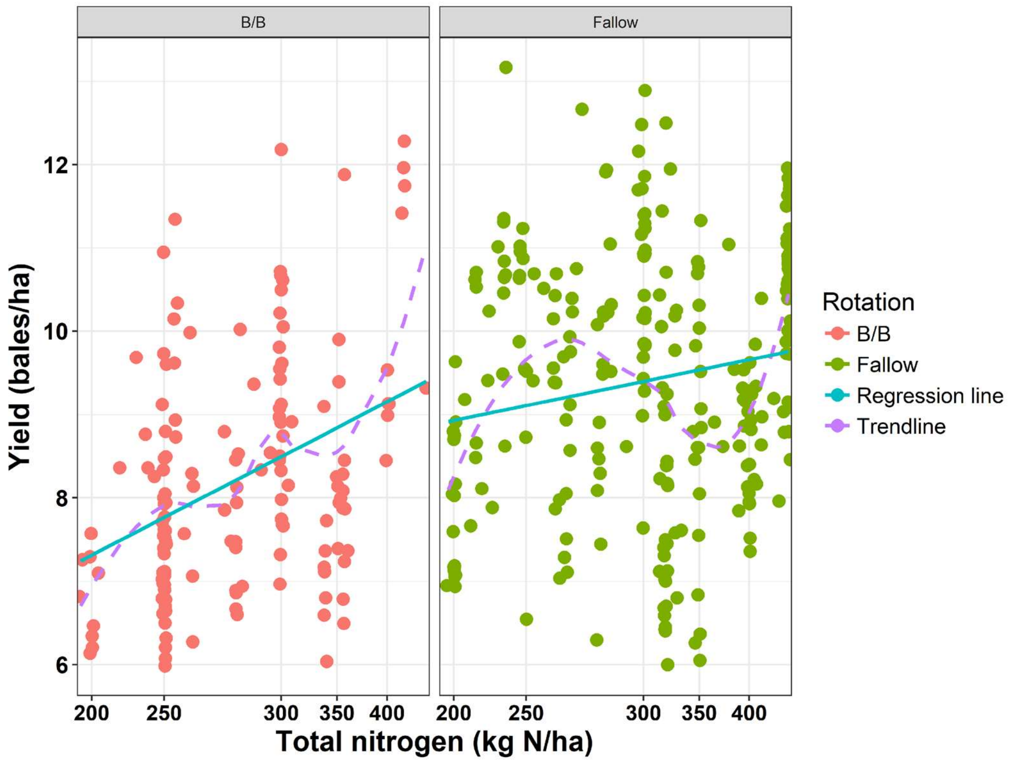


Figure 11. Cotton yield as a function of total N applied (kg N/ha) in the 2016-17 season on back-to-back and fallow fields.

## Discussion and conclusions

The 2016-17 cotton season in the southern growing region was challenging. Creating a database that brings together the majority of growers' fields and some key drivers of yield can aid education and management decisions in the future. In spite of the challenging field preparation and growing conditions (extreme maximum and minimum temperatures within the early part of the season and in late flowering) the season showed cotton production can still be viable.

From the data it would appear the optimum crop in the 2016–17 season would have been grown on hill spacing, after a summer fallow, planted with variety Sicot 71-6B3F around the second week of October. Nitrogen would have been monitored through the season and an application rate of around 250 kg N/ha would have been adequate.

Areas of further research raised by the data include:

- The effect of excess applied nitrogen on crop termination, defoliation and picking period and the consequent effect on quality.
- Farm design and bed shape as it relates to crop rotation, irrigation efficiency, compaction and water infiltration.
- Choosing the best sowing date to minimise exposure to extreme temperature ranges and challenging germination conditions early in the season. This has to be balanced by

delayed sowing and the effects of low temperatures (defoliation and reduced picking opportunity) causing possible yield decline and quality issues.

The cotton industry has long had a reputation of learning from each other and a culture of sharing of ideas and research. This has helped the industry grow when many other commodities have declined. Thank you to all of the growers, consultants, cotton gins and others who participated and contributed to the collection of data. There is still more analysis to be done on the data collected. It is hoped that the database will continue and that further trends and farming practices can be identified across seasons and locations to aid industry education and research.

## References

Australian Cotton Production Manual, 2017. *Cotton Research and Development Corporation* Narrabri. NSW

# Appendix 2

# Review of Farming Practices and Opportunity for Research in the Southern Cotton Growing Region

February 2017,
Steve Buster,
Yanco

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## Pre Plant Field Management

Depending upon the farm there is a mixture of fallow and back to back crops. As the industry is in an expansion mode the percentages of back to back cotton is probably higher than those employing a 100% rotation.  Depending upon the growing area this is a consequence of being land poor and water rich (around Griffith, Coleambly areas) compared to land rich, water poor (areas further west of Carathool/Hay).

Generally for both cotton and grain rotations many fields are ploughed/disced down to remove trash and then re-hilled.  There seems to be very little effort to try and retain existing hills and go to a more permanent bed situation. Farm-rotation system needs to be explored to remove cotton trash, plant cereal crops for weed and disease break and retain hills without heavy tractor usage.

*Is there a need to reinforce the advantages of retaining existing hills and plant line if rows are in good condition?*

There may be advantages of sowing into standing stubble to reduce wind damage of seedlings. The down side is standing trash may restrict water flow and also delay warming of beds coming out of winter (Cutforth and McConkey, 1997, Hulugalle and Daniells, 2005). Advantages are much greater soil tilth and soil organic matter and bed protection.

In back to back cotton, fields are sometimes mulched but not root cut (*is it to wet?*), hence ploughed to remove standing stalk. (*If it is too wet for cut off then is it too wet for the disc?*) Soil ends up in small hard, tight peds that do not break down when water hits them at sowing. Sowing into this soil has issues with seed/soil contact, hence imbibition and subsequent radical growth. (This might be only a function of the wet winter experienced this year but if it is a winter dominate rainfall this may be normal.)

(Hulugalle and Daniells, 2005) reviewed permanent bed use in the Australian cotton industry. They cite work done by McGarry and McKenzie 'that permanent beds were first introduced into the mid 1980's after yield declines occurred in the Australian cotton industry due to causes related to soil structure'. Benefits cited of permanent beds include better soil physical and chemical quality and lower costs than full tillage each year. Yields are not necessarily higher but reduced costs give greater returns. Higher yields and further improvements in overall soil quality can be achieved by using suitable rotation crops such as wheat and by planting cotton into retained stubble. Problems associated with managing permanent beds in cotton systems include;

- Beds shifting over compacted furrows with time
- Managing both wheat and cotton stubble to optimise water flow during irrigation
- Applying anhydrous ammonia through crop stubble
- Excessive tillage during compulsory pupea control

They conclude that these problems can be overcome by using appropriate machinery and agronomic management practices.

