COTTON IRRIGATION USING SUBSURFACE DRIP: GROWTH, CUTOUT AND YIELD DEPEND ON AMOUNT OF WATER APPLIED

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Abstract

The main objective was to find the optimum level of water application to Acala Maxxa and Pima S-7 cottons, on sandy soil. The field test consisted of 6 different water application rates through a subsurface drip system on a 2-acre plot. Cutout occurred 4 days earlier for each 10% decrease in the full-canopy pan coefficient, for both Pima and Maxxa. The Maxxa was ready to defoliate 4.8 days earlier for each 10% decrease in the pan coefficient. The driest Maxxa treatment was ready to defoliate 37 days earlier than the wettest treatment. Plant height was found to be a linear function of the total depth of water applied from planting to July 7, with a 2.7" gain in height for every 1" of water applied. The concept of nodes-above-white-flower (NAWF) did not work well for determining the cutout date of the wetter treatments. A slight deficit irrigation treatment was found to produce optimum yields, which occurred at a full-canopy pan coefficient of 74% for Pima and 80% for Maxxa. Maximum yields for Maxxa occurred at a pan coefficient of 94%. The yield on Maxxa dropped off sharply with application rates higher than 105% of pan evaporation. By comparison, the Pima yields did not decrease at all with the wetter treatments; they remained essentially constant for application rates above 100% of pan evaporation. Using a slight deficit irrigation not only saves water, but because of the smaller plants, reduces PIX requirements, and defoliation is much easier. Because of the shorter season produced by deficit irrigation, a generation of whitefly development can be avoided.

Introduction

We can always do a better job of irrigating. More precise irrigation means less water wasted, fewer drainage problems, less nutrient leaching, and, with cotton, it also means better control of that delicate balance needed between vegetative and reproductive growth. Our goal is to fine-tune an automatic irrigation system. We have been using a datalogger-controller to provide daily irrigations through a subsurface drip irrigation system. Programmed into the datalogger is a truncated polynomial as a crop coefficient to use with pan evaporation, which we call a pan coefficient. Some limited previous experience has shown that at mid-season, soil moisture will gradually increase if the water application is greater than about 85% of pan evaporation, so this is the level at which we have truncated the curve. The result is a constant pan coefficient for about 45 days from early July to mid-August. But maybe there are some better pan coefficients. This is a progress report on the first two years of an experiment set up to find the proper amount of water to apply to cotton, using a broad range of application rates.

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Procedures

A two-acre field plot was set up at the Shafter Research Station to determine the optimum level of water application to Acala Maxxa and Pima S-7 cotton using subsurface drip irrigation. A randomized complete block design was used with two replications of 6 irrigation treatments. Each of these main treatments was then split into subplots, one half for the Maxxa and the other half for Pima. Each of the main plots consisted of eight 30-inch rows, 328 ft long. A dripper line was buried 10 inches below grade under every plant row, running the full length of the field. The dripper line is T-Tape TSX-710-12-450 (7/8" ID, 10-mil wall thickness, emitter outlets every 12 inches) which we operated at a pressure of 9.4 psi, producing 0.30 gph emitter flow. Each of the 6 circuits at the control center feeds 16 dripper lines and carries 26.4 gpm. Water is applied once a day, using manually adjusted time clocks. The field is level in both directions, and pressures throughout the system vary no more than 0.2 psi from one side to the other. A proportional-type fertilizer pump was used to inject liquid urea (UN32) into the irrigation water, at a rate of 10 lbs N/acre for each inch of water applied from mid-May to the first week in August. The planting dates were April 9, 1996 and April 14, 1997, with plant rows running N-S. The final emerged plant population was 40,000 to 50,000 plants per acre. The soil is a uniform Wasco sandy loam (*coarse-loamy, mixed, nonacid, thermic Typic Torriothents*) that had been in potatoes for the three years prior to planting cotton. The field has a history of good productivity.

