# Timing Initial Post-plant Irrigation Based Upon Plant-Water Status

A.J. Steger, J.C. Silvertooth, and P.W. Brown

## *Abstract*

*A two year study was conducted to determine the optimum timing of the initial post-plant irrigation using leaf water potential (LWP) measurements. A short-season Upland cotton (Gossypium hirsutum L.), variety DPL 20, was planted on 19 April 1993 and 15 April 1994 at the Marana Agricultural Center on a Pima clay loam (Typic Torrifluvent) soil. Treatments, designated T1, T2, and T3, were such that the initial post-plant irrigation would be applied when the midday LWP of the uppermost, fully-developed leaf exposed to full sunlight measured -15, -19, and -23 bars, respectively. All treatments received the same irrigation regime following the initial post-plant irrigation. Basic plant measurements, including plant height, mainstem node number, fruit retention, number of nodes above the uppermost white bloom, fresh bloom count within a 166-ft² area, and percent canopy cover, were taken weekly from each plot. Soil-water data was collected at 10 inch depth increments, to a depth of 60 in., from access tubes located in each experimental unit. Yields were 1112, 1095, and 977 lbs lint/acre in 1993 and 1082, 1035, and 964 lbs lint/acre in 1994 for T1, T2, and T3, respectively. Yields were reduced when the midday LWP was allowed to fall below -19 bars, however, reduction was significant ($P \leq 0.05$) only in 1993. At the time of the initial post-plant irrigation for each treatment, approximately 83, 62, and 32% of the total plant available water was present in the upper 60 in. of the soil profile for T1, T2, and T3, respectively.*

## Introduction

Cotton (Gossypium spp.) is an important agricultural crop in the desert Southwest. Approximately 400,000 acres are planted annually to Pima (G. barbadense L.) and Upland (G. hirsutum L.) varieties in Arizona. Water is a critical limiting factor in agriculture. When input is controlled by irrigation, good management is required for optimum yield potential and production efficiencies.

Early season growth provides the initial framework for fruiting sites and is influenced by climatic conditions and soil moisture content. Timing the first post-plant irrigation is an important management decision that is dependent upon root and crop canopy development, soil water retention characteristics, and climatic conditions. Often there is variability in year-to-year spring weather conditions, such that timing irrigations in accordance with days after planting is difficult and may result in poor management.

Traditionally, growers in the Southwest have planted full-season cotton varieties in order to take advantage of the long growing season afforded by the climate and the general indeterminate nature of the crop. The initial post-plant irrigation is often delayed in an attempt to encourage deep rooting and control vegetative growth. For example, a common practice in the San Joaquin Valley of California has been to stress cotton to leaf water potentials (LWP) of -18 to -23 bars prior to the first irrigation (Johnson et al., 1989).

Short- and mid-season cotton varieties can shorten the active growing season by two to six weeks, thereby decreasing total production costs and potentially reducing late season insect problems. These varieties are of a more determinate nature with a more compact primary fruiting cycle. Yield can be significantly reduced if the crop is exposed to early season water stress. This is due to an apparent inability of the plant to recover and produce harvestable bolls later in the season (Johnson et al., 1989 and Brown et al., 1993).

Research experiments performed on cotton in Israel suggested that the first irrigation could be delayed until flower initiation as long as the water content of the root zone remained at or near 50% of the plant-available soil moisture (Levin and Shmueli, 1964). However, low yield was realized when the first irrigation was applied at residual moisture levels of 25% of the available soil water, followed with frequent irrigations later in the season. Plants exhibited excessive (rank) growth, a delay in peak flowering, boll shedding, low yield percentage at first pick, and a high percentage of green bolls at the end of the season.

Grimes et al. (1978) conducted a two-year field study in the San Joaquin Valley of California to determine the optimal timing of the initial post-plant irrigation using LWP measurements. Plants that were irrigated at LWP values of -13 bars experienced increased vegetative growth and a reduced number of open bolls later in the season, indicating a delay in maturity. Response was similar in the late treatment (LWP = -18 bars), except that stem elongation was reduced early in the season with more rapid vegetative growth occurring during the fruiting cycle when all treatments were being irrigated in a similar manner. Highest yields were observed when the initial post-plant irrigation was applied at a LWP = -16 bars.

The timing of the first post-plant irrigation and its impact on growth, fruiting, and yield in Upland cotton, variety DPL 61, were investigated by Guinn et al. (1981) in Arizona. The study was conducted for two years with slightly conflicting results. During the first year, delaying the irrigation until two weeks following the initiation of pinhead square, reduced plant height and delayed flowering. This also resulted in a shorter flowering period since plants went into cut-out sooner, contributing to increased earliness and a decreased number of fruiting sites. Yield, however, was significantly lower when the first irrigation was applied at the appearance of pinhead square. This was attributed to increased competition between leaves and bolls for available assimilates and to the higher percentage of damaged bolls due to insect feeding in the early treatment. Yields in the following year did not differ significantly between the two treatments, although there was a temporary increase in flowering rate with early season water deficit.