**Trials: Promote/discuss concept of retained hills to reduce winter traffic and disturbing the plant line particularly when it is wet. Look at shoulder bust retained hills so when it does rain, water drains (compared to ploughed fields), and not trying to pull up hills/beds in the wet.**

## Pre-Emergent Herbicide and Weed control

Some farmers are using pre-emergent herbicides- Stomp, some using fluometron or similar. Concern is over glyphosate resistant ryegrass and possible barnyard grass. This just needs to be watched. It does have implication for retained stubble as application of pre-emergent herbicides onto trashy soil becomes an issue.

## Fertiliser

There is a mixture of techniques being used. N rates appear in the range 250-350 kg N/ha. Most practice is split application, some as early as March before winter applying either anhydrous or urea. There is some discussion of the amount of loses from applying too early, but considered it is better to have some fertiliser down in the dry than trying to apply in the wet. Some proposed that because of the cool winter conditions the amount of denitrification and loss is minimal. A lot of farms are water running either urea or anhydrous. Smaller farms appear to use urea as access to anhydrous is taken up by the bigger farms. Some spread urea with a spreader, then water in.

*One aspect of concern was the spreading onto a bed with no cultivation and urea sitting on top, at face value this seems a very inefficient use of N, as unless there is rain, there is no way for N to move down the profile to the roots.*

**Exp: There is room/need of N rate trials to determine rates of economic benefit. Trying to shut plants down due to season length with excess nitrogen appears to just add unnecessary cost to the crop both for excess fertiliser and excess Pix and defoliant required.**

There is mixture of growers using different P types and amounts.  Some farmers using chook manure. Some growers are applying zinc and other nutrients (some boron) at different time periods, some early, some late flowering. The science behind it all seems unclear so could be analysed for economic return.

## Bed Shape and Spacing

Most farms are on either 2 metre beds or 1 metre hills. There are some planting on 36″ on 72″ beds. There are a handful of growers trying 30″ (75cm) on 60″ (150cm) beds. Swan Hill it is all 30″ row on 60″ beds as this fits with the drip and sprinkler designs.

There is a definite row effect on the cotton growth of cotton sown onto the north side hill on beds that are running east-west. Unverified discussion was that the cotton was 3-4 days earlier in emergence compared to the south side. Whether this early growth translates into yield has yet to be determined.

30" cotton is a separate discussion and needs consideration after season length is analysed. Ultra narrow row (15 inch or 38cm) while it may have a fit for some growers, is probably at a higher level of management and equipment/machinery set up than where most growers are at.

**Exp: Trials of bed shape (hill v bed) need to be done to verify the agronomic difference between them and whether it is worth changing farmer configuration.**

## Sowing

Seeding rates range between 16 to 20 seeds/mtr, with most around the 16 seeds. Target plant stand establishment of 10-12 plants/meter. Some growers targeting 12-15 plants/mtr to ensure they get
10. Some are targeting 8 and only sowing 12 seeds/metre.

**Exp. Trials or desktop review of plant density per linear meter and its effect on first fruiting node should be done.**

Majority of growers are planting high and flushing/irrigating up. Some pre-irrigate and then plant high to flush up. This year some tried sowing into moisture with mixed results as claim soil moisture ran away (dried back) to fast. This is varied between growers and consultants, some have issues with cracking of the hill planting into moisture, others do not and plant majority of crop that way, but this seems a minority of growers. It does not appear that many farmers are geared up to chase moisture in the hill like northern growers. No water injection except at low rates to apply either
'pop-ups', fungicides or insecticides like (rizolex and bifenthrin). No one appears to have tried high water rates of 400 ltr/ha down the slot to increase seed/soil contact and reduce dry soil affecting imbibition.

### Sowing time and temperature

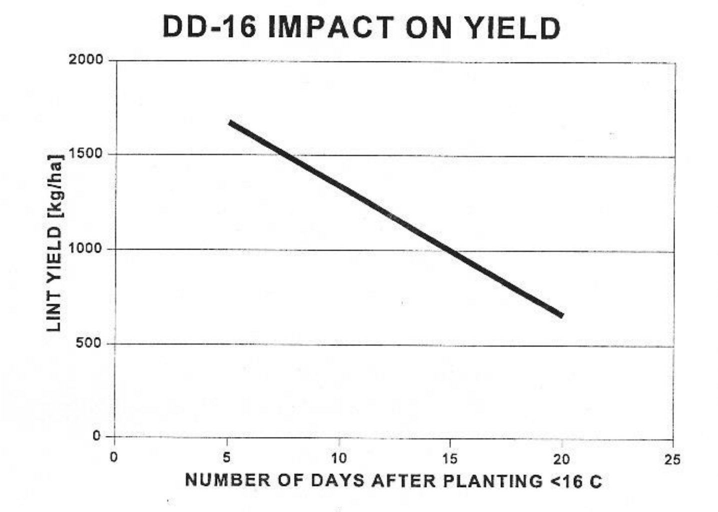
Some growers are sowing at a pre-defined date, normally with reference to a warming trend. This appears to be trying to sow at start of 4$^{th}$ week of September or 1$^{st}$ week of October with warming trend (but unsure what 'warming' implies). This year was different, it is assumed because it was too wet as opposed to being too cold. It does not appear that absolute soil temps are used, more a warming trend. The push to plant early is due to the shorter season length compared to further north.

*Season length drives everything. It has implication for planting date, early season insect control, fertiliser management and end of season management. We need to get a handle on how long the season can be and how to drive 'earliness'.*

Irrigating up can also decrease soil temperature, thus as soil temps are marginal at sowing time, what is the effect of flushing with water on the soil temp when the seed is imbibing? The literature would suggest significant. Reviews by Christiansen and Rowland (1986) and Bradow and Bauer (2010) summarise:

- 'Metabolic activity is greater and more complex during germination than at any other period in cycle of life'. 'All events occur in a more or less orderly fashion unless disrupted by unfavourable external forces.'
- Imbibition of the seed coat is by the chalazal pore. Not all varieties have a plug, but 'hard seeded' varieties have a water insoluble plug. This gives the seed dormancy. Can be removed with soaking in hot water treatment 85°C.
- Rate of water entry into the embryo is initially rapid – 12 hours to go from 8-10% moisture to 40-80% moisture. There is variation depending upon genetic source and seed damage. Range from 4 – 30 hours, majority appears to be by 4-12 hours.
- After imbibition there is a 'lag' phase characterised by reduction in the rate of water uptake, and rapid increases in metabolic activity.
- Significant water uptake resumes when protrusion of the radicle through the seed coat equals 'true' germination.
- Very early germination is supported by soluble carbohydrate reserves. Energy is provided by stored lipid and proteins. There is generally very little overall weight loss from germination to emerged seedling, indicating that most activity is conversion of stored material to structural components.
- Storage lipid was found to be depleted after 14 days by White (1958). The pathway concluded was the continuous metabolism of fatty acids to organic acids and sugars via the glyoxylate pathway. Involved in this glyoxylate pathway is Isocitratase. This enzyme is more chilling sensitive than other enzymes of the pathway.
- Nearly all lipid reserves in oil-rich seeds like cotton are mobilised after radicle protrusion. Once lipid mobilisation is initiated during the imbibition period, lipid utilisation is rapidly completed during the first week of cotton seed development.
- Periods of stress states of germination to temperature are;
  - Imbibition 4-6 hours
  - 18-48 hours- depending upon temperature when the radicle is first protruding. This is a time of increased metabolic activity.
  - Period of 'early crook' when the hypocotyls were near the surface and ready to emerge.
- Low soil temp during cotton seed germination has both immediate and long term effects. (Christiansen, 1963, Christiansen, 1967) Immediate is two types of effect. A) Radical tip abortion induced by chilling at the onset of seed hydration and B) root cortex disintegration induced by chilling the seedling after elongation of the embryonic axis has commenced. Temperature this occurred at and below 10°C.
- Exposure of imbibing Upland cotton seeds to temperatures below 5°C during the initial phase of imbibition results in seedling death (Christiansen, 1967, Christiansen, 1968). Depending on the duration of chilling exposure, imbibitional temperatures below 10°C cause radicle abortions or, in cotton seedlings that survive chilling injury, necrosis of the tap root tip and abnormal lateral root proliferation (Christiansen, 1963)
- Chilling after radicle is 2-3cm long causes cortex sloughing, slowing of early growth, increased sensitivity to pathogens, membrane leakage of sugars and amino acids and long term growth reduction and flowering delays.