The basic system control equation is

$$E_t = C_p * E_p \qquad [1]$$

where E_t is the depth of water to apply, E_p is the evaporation from a USDA Class A evaporation pan, and C_p is the pan coefficient. The pan coefficient is a variable, normally dependent on plant development, and in this case includes a treatment effect, so that

$$C_p = F_t * C_n \qquad [2]$$

where C_n is the crop canopy (ground cover), as a decimal fraction, and F_t is a treatment factor with the values of 0.45, 0.65, 0.85, 1.05, 1.25 and 1.45 for treatments numbers 1, 2, 3, 4, 5, & 6 respectively in 1996. In 1997, these treatment factors were 0.45, 0.65, 0.85, 1.05, 1.25, & 0.75 . At full canopy, the treatment factor is the same as the pan coefficient, and will be referred to as the full-canopy pan coefficient. Combining equations 1 and 2 produces

$$E_t = F_t * C_n * E_p \qquad [3]$$

Treatment number 3 (F_t =0.85) was considered the "normal" for local conditions. It is important to note that the ratios of water applied to the various treatments remained constant throughout the entire season, e.g., treatment 2 always received 0.65/0.85 of the water received by treatment 3. It was hoped that the range of water applications would be large enough to provide significant differences in yield and show definite trends. The time clocks, which were adjusted twice a week, were set by estimating the pan evaporation for the coming 3 or 4 days, using the 21-year normal pan evaporation and adjusting it by as much as 20% depending on weather forecast information. Ground cover was measured weekly (dividing the average width of the plant canopy by the row spacing), and estimates were made by forward extrapolation to help with the time clock setting. The moisture in the soil profile was measured weekly with a neutron probe. One neutron probe access tube was located near the center of every subplot. Each of the 24 tubes was 2" in diameter (OD) and five foot long, made of an aluminum alloy. Readings were taken at one-foot intervals. In the final layout for 1996, Pima was planted in the SE quarter of the field and was labelled Pima-I. Pima in the NW quarter of the field was labelled Pima-II. Maxxa in the NE quarter was labelled Maxxa-I, and Maxxa in the SW quarter of the field was labelled Maxxa-II. In 1997 the Pima and Maxxa locations were switched. In 1996 the plants grew rapidly with those in treatment 3 reaching 91% ground cover at first bloom on June 17. At this point the plant heights were 27 inches for the Pima and 34 inches for the Maxxa. The timing for first bloom was normal, but these plant sizes were reached two to three weeks earlier than usual. There was no visible or measurable moisture stress on the plants in treatment 3 through 6. Over the season, the mid-day leaf moisture potential in treatment 3 averaged -12.8 bars on the Pima and -11.7 bars on the Maxxa; the coefficients of variability (CV) were 9.0% and 6.7% respectively. By comparison, in 1997, the Maxxa plants in treatment 3 reached 48% ground cover by first bloom on June 13 and had a height of 22 inches. Since water application was proportional to the canopy, and the plants grew much faster in 1996 than in 1997, there was about 13% more water applied in 1996, for a given treatment.

Results and Discussion

As can be seen in Figures 1 and 2, for a given treatment, about 13% more water was applied in 1996 than in 1997. Part of this difference can be attributed to the fact that the canopy developed much faster in 1996, and water application is directly proportional to the canopy. But in addition, pan evaporation averaged about 10% higher in 1996 than 1997, for May through August. The after-planting water application for treatment 6 (F_t = 0.75) in 1997 was about the same 21 inches as for treatment 2 (F_t = 0.65) in 1996. In general, the driest treatment received about half of normal and the wettest treatment received about 1.7 times normal.

Figure 3 shows an example of how markedly water application affects plant height. There is a distinct separation in plant height between all treatments. The final height of 67 inches for treatment 5 is excessive, but considerably lower than the 80 inches measured in 1996. In Figure 4, plant heights on June 23, 1997 are plotted against the total water applied up to that date. Then the same thing is done for July 7. The same regression line fits both groups of data. One obvious outlier for the July 7 data is treatment 1, which cut out on June 23. For these particular set of conditions, the plant height is a linear function of water applied after planting, with the plant height increasing 2.7 inches for every inch of water applied.

