Hold your nerve – what to do when you don't have enough water

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AT A GLANCE…

- Under limited water scenarios you need to accept that the crop will suffer water stress and have reduced yield.
- Under limited water scenarios it's important to hold your nerve – don't water too early.
- Yield response to water is highest during peak flowering.
- A single irrigation during peak flowering can achieve yields of almost half a 60 mm deficit irrigation crop.
- Although gin turnout and fibre length were reduced under partial irrigation, length discounts were not observed. Fibre strength and micronaire were unaffected.

FARMING has been described as gambling; partially irrigated cotton is no exception to this rule. Deciding when to apply water in a partially irrigated cotton system is a bit like some of Kenny Rogers' opinions on how to play poker: "If you're gonna play the game, boy, you gotta learn to play it right. You've got to know when to hold 'em…"

While the analogy stops here (there's no reason to fold, walk or run away from partially irrigated cotton!), research conducted by CSIRO shows that holding your nerve when deciding to apply the limited water is paramount.

Background

This research has stemmed from developing methods to improve the reliability and performance of varieties selected in the CSIRO dryland cotton breeding program. The majority of Australian dryland cotton growing regions display variable rainfall environments, with in-crop rainfall varying from almost zero through to 800 mm. To add insult to injury, the distribution of this rainfall pattern is such that more years are on the drier end of the spectrum.

Growing dryland cotton in this environment is tough. But in a variety development context where timelines are in excess of 10 years, the effect of a poor season has far reaching and ongoing consequences. As a result, since 2013 the CSIRO dryland cotton breeding program has been applying a single irrigation to dryland evaluation experiments at our core breeding site, Myall Vale, in years with very low in-crop rainfall. At face value, this might seem a bit backwards for a dryland breeding program. But the application of this single irrigation has yielded returns for the

TABLE 1: Seasonal rainfall (mm) and heat shock days observed during the six experiments

Sowing year	Early season rain	Early repro. rain	Rain: peak flowering window	Rain: late repro.	Rain: Late season	Total in-crop rainfall (mm)	Heat shock days (No.)
	<41 DAS	41–71 DAS	72–100 DAS	101–121 DAS	>121 DAS		
2013	41	34	12	36	4	126	53
2014	5	53	75	10	24	168	56
2015	121	100	113	1	16	350	49
2016	11	14	35	31	106	198	64
2017	81	15	34	20	41	191	62
2018	45	38	30	0	14	128	70

Rainfall is also divided into five periods: Early season rain is up to 500 day degrees, approx. <40 DAS; early reproductive rainfall represents the period between 500 to 1000 day degrees, i.e. squaring and early flowering (approx. 41–71 days after sowing, DAS); the peak flowering window is between 1000 to 1500 day degrees (approx. 72–100 DAS); the late reproductive growth period is between 1500 and 2000 day degrees (approx. 101–121 DAS); and late season rain is from 2000 day degrees (approx. >122 DAS) to crop maturity. Heat shock days are those where maximum temperature ≥35°C.

breeding program as the environment in which germplasm is tested is better matched to our breeding target environment.

This work has led to the development of a breeding system where dryland experiments at Myall Vale are irrigated when soil water deficits have reached 90–100 mm (40 per cent plant available water) just before peak flowering (95–105 days after sowing). As part of the development of this breeding system, field experiments assessing crop yield and quality under dryland, partially irrigated and 60 mm deficit irrigation treatments have been conducted between 2013 and 2018.

Although this research was originally designed to validate the application of the single furrow irrigation to dryland breeding trials, this rich dataset can provide insights into how to get the most out of irrigation water in a partially irrigated cotton scenario.

The trials

Experiments were conducted at Myall Vale, Narrabri. The site has an average in-crop rainfall of 392 mm (327 mm median); the soil is a uniform grey cracking clay (Grey Vertisol) with 160–180 mm plant available soil water to 1.2 m. Experiments consisted of 21 varieties established on one metre beds in a replicated design under dryland, partially irrigated and 60 mm deficit irrigated conditions. Experiments were repeated across six seasons (2013 to 2018 planting).

For the purpose of brevity, only the results of Sicot 74BRF will be presented as this variety is representative of the results. Dryland and partially irrigated treatments were grown in a single skip row configuration while the 60 mm deficit irrigated crops were grown in a solid configuration. Therefore, results should be kept in the context of these row configurations.