- Losses of sugars and amino acids occur at 5mm from root tip when chilled after radical emergence. Loss was minimised by removal of cotyledons showing them to be a solute source. Enriching the soils around the root and opening up the membrane could lead to more susceptibility to pathogen attack.
- Both chilling injury and solute leakage reduce seedling vigour and increase seedling to pathogens.
- Chilling at 10°C degrees during the 2nd period of increased metabolic activity resulted in plants that were shorter, had less leaf area and weighed less 4 weeks after chilling, had delayed first flower and delayed maturity as shown by less 1st picked yield at harvest (Christiansen, 1967, Christiansen, 1964).
- Loss of membrane integrity was also caused by anaerobic conditions.
- In short season areas of US cotton belt east of the Mississippi River advice growers.
    - Soil temp at 7.5cm has reached 18°C at 10am
    - More than 25DD-60 heat units are predicted with the temperature to >10°C for the first two nights after planting.
- Kerby et al. (1989) concluded that cotton should not be planted when fewer than 10 DD-60 heat units per day were expected for the five days after planting.
- The impact on yield of the number of days after planting on which the minimum temps were <16°C is below (Bradow and Bauer, 2010).




*We need to look at ways to reduce chilling of the seed bed upon planting. The application of water to imbibe the seed and its effect on germination is of particular concern particularly if growers are planting at temperatures below 12°C and then watering up and dropping the soil temperature by 2-4 degrees.*

**Exp: Sowing date and temperature/germination interactions need to be examined. This could be done with associated treatments.**

## Plastic Mulch

The use of plastic with vegetable production has been used for years. There have been trials in central Queensland and also on two fields in the southern districts trialling plastic laid after sowing.

Research on plastic presents:

Bennett et al. (1964) tried various Ca compounds, soil conditioners, asphalt mulch and back plastic, with black plastic the most effective. They found that an average of only 10.8% of the seedlings emerged from conventional planting, whereas 77.8% of the seedlings emerged when rows were covered with black plastic film. Under the plastic film, the seed germinated and seedlings emerged within 5 days after planting. Seven to 9 days were required for seedlings to emerge from other treatments. Minimum soil temperature under the plastic was 5 to 7° F higher than in uncovered soil. Nine days after planting, the soil moisture content was at or near field capacity under the plastic.
Lament (1993) reviewing the use of plastic in vegetables, reports that the soil temperature under a plastic much depends on the thermal properties (reflectivity, absorptivity, or transmittancy) of a particular material to incoming solar radiation (citing Schales and Sheldrake, 1963).

Black plastic absorbs most wavelengths of the visible and infrared spectrums, often re-radiating absorbed energy in the form of thermal radiation or long-wavelength infrared radiation. Soil temperatures under black plastic during the daytime are generally 2.8°C higher at 5 cm depth and 1.7°C at 10 cm depth compared to bare soil.

By contrast clear plastic absorbs little solar radiation but transmits 85% to 95% with relative transmission depending on the thickness and degree of opacity of the polyethylene. The lower surface of clear plastic mulch usually is covered with condensed water droplets. This water is transparent to incoming short wave radiation, but is opaque to outgoing longwave infrared radiation, so that much of the heat lost to the atmosphere from a bare soil by infrared radiation is retained by clear plastic mulch. Thus daytime soil temperatures under clear plastic mulch are generally 4.4 - 7.8°C higher at 5 cm depth and 3.3 – 5.0°C higher at 10 cm depth compared to bare soil.

Lament (1993), concludes;

- Clear plastic mulches are generally used in the cooler regions (of the US).
- Herbicide is often needed to prevent weed growth under clear plastic.
- Other benefits of plastic used in vegetables include; earlier and higher yields, reduced evaporation and reduced soil compaction

There has been some work done with liquid mulches in China. (Yang *et.al.,* 2008) report yields increase of up to 34%. Finding reports and product available in English is proving elusive.

**Exp: Need to conduct trials; On the use of plastic to heat the bed;**

**Water injecting to help improve moisture planting early to remove the need to flush up;**



## Seedling Disease

Seedling disease seems to be the sleeping elephant. One agronomist thought the yield costs at Hillston about 1 bl/ha and Whitton up to 3 bl/ha. It was thought cotton grown back to back have incidences between 30 to 75% of seedlings.

Rothrock et al. (2012) in a multiyear study on the importance of fungicide treatments on cotton seedlings concluded that little to no stand improvement was found when minimal soil temperatures averaged 25°C the first 3 days after planting. Stand losses due to seedling pathogens increased dramatically as minimal soil temperatures decreased to 12°C and rainfall increased. The importance of Pythium increased dramatically as minimal soil temperature decreased and rainfall increased, while the importance of R. solani was not affected greatly by planting environment.

One farm in 2016/17 season is trialling growing rice to ascertain whether flooding will reduce black root rot inoculum. There appears to be issues with growing summer crops after a rice crop. Issues of P tie up with Fe, soil compaction, acid top soil and lack of VAM have been raised.

Nehl and McGee (2010) reviewed Arbuscular Mycorrhisas (AM or VAM) in cotton. They cited work that indicates cotton inoculated with AM fungi has resulted in reductions in the severity of Verticillium wilt, Fusarium wilt and black root rot. However, they also cite work that AM may increase severity of disease. They conclude that the influence probably depends upon the species of AM fungus.

Unpublished (yet to be published) work by Moore et.al., (2016) from Charles Stuart University at Wagga Wagga evaluated a number of commercial products supposedly containing VAM and used to enhance seedling development. They concluded that no products worked even up to 20 times the recommended rate in any significant manner to cause colonisation in the cotton seedling roots.
Comparing rotation crops, wheat was found to provide the greatest colonisation of VAM in subsequent cotton seedling roots.

