PLANT RESPONSES TO LATE SEASON WATER DEFICITS IN ACALA COTTON CULTIVARS

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Abstract

Continued development of irrigation strategies that minimize crop yield losses, while increasing water use efficiency are needed in many semi-arid and arid cotton producing areas world wide. Controlled deficit irrigation (CDI) incorporates the knowledge of crop physiology and phenology to identify specific plant growth stages in which water deficits have a minimal impact on crop yield and quality. Previous research in California and other irrigated agricultural regions have documented the severe yield impact when moderate early season water stress is allowed to accumulate in cotton (*Gossypium hirsutum* L.). Conversely, similar late season water stress following plant cutout has had a minimal impact on crop yield and quality. This paper is a report of recent studies that were undertaken in an effort to apply the concepts of CDI for cotton (*Gossypium hirsutum* L.) and suggest approaches to farm water managers which enable a greater understanding of deficit irrigation strategies. Studies conducted in the San Joaquin Valley of California from 1991 to 1993 have consistently demonstrated that high yields can be obtained although late season water deficits in cotton were present. The optimum timing of the final in-season irrigation for cotton was shown to be dependent on the cultivar. The determinant plant types tended to have more significant yield reductions as water stress is increased following plant cutout, while the indeterminate types were found to be less sensitive to the timing of late season water stress. The timing of late season water directly alters the stress accumulated in the crop thereby impacting late season boll retention, boll maturation and crop yield.

Introduction

The absence of new water development projects in the irrigated western United States coupled with an increased demand of existing water resources for urban and environmental uses, has reduced the quantity of water available for agriculture. California's most prime cotton acreage is found within a region that is particularly vulnerable to water shortages since less than 20% of the annual water requirement is supplied by annual rainfall. As water shortages become increasingly frequent within the region, it is critical that local farm managers develop strategies and techniques for managing a limited water supply, while maintaining high crop yields.

Earlier research work conducted in California has demonstrated significant yield penalties for cotton when water stress was allowed to accrue prior to or during early flower (Grimes *et al.*, 1970). When similar water stresses accumulated following plant cut-out (four to five nodes above white flower), the impact on yield was either non-existent or minor. The authors suggested that early season water stress in cotton results in decreased leaf matter production and canopy cover which ultimately reduces the plants light harvest capabilities thereby reducing total leaf photosynthate earlier in the season. With a suppressed carbohydrate supply available for boll production, flowering initiation and total fruit load is compromised as well as the plants ability to compensate early in the season for any lost fruiting positions. The result is delayed canopy development, plant carbohydrate production and bolls harvested at seasons end.

When cotton managers are faced with water shortages and deficit irrigation practices are unavoidable, the adoption of controlled deficit irrigation (CDI) strategies can be useful in maximizing yields and increasing water use efficiency. Controlled deficit irrigation incorporates the knowledge of crop phenology and physiology by identifying specific plant growth stages in which crop water deficits have a minimal impact on crop yield and quality. In establishing a crop data base that can ultimately result in the development of water management guidelines for controlled deficit irrigation, a knowledge of the degree of crop water stress, crop growth stage, and plant performance can assist in identifying the stages of crop development least likely to affect the economic impact to the grower.

Methods

The research trials reported were conducted during 1991 and 1992 at the University of California's West Side Research and Extension Center in Fresno County, California. The soils are classified as Panoche clay loam series, members of the fine-loamy, mixed, thermic family of Typic Torriorthents. The Panoche soils are deep, well drained soils with simple slopes of less than 1% and derived from recently deposited alluvium of calcareous sandstone and shale located on the eastern slopes of California's inner coast range. Cotton rooting depths in these soils commonly range from 1.5 to 1.8 m, with plant available soil moisture of 200 mm per metre throughout the soil profile.