The yields for both years are shown in Figure 5 for the Pima and in Figure 6 for the Maxxa. They are plotted against the water application after planting, and as such could be considered a water production function. For the Pima, a quadratic equation was fitted to the data for each year. The results show essentially the same slope and curvature for both years. Maximum yields projected by the equations are 1.96 bales/acre in 1996, occurring at 34.25 inches of water, and there is a corresponding value of F_t =1.05; for Pima in 1997 the maximum yield was 2.28 bales/acre occurring at 31.81 inches of water, and the corresponding F_t was 1.14. For the Maxxa in Figure 6, a quadratic equation fitted to the 1997 data indicated maximum yield 2.71 bales/acre at 26.22 inches of applied water and a corresponding F_t = 0.95. The 1996 data for the Maxxa indicates a problem. A heat wave occurred during the second week of August 1996, causing a great deal of damage to the Maxxa (but not to the Pima). The same problem occurred throughout the entire San Joaquin Valley. The maximum temperatures ranged from 102 to 105 F for 8 days starting August 9, 1996. It is assumed that the four wettest treatments had a delay in boll maturation which made them more susceptible to heat damage. The actual peak yield came from treatment 2 (F_t = 0.65) with 2.8 bales/acre at 20.9 inches of water.

For curvilinear functions to the left of the peak, the economic law of diminishing returns can be applied, i.e., incremental increases in input (water) produce incremental increases in output (yield) but at an ever decreasing rate, until at some point, the value of the increased output equals the value of the increased input. Where this happens is called the point of diminishing returns. A related procedure can be used by backing down the curve to the left from the peak, until the savings in water applied is equal to the value of the yield lost. We are calling this the optimum yield point. Assuming that water is worth $100/acre-foot and cotton fiber is worth $360/bale for Maxxa and $480/bale for Pima we have found the optimum yield points on all 3 curves. For Pima these are 1.76 bales/acre at 23.25 inches of water and F_t =0.73 in 1996, and 2.09 bales/acre at 21.31 inches of water and F_t = 0.75 in 1997. These data represent a saving of 10 to 11 inches of water and a corresponding loss of about 0.2 bales/acre of Pima. For the Maxxa in 1997 the optimum yield is 2.63 bales/acre at 22.85 inches of water with F_t = 0.80, a saving of 3.4 inches of water and a 0.08 bale/acre loss in yield. Maximum yields can also be determined from a quadratic fit of yield data vs F_t. The yields are the same as in the above, but the point at which they occur vary a little. For Pima in 1996, maximum yield occurred at F_t = 1.098, and in 1997 at F_t = 1.126; for Maxxa in 1997, maximum yield occurred at F_t = 0.928 . The quadratic fit for the Pima seems to be appropriate to the left of the peak, but there is some doubt about any decreases in Pima yield with high water applications. The yield from treatment 6 in 1996 was numerically less than with treatment 5, but the difference is not significant. So far, it appears that the Maxxa yield is definitely reduced by over watering.

The procedure used for determining the date of cutout is shown by the sample in Figure 7. The nodes-above-white-flower (NAWF) for Maxxa in 1997 was plotted over time for each treatment. Cutout occurs when NAWF reaches a value of 5 for Maxxa. The drier treatments cutout early. The wettest treatment, treatment 5, did not cutout at all. This was not an isolated incidence; the wetter treatments in both years in both varieties had this same problem. The normal cutout rate is shown as a straight line, and was obtained from the University of California Cooperative Extension (UCCE) (Hake et al., 1996). The normal cutout line is located between treatments 3 and 4, and is a little closer to treatment 4, so that it might possibly be obtained by using an F_t of 0.95 or 1.00 .

When the day of cutout is plotted against the water application rate (100*F_t), the result is as shown in Figure 8, for Maxxa in 1997, for the two different parts of the field. Covariance analysis showed a significant correlation, with no difference in the slopes of the 2 lines. The slope is 0.408, which means that for each 10% increase in the full-canopy pan coefficient, there is a corresponding 4.08 days delay in cutout, and about a 4-day increase in the length of season. Field conditions can also be very important, as can be seen in the significant difference in cutout between the two parts of the field (5.3 days).