Maximum yields were obtained in three Acala varieties, SJ-2, SJC-1, and GC-510, when the first irrigation was applied at LWP of -15 bars in the San Joaquin Valley (Johnson et al., 1989), with all other irrigations managed similarly. Postponement until LWP of -19 and -23 bars resulted in significantly reduced yields. With continued plant water stress, the more determinate varieties, SJC-1 and GC-510, had a greater number of blooms early in the season resulting in early cut-out. First irrigations based on adjusted LWP, according to a climate-normalization technique (Grimes et al., 1987), resulted in a 300 lb. acre$^{-1}$ lint yield increase when compared with those based on actual LWP measurements. These adjustments in LWP values are based on air temperature and vapor pressure deficit (VPD) and are site specific.

The use of the pressure chamber for making initial post-plant irrigation decisions in short-season cotton was also evaluated by Brown et al. (1993) in Arizona. Yields were significantly reduced with Upland cotton, variety DPL 20, when irrigation was delayed until LWP was less than -19 bars. Plants in the late treatment (LWP = -23 bars) exhibited reduced node number, decreased height to node ratio (HNR), lower fruit retention, and early cut-out. This experiment served as a pilot study for the experiment described in this paper.

The objectives of the present study were: (1) to determine the optimum timing of the initial post-plant irrigation for a short-season Upland cotton using LWP measurements; (2) to evaluate the season-long effects of delayed irrigation on subsequent plant growth patterns; and (3) to identify the level and pattern of soil water extraction associated with the optimum timing identified in (1).

## Materials and Methods

A field experiment was conducted in 1993 and 1994 at the Marana Agricultural Center. The center is located 25 miles northwest of Tucson, at an elevation of approximately 1970 ft above sea level. The soil type is a Pima clay loam (Typic Torrifluvent).

Pre-plant irrigations of 6.0 and 9.6 acre-inches were applied on 1 April 1993 and 27 March 1994, respectively. Upland cotton (DPL 20) was planted with a 40 in. row spacing on 19 April 1993 and 15 April 1994. Heat unit (HU, 86/55 °F threshold), accumulation since 1 January for this location totaled 554 (1993) and 602 (1994) at planting. Treatments, designated T1, T2, and T3, consisted of applying the first post-plant irrigation when the midday LWP reached -15, -19, and -23 bars, respectively. All irrigation water was applied via furrow irrigation. The experimental design was a randomized complete block with four replications. Each plot (experimental unit) was eight, 40 in. rows wide, and extended the full length of the irrigation run (600 ft).

Leaf water potential was measured at midday (13:00 to 15:00 MST) on the uppermost, fully-developed leaf exposed to full sunlight. Daily measurements were made with a pressure chamber (PMS Model 600) from 31 May through 6 July 1993 and from 23 May through 30 June 1994. Leaves were covered with a damp cotton cloth, excised at the base of the petiole, placed in a plastic bag, and transported to the pressure chamber, located at the edge of the field immediately adjacent to the appropriate treatment. The leaf, still enclosed in a plastic bag, was placed into the chamber with the cut surface of the petiole exposed for observation. The sealed chamber was pressurized with $N_2$ gas until moisture appeared at the exposed surface. Time expended from sample excision to final measurement was two to four minutes depending on the level of plant water stress. Two leaves per experimental unit were sampled per day in both years.

Soil water content was monitored using a neutron moisture meter probe (CPN 503 DR Hydroprobe). Steel, two-inch diameter electrical conduit served as access tubes and were inserted to a depth of five ft. in one of the middle rows of each plot after planting. Three access tubes per plot were used in 1993 and two per plot in 1994. Neutron probe readings were taken prior to initiating treatments, on 17 May, 25 May, and 1 June 1993, and on 23 May and 28 May 1994. Subsequent readings were made one day before and five to six days following an irrigation event during both years. Readings were taken at depths of 60, 50, 40, 30, 20, 10, and 6 in. in each access tube. The soil water measurements were used to evaluate the treatment responses but not to schedule irrigations.

Field capacity (FC) and permanent wilting point (PWP) were determined at opportune times during the two years of the study. FC of the soil profile was estimated by determining the volumetric water content ($\Theta v$) with the neutron probe five days following the 1994 pre-plant irrigation. Measurement of PWP was estimated from neutron probe readings taken after harvest in 1993, when the soil profile was essentially depleted of available water. Table 1 shows $\Theta v$ at the two extremes and plant available water (FC-PWP) in the upper 60 in. of the soil profile. Total plant available water in the 60 in. profile at FC was approximately 7.6 in.

