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**UC Water Resources Center
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**Irrigation Management Improvements for
San Joaquin Valley Pima Cotton Systems**

1. Abstract

California Pima cotton production has and been particularly hard hit resulting in acreage declines caused by water supply reductions in the western San Joaquin Valley. Water management methods that improve water use efficiency while maintaining high agronomic yield are of value to the cotton producers that face water supply limitations. We tested structured and predictive approaches to water management and collected field water management information that evaluated our ability to match varying water supply amounts in a way that maximized production and limited economic losses due to reductions in crop quality. Evaluations at four separate sites conducted during the 2005 and 2006 cropping seasons confirmed Pima cotton's ability to respond favorably to irrigation guidelines recently developed by the UCCE and to modest deficit irrigation approaches that have been developed for Acala type Upland cottons. Variations in soil water storage at each site were large and played a critical role in how Pima cotton responded to in-season water deficits.

2. Introduction and Problem Statement

Numerous water districts in the western San Joaquin Valley have been especially impacted by reductions in surface water deliveries to farmland as water is increasingly being diverted from agriculture uses to environmental uses. Meeting the water demand of cropping systems that have proven to be very successful over the past few decades has become particularly difficult as water has become prohibitively expensive or unavailable to grow these crops. Pima cotton, *Gossypium Barbedense*, has been an especially attractive as a west side San Joaquin Valley cropping system option due to its combined lint and seed value linked to its high yield and quality when compared to other regions of the world. With previous water management research focused on short-season Acala type Upland cottons, *Gossypium Hirsutum*, there is a need to identify and validate primary water management parameters for Pima cotton. More detailed information is needed to better understand and predict Pima cotton's response to water stress and develop approaches that help the industry improve production efficiencies.

Producers have long realized and applied practices in dealing with drought that include manipulating crop selections, changing irrigations systems and management to be more efficient, managing conjunctive use options such as increased well water use and district transfers and in some cases producers have fallowed highly productive agricultural lands. In order to limit the risk associated with reduced water supply, few growers have adopted practices that include irrigating their field and row crops with less than their reported full season water

needs. However many growers use irrigation scheduling guidelines developed by UC Cooperative Extension to assist in irrigation scheduling for the Upland Cotton types as well as recently developed guidelines for Pima cotton. There remains very little information about the consequences of moderate and severe water stresses on Pima cotton and the specific implications of irrigation deficits when water supplies are very tight. Refining Pima irrigation management practices that include production and quality responses to deficits could allow growers the additional option of applying irrigation volumes below those of crop ET thereby increasing water use efficiency and gaining a better understanding of the economic tradeoffs when deficit irrigation approaches are used.

3. Objectives

Combination field evaluation approaches were incorporated that included small scale testing conducted at the University of California West Side Research and Extension Center (WSREC) and at large scale grower trial sites. Locations were established to provide more immediate term information to growers while the studies conducted at the WSREC provided information on crop responses to more stringent deficits that can be used for long term planning or developing worst case water availability scenarios. Our overall goals were to:

- Expand our information and compare water use and stress responses of at least 2 modern Pima cotton varieties differing in growth habit and determinancy.
- Establish field trials that quantify yield, growth and quality impacts resulting from a range of irrigation management strategies that involve manipulating irrigation quantities and plant water stress levels at key stages of Pima cotton development.
- Validate current pressure chamber guidelines and improve our understanding of how to monitor water stress levels in cotton. To improve irrigation scheduling methods by reducing the risk of over-applying irrigation water to Pima production fields.
- Provide extension outreach programming on irrigation scheduling that includes deficit irrigation approaches that can be used successfully with Pima cotton, while providing some comparative information on Acala type cottons.