The normal cutout rate for Pima, from UCCE, is shown in Figure 9, along with some 1997 data. It is assumed that Pima cuts out when NAWF = 3.5 . Again, the drier treatments cutout earlier than they should have, and the wetter treatments didn't cut out at all. The normal line seems to be closest to that for treatment 3 (F_t = 0.85) for Pima.

When the day of cutout for Pima is plotted against the application rate,as in Figure 10, a significant linear regression can be found, but only for the 4 drier treatments. The slope is 0.398 which is about the same a with the Maxxa. It appears that the effect of irrigation treatments on earliness is about the same for both Pima and Maxxa.

The criteria for defoliation was also set up by UCCE as 4 nodes above cracked boll. The weather between cutout and defoliation can affect the total length of season and the relative effect of the irrigation treatment, as can be seen in Figure 11. Here, the date that each treatment was ready to defoliate was plotted against the application rate, and the slope of the regression line is 0.48 . So that by the time that the end of the season is reached, the irrigation effect has increased from 4.08 days to 4.8 days delay in harvest for each 10% increase in the full-canopy pan coefficient. Treatment 5 was ready to defoliate 37 days later than treatment 1.

The total moisture in the top 5 feet of soil is plotted over time in Figure 12 for 1996 and in Figure 13 for 1997. Leaf moisture potential (LMP) data for Maxxa was added to the 1996 data in an attempt to verify appropriate levels for future use. Unfortunately, the 1996 weather caused an irregular yield function for Maxxa, and about all that can be said is that if the LMP is maintained at about -12 bars, soil moisture will remain rather constant, as seen in treatment 3 (F_t = 0.85) on Figure 12. The best Maxxa yield in 1996 was from treatment 2 (F_t = 0.65), which had LMP's which averaged about -13 bars in June, gradually changing to -15 bars by the end of July, and reaching -19 bars one day in early August.

As mentioned earlier the maximum yield for Pima in 1996 occurred at F_t = 1.05, which is the same as treatment 4, and as can be seen in Figure 12, this would correspond to a soil moisture curve of gradually increasing wetness, but never reaching the stage of standing water as happened with treatments 5 & 6. The optimum yield from Pima in 1996 came from F_t = 0.73, which corresponds to a treatment somewhere between 2 & 3, and the soil moisture for such a treatment would show a gradual decline (very slight deficit irrigation).

In 1997, the soil moisture for treatment 3 decline slightly over time, as can be seen in Figure 13. The maximum yield for Pima in 1997 occurred at F_t =1.14, about halfway between treatments 4 and 5. The corresponding soil moisture levels are very similar to those for maximum Pima yield in 1996, i.e., gradually increasing moisture levels over time, but not overly wet. The optimum yield for Pima in 1997 occurred at F_t =0.75, which is treatment 6, and as can be seen in Figure 13, this treatment has a soil moisture which decreases over time, and can safely be labelled, deficit irrigation. The maximum yield for Maxxa in 1997 occurred about halfway between treatments 3 and 4, which corresponds to a constant soil moisture. The optimum yield on Maxxa occurs between treatments 6 & 3 and is about the same as for optimum Pima yields, i.e., under slight deficit irrigation. Soil moisture data from the UC West Side Field Station for furrow-irrigated, heavy soils on the west side of

Fresno County, CA, (Howell et al., 1984) is shown in Figure 14. It is interesting to note that the overall trend is of slightly decreasing soil moisture over time, and this area is known for very high cotton yields.

