SOIL WATER EXTRACTION OF BOLLGARD® II COTTON IN A HEAVY-CLAY SOIL

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Abstract

Water scarcity is the main limiting factor in cotton (*Gossypium hirsutum* L.) production in Australia, and sustaining productivity and profitability with limited water is one of the biggest challenges facing the industry. A good understanding of the magnitude, timing and spatial distribution of cotton soil water extraction is important for proper irrigation management, and for development of accurate crop models and decision support systems. The overall objective of this study was to evaluate the water extraction distribution of Bollgard® II cotton under different irrigation regimes. Specific objectives were to quantify: (1) the depth of soil water extraction as a function of time, (2) the percent of seasonal water extraction from each soil depth, and (3) the relationship between depth of soil water extraction and canopy height (h). To meet these specific objectives, daily and seasonal cotton soil water extraction was determined from continuous records of water content in the soil profile measured from four irrigation treatments at a field experiment conducted at Kingsthorpe, Queensland. We found that cotton extracted soil water from as deep as 150 cm, but the percent of seasonal extraction sharply decreased with soil depth. The top 50 cm soil layer accounted for 75% of the seasonal extraction and the top 80 cm, for 90%. We also found that from 32 to 100 days after sowing, the depth of soil water extraction increased linearly at a rate of 1.89 cm day^{-1} or 2.36 times the increase in crop canopy height. These findings suggest that cotton producers should manage irrigations to maintain adequate moisture in the top 80 cm of the soil profile rather than relying on moisture stored deeper in the profile.

Introduction

Water scarcity is the main limiting factor in cotton production in Australia. Therefore, how to sustain or increase productivity and profitability with limited water is one of the biggest challenges facing the industry. Meeting this challenge will require increasing the beneficial use of water by producing more crop quantity and quality with the same amount or even less water. It will also require improving water management at the basin, farm, and field scales. At the field scale, one of the important issues is knowing how much water to apply and when to apply it, commonly referred to as irrigation scheduling. If water is limited, then it is important to know the impact of crop stress at different times during the season, so that irrigation is applied when benefits to the crop are maximized and/or negative impacts are minimized. To properly manage water under limited water situation it is important to know how crops subjected to different water regimes use soil water. Some of the relevant questions include: How much water is extracted? when is water extracted?, and from which soil depths is water extracted? A good understanding of the magnitude, timing and spatial distribution of cotton soil water extraction is important for proper irrigation management, and for development of accurate crop models and decision support systems. The overall objective of this study was to evaluate the water extraction distribution of Bollgard® II cotton grown under four irrigation regimes. Specific objectives included evaluating: (1) the depth of soil water extraction as a function of time, (2) the % of seasonal water extraction from each soil depth, and (3) the relationship between depth of soil water extraction and canopy height.

Materials and Methods

A field experiment with four irrigation treatments and three replications was conducted at Kingsthope (27°30’44.5” Latitude South, 151°46’54.5” Longitude East, 431 m above mean sea level), Queensland, during the 2007-08 cotton season. The soil at the site is a haplic, self-mulching, black, vertisol with a heavy clay texture in the 1.5 m root zone profile, with 73-76% clay, 17-19% silt, and 8-12% sand. The irrigation treatments included a fully-irrigated (T50%), deficit-irrigated 1 (T60%), deficit-irrigated 2 (T70%), and deficit-irrigated 3 (T85%) treatment, for which irrigation was applied when 50%, 60%, 70%, or 85% of the plant available water capacity (PAWC) was depleted, respectively. The cotton hybrid Sicala 60 BRF, Bollgard® II Roundup Ready Flex® variety (medium maturity), was planted on 12 November, 2007. Soil water content to schedule irrigations was measured weekly using the neutron probe method. A neutron probe access tube was installed in each plot and readings were taken at 10 cm depth increments to a depth of 150 cm with a 503DR Hydroprobe (CPN International, Inc., Martinez, CA, USA), which was calibrated for the soil at the research site against gravimetric soil moisture measurements. Also, soil water content was automatically monitored every 30 min using EnviroSCAN® Solo (Sentek sensor technologies, Stepney, South Australia) capacitance probes installed in each treatment. This information was used to determine the depth of soil water extraction and the percent of water extraction from each soil depth. The EnviroSCAN® Solo data was used for this purpose, rather than the neutron probe data, because it provided a continuous record of soil water content in the different soil depths, which allowed a more accurate assessment of the time when soil water extraction started from each depth. Each EnviroSCAN® Solo probe was customized to measure soil water from twelve soil depths, including 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 120, and 150 cm. Plant canopy height (h) was measured eighteen times during the season, from soon after crop emergence to defoliation. Weather variables at the site were measured with an EnviroStation electronic weather station (ICT International Pty Ltd, Armidale, NSW, Australia). Daily growing degree days (GDD, ^{o}C day) were calculated using “Method 1” of McMaster and Wilhelm (1997), from which cumulative growing degree days (CGDD, ^{o}C day) from sowing were determined.