Five Acala cotton varieties were evaluated using four contrasting irrigation termination dates. Split plot - randomized complete block field design was adopted with irrigation termination designated as the whole plot. Four replications were used on a 1 ha field. Optimum stand densities were achieved both years of the study and were found to be between 100,000 and 110,000 plants per ha using 1 m beds. Acala varieties planted included DP6166, GC510, Maxxa, Royale and SJ2; all varieties approved for California's San Joaquin Valley. Acala SJ2 and DP6166 both exhibited indeterminate growth. GC510 is considered a short-season, determinate cultivar. Very little growth habit data was available for Maxxa and Royale at the time this study was initiated. Final irrigation dates were scheduled at seven-day intervals beginning July 27, with the last irrigation treatment scheduled on August 17; IT-2 corresponds to the second irrigation termination of August 3, while IT-3 and IT-4 represent the August 10 and August 17 irrigation termination treatments. All treatments were scheduled prior to plant cutout with an optimum irrigation regime as described by Grimes *et al*. (1978). The first post-plant irrigation was scheduled when mid-day leaf water potential (LWP) reached approximately -15 bars while the second irrigation ensured when mid-day LWP readings reached -18 bars. Equivalent water quantities were delivered at each of the four separate dates keeping total applied water constant across all irrigation treatments and varieties.

Plant growth and development characteristics were monitored prior to during, and following the imposition of irrigation treatments. The plant data collected included plant height, number of nodes, presence or absence of first position squares/bolls, position of white flower and bolls remaining unopened prior to harvest. Soil moisture at planting and at harvest was determined and applied water monitored to obtain estimates of total Crop Evapotranspiration (ET). Water loss to deep percolation was observed to be negligible.

Results and Discussion

Yield averages from the 1991 season were consistently higher, 2101 kg lint ha^{-1}, than 1992 season yields 1513 kg ha^{-1}, (Fig. 1). A crop water deficit of 114 mm was estimated for the 1992 season compared to a 50 mm deficit observed in 1991. The resulting crop water stress that accumulated late season was of longer duration and was generally more intense. The lower crop water deficit experienced in 1991 led to an ideal irrigation termination date of August 3, while the August 17, termination resulted in lowest yield obtained. Higher cumulative water stresses were experienced in 1992 with a maximum benefit coming from an August 10, termination. As in 1991, more dramatic yield penalties were observed as the irrigation termination was delayed until August 17.

The pattern of duration, intensity and timing of water stress varied greatly for each of the irrigation termination treatments. Although varietal differences were not observed regarding the degree of water stress within an irrigation treatment, pressure chamber measurements recorded rapid decreases in leaf water potential following irrigation events. As an example, mid-day LWP readings of -15.5 bars were observed two days following the final irrigation in IT1, while the remaining unirrigated treatments averaged a LWP of -21.9 bars (Fig. 2). Moderately high plant water stress levels accumulated by August 11, and continued throughout the season. Moderate water stress levels dominated the IT2 treatment during the first half of August, with high stress levels (-29 bars) encountered following the August 11, measurements. However, the duration and degree of water stress in IT3 contrasted with all other irrigation termination treatments as average mid-day LWP levels never exceeded -23.0 bars. The IT3 treatment clearly stands out as the irrigation treatment that experienced the lowest cumulative plant stresses overall. The minimum LWP recorded in IT3 was to be -22.7 bars, a level of stress previously thought to have minimal impact on yield or quality. Irrigation termination initiated August 17, experienced a decrease in LWP to -31 bars recorded at the August 11 measurement and later decreasing to -18.6 bars following the final crop irrigation. Easily detectable signs of leaf wilting and leaf darkening were observed eight to ten days prior to the final irrigation on August 17. In an effort to quantify plant responses to a range of water stress regimes, plant growth and fruiting pattern were monitored into late season.

Plant mapping and harvested boll count data suggest differences in observed growth characteristics when monitored shortly after the IT4 treatment (August 27). The number of nodes above cracked boll (NACB) tended to increase and later decreased as irrigation termination date progressed through the season (Fig. 3). Total number of NACB increased from 11.3 to 13.3 and then decreased to 11.4 for IT4. Lower NACB observed in IT1 were caused by the decreased plant vigor resulting from the high water stress levels encountered August 11, and continuing throughout the month. Lack of new node and leaf production, coupled with accumulated plant stresses that encourage leaf aging and reduced photosynthate production may also explain lower overall yields for the July 27, termination treatment. The high plant water stresses that followed the August 4, measurements for IT 4 would similarly explain the reduced NACB and yield levels. The trends observed in NACB were common across all five varieties tested. The plants production of unharvestable bolls can also be related to water stress levels during late season.