4. Procedures

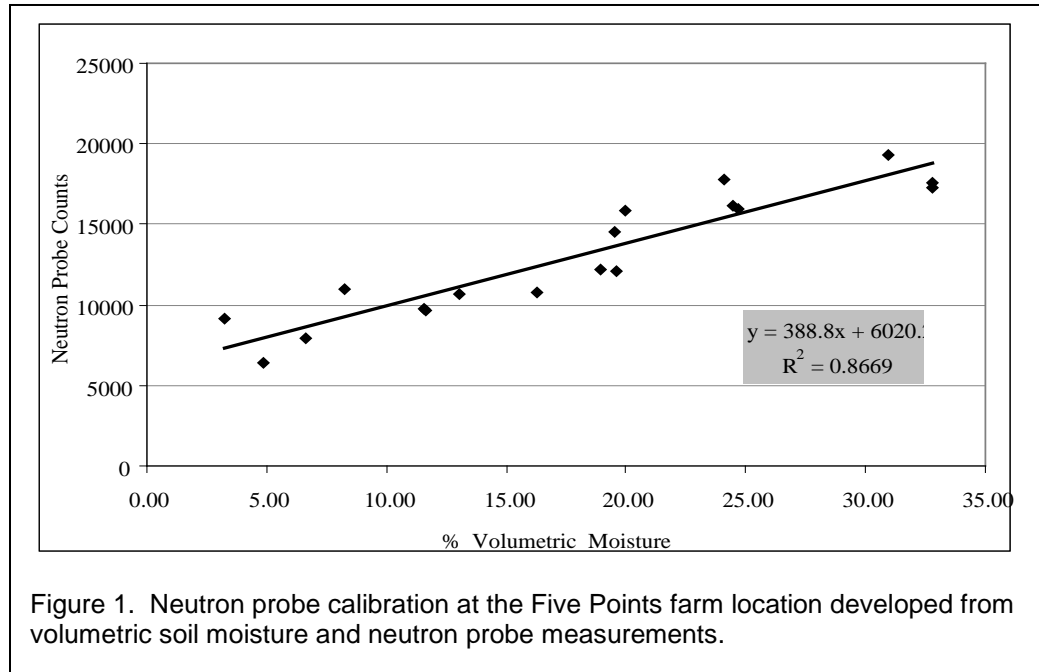
During the 2005 growing season, we conducted crop water stress evaluations on three large scale grower sites. Our 2006 investigations focused a single research

site at the West Side Research and Extension Center in Five Points, CA. Irrigation treatments varied somewhat from site to site with all sites irrigated with one guideline treatment based on UCCE irrigation scheduling guidelines. At all sites midday leaf water potential (LWP) was monitored on a 7 to 10 day schedule prior to first flower using a -15 bar value to trigger the first irrigation and -18 to -20 bars to schedule subsequent irrigation events; Hutmacher et al., 2004. Additional irrigation treatments were imposed at each site that included one low stress irrigation treatment that increased the number of irrigations by one or more and at least one high stress treatment that was scheduled using a deficit approach that minimizes production impacts caused by water stress; Munk et al., 1995.

We established a randomized complete block design at each site with either 3 or 4 replications and monitored soil moisture at one foot intervals and on the same day we conducted our LWP readings. A Campbell Pacific model 503 DR Hydroprobe was used with access tubes extending to the depth of the root zone which varied from 6 to 8 feet at seasons end. A calibration statistic was developed for each site and year that related soil moisture content to the neutron probe readings, Figure 1. Statistical analysis was performed at each site to evaluate yield and quality effects. Root zone depth and water extraction volumes and patterns were estimated based on neutron probe measurements.

To better understand the timing and location of fruit set for each crop, a cotton plant monitoring program was developed for early, mid- and late-season crop growth evaluations; Kerby et al., 1996. From each treatment and plot we monitored 5 to 7 plants per plot to arrive at a 20 plant average value defining parameters such as plant height, vegetative and fruiting node number, flower location, as well as fruit retention from pre- and post-anthesis fruiting bodies. Boll count and position were recorded late in the season to assess the timing and magnitude of the harvestable portion of the crop.