Results and Discussion

Depth of soil water extraction

Figure 1 shows the depth of extraction as functions of DAS and CGDD when extraction started from a given depth, pooling data for all irrigation treatments. Since depth of extraction or rooting depth cannot normally be seen in the field and it is difficult to accurately account for this variable when scheduling irrigation, the depth of extraction was also related to the plant canopy height (Figure 2), which can easily be measured in the field.

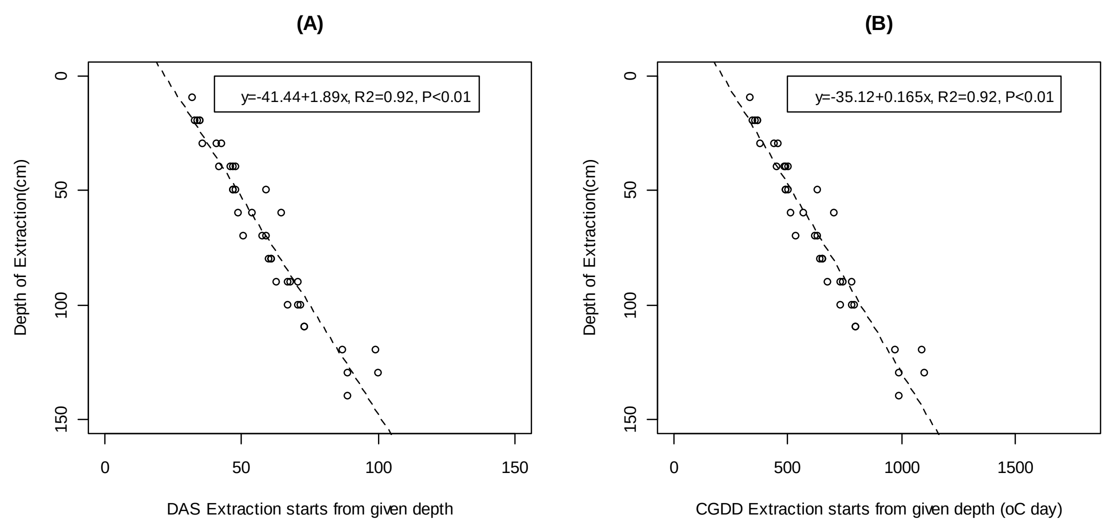

Figure 1. Depth of soil water extraction as a function of (A) days after sowing (DAS) extraction starts from a given depth and (B) cumulative growing degree days (CGDD) extraction starts from a given depth, for cotton grown at Kingsthorpe in 2007-08. Points include data from four irrigation treatments. The regression line is shown.

Even though there were slight variations due to irrigation treatment, the depth of extraction tended to increase nearly linearly with DAS, CGDD, and plant canopy height. Because EnviroSCAN® Solo data was only available after 32 DAS; there was no data to characterize the relationships earlier in the season. However, it is not expected that the linear relationships will apply earlier in the season. The depth of extraction increased at a rate of 1.89 cm day^{-1} from 32 DAS to about 100 DAS with no noticeable increase in depth of extraction after that time. The depth of extraction also increased linearly with CGDD at an average rate of 0.165 cm per ^{o}C day. It should be noticed that 100 DAS was also the time when plant canopy height peaked for all treatments, except the T50% treatment which continued to increase in height after that time, but only slightly. This could suggest that at that time the crop root system also stopped growing. Extrapolation of the linear function in Figure 1 (A) to the origin allows determination of the “lag period,” the time it took for the depth of extraction to start increasing linearly (Robertson et al., 1993). In this case the lag period was 23.5 DAS. The depth of extraction increased much faster than the canopy height, increasing at an average rate of 2.36 times that of the crop canopy height. This linear relationship provides an easy way for cotton growers to estimate the depth of extraction from canopy height, which is easy to measure in the field.