The number of unopened bolls remaining prior to harvest was more closely related to the irrigation termination treatments, than within varietal variation (Fig. 4). The number of unharvested bolls averaged across all varieties increased from 6700 bolls ha^{-1} to 33345 bolls ha^{-1}, as termination date increased from July 27 to August 17. Cotton plants have been reported to respond to severe water stress by shutting stomata thereby reducing transpiration, CO_2 assimilation, and young fruit retention. Reduced fruit load and carbohydrate demand caused by severe water stress may explain the subsequent increased boll retention on upper fruiting branches of the IT3 and IT4 treatments. Increases in unharvestable boll production for IT4 can be linked with the plants ability to recover from severe moisture stress allowing a delayed delivery of photosynthates to the plants upper canopy fruit.

Cotton lint yield measurements were found to have some consistent yield differences between irrigation treatments and varieties (Fig. 5). The varieties SJ2, DP6166 and Maxxa all demonstrated a yield increase as irrigation termination was delayed from July 27 to August 10. Royale and GC510 on the other hand demonstrated steadily declining yields when the final irrigation was delayed beyond July 27. In contrasting IT1 with IT3, yields of GC510 and Royale decreased while SJ2, Maxxa and DP6166 increased. The differences between these two groups of varieties were highly significant at p=0.001, indicating a heightened tolerance to water stress by SJ2, Maxxa and DP6166.

Physiologic events suppressing carbohydrate allocation to fruit were likely triggered in Royale and GC510 by moderately high plant water stress levels thus indicating a trend toward determinate plant growth. Maxxa yields responded in a similar manner to the indeterminate cultivars which apparently continued to fill bolls higher on the plant.

Field observations by the second author may explain the yield advantage of Maxxa in this trial. Limited data on CO_2 assimilation rates have shown that at high plant water stress levels, varieties like Maxxa are able to maintain higher CO_2 assimilation rates when compared to other cultivars. If this is the case, it is also likely that more total photosynthates are available to the plant during periods of high water stress, and that subsequent yield impacts will be minimized in those cultivars. Future studies will be required to confirm this hypothesis.

Conclusions

The monitoring of cotton plant performance characteristics following periods of induced late season water stress can assist in developing deficit irrigation management strategies. To date, very little information is available regarding modern cotton cultivators and their tolerance to late season water stress. By varying the degree and timing of water stress accumulation, we can begin to recognize both general trends for timing the final irrigation and select varieties that suit an individual field managers needs with respect to timing the final irrigation. Moderate plant water stress induced late in the season, can reduce consumptive water use without severely impacting on crop yield or quality. The decision of when to time the final irrigation for cotton, is dependent upon the variety and the degree of water deficits. Delayed scheduling of late season water is preferred for more indeterminate plant types resulting from their improved tolerance to water deficits. Shorter season, more determinant plant types, experienced significant yield reductions when moderate late season water stress was allowed to build. The preferred irrigation strategies for determinant varieties would therefore favor the deliver of available water supplies prior to the development of moderate water stress levels (-21 bars).

The pressure chamber can be an effective tool in evaluating the intensity and duration of cotton water stress. Generally, plants performed well with highest yields obtained when LWP readings were not allowed to exceed -23 bars. Significant impacts on plant growth and fruit retention were observed when LWP readings were allowed to reach the wilting point of -30 bars. At these high water stress levels, decreases in transpiration rate and photosynthesis are likely causes of delayed fruit set and hence the production of unharvestable late season bolls. The production of these late season bolls, although not equivalent to the lost production of lower fruiting positions, does demonstrate a resiliency of cotton to partially recover from severe water stress levels.

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Figure 1. Yield trends across four irrigation termination treatments conducted during 1991 and 1992 at the U.C. Research and Extension Centre, Five Points, California.

Figure 2. Late season midday leaf water potential variations for the four irrigation termaination dates in 1992.

Figure 3. Irrigation termination effects on nodes above cracked boll for five Acala cotton varieties monitored at the U.C. Research and Extension Center, Five Points, California.

Figure 4. Variety and irrigation termination effects on the number of unharvestable bolls, measured October 15, 1992.

Figure 5. Yield response to irrigation terminatin date on five Acala cotton varieties grown at the U.C. Research and Extension Center, Five Points, California. Yield responses are averages for the 1991 and 1992 cropping year.