Summary

The full-canopy pan coefficients ($100*F_t$) for maximum and optimum yield for both varieties of cotton are summarized in Table 1. Although the results are based on limited data, it seems very likely that if you want maximum yields on Pima S-7 on sandy soil, you'll need to apply enough water to cause a gradual increase in soil moisture, and this would require a full-canopy application equal to 110% of pan evaporation. If water is expensive and you want a shorter season, then use deficit irrigation with about 74% of pan evaporation. For Acala Maxxa, it appears that maximum yield would result from a full-canopy application of 94% of pan evaporation, which would hold the soil moisture constant; the optimum yield for Maxxa would occur with an application of about 80% of pan evaporation. Both the Maxxa and Pima have optimum yield under slight deficit irrigation. Holding the leaf moisture potential constant at -12 bars on Maxxa should lead to constant soil moisture and maximum yields in a normal year. Leaf moisture potentials of -13 bars in June and changing gradually to -15 bars by the end of July will correspond to a deficit irrigation. The effect of the irrigation treatment on earliness of cutout was the same for both Pima and Maxxa, with the cutout occurring 4 days earlier for each 10% reduction in the full-canopy pan coefficient. For Maxxa in 1997, the plants could have been defoliated 4.8 days earlier for each 10% decrease in the full-canopy pan coefficient. Holding the NAWF vs time to the UCCE normal for Maxxa corresponds to use of 95-100% of pan evaporation, and should produce near maximum yields. For Pima, the UCCE normal for the NAWF line corresponds to a slight deficit irrigation and optimum yields. Up through cutout, plant heights are directly proportional to total water applied after planting.

The term "optimum" as used above refers only to that balance between water savings and yield loss. There are some additional economic benefits to deficit irrigation, and these are: 1) fewer defoliations because of the smaller plants; 2) less PIX needed, again because of the smaller plants; 3) fewer insecticide applications, because of the shorter season (also smaller plants may be less attractive to some insects).

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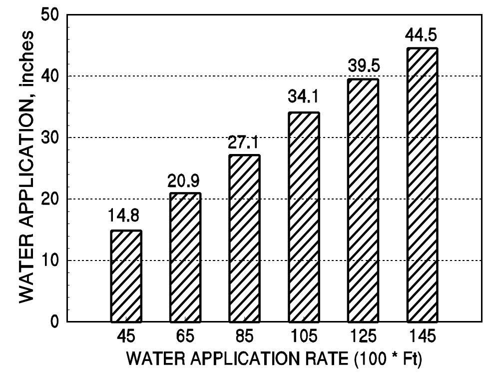

Figure 1. Depth of water applied after planting, in inches, for treatments 1 through 6 (l. to r.) in 1996.

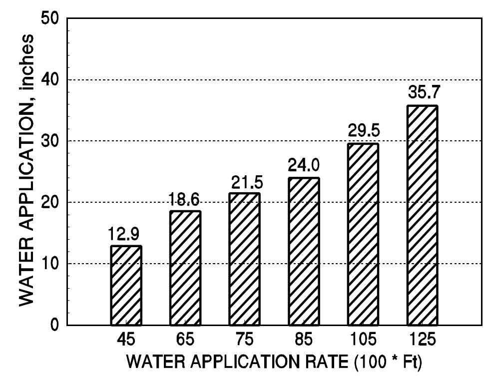

Figure 2. Depth of water applied after planting, in inches, for treatments 1,2,6,3,4 & 5 (l. to r.) respectively in 1997.

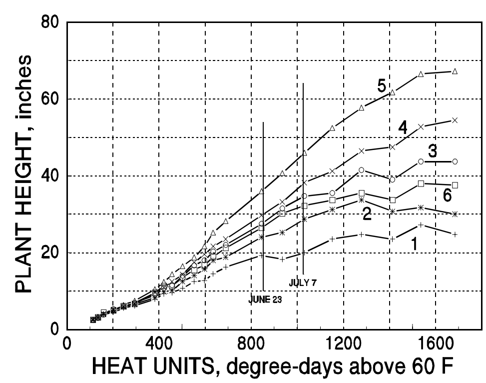

Figure 3. Plant heights vs heat units for various treatments with Acala Maxxa in 1997. Plant population: 51,000 ppa.