Evaluations at the WSREC in 2006 included one Pima variety, one Pima hybrid type and one Acala cotton. In the experimental design at this site, the irrigation treatments made up the main effect, with each of the commercial cotton cultivars evaluated as subplots. The moderately determinate Acala cotton, PHY72, was planted with the moderately indeterminate Pima type, DP744 and the highly indeterminate Acala-Pima interspecific hybrid, HA195.



5. Results and Discussion

Basic water resource economics varies at each of the grower sites evaluated and is cause for different grower irrigation and crop management practices. Water costs for our grower cooperators ranged from just under \$50 per acre foot for well water that supplemented irrigation district water, to more than \$200 per acre foot for supplemental water purchased and delivered by the irrigation district through inter-district transfers. The upper value of these costs continues to increase as irrigation water availability declines further during the 2008 cropping season. Because water costs range so widely depending on district, transfers and groundwater availability, irrigation decision making and approaches to confining water managing risks will be different.

Results from our grower and WSREC trials demonstrate the benefits of using UCCE guidelines for scheduling Pima cotton irrigation events. At each of the grower sites, the guideline treatment achieved high yield with no significant increase in yield for increasing applied water. However large reductions in yield were experienced when reductions in applied water fell substantially below guideline levels, Table 1. Assuming a highly efficient irrigation system and using soil water depletion measurements at the beginning and end of the season, we estimated crop water use. This translated to crop water use estimates ranging from 27.6 in the stressed treatment to 48.5 inches in the low stress treatment at the Five Points site. The guideline treatment that had comparable yields to the low stress treatments resulted in a crop water use estimate of 30.4 inches and is consistent with water use figures for high producing Acala cottons. Lint yield was not

significantly improved by increasing applied water above the guideline treatment and WUE was greatest for this treatment and site.

	Stressed	Guideline	Guideline + 1	Low Stress
Inches Applied	12.8"	19.2"	25.6"	38.4"
Soil Water Depletion	14.8"	11.2"	10.7"	10.1"
Est. Crop Water Use	27.6"	30.4"	36.3"	48.5"
Lint (lbs./acre)	1552	1752	1784	1789
Lint lbs. / inch of Water	56.2	57.6	49.1	36.9

Table 1. 2005 water use and production data for 4 irrigation treatments, Five Points, CA

Plant responses to irrigation deficits and excesses typically translate to changes in vegetative and reproductive development. Not only is yield commonly impacted, but the partitioning of carbohydrates is impacted as well, table 2. Stresses developed in the low water treatment resulted in shorter plants containing fewer fruiting branches. The water stress that developed in the deficit irrigation treatment impacted fruit development by decreasing the number of fruit per plant and reducing the retention of first position main stem bolls. While some reductions in vegetative and reproductive growth were also observed in the guideline treatment, they were not severe enough to impact crop yield.

<u># of In-Season Irrigations</u>	<u>Bolls per Plant</u>	<u>#Fruiting Branch</u>	<u>Average Height</u>	<u>% FP1 Ret. in 95% Zone</u>	<u>Yield Lint Cotton/ Acre</u>	
2	14.9	13.5	36.3	49.2	1552	<i>b</i>
3	17.2	13.8	37.8	61.8	1752	<i>a</i>
4	23.6	17.9	43.8	55.6	1784	<i>a</i>
6	28.8	19.2	46.7	61.5	1789	<i>a</i>

LSD .05 = 142.5
CV% = 5.18

Table5. Final plant map and yield at the 2005 Five Points location.

Total applied water and estimated crop water use were much lower at the Tranquility grower site where soil clay content and irrigation efficiency are considered high, table 3. Only small increases in stored soil water were observed in the stress treatments compared to the guideline and low stress treatments indicating a more confined root zone and minor differences in the plants ability to exploit soil water reserves at the seasons end. The water stressed treatment

exhibited reduced productivity and higher water use efficiency than the guideline treatment however the treatment differences were small. We observed relatively small differences in productivity between irrigation treatment yields at the San Joaquin site although sizable differences in irrigation volumes were imposed, table 4.