Partially irrigated and dryland experiments were grown under skip row planting configurations as per industry guidelines. These guidelines outline that unless production systems are located in environments with very favourable soil types and milder conditions, a solid row configuration is not recommended for limited water scenarios.

All experiments were pre-irrigated or watered up to simulate a full profile of stored soil moisture. A 60 mm deficit irrigation treatment was not grown in 2013, and due to adequate in-crop rainfall in 2015 no partial irrigation treatment was imposed. Measurements consisted of lint yield and quality (HVI length, strength and micronaire) as well as monitoring weather and soil water conditions (via neutron attenuation).

Rainfall and soil water monitoring were used to calculate crop water use, and neutron probes were used to measure the soil moisture deficit immediately before and then 48 hours after an irrigation event, i.e. the amount of irrigation water required to fill the soil profile to field capacity. This is an important distinction as the volume of irrigation water applied was not measured, only crop water use. So it is more difficult to derive irrigation efficiencies and economic analyses from this work, which are outside of the scope of this research.

TABLE 2: Yield (bales/ha) observed under dryland, partially irrigated and fully irrigated conditions across the six experiments

Sowing year	Dryland yield (bales/ha)	Partially irrigated yield (bales/ha)	60 mm deficit irrigation yield (bales/ha)	Partial: 60 mm deficit
2013	2.7	5.4	—	—
2014	3.6	5.7	11.2	0.51
2015	4.2	—	13.2	—
2016	1.5	4.5	10.8	0.42
2017	3.2	5.3	11.7	0.46
2018	1.5	5.3	12.2	0.43
Average (std. error)	2.8 (0.45)	5.2 (0.20)	11.8 (0.42)	0.46 (0.02)

Results

Environmental data, in-crop rainfall, the distribution of this rainfall throughout the flowering period and the number of days ambient temperature exceeded 35°C is shown in Table 1. Some seasons had close to the average in-crop rainfall for Narrabri, with significant falls during the flowering period and minimal heat shock days (2015). At the other end of the scale, there were very dry seasons where in-crop rainfall was approximately 32 per cent of the long-term average (2013 and 2018) and a high number of heat shock days (2016, 2017 and 2018).

The patterns of crop water use was broadly similar across seasons and an example from 2014 is shown in Figure 1. Dryland treatments gradually depleted soil water to deficits of 140–160 mm. Partial irrigation treatments followed the same pattern of soil water depletion, until the single irrigation was applied.

This water was rapidly used by the crop, whereby 20–30 days after this irrigation the crop had extracted soil water to a similar deficit as the dryland treatment. The 60 mm deficit treatment was maintained above the target deficit with six to eight in crop irrigations. It is important to note that the amount of irrigation water applied in the single irrigation was around double that of an irrigation in the 60 mm deficit treatment.

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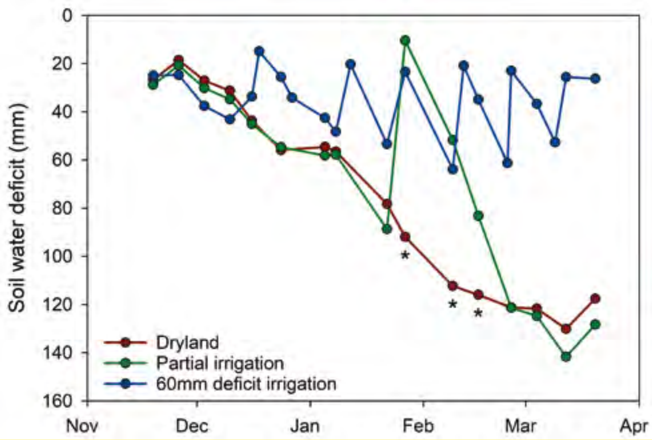
FIGURE 1: Soil water deficits observed in dryland, partially irrigated and 60 mm deficit irrigation treatments in the 2014 planting season



Observed lint yields varied from season to season. The highest yield in the 60 mm deficit irrigation was observed in 2015 (13.2 bales per hectare), while 2016 produced the lowest observed 60 mm deficit irrigation yields (10.8 bales per hectare). Dryland yields followed in-crop rainfall patterns, while partially irrigated yields were relatively stable at approximately five bales per hectare (Table 2). Partially irrigated yield levels were on average 46 per cent, with a range of 42–51 per cent, of the 60 mm deficit yield.