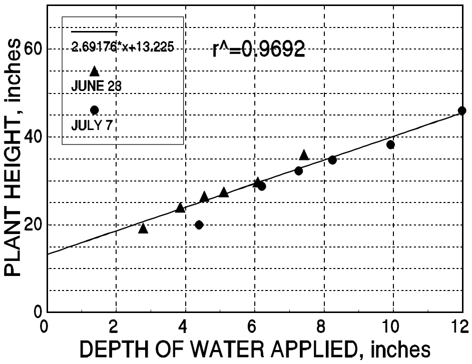

Figure 4. Plant height vs depth of water applied after planting for Acala Maxxa in 1997.

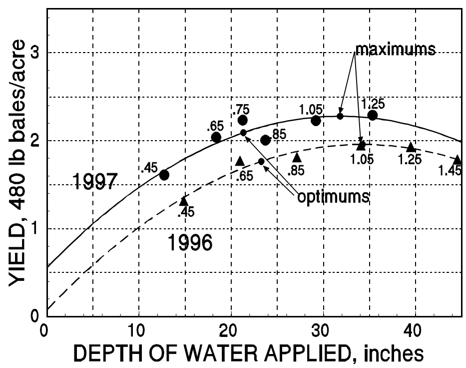

Figure 5. Water production function for Pima S-7 in 1996 and 1997. Yield vs total depth of water applied after planting. Numbers by markers are F_t, full-canopy pan coefficients.

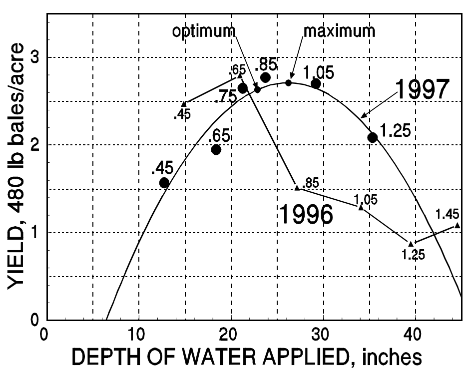

Figure 6. Water production function for Acala Maxxa 1996-1997. Yield vs total depth of water applied after planting. Numbers near markers are F_t, full-canopy pan coefficients.

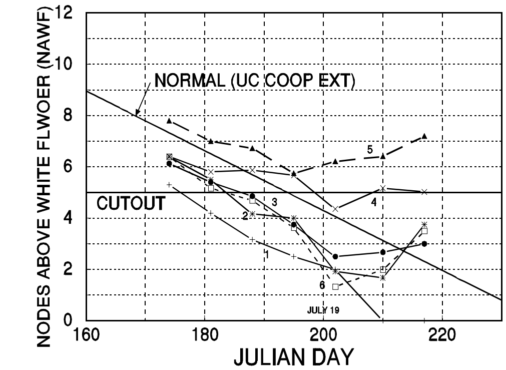

Figure 7. Nodes above white flower (NAWF) vs time for Acala Maxxa, 1997.

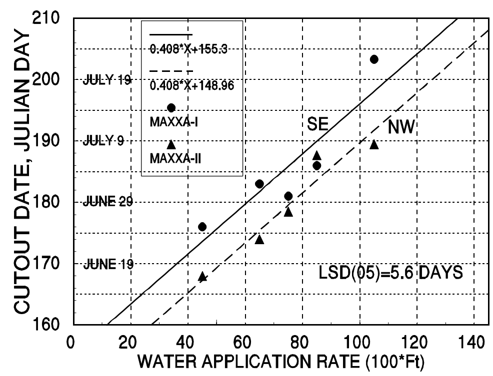

Figure 8. Cutout date as a function of irrigation treatment, Acala Maxxa, 1997.

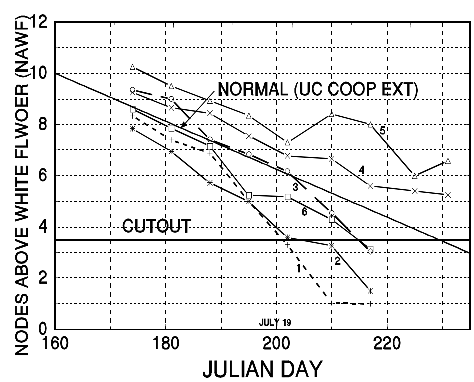

Figure 9. Nodes above white flower (NAWF) vs time, for Pima S-7 in 1997.

