Dynamic Deficits for Irrigated Cotton – matching the soil water to plant requirements.

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Abstract

Current irrigation strategies for cotton rely strongly on irrigation scheduling based on soil moisture content using fixed whole season deficits. There may be an opportunity to refine irrigation scheduling by dynamically changing the soil water deficits to improve growth by avoiding plant stress during periods of high evaporative demand (lower deficits) and improve water use efficiency by reducing the need for irrigation during periods of low evaporative demand (larger deficits). Measurements of plant stress using leaf water potential showed that the plant stress response to soil water availability changed in response to differences in evaporative demand (ETo). One field experiment tested the concept of a dynamic deficit where irrigation timing was based on soil water measurements and weather forecasts of short term periods of high or low ETo. Three irrigation treatments were applied to the experiment; a control treatment, with irrigations scheduled at the normal 65-75 mm deficit for that soil type; a high ETo treatment which was irrigated earlier than the control at a smaller deficit in response to forecasted ETo; and a low ETo treatment which was irrigated later than the control at a larger deficit in response to forecasted low ETo conditions. There was no difference in yield between irrigation treatments, however, delaying the irrigation in response to forecasted low ETo enabled more rainfall to be captured than the other treatments leading to 0.8 ML/ha saving in irrigation water. These results indicate there is flexibility in irrigating cotton in response to future forecasts potentially saving water, however this study has highlighted the need for a definitive measure of plant stress to assist irrigation decisions to match plant requirements.

Introduction

With increased attention to water use in Australia it is critical to develop new scientific approaches to increase irrigation water use efficiency (IWUE). Current irrigation strategies rely strongly on assessment of soil moisture by soil moisture probes, or use irrigation schedules that are aligned to fixed soil water deficits based on measurements on previous experiences for particular fields. In many instances however the irrigation point (deficit) is based on average climatic conditions to prevent plant stress and does not take into account the current or future level of plant stress. Denmead and Shaw (1962) showed that the impact of a given water deficit on plant function is greater when the evaporative demand is high. To improve water use and efficiency a flexible or 'dynamic' soil deficit may need to be employed in irrigation scheduling by more effectively accommodating the current crop stress, the current soil water, and whether the short-term forecast of evapotranspiration will increase or decrease future crop stress. This is important as most of Australia's cotton experiences significant in-crop climatic variation.

This study aimed to:

(1) establish that variation in ETo at different plant available water contents (PAWC) changes how a crop responds to PAWC; and
(2) test the concept of dynamic deficits on crop production and IWUE.

Methods

Two field experiments were completed to measure plant stress response to evaporative demand under varying soil water conditions in Narrabri (30.318S, 149.788E), Australia in the 2003-04 (Exp. 1) and 2004-05 (Exp. 2) seasons. Each experiment was sown with the cultivar Sicot 289BR developed by CSIRO Australia. The experiments were established at two sites with soils of different water holding capacities (self-mulching vertosols, with a total plant available water content of 130 mm in one site; and 200 mm in the second site to a depth of 120 cm). Plots were 50 m long and 20 m wide with four replicates.

A third field experiment (Exp. 3) was sown into moisture using the cultivar Sicot 71BRF on 14 October 2010 in Narrabri, Australia. Yield and water use were measured to determine the response to different irrigation treatments. Treatments were designed to enable comparison of a control - scheduled according to normal irrigation point for that soil, equivalent to 55% FTSW, to treatment irrigations which were scheduled dynamically between flowering and cutout. Treatment 1 had one irrigation treatment applied 3 days earlier compared with the control when the forecasted 72 hr ETo exceeded 7 mm/day and Treatment 2 had one irrigation applied 8 days later than the control where the forecasted ETo was for <5 mm/day. A randomised complete block with three replicates was used. Plots were 60 m long by 16 m wide.

All three experiments were sown using a commercial row crop planter, and grown using high input management and insect control, typical of commercial practice, as described in Hearn and Fitt (1992).

In Exps. 1 and 2 measurement of leaf water potential (LWP) was made using a PMS model 600 pressure chamber with compression gland using the method described by Turner (1987). Pressure chamber readings were taken around solar noon approximately weekly from flowering to cutout. Readings were conducted on the first fully expanded leaf (third from the terminal) and 2 readings per plot were conducted at each measurement.