	Stressed	Guideline	Low Stress
Inches Applied	13.3"	19.2"	25.2"
Soil Water Depletion	7.6"	7.3"	7.1"
Est. Crop Water Use	20.9"	26.5"	32.3"
Lint (lbs./acre)	713	853	903
Lint lbs. / inch of Water	34.1	32.2	28.0

Table 3. 2005 water use and production data for 3 irrigation treatments, Tranquility, CA

	Stressed	Guideline	Low Stress
Inches Applied	21.5"	30.1"	34.4"
Lint (lbs./acre)	1466	1515	1597
Lint lbs. / inch of Water	68.2	50.3	46.4

Table 4. 2005 water use and production data for 3 irrigation treatments, San Joaquin, CA

Accounting for the depletion of soil moisture stored from winter irrigation and rainfall is crucial in estimating crop water use and is especially demonstrated at the WSREC study site in 2006, table 5. Not including seasonal applied water, 19.4 inches of soil water were extracted by the crop in the stressed treatment that had 2 in-season irrigation events. Late season soil moisture was depleted to a depth of 8 feet with an average depletion of 2.4 inches per foot while the guideline and low stress treatments depleted 10.2 and 10.5 inches. As with the Five Points and Tranquility sites evaluated in 2005, plants partially compensate to water stress treatment levels we imposed by tapping additional soil water reserves as compared to the guideline and low water stress treatments.

Plant responses to in-season irrigation deficits are therefore highly site specific making production response predictions difficult without good information on the

sites water storage potential. In the example of the 2006 trial, the crops ability to exploit deep stored soil moisture was so great, no significant yield differences were detected between the stressed, guideline and low stress treatments although the in-season application of irrigation water differed by 10 inches. Though normally counterintuitive, the estimated water use was slightly higher for the stressed irrigation treatment due to the large contribution from water stored in this soil. Our estimates of crop water use are also consistent with the fact that the highest yielding treatments, stressed and low stress, were also the treatments that achieved the highest yield.