*It is proposed that it is in both industries interest to work to together on this issue. Cotton may need a rice rotation to reduce disease inoculum and also give the farmer an alternative crop when faced with unsuitable planting conditions and or price. Rice growers will benefit by having alternate market and water use and allow growers move in and out of production and not being squeezed out of production due to enforced fallow periods.*

## Post Emergence Growth.

Emergence time takes between 10 to 21 days. As it is a function of seed size (lipid reserves) and temperature. Planting larger seeded cotton varieties will result in earlier emergence but these varieties have lower lint turnout and consequently lower yield potential in a 'normal' season.
Many farmers will irrigate very early cotton, - "give it a quick flush". The concern is that the soil is drying faster than the speed the roots are growing at, so the plant is possibly drying out. Some are flushing to see if they can improve germination as stands were patchy and

the thinking was some of the seed may have dried out so flushing may help. It is not uncommon to have two (2) irrigations before the plant is 8 nodes. Some farmers had the view that black root rot appeared to increase its presence after flushing seedlings hence causing more damage.

Patterson and Flint (1979) showed chilling at 13°C reduced stomate conductance and reduced photosynthesis in seedling cotton. Changes in size and shape of 1st and 2nd true leaves are caused by chilling during germination (Christiansen, 1964).

Losses of sugars and amino acids occur at 5mm from root tip when chilled after radical emergence. Loss was minimised by removal of cotyledons showing them to be a solute source. Enriching the soils around the root and opening up the membrane could lead to more susceptibility to pathogen attack (Christiansen et al., 1970). Loss of membrane integrity was also caused by anaerobic conditions.

Some researchers observed that emerged seedlings suffer water stress under chilling conditions. Christiansen and Ashworth (1978) demonstrated that chilling injury at 8°C did not occur if aerial parts were in high humidity. Work was done in a glass house with a chemical anti-transpirant to prevent cold injury. It was suggested it needed to be evaluated in the field.

Christiansen and Thomas (1969) showed the cumulative effect of cold incrementally affecting final plant height, date of flowering and earliness, suggesting cold stress during germination affects a very basic control system in the seedling.

## Cold Effect on Roots

Mcwilliam et al. (1982) chilled only the roots of cotton. They found that leaf water potentials were reduced below -1.5 MPa within 1-2 hrs.  This response was reduced when seedling were chilled in the dark. Their results suggest that water deficits chilling in the light are caused by a reduction in the hydraulic conductivity of the root membrane.

Experiments on chilling roots of cotelydon cotton by Radin (1990) found that;
Transpiration rate was little affected between root temperature from 13°C to 35°C. Cooling roots below caused sharp reduction in transpiration.
Leaf water potential began to decrease as root temperature fell below 20°C. At 13°C leaf $\Psi_w$ was near -1.0 MPa which corresponded to near zero turgor pressure in cotelydons.
Hydraulic conductance of the plant was high at >20°C but decreased quickly at temperatures below down to zero about 10°C. Cooling roots resulted in increased ABA accumulation in leaves, but required nutrient (N and P) stress to lead to closure of stomates. So if no nutrient stress then stomates stay open causing decreased leaf water potential.

Bolger et al. (1992) looking at chilling on cotton at the 9 leaf stage and found that; Cotton plants wilted severely on the afternoon the root zone temperature was decreased from 30°C to 18°C. Root hydraulic conductance decreased with temperature in a curvelinear manner. Their results showed that at 20°C conductance was 57% of control, at 18°C was 43% and at 7°C was 18% compared to control of 30°C.

*What is the effect of early irrigations on seedlings? Does the perceived benefit of keeping roots moist outweigh the potential downside of waterlogging, chilling of roots, increased disease risk?*

Hake et al. (1996) developed guidelines for timing of first irrigation. They proposed the use of the pressure bomb and timing irrigation to the day after leaf water potential was -15 bars or -1.5 MPa. Subsequent irrigations are suggested at -18 bars. *This plant measurement should be evaluated with respect to early seedling irrigations.*

**Exp: Trials could include the use of anti-transpirants if cool weather was forecasted (particularly nights) to reduce water stress and at different growth stages.**

***Exp: Trials on field management methods to reduce early soil drying out. In particular the use of cover crops and stubble to reduce wind effect of drying soil and improve soil physical properties.***

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## Environmental Conditions and their Effect on Growth