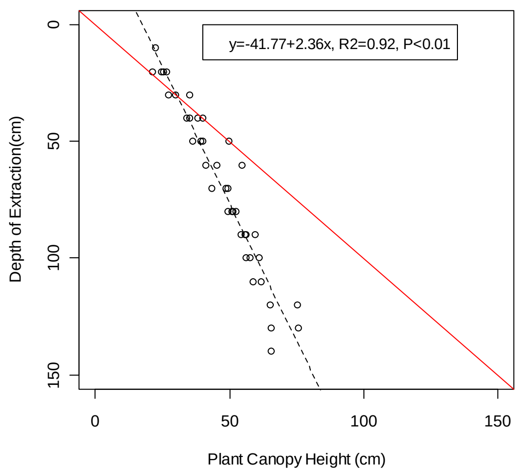

Figure 2. Depth of soil water extraction as a function plant canopy height, for cotton grown at Kingsthorpe in 2007-08. The regression (dashed) and 1:1 (solid) lines are shown. Points include data from four irrigation treatments.

Seasonal water extraction from each soil depth

Figure 3 shows that the fraction of seasonal soil water extraction decreased with depth from an average of about 0.20 (20%) at a depth of 25 cm to about 0.05 (5%) at a depth of 60 cm. Depths deeper than 60 cm accounted for less than 5% of the seasonal water extraction. Figure 4 shows that approximated 25% of the total seasonal water extraction came from the top 10 cm, 50% from the top 25 cm, 75% from the top 50 cm, 90% from the top 80 cm, and 95% from the top 110 cm. Low extraction from deeper depths could be due to a combination of low root density, lower water availability, and insufficient time between the arrival of the extraction front and crop maturity, especially considering that by the time the extraction front reached the deeper depths the crop water demand (evapotranspiration) had already started to decrease significantly. Figure 5 shows that taking the maximum root zone depth as 150 cm and dividing the root zone into quarters, 65% of the seasonal water extraction came from the top 25% of the crop root zone, 89% from the top 50%, and 95% for the top 75%. The bottom quarter only accounted for 5% of the seasonal water extraction. Therefore, the top quarter extracted 65%; the second quarter, 24%; the third quarter, 6% and; the bottom quarter, 5%.

These results are quite different from the 4:3:2:1 rule of thumb commonly used to estimate the crop water absorption over the course of a season. This rule of thumb suggests that of the seasonal crop water extraction, 40% comes from the top quarter layer of the crop root zone, 30% from the second quarter, 20% from the third quarter, and 10% from the bottom quarter (Scherer et al., 1999). Our results suggest that irrigation for cotton should be targeted at wetting only the top 80 cm of the soil profile during each irrigation event, which accounted for 90% of the seasonal water extraction. This means reducing irrigation depths during each irrigation event and increasing irrigation frequently. Currently, the common practice in the Australian cotton industry is to allow relatively high soil water depletions in the crop root zone and then apply furrow irrigation to refill the profile to depths far exceeding 80 cm. This common practice is likely to produce water losses by deep drainage and runoff. Many growers believe that no deep percolation losses occur in the heavy soils common in Australia due to low infiltration rates. However, recent studies have shown that significant losses do in fact occur. For example, Smith et al. (2005) evaluated surface irrigation events in cotton fields in Queensland and found that deep percolation losses averaged 42.5 mm per irrigation event, representing an annual loss of up to 2.5 ML/ha (250 mm). Also, Silburn and Montgomery (2004) reported that for furrow–irrigated cotton fields in Australia, annual deep drainage rates of 1-2 ML/ha (100-200 mm) were typical, and that values ranging from 0.03 to 9 ML/ha (3 to 900 mm) had been observed.

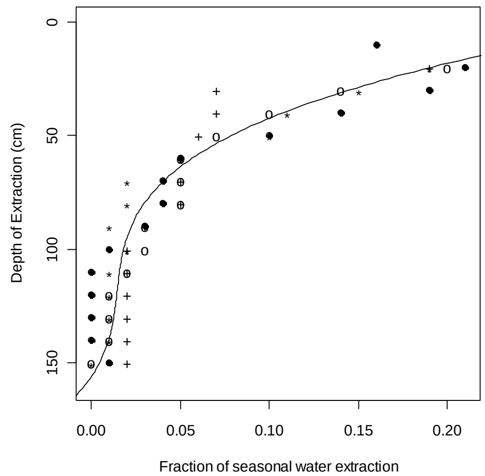

Figure 3. Fraction of seasonal water extraction as a function of depth of extraction measured with EnviroSCAN® probes for cotton grown under four irrigation treatments (T50%= "●", T60% = "○", T70% = "*", and T85% = "+") at Kingsthorpe during 2007-08.