Basic plant measurements were taken weekly from each experimental unit from 24 May until 4 August 1993 and 24 May through 1 September 1994. These included plant height, number of mainstem nodes, location of first fruiting branch, fruit retention at the first two positions on each fruiting branch, number of nodes above the uppermost white bloom (NAWB), fresh bloom count in a 166-$ft^2$ area, and percent canopy closure.

The final irrigation of 5.0 acre-inches was applied on 11 August 1993 and 9 August 1994. The field study was defoliated on 20 September 1993 and 19 September 1994. The entire center four rows of each plot were harvested with a mechanical two row picker on 11 October 1993 and 4 October 1994.

## Results

Measured midday LWP values decreased with increasing plant water stress in both years (Figures 1 and 2). Treatment 1 received the initial post-plant irrigation on 4 June 1993 and on 29 May 1994. The measured LWP value was approaching -15 bars. The plant growth stage was matchhead square (900 heat units after planting (HUAP)) in 1993 and pinhead square (711 HUAP) in 1994. Immediately following irrigation, LWP of T1 increased to greater than -10 bars in 1993. This may have been due in part to the arrival of abnormally cool weather, which lowered evaporative demand, rather than as a result of increased soil water availability as LWP of both T2 and T3 increased also during that same period in 1993 (Figure 1). Leaf water potential increased to -12 bars in T1 following irrigation in 1994. The LWP in T2 and T3 remained below -15 bars indicating continued plant water deficit (Figure 2).

Plants in T2 were irrigated on 18 June 1993 and 10 June 1994 when LWP reached -19 bars, which corresponded to the very early stages of the crop's bloom period in 1993. A second irrigation was applied to T1 plots following irrigation of T2 to prevent water stress in both years. On 29 June 1993 and 25 June 1994, when the entire study was in early bloom, T3 plants were irrigated. Measured LWP values for T3 plots had reached an average level of -22 bars in 1993. Levels in 1994 had exceeded -19 bars in both T1 and T2 with midday potentials measuring -23 bars in T3 (Figure 2). The T1 and T2 plots also received an irrigation with the T3 irrigation in both years.

Following the application of water, LWP in all three treatments increased to greater than -15 bars, with T1 and T2 recovering more than T3. All subsequent irrigations were made on a common basis for all treatments. Total irrigation inputs for the three treatments for both years are given in Table 2. Total monthly precipitation from 1 January until defoliation is given in Table 3. Precipitation during January and February was lower in 1994 when compared with 1993, consequently, the pre-plant irrigation was greater in order to adequately refill the soil profile.

Height-node ratios (HNR) of T1 and T2 plants were at or above the established upper threshold for DPL 20 throughout the 1993 growing season (Figure 3), while the HNRs for T3 remained close to the expected baseline. High HNRs also directly reflect low fruit retention levels. Fruit retention levels were low in all treatments throughout the growing season, in part due to season long insect pressure from lygus bug (Lygus hesperus) (Figure 4).

HNRs in 1994 followed a similar response curve except that T3 plots remained below the expected baseline following peak bloom (HUAP 1750)(Figure 5). This could be an indication of a move towards early cut-out in the T3 plots. Cut-out occurred in all the treatments at approximately 2500 HUAP as illustrated by the HNR response. This was followed by an increase in HNR when the plants began to show renewed top growth. However, fruit retention remained below the expected baseline in all treatments following peak bloom (Figure 6). This was partially due to insect pressure from lygus bug.

Plant available water (in. water/60in.profile) and percent of total plant available water one day prior to the initial post-plant irrigation for each treatment is given in Table 4. Approximately 83% of the total plant available water was present in the upper 60 inches of the soil profile when T1 received its initial post-plant irrigation. The soil in the T2 plots contained 59 and 65% of the total available water in 1993 and 1994, respectively. The soil in the plots receiving the highest level of stress, T3 (LWP = -23 bars) contained 35% (1993) and 28% (1994) of the total available water in the measured profile.

Total water use (inches) per measured soil layer (inches) at the time of the initial post-plant irrigation is given in Table 5. Water use increased with increased exposure to stress and the roots extracted water from deeper in the soil profile. In T2 and T3, approximately 68% of the total water uptake was extracted from the upper 30 inches of the profile. Water extraction patterns from the root zone by T1, T2, and T3, at the time of the initial post-plant irrigation, are illustrated in Figure 7 (1993) and Figure 8 (1994).

Yields were 1112, 1095, and 977 lbs lint/acre in 1993 and 1082, 1035, and 964 lbs lint/acre in 1994 for T1, T2,

and T3, respectively (Table 6). Yields were reduced when the midday LWP was allowed to fall below -19 bars. However, reduction was significant ($P \leq 0.05$) only in 1993, when results were highly significant statistically with an observed significance level (OSL) = 0.0014 and a very low level of variability (CV = 2.82%). A comparison of lint yields vs. measured leaf water potential values at first post-plant irrigation for 1992 (Brown et al.,1992), 1993, and 1994 (Figure 9) shows a consistent trend towards reduced yields with increasing plant water stress.