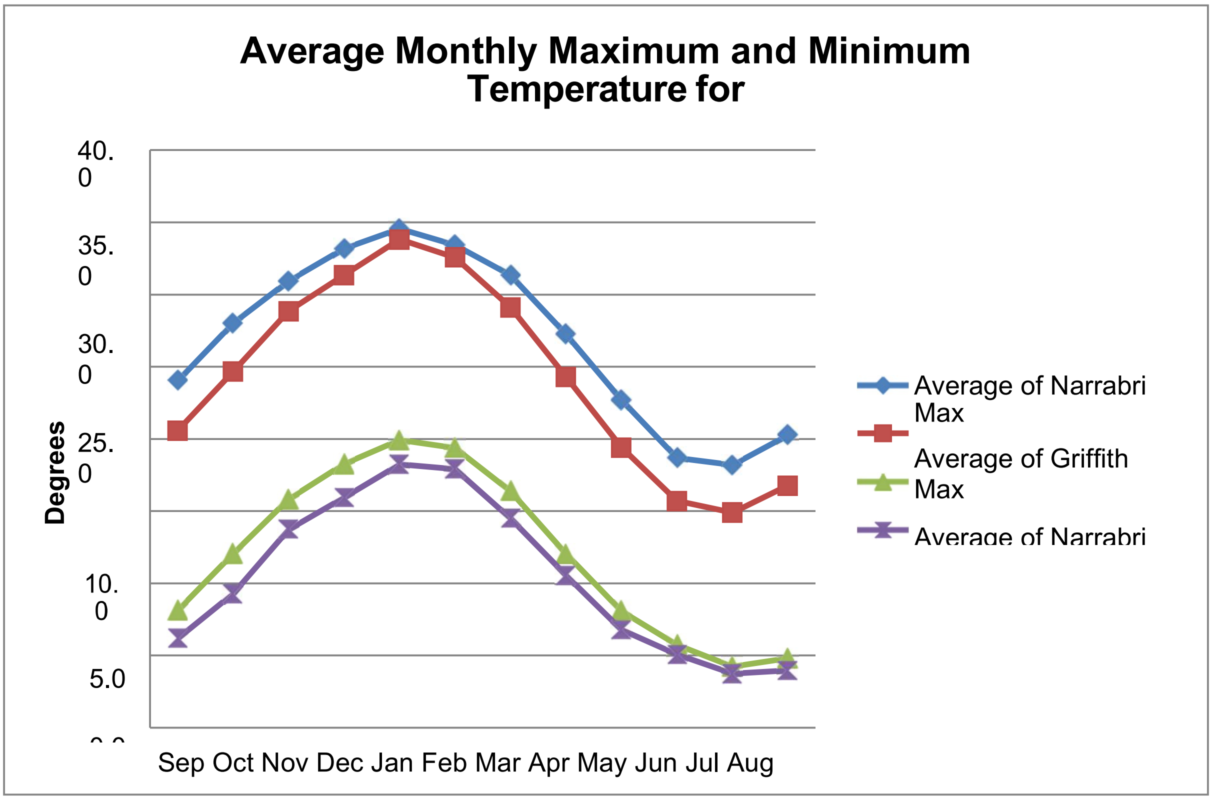
### *Temperature*

'Temperature is the paramount environmental factor which influences cotton growth' (Wells and Stewart, 2010). The rate of phenological development is largely dependent upon temperature. Days between growth events (i.e. appearance of leaves, floral buds, and flowers) are decreased as average growth temperature is increased from 13 to 30°C (Hesketh et al., 1972). Work was done by Reddy et al. (1992) on the effect of different temperature regimes applied in the first 56 days after emergence. It was found that the greatest stem elongation, leaf area expansion and dry weight accumulation occurred at 30/22°C day/night temperature. The leaf area and biomass per plant was approximately 530 and 550% greater than 20/12°C and 67 and 76% greater than 25/17°C. At higher temperatures of 40/32°C resulted in 88 and 95% of growth compared to the optimum of 30/22°C.

Critical minimum temperatures for growth are reported in the range of 11.4-15°C (Bange and Milroy, 2004, Constable, 1976). Cold shock as defined by every night below 11°C adds 5.2 day degrees (base 12°C) to the first flower day degree requirement (Hearn and Constable, 1984).

The differences between the locations of Griffith (as a representative area of the southern region) and Narrabri (representative of northern ‘traditional’ growing area) is shown in graph below. As can be seen the average minimum temperature for the month of October in Griffith is 9.3°C compared to Narrabri at 12.1°C. Obviously, there is a critical difference between zero growth and cold shock, versus some growth between the two locations. As this is a monthly average, the early part of the month is presumably cooler than the later part of the month. Hence, more damage is likely to be done to plants from cool temperatures in the early part of planting window of late September to early October. It is no surprise that the cooler temperature in the southern areas result in longer periods of time to reach critical growth events like node production, square formation and flowering. Similarly the end of season in March/April the minimum temperatures become important in finishing the crop.

*This raises the question of whether there is enough time in the season to achieve 'economic' yields in all years or what proportion of years?*

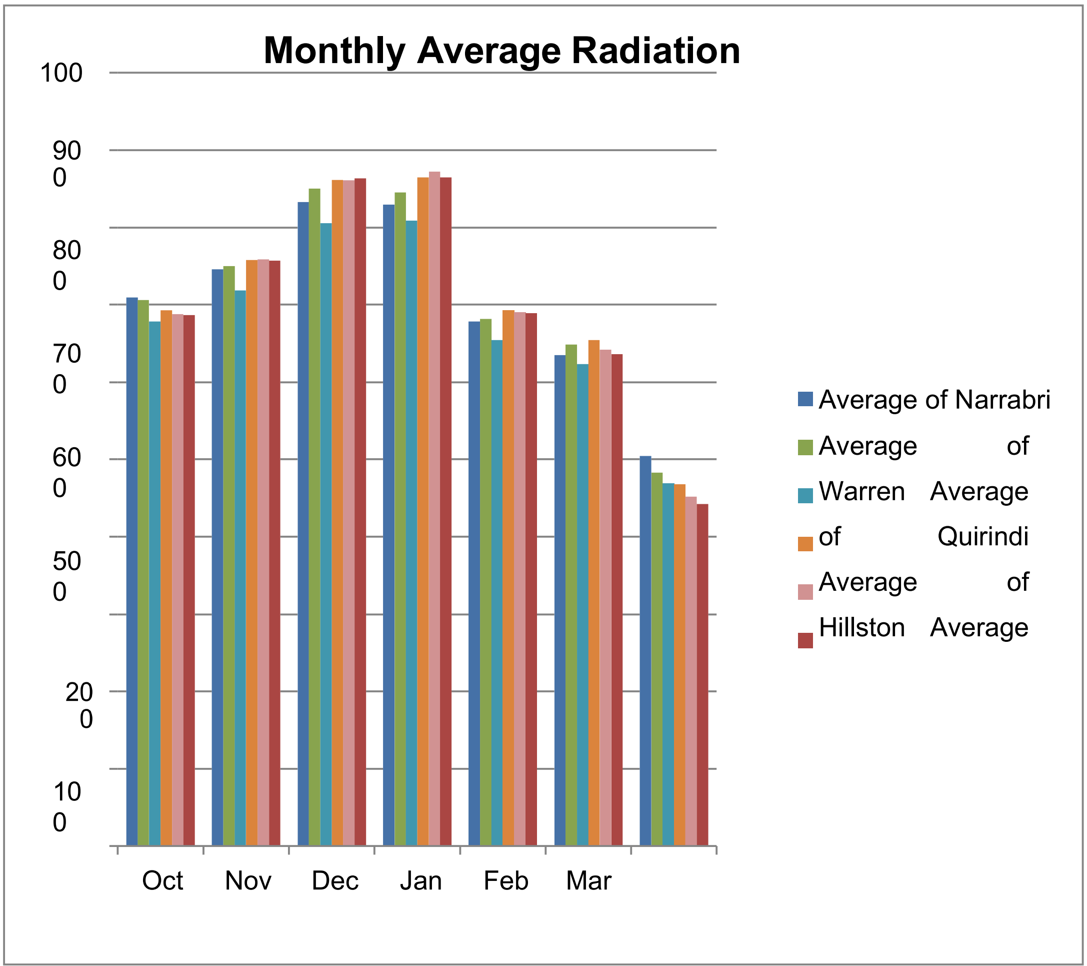


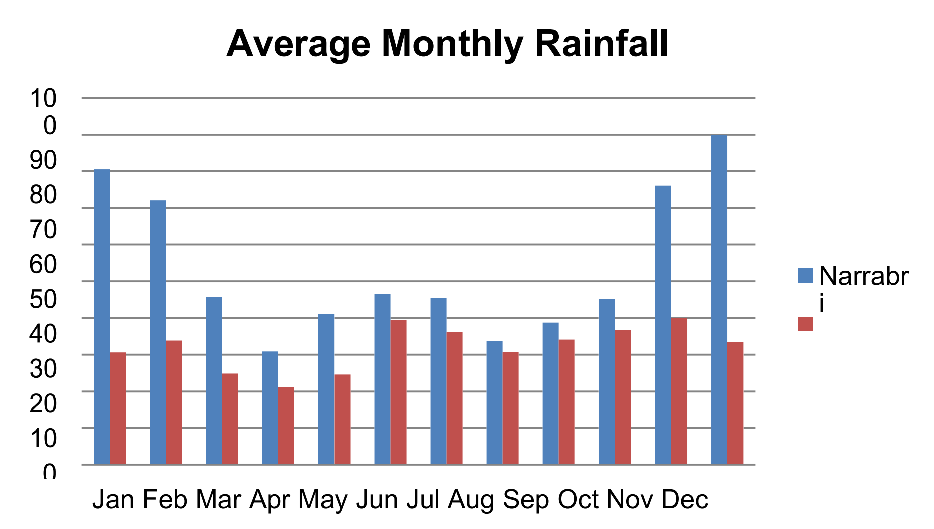

Temperature, while limiting phenological events may be partly overcome by near optimum temperatures in January when many factors affecting yield are being determined. This time period coincides with days of high solar radiation as discussed below.