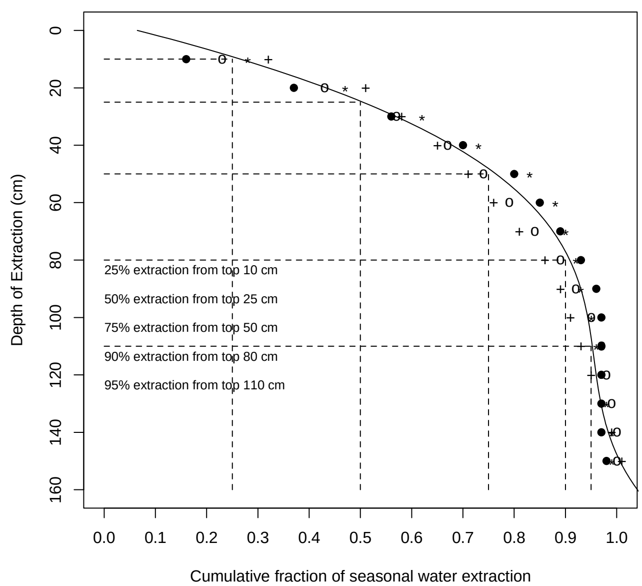

Figure 4. Cumulative fraction of seasonal soil water extraction as a function of depth of extraction measured with EnviroSCAN® probes for cotton grown under four irrigation treatments (T50%= "●", T60% = "○", T70% = "*", and T85% = "+") at Kingsthorpe during 2007-08.

<u>Summary</u>

In this study we found that cotton extracted soil water from as deep as 150 cm, but the percent of seasonal extraction sharply decreased with soil depth. The top 50 cm soil layer accounted for 75% of the seasonal extraction and the top 80 cm, for 90%. We also found that from 32 to 100 days after sowing, the depth of soil water extraction increased linearly with DAS, CGDD, and plant canopy height, at rates of 1.89 cm day^{-1}, 0.165 cm per ^{o}C day, and 2.36 times the increase in crop canopy height, respectively. These findings suggest that cotton producers should manage irrigations to maintain adequate moisture in the top 80 cm of the soil profile, rather than relying on moisture stored deeper in the profile to meet crop water demands.

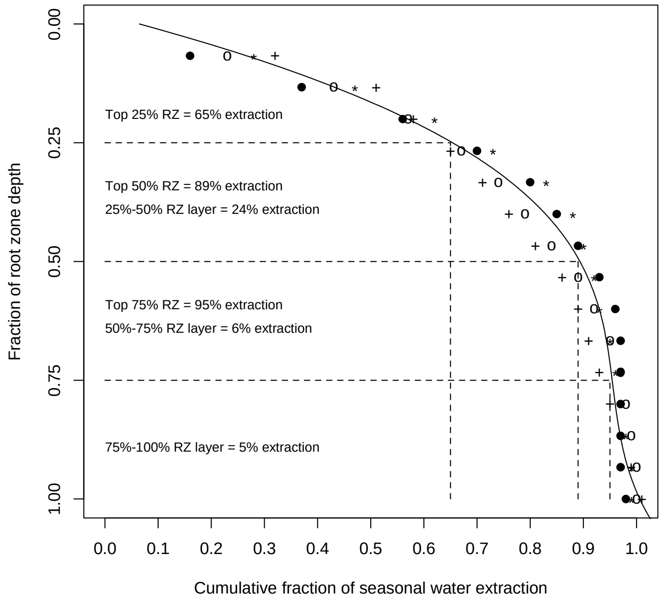

Figure 5. Cumulative fraction of seasonal soil water extraction as a function of fraction of root zone depth measured with EnviroSCAN® probes for cotton grown under four irrigation treatments (T50%= "●", T60% = "○", T70% = "*", and T85% = "+") at Kingsthorpe during 2007-08. RZ = root zone. The maximum root zone depth was 150 cm.

Acknowledgements

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