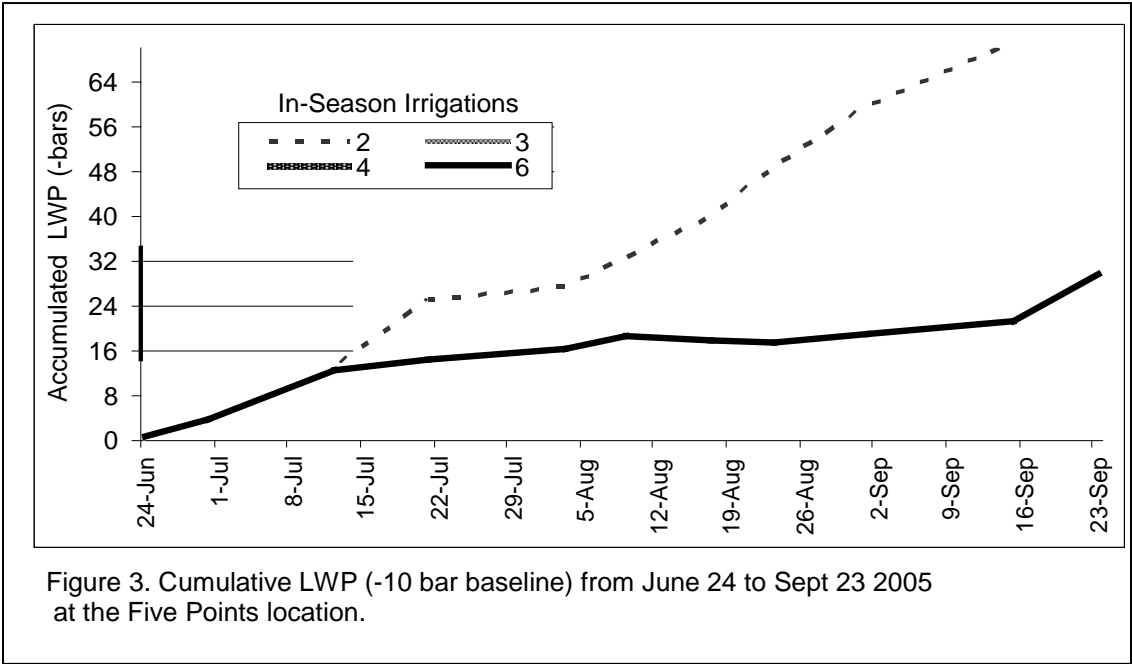
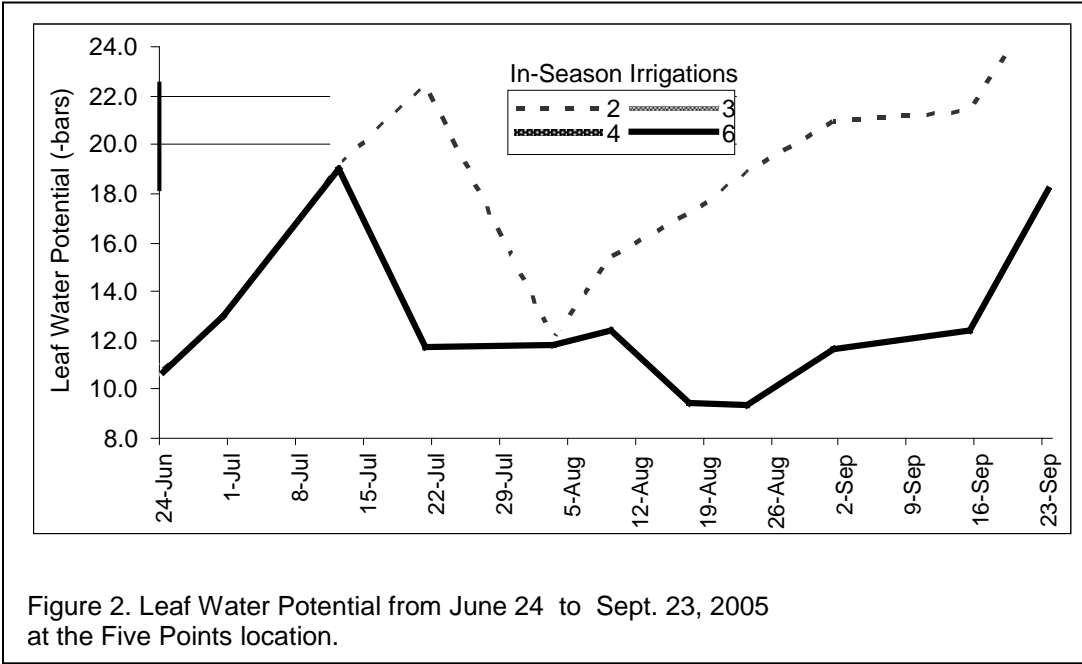
	Stressed	Guideline	Low stress
Inches Applied	12.6"	19.4"	22.6"
Soil Water Depletion	19.4"	10.2"	10.5"
Est. Crop Water Use	32.0"	29.6"	33.1"
Lint (lbs./acre)	1732	1660	1709
Lint lbs. / inch of Water	54.1	56.1	51.6

Table 5. 2006 water use and production data for 3 irrigation treatments, Five points, CA

A crops water status is affected by climatic conditions, largely unmanageable, as well as its access to soil water which will be influenced by irrigation activities and crop characteristics. The ability of the crop to exploit new soil water reserves will change as the crop expands its roots and we observed large variations in how irrigation management and soil type affect the crops ability to use soil reserves. As an integral component of these field studies, we incorporated the use of the pressure chamber as originally developed by Scholander in 1965, as a tool to evaluate the magnitude of crop water stress. Our confidence in this method as outlined by Grimes et al. 1982, and supported by considerable work in and outside of the San Joaquin Valley, allowed us to establish irrigation treatments that normalize the highly variable nature of soils by integrating the plant component and recognizing the preferred method for scheduling San Joaquin valley cotton.