### *Solar Radiation*

One of the most import factors determining growth of plants is the ability to intercept light before significant inter-plant competition. Therefore, leaf area development is a critical determinant of plant growth (Wells and Stewart, 2010). Muramoto et al. (1965) cited by Wells and Stewart (2010) reported that the rate of leaf area development among cotton genotypes was directly associated with differences in dry matter production. By early reproductive growth, the advantage of greater leaf area per plant is abated as critical leaf area indices (LAI) is approached, indicating that light interception is no longer a limiting factor. By definition, a critical LAI is one which intercepts 95% of available PAR (photosynthetically active radiation, 400-700 nm wavelengths). Cotton's critical LAI is approximately 3 to 3.5 $m^2$ leaves/$m^2$ ground (Hearn, 1969, Constable and Oosterhuis, 2010). Heitholt and Sassenrath-Cole (2010) summarise that plant densities which result in an LAI between 4 and 5 are usually associated with optimal yield. It is impossible for a plant canopy which does not 'close over the middles' to reach its maximal growth potential because interception of solar radiation will not be maximised. Thus the challenge is reaching a balance between light interception capability by the canopy, greater air movement at deeper canopy levels and increased light penetration to leaves which would otherwise be shaded or nearly so.

The PAR would appear to be of significance for the crops in the southern areas. Analysis of the available solar radiation shows levels higher than those growing regions further north over the months of December to February. While this is intuitive as the latitude is further south (34.3°S at Griffith compared to 30.2°S at Narrabri) it is also helped by reduced cloud cover being a more winter dominant rainfall. (This is based upon assumption that more rain implies more cloudy days). The differences between Narrabri and Griffith in solar radiation and rainfall can be seen on charts below.






These months of extra PAR correspond to when the cotton crop is in fruiting mode and able to utilise as much carbohydrate as possible also corresponds when temperature is not limiting.

*How this utilisation of extra PAR is apportioned is yet to be verified.*

Phenological events for cotton grown in the Griffith area with no influence from adverse conditions like insects or cold shock is presented in the table below. Days are the average of the records, (CSD, New Growers Guide, Growing Cotton in the South, 2013). It is assumed planting date is the 1st October. Implied in the table below is a fruiting period of 40 days and an accumulation of 2050 day degrees for crop maturity before defoliation. The question arises as to whether this period and temperature accumulations are achievable, and if not, then what can be done to alleviate the consequential reduced yield by stopping the crop early. As temperature sets the timing of the events and photosynthesis provides the energy to achieve these events, the challenge is to set the crop to utilise the maximum of the resources (temperature, sunlight, water and nutrients), provided.

**Phenological Events for Griffith sowing 1st October**

| **Griffith Airport data** | **Date** | **Days** | **Ave DD** (no cold shock) |
|---|---|---|---|
| Sowing Date | 1-Oct | | |
| Emergence | 17-Oct | 16 | 80 |
| 1st square | 9-Dec | 69 | 505 |
| 1st flower | 2-Jan | 93 | 777 |
| Peak Flowers | 12-Feb | 134 | 1302 |
| Last Effective Square | 9-Jan | 100 | |
| Last Effective Flower | 11-Feb | 133 | |
| Open Boll | 3-Mar | 153 | 1527 |
| 60% open | 9-May | 220 | 2050 |

**Yield, its components, temperature and solar radiation**

Cotton yield per hectare can be broken down into two main factors;

1. Boll number/ha. This number is then a function of filled fruiting sites/ha, that being made up of plant density/ha, fruiting sites per plant and fruit retention. Plant density and fruiting sites will be discussed later.
2. Boll size. This is a function of carpel/lock number, ovule (or seed upon fertilisation) per lock and lint fibres per seed. (It is assumed that there are no quality issues like short fibre and low micronaire to reduce yield even though individual fibre weights make up a component of yield.)

Stewart (1986), has tabled factors influencing each of the boll components which are presented below and modified by Robertson et al. (2007). As can be seen from the table below, carbohydrate levels in the plant can affect lock number, ovule number and seed fibre density. All these processes are occurring during the higher PAR months of December to February with fibre quality being determined in January and into March.

| Phenological Event | Days before Flower | 1st Flower | Last Flower | Size | Comments |
|---|---|---|---|---|---|
| Flower based on DD | | 2-Jan | 11-Feb | | Average for Griffith Airport |
| Square initiation | 40 | 23-Nov | 2-Jan | microscopic | Sqr initiation can occur as early as 2nd true leaf. Hot weather induces 4 bract, cool weather delays sqr initiation |
| Lock Numbers | 32 | 1-Dec | 10-Jan | microscopic | Lock numbers determined. Carbohydrate stress decreases number from 5 to 4 |
| Ovule number | 23 | 10-Dec | 19-Jan | 2mm PHS | Ovule number determined. Carbohydrate stress decreases potential seed number |
| Pollen cells divide | 22 | 11-Dec | 20-Jan | 2mm PHS | Pollen Cells divide |
| Pollen viability affects | 19 | 14-Dec | 23-Jan | 3mm MHS | Pollen viability reduced by high night time temperature |
| Squares start expanding | 5 | 28-Dec | 6-Feb | 13mm | Square expanding rapidly |
| Fibres begin to form | 3 | 30-Dec | 8-Feb | 17mm | Fibres begin to form |
| Pollen sheds | 0 | 2-Jan | 11-Feb | Flower opens | Pollen sheds and fibres start to elongate. Extremes in humidity or water disrupts pollen function |
| Flower | -1 | 3-Jan | 12-Feb | Flower | Fertilised ovules are now referred to as seeds. |
| Fibre density 2 to -12 | -12 | 14-Jan | 23-Feb | Fibres per seed | Affected by temperature and carbohydrate levels |

Assuming the plants ability to set a lot of fruit in January due to the higher PAR available, is it able to compensate for slower growth from cooler temperatures and/or delayed growth from insect damage early in the season? If it is, then how is the growth expressed? Is it through increased boll set in January or increased boll size, or increased vegetative branch fruit or increased fruit on position 3 on the same lateral branch? Constable (1991) mapping fruit over three years at Narrabri concluded that the loss of a boll was not fully compensated for by bolls further out along the same fruiting branch. First fruiting branch has reduced boll survival and size when compared to subsequent fruiting branches. Bolls at inner positions on fruiting branches 7-13 located on the node above FFB (node6.6) contributed most to yield. The assumption is that this would be true for the southern growing areas; however the crops here struggle to get to physiological maturity due to the reduced time available with adequate day degrees. *(This premise needs to be examined at what NAWF were fields cut out at).* By implication this means that if the crop is not physiological mature (cutout) at effective last flower (ELF), there has there either been not enough boll load (carbohydrate sink), and/or wasted inputs like water and fertiliser, or there just has not been enough time to grow sufficient nodes and position 1 and 2 fruit to cut the plant out.