In all three experiments, to measure soil water two access tubes were located in each plot measurements taken at 0.20, 0.30, 0.40, 0.50, 0.60, 0.90, 1.0 and 1.2 m depths. The moisture content of the top 0.15 m of soil was determined by a calibrated impedance probe (ThetaProbe, Delta-T Devices, Cambridge UK). The depth of extraction was determined over time to be when the next layer down in the soil profile had been depleted by 5% the roots were determined to be extracting water from that layer.

In Exps. 1 and 2 soil water was measured at approximately weekly intervals on the same days as leaf water potential. In Exp. 3, soil water was measured at approximately weekly intervals and the day prior and two days following an irrigation and following rainfall. At the end of the season, yield was determined by machine picking of the measurement row in each plot. The soil moisture deficit was calculated as the difference between the plant available water content of the soil on the day of measurement and the maximum plant available water content of those layers of soil that the roots were extracting moisture from.

Soil moisture contents obtained using the neutron probe, have been normalized using the fraction of transpirable soil moisture content (FTSW). The amount of water available in the soil is expressed as a percentage which normalises the water holding capacity of the soil.

Meteorological data for the experimental period in all experiments was measured by a nearby weather station. 72 hr meteogram forecasts of ETo were accessed under subscription from the Bureau of Meteorology.

Results and Discussion

Plant Stress Response to Evaporative Demand

The wide variability in LWP at the same FTSW in Exps. 1 and 2 (Figure 1) indicated that climatic conditions were likely to be having a large influence on the level of plant stress even under the same soil water conditions. To account for climatic influence on LWP in Exps. 1 and 2, ETo and FTSW were used in the multiple regression analysis. Accounting for changes in ETo significantly improved the relationship between LWP and FTSW by 5.5% ($p<0.001$; $r2 = 0.678$). To determine if our simple rule of thumb of “high ETo” and “low ETo” days could be used to determine the stress response, these data were grouped into high (ETo>7 mm/day) and normal (ETo<7 mm/day); however, there were not enough data points to allow a low (ETo<5 mm/day) category to be tested. A simple linear regression with groups showed that LWP measured on “High ETo” days experienced greater stress at the same level of FTSW compared with “Normal ETo” days (Figure 1, $p=0.004$; $r2=0.648$).

Although, more data is required to quantify this relationship, short-term forecasts of high or low ETo may provide an indicator of potential triggers for a dynamic deficit scheduling approach. As changes in evapotranspiration (ETo) affected the level of stress a plant regardless of the level of soil moisture, there is an opportunity for the deficit for optimum yield and IWUE to be dynamic, e.g. increase under cool humid conditions and decrease in hot dry conditions. For example, it is common in the cotton industry in clay soils to irrigate at a deficit of 80 mm. Under average summer evaporative demand of 8 mm per day, this deficit would lead to a 10 day irrigation cycle. Under low evaporative demand of 5 mm per day, 80 mm would last for 16 days before irrigation was required. With dynamic deficits, under low evaporative demand the irrigation interval could potentially be more than 16 days and save considerable irrigation water in more humid areas and seasons, avoid waterlogging and appear as increased IWUE. A dynamic deficit approach could apply to all methods of irrigation: flood, spray and drip.