Monitoring leaf water potential at each site provided information on the intensity of the crop water stress incurred in each treatment, Figure 2, and allowed us to develop a new approach that integrates magnitude and duration components using the LWP readings, figure 3. Plant water stress measurements conducted at all trials sites allowed us to consistently distinguish irrigation treatments and record the extent of stress incurred. We concluded that crop productivity was not greatly impacted in Pima cotton when in-season water stress levels were limited to -20 bars for the duration of the effective flower period and 4 weeks after last effective bloom. The water stress data has not only assisted us in characterizing stress in

each irrigation treatment, but has also been used to compare water stress treatments between cotton varieties.



6. Extension Activities

Although no budget was requested for extension component activities, the information collected at the study sites proved useful in developing discussion and reporting impacts of water deficits to cotton producers and the cotton industry. The P.I. developed cotton irrigation management presentations for a Fresno County Cotton Production meeting held in August 2007 and at the West Side research and Extension Center Cotton Field Day in September 2007. Conference talks communicating research results were also given by the P.I. at the September 2007, World Cotton Research Conference in Lubbock, TX and two papers presented at the January 2008 Beltwide Cotton Production conference in Nashville, TN.

7. References

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8. Summary and Conclusions

Similar to the more widely grown Acala type cottons, Pima cotton has an ability to tolerate moderate water stress between irrigation events in San Joaquin Valley cropping systems. However production declines can be severe and costly when

water allocations are grossly reduced and crop water stress levels increase for an extended period above the guideline treatment. Under severe water deficit conditions, it makes sound economic sense to provide additional water to the crop to avoid large reductions in productivity and modest declines in crop quality.

Using current irrigation guidelines developed by UCCE, modest reductions (4 to 6 inches) in applied irrigation water below the recommended level did not have a large impact on yield or fiber quality at these study sites. The water deficit conditions developed in this study assumed that at planting, there was a full soil water profile and we demonstrated that deficit treatments partially compensate by mining soil water stored from winter and spring irrigation and rainfall events. Pima cotton demonstrated considerable tolerance to water stress by making use of stored soil moisture late in the season indicating its successful ability to tap deep soil reserves, particularly under moderate and high stress conditions. We observed that the compensation that occurs from taking up deep soil reserves can mitigate the potential impacts caused by reductions of in-season water applications, however less flexibility exists at locations that experience a more confined rooting zone or in soils that have low available water storage.

Although the low water stress treatments have the advantage of reduced risk in terms of production impacts, high water costs and low availability are limiting the grower's ability to apply irrigation water beyond crop ET demands. This can have a long term impact in many cotton production areas by reducing the leaching fraction necessary to remove salts that accumulate in the soil profile. But if growers are able to achieve relatively high irrigation uniformity, managing Pima cotton according to current UCCE guidelines or with moderate stress levels as outlined in these studies, high production levels and improved water use efficiencies can result in the short term. Study results can be used to increase the flexibility of cotton producers and assist in the crop planning phases when water availability is limited or sporadic. The information developed here provides a basis for supporting the concept that water allocations in cotton need not be fixed and that considerable flexibility may come from storing water during preirrigation events with additional contributions coming from winter rainfall when a wet winter is observed.

9. List of Publications

Munk, D.S., R.B. Hutmacher, B. Marsh, and S. Wright. 2006. UC's Pima cotton research bolsters California's cotton industry. University of California Delivers. <http://ucanr.org/delivers/storylist.cfm>

Munk, D.S., R. Hutmacher, and J.F. Wroble. 2007. Comparing pima and upland cotton growth, development and fruit retention in California's San Joaquin Valley. In: Hutmacher, R., Plant Growth Evaluations & Management Practices.

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