***District area field analysis of planting date, defoliation date and most plant growth parameters would highlight how the crop grows in this region.***

***Exp: Boll size, number and position need to be evaluated to ascertain where the additional carbohydrate is being partitioned. This may show the importance of fruit position in the crop and its implication for management.***

### *Fruit Retention*

There is varied discussion between agronomist on the optimum fruiting zone and the ability of the crop to compensate for slow early growth and/or early fruit loss. Kerby et al. (2010) reviewing the physiological rational of plant monitoring and mapping discuss the importance of the 95% fruiting zone.  This zone is the fruiting nodes (or sympodia) where 95% of the yield comes from.  The effective fruiting period is defined as the time required to set 95% of all harvestable bolls. Data from the US –San Joaquin, California over a number of years show the average 95% zone occurred at main stem node 16.3. Data from Australia from both Constable and Kerby, have the 95% zone near main stem 17 and 17.6 respectively (Kerby et al., 2010).  Last harvestable flower/boll is considered to be  at 4 to 5 NAWF due to carbohydrate limitations in the plant. CSD literature uses cutout at 4.5 NAWF. This would mean a plant will be around 22 nodes tall. Depending upon the nodal position of the first fruiting branch (FFB) which can range from 6 to 10 will result in 10.5 nodes of fruit, (22nodes - 4.5 cutout – 7 (FFB on 8)). First fruiting branch position is largely determined by variety but high plant populations, cool temperatures (night temperatures below 15.5°C) during the weeks after emergence, thrips damage or unusually high temperatures (nights remaining above 26.7ºC) can raise the node of the first fruiting branch as much as 3 nodes (Edmisten, 1993).

This raises the core issue. As temperature determines phenological events like node development, then it may be possible that the plant does not have the 'thermal time' to make up for events that have raised the FFB that is holding/retaining fruit. This 'raised' FFB is due to shedding caused by insects or environment. This current season have lot of crops with retained FFB at node 11. Fruit below have been shed. Using the maximum nodes of 22 and cutout at node 4.5 means there will only be 7.5 nodes of fruit or 75% of that reported as average above. *This needs to be ground tested with number of harvestable bolls and weight this season compared to seasons with the 95% zone at 10.5 to 11 nodes of fruit.* This has implications for management.

### Early Insect Control

Given the growth parameters above, farmers/agronomists have a range of attitudes and practices to early insect control like thrip spp. Control practices range from no control, the use of crop oils and heavier chemistry like dimethoate. Early squaring cotton has the same issues. Insects observed are jassids, green mirids, apple dimpling and Rutherglen bugs. There is some concern regarding Rutherglen bugs when the tip is covered in bugs the thought is that they have to be eating/sucking something. Questions are being asked on the efficacy of the BT genes and their expression in early cool weather. Are heliothis spp. doing more damage because of lack of expression in the cotton plant? There is mixed opinion on this issue.

*The issue appears to be what thresholds should be adopted in this shorter season area? Are the economic thresholds still the same as for the northern valleys? Most growers and agronomists would contend they are not, due to the length of season. This is a major research issue for agronomist in the south. What insect thresholds should be applied to the crop?*

***Exp: Trial work needs to be done to ascertain early insect thresholds. Questions to be asked could include;***

***Thrips effect on seedling growth, either as tipping out or as reduced leaf area of the first 4 to 6 leaves.***

***Is there a yield cost with early tipping out by sucking pests like AD, Jassids, Mirids say at 6 true leaves? Is there a threshold for Rutherglen bugs? What are they eating?***

***Do heliothis need controlling in cool weather when the early crop is not growing?***

### *Environmental Shedding*

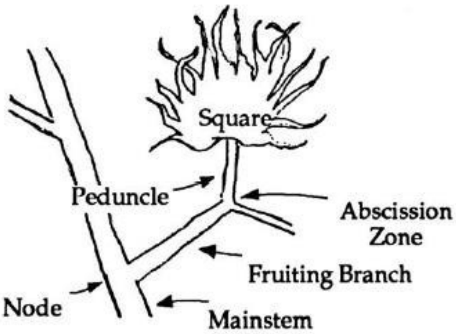
Environment also plays apart with fruit shedding. Observation this year show most crops with first fruiting branch at node 9 but only holding fruit on node 10-12 and most appear in the 11-12 node range. Was this caused by insects or environment? Square shedding before flowering can be caused by sucking pests but also cool night and cloudy days.

Cold temperatures also may increase square shed by slowing photosynthesis and plant growth. Night temperatures below 55**°F** (13°C) was shown to reduce photosynthesis by 30% independent of warming night temperatures (Hake et al., 1989). Constable (1991) regarding the loss of young squares, postulated the due to the poorly developed vascular system in young fruit, they have to rely on diffusion to supply assimilates. A high concentration gradient is required to drive this diffusion process so local assimilate supply would be indirectly important for square survival. Therefore, shading in cloudy weather and other stress can trigger loss of squares.

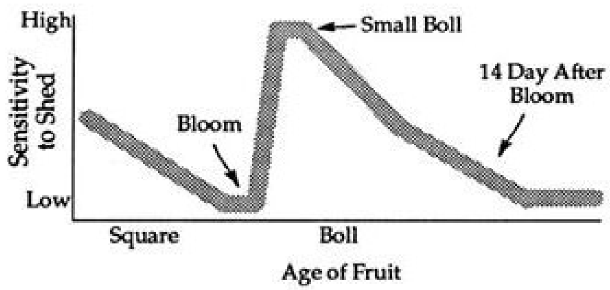
The process of fruit abscission has been outlined by Hake et al. (1989) and presented below.

### Abscission Process

Cotton fruits shed because an abscission zone forms between the fruiting branch and the boll stem or peduncle (see drawing below). In the abscission zone, enzymes loosen the connection between cells allowing the weight of the square or boll to break the peduncle. Due to their light weight, pinhead squares with complete abscission zones often stay attached to the fruiting branch. The weakening of this abscission zone is controlled by the balance of plant hormones, ethylene (the active form of PREP), abscisic acid (ABA) which promotes abscission, and indole acetic acid (IAA) which inhibits abscission zone formation and promotes shoot growth. When the balance of these hormones swings toward ethylene and ABA and away from IAA, the square or boll starts the same abscission process that leaves undergo when a defoliant is applied. And just like defoliation, several days elapse between the stimulus (defoliant application, insect injury, or environmental stress) and the separation. During these ensuing days, when cells in the separation zone are softening, visual clues such as flared and yellow bracts tell the observant producer that this fruit will not make it to harvest.