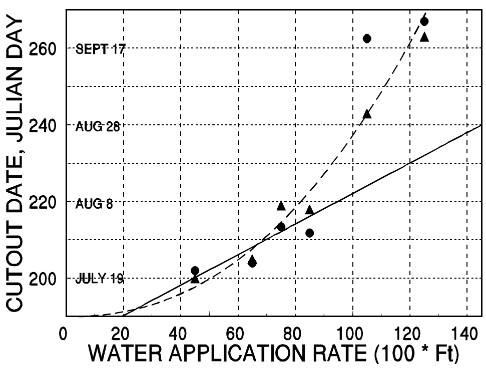

Figure 10. Cutout date as a function of irrigation treatment, for Pima S-7, 1997.

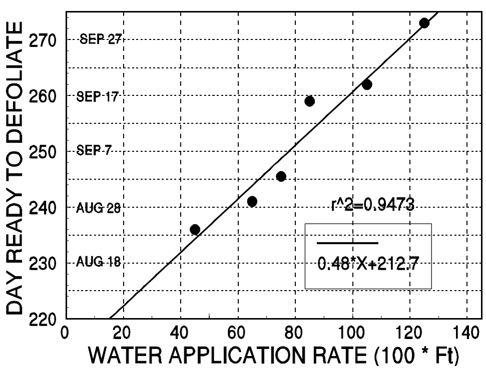

Figure 11. Julian day ready to defoliate as a function of irrigation treatment, Acala Maxxa, 1997.

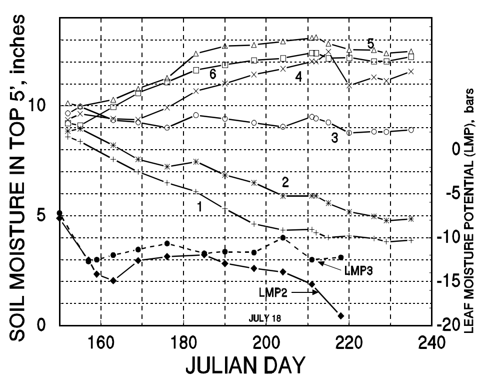

Figure 12. Moisture content of top 5 ft of soil and leaf moisture potential during the 1996 season.

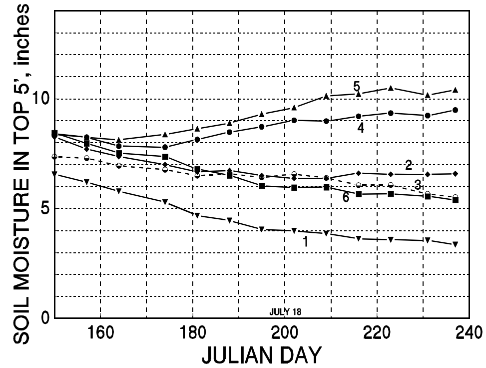

Figure 13. Moisture content of top 5 ft of soil during the 1997 season.

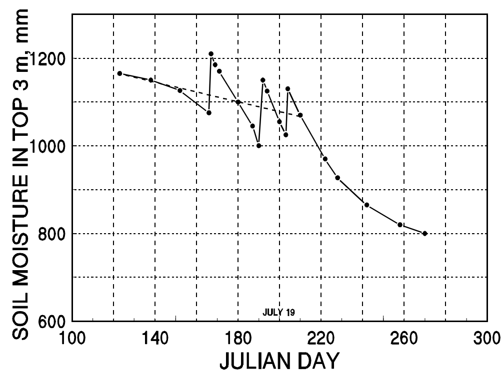

Figure 14. Soil moisture data from Howell et al., 1984. UC West Side Field Station. Furrow irrigated NR-FI trt.

Table 1. Full-canopy pan coefficients, $100*F_t$.

	For Maximum Yield	For Optimum Yield
Pima S-7	105 - 114%	73-75%
Acala Maxxa	93 - 95%	80%