Average fibre quality parameters across the seasons of the study are outlined in Table 3. Gin turnout was highest in the 60 mm deficit irrigation treatment. Gin turnout in the partially irrigated treatment followed the same pattern as the dryland treatment. Fibre length was strongly influenced by water availability, where length was highest in the 60 mm deficit irrigation treatment, followed by the partially irrigated treatment, with the dryland treatment exhibiting the lowest fibre length. The strong influence of water availability on fibre length is a result of the effects of water deficits on carbon assimilation (photosynthesis) as cotton fibres are primarily cellulose, as well as reduced water status impacting fibre elongation due to reduced

FIGURE 2: During the peak flowering window (1000 to 1500 day degrees, approx. 72–100 DAS) the lint yield response to water availability (rainfall and/or irrigation) under limited water scenarios describes an increase in yield of one bale/ha for an additional 47 mm of water

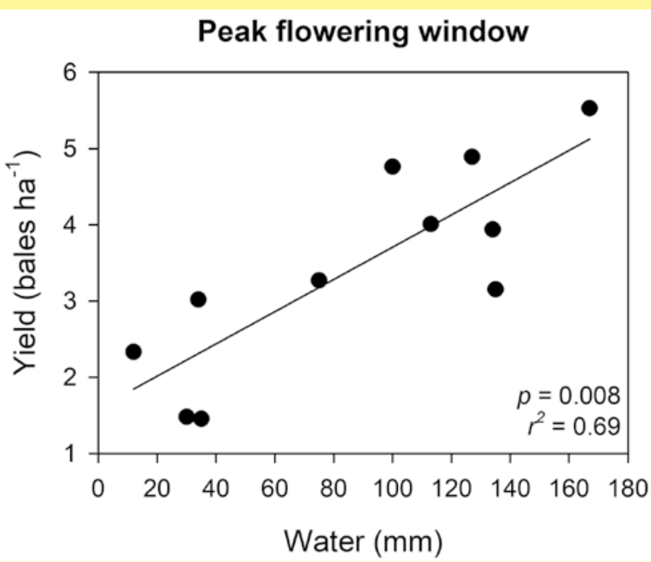
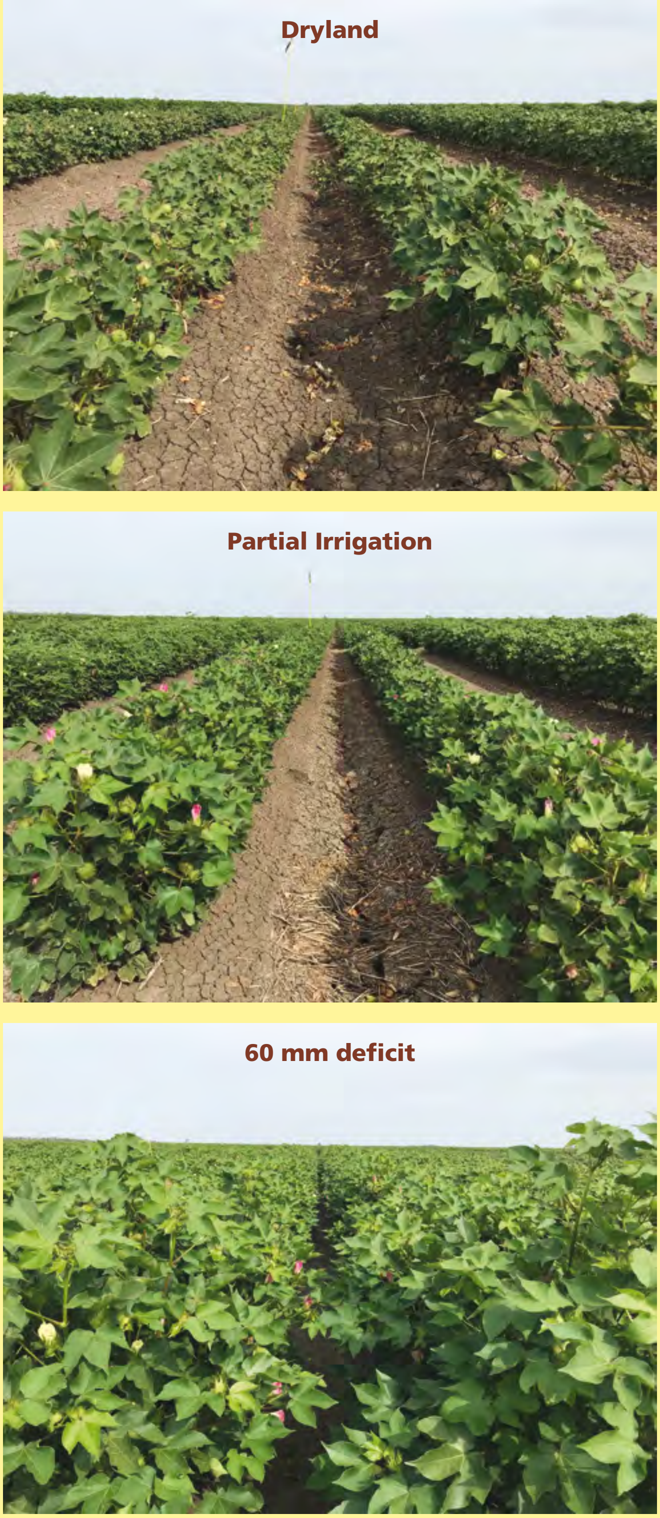