Shedding of fruit normally is small bolls when the boll load cannot be sustained by the plant. They are more sensitive than small squares. Cool, cloudy weather with significant boll load will result in small boll loss, particularly after irrigation. Large squares, blooms and medium size bolls are very resistant to environmental shed, possibly due to their high concentrations of IAA. Therefore under typical environmental stress, the plant will shed only small bolls and small to medium size squares. The diagram below demonstrates the relative sensitivity of fruit to shedding. (Taken from Hake et al. (1989)).




Waterlogging can also cause fruit shed because when roots loose oxygen they shut stomata which intern reduces photosynthesis and evaporative cooling, both of which increase fruit shed (Hake et al., 1989).

## Plant Hormones

Cothren and Oosterhuis (2010) did an extensive review of most hormones used in cotton. Most positive results have been with the use of PGR-IV which combines both GA and IAA and some micro nutrients (Oosterhuis, 1994). GA is associated with rapid emergence and taller seedlings and reduced chilling injury in germination cotton. IBA (precursor to IAA auxin) is involved in a number of plant processes promoting growth.

The was work done by Oosterhuis and Zhao (1994) in Arkansas found when PGR-IV is soil applied down the seed slot at 72ml/ha, at first pin square at 144ml/ha banded and at first flower at 292 ml/ha. Results have shortened emergence time by 1 day in warm temperatures, increased root growth, increased nutrient uptake, increased seedling development and accelerated early crop development. Plant height was either unaffected or shortened. PGR-IV was shown to increase fruit retention and final boll number. There are also reports of better conductive tissue which may lead to better retention of fruit in adverse weather conditions. There have been reports of up to 168kg Lint/ha (0.75 bale/ha) increase in yields. As Pix is antagonistic to GA, if it is to be used in combination with PGR-IV they should be applied at least 1 week apart.

*As fruit abscission is promoted by ABA and ethylene and GA and IBA work antagonistically towards them, could GA/IBA be used to prevent shedding of small squares if cool nights are forcasted?*

***Exp: Trial the use of growth promoting plant hormones (PGR-IV being a mixture of IBA and GA) to increase root growth in order to keep up with the drying soil profile and to increase early fruit retention.***

***Early fruit retention- Does it matter, or is the loss of position 1 on the first two fruiting branches compensated in the middle of the crop? This has to do with how the crop in the south partitions its growth to utilise the extra sunlight in Dec/Jan/Feb.***

## Row Spacing

One way to increase the number of fruiting sites per unit area and utilise the extra solar radiation in December to March is to evaluate higher density planting by decreasing row width and maintaining plant number in the row. This potentially increases the possible fruiting sites by 33% by going from 1 metre to 0.75 metres row spacing. If the crop can set more fruit in the January period and not be looking for fruit set later in February to make up short fall for fruit shed either from insects of temperature, it may be possible to move the planting date back to more favorable conditions and not compromise yield. The photos of crops below demonstrate this point. The first is of two is of 75cm and 100cm at same age. The last photo is of 100cm and has been cutout by pix one week earlier.

Row spacing of 100cm planted same time as 75cm row cotton. Photo taken on 26th January

Row spacing of 75cm cotton at same planting time as 100cm

Row spacing of 100cm showing lack of filled in rows. Crop was cut out 5th February with Pix.

Research results have been mixed on the worthwhileness of narrow-row cotton. Kerby et al. (1996), concluded after reviewing large scale trials in the California in the 1970's that examined row spacing from 25cm, 50cm, 75cm and 100cm that the potential for narrow-row cotton was greatest where growth was restricted; optimum plant density was similar to conventional spacing's; good management was more critical for narrow-row cotton; narrow-row did not necessarily mature earlier; grades were reduced due to harvest with strippers and fibre-length was reduced. Other studies in narrow-row and ultra-narrow row systems have had mixed results with respect to yield and or earliness. (Brodrick et al., 2012) comparing UNR 25cm to 100cm found UNR increased boll number and yield but decreased boll size. (Williford, 1992) comparing 76cm to 102cm rows found yield increases from 6.5-9% in favour narrow-row cotton. Tracy and Sappenfield (1992) in the shorter growing season of Missouri found 75cm cotton yielded 1.16 bales/ha compared to 94cm row cotton when treated with Pix. Results without Pix were variable.

Kerby et al. (1996) suggest that there are two basic reasons for converting to narrow-row production: an understanding of the plant's ability to harvest sunlight and the quantity of vegetative growth required to harvest that sunlight. Since rows are closer together, plants do not need to be as large to intercept sunlight. This allows the use of cotton varieties with a higher harvest index. Yields could be improved with early capture of sunlight as long as the additional growth is converted into reproductive growth. Narrow-row cotton can optimize sunlight capture and harvest index using
non-stressed conditions along with more equidistant plant spacing. This results in improved leaf efficiency, which can translate into earlier crop maturity. More efficient use of leaves

does mean narrow-row systems are more highly subject to stresses that reduce leaf function. Consequently the need for greater crop management is required to ensure minimal stress on the crop and leaf function. Kerby et al. (1996) found an average yield increase of 6.6% over a thirteen year period from 1971 to 1989 of 75cm cotton compared to 100cm cotton.

Kerby et al. (1996) summarizes the main practices which influence a response to narrow-row.

*Variety*;
The shorter, determinate variety 2086 which fruits earlier compared to Acala SJ-2 yielded up to 13.8% greater in 75cm cf. 100cm rows. The more indeterminate type SJ-2 yielded 5.4% in narrow- row cotton when grown on highly productive soil.

*Nitrogen*;
Increasing nitrogen rates from 200 kg N/ha to 270 kg N/ha had a greater effect on the smaller determinant variety. The increase in nitrogen caused a yield decrease in the indeterminate varieties like SJ-2. Comparing the determinate variety 2086 on 75cm row and 270 kg N/ha to SJ-2 on 100cm row at 200 kg N/ha resulted in a yield increase of 408 kg Lint/ha or 1.8 bale/ha. The research also underscores the need to compare optimal conditions for each row system.

*Plant Density*;
More determinate varieties are more sensitive to lower plant densities per linear row. Indeterminate varieties suffered with too high a plant density.

*Pix;*
The use of Pix to increase harvest index has been well documented. Yield was improved by Pix on both 100cm and 75cm row spacing with a greater effect on the 75cm spacing. This is supported by work done in Missouri by Tracy and Sappenfield (1992).

*Water Management*;
Their research suggests that cotton is more sensitive to early water stress under narrow-row conditions. Both row spacing's had the same total seasonal water use but with the higher yields in the narrow-row cotton the water use efficiency was greater in 75cm rows. There would need to be more work done on this management aspect.

Based upon the California research and that elsewhere the narrow-row production system should be evaluated in the southern area with its potential for better utilisation of solar radiation in January during fruit set. It is suggested that many growers are still to come into the industry so the ability to change row configuration would not be as significant cost if done early before extensive machinery capitalisation has occurred.

***Exp: Trials and comparisons of 75cm row v 100cm need to be done. Associated with those trials should be variety, planting date, N fertiliser rate and Pix management***

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