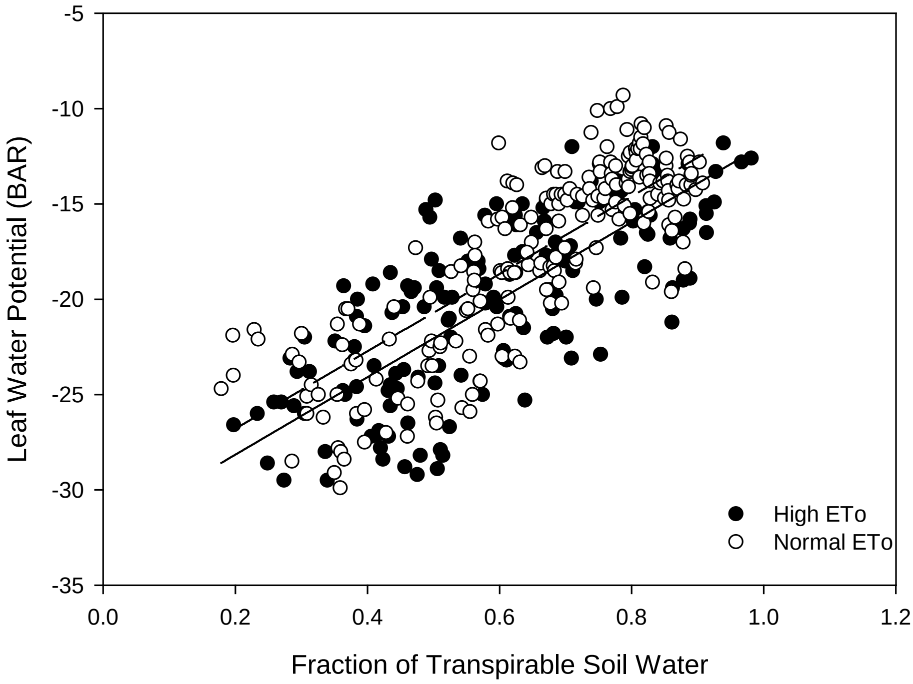

Figure 1. The effect of evapotranspiration (ETo) on the relationship between plant stress (leaf water potential) and fraction of transpirable soil water. LWP less than -20 indicates the plant is suffering stress. Data from Exps. 1 and 2 is grouped into high ETo (ETo>7mm/day; solid circles and solid line) and normal ETo (ETo<7 mm/day; open circles and dashed line).

Dynamic Deficit Experiment

To test the hypothesis of dynamic deficits in response to forecasted ETo, Exp. 3 had a total of three irrigation treatments applied during the course of the season. In treatment 2, an irrigation was applied at a smaller deficit (40 mm) compared with the control (60 mm) in response to a high ETo forecast. In the second treatment in response to forecast low ETo, irrigation was delayed 4 days compared to the control (61 mm deficit) to a planned deficit of 90 mm, and in that period there was 33 mm of rain which further delayed the irrigation another 4 days. The low ETo treatment reached a deficit of 88 mm before the rainfall event and was irrigated at a 60 mm deficit. This resulted in this treatment receiving one less irrigation over the season translating into irrigation water savings of approximately 0.8 ML/ha compared to the control (Table 1).

Table 1. Lint yield and water use for Exp. 3. ns, no significant differences

Treatments	Average Lint Yield (kg/ha)	Irrigation Water Applied (ML/ha)	Effective Rainfall ML	Total Water (mm)	Total WUE (kg/mm)	Irrigation WUE (kg/mm applied)
Control	2892	3.92	2.84	736	3.92	7.38
Treatment 1 (High ETo)	2735	3.65	2.88	731	3.74	7.50
Treatment 2 (Low ETo)	2609	3.11	2.90	682	3.82	8.38
L.S.D (0.05)	323.8	0.34	ns	43.2	ns	0.02

There were no differences in yield or total water use efficiency in Exp. 3 (Table 1). Importantly, during the period of low ETo, despite the delay of 4 days in the irrigation for treatment 3 there was no impact on lint yield. Delaying irrigations to larger deficits during flowering without taking into ETo can have significant impacts on yield with previous research reporting a yield loss of 2.7% for every day that an irrigation was delayed (Yeates et al., 2010). The forecasted low ETo also allowed an opportunity to capture rainfall events resulting in irrigated water savings of 0.8 ML over the season in one treatment. Periods of low ETo are often associated with a depression or low pressure weather front which may bring an opportunity to capture rainfall.

The lack of a response to the high ETo, earlier irrigation treatment, needs further investigation, as does the high variability in the response of LWP to soil water. We are assessing in more detail when the crop was stressed and for how long it was under stress in the different irrigation treatments. One of the difficulties in using leaf water potential as an indicator of plant stress is that it is still an average, discrete method of sampling, and there is a need for continuous monitoring of plant stress to determine whether accounting for current and future crop stress in irrigation scheduling can bring greater savings in water use.

Conclusion

This preliminary study showed an opportunity to refine irrigation scheduling by dynamically changing the soil water deficits to improve growth by avoiding plant stress during periods of high evaporative demand (lower deficits) and improve water use efficiency by reducing the need for irrigation during periods of low evaporative demand (larger deficits). Measurements of plant stress using leaf water potential showed that the plant stress response to soil water availability changed in response to differences in evaporative demand (ETo). However, neither irrigating earlier or later in response to high or low forecasted ETo resulted in any yield penalty. We are currently investigating in more detail when the crop was stressed and for how long in these treatments to ascertain why irrigating earlier to prevent crop stress had little effect. The results of one field experiment showed that there may be considerable utility in delaying irrigation timing and extending opportunities to capture rainfall when ETo is low. This would allow for more flexibility in cotton farming systems that require a significant number of fields to be irrigated at a point in time, and potential irrigation water savings.

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