FIGURE 3: Dryland, partially irrigated and 60 mm deficit irrigated treatments 100 DAS in the 2018 experiment



The partially irrigated treatment was irrigated 15 days prior to this image.

cell turgor. Fibre strength, which is largely influenced by variety and season, and micronaire which is influenced most strongly by season, did not differ between water treatments.

TABLE 3: Average lint percentage and fibre quality (length, strength and micronaire) for dryland, partially irrigated and fully irrigated water treatments

	Dryland	Partially irrigated	60 mm deficit irrigation
Gin turnout (%)	41.4a	41.3a	44.4b
Length (inches)	1.16a	1.19b	1.22c
Strength (g/tex)	31.2	31.7	31.4
Micronaire	4.7	4.6	4.6

Values within a measurement followed by the same super script letter are statistically similar. No water treatment difference was observed in strength or micronaire.

When does irrigation get the most bang for buck in a partially irrigated crop?

When data from the six seasons is pooled the relationship between lint yield and water under limited water scenarios can be scrutinised during different crop development stages. This approach can identify the periods during a cropping cycle that water applied to the crop has the largest response in terms of yield. We divided the cropping season into:

- Early reproductive period, between squaring and first flower;
- Peak flowering window, approximately three weeks before and one week after peak flowering; and,
- The late reproductive growth phase, just before first open boll through to crop maturity.

The response to water was the strongest during the peak flowering window. At the water availability levels observed throughout our experiments, an additional 47 mm of water during the peak flowering window resulted in a one bale per hectare increase in yield (Figure 2). Under these scenarios no significant response to water was observed in the early and late reproductive periods ($p=0.354$ and $p=0.712$, respectively).

Clearly, in a situation where a single in-crop irrigation is to be applied, the peak flowering window is the developmental stage that should be the target for the timing of this event. This timing makes sense as cotton, as with all crop species, is most susceptible to water stress related yield losses during the flowering period.

This research also shows that using limited water resources earlier in the season won't result in the highest returns for the water applied. This strategy places the crop at risk of water stress during the peak flowering period when yield producing bolls are retained. Not only does the application of water in the early reproductive period allow the plant to use a greater proportion of water applied to support vegetative growth, purely because reproductive growth is minimal at this stage, it may also restrict the crop's rooting depth.

Under water limited scenarios early season stress encourages deeper rooting, allowing the crop to access a larger bucket of water within the soil profile. Finally, under the environmental conditions observed in the six years of the study, provided the crop starts with a full profile of moisture it has enough water to get through to the peak flowering window. This enables the application of irrigation water at the critical yield producing period.

As in the early reproductive growth phase, water applied

Partially irrigated crop at maturity (140 DAS) in the 2016 sowing experiment. The partially irrigated treatment was irrigated 56 days prior to this image.

only a week to 10 days after peak flowering is also ineffective in increasing yield. This is in part due to season length limitations, as well as the lag between water application and re-initiating reproductive growth. By this stage the crop has ceased reproductive growth and development in an effort to focus on the retention and development of the existing bolls. Thus, additional later season water is at a higher risk of not leading to the production of additional harvestable yield.

In summary

The response of an extra bale from just 47 mm of water in the flowering window is impressive. But this must be kept in the context of limited water scenarios. As such, realistic yield expectations need to be applied to partially irrigated cotton. It seems glaringly obvious, but the yield potential of partially irrigated scenarios is inherently lower than fully irrigated scenarios. Therefore, under a partially irrigated scenario it is important to realise that your crop will be exposed to moisture stress

Once this is acknowledged, the timing of the irrigation is of vital importance. Ensuring that stress during peak flowering is minimal is key to playing the game right.

While our experiments were only conducted in the context of a single irrigation, the principal of reducing water stress in the peak flowering period can be extended to scenarios where two or three in-crop irrigations are available. Under these scenarios, the key is to minimise crop stress during flowering. Across the seasons of this study, a 60 mm soil water deficit was observed in the partially irrigated treatments in approximately 16 days after the irrigation was applied. Therefore, we can extrapolate that two irrigations should be split during the peak flowering period, applied approximately two weeks apart. Under scenarios where water for three irrigations is available, this recommendation can be extrapolated to applying the first irrigation at first flower, and the following two irrigations at fortnightly intervals.

Finally, a sensible approach to irrigating limited water crops must take into account short and long-term rainfall forecasts, on farm rainfall reliability, and your operation's approach to risk – how much of a gambler are you? Importantly, if you do jag significant in-crop rainfall before or during the peak flowering window, irrigation water can be used to further increase yield potential. But if available water is exhausted before the peak flowering window and in-crop rainfall doesn't come to the party, the yield penalty for not holding your nerve can be significant.

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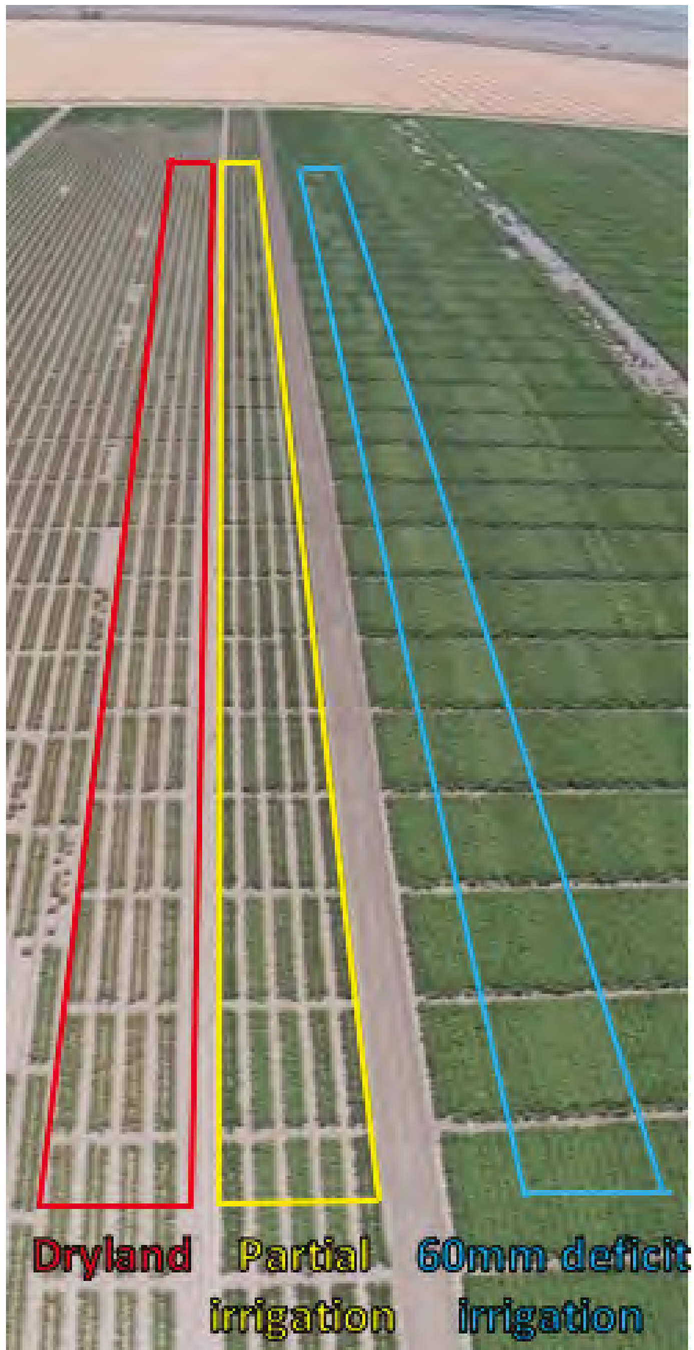

Aerial image of the experimental layout in the 2014 season.