## Conclusions

When the first post-plant irrigation was applied at LWP = -15 bars, the plants produced adequate yield, but exhibited increased vegetative growth. The HNR was reduced without a significant decrease in yield when the irrigation was applied at -19 bars. Delaying the first irrigation (LWP = -23 bars) and allowing the plants to experience early season water stress resulted in reduced yields. There was an alteration in the vegetative/reproductive balance and an apparent inability to recover from early season water stress. In addition, plants showed an acceleration towards maturity, as demonstrated by a lower HNR following peak bloom in both years, and a reduced number of fruiting sites. There was an indication of renewed top growth in all treatments following cut-out, however, these squares did not contribute to yield. The significant decrease in yield for T3 (1993) indicates that the timing of the initial post-plant irrigation has a season-long effect on the yield potential of the crop.

There was some year-to-year variability in climatic conditions which resulted in variation in the timing of initial post-plant irrigations and the soil water extraction patterns among the three treatments. This clearly supports the need to base irrigation timing on plant and soil water status rather than days after planting. The study should be repeated at other locations using mid-season Upland varieties and Pima cotton (G. barbadense L.)

## References


Brown, P., J. Silvertooth, and J. Malcuit. 1993. Evaluation of the pressure chamber for timing early season irrigations. 1993 Cotton Report. Series P-94,pp.181-187. College of Agriculture. University of Arizona.

Grimes, D.W., W.L. Dickens, and H. Yamada. 1978. Early season water management for cotton. Agron. J;. 70:1009-1012.

Grimes, D.W., H. Yamada, and S.W. Hughes. 1987. Climate-normalized cotton leaf water potentials for irrigation scheduling. Agric. Water Mgmt. 12:293-304.

Guinn, G., J.R. Mauney, and K.E. Fry. 1981. Irrigation scheduling and plant population effects on growth, bloom rates, boll abscission, and yield of cotton. Agron. J. 73:529-534.

Johnson, S.R., T.A. Kerby, and D.W. Grimes. 1989. To stress or not to stress-irrigating cotton for maximum yield. In: Proceedings of the 1989 Beltwide Cotton Research and Production Conference, Nashville, TN. pp.525-527.

Levin I. and E. Shmueli. 1964. The response of cotton to various irrigation regimes in the Hula Valley. Israel J. Agric. Res. 14 (4):211-225.

Table 1. Volumetric soil water content (Θv) at field capacity (FC) and permanent wilting point (PWP) in the upper 60 in. of the soil profile. Irrigation Timing Experiment. Marana, Az.

| | Θv (in.$^3$water/in.$^3$soil) | | Plant Available Water (in. water/60 in. soil) |
|---|---|---|---|
| Depth (in.) | FC | PWP | |
| 6 | 0.25 | 0.11 | 0.7 |
| 10 | 0.27 | 0.13 | 1.4 |
| 20 | 0.26 | 0.12 | 1.4 |
| 30 | 0.23 | 0.11 | 1.2 |
| 40 | 0.21 | 0.09 | 1.2 |
| 50 | 0.18 | 0.07 | 1.1 |
| 60 | 0.18 | 0.06 | 0.6 |

Table 2. Irrigation dates and irrigation input amounts(inches) for T1,T2,and T3 (LWP = -15, -19, and -23 bars).
Irrigation Timing Experiment. Marana, AZ.

| | 1993 | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 4/01 | 6.0 | 6.0 | 6.0 |
| 6/04 | 4.0 | . | . |
| 6/18 | . | 4.0 | . |
| 6/22 | 2.0 | . | . |
| 6/29 | 4.4 | 4.4 | 4.4 |
| 7/15 | 3.6 | 3.6 | 3.6 |
| 7/30 | 3.6 | 3.6 | 3.6 |
| 8/11 | 4.8 | 4.8 | 4.8 |
| **Total** | **28.4 in.** | **26.4 in.** | **22.4 in.** |

| | 1994 | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 3/27 | 9.6 | 9.6 | 9.6 |
| 5/29 | 2.5 | . | . |
| 6/10 | . | 2.5 | . |
| 6/16 | 2.5 | . | . |
| 6/25 | 5.4 | 5.4 | 5.4 |
| 7/12 | 4.8 | 4.8 | 4.8 |
| 7/26 | 4.8 | 4.8 | 4.8 |
| 8/09 | 4.8 | 4.8 | 4.8 |
| **Total** | **34.4 in.** | **31.9 in.** | **29.4 in.** |

Table 3. Total monthly precipitation (inches) from 1 Jan until defoliation. Irrigation Timing Experiment. Marana, Az.

| | 1993 | 1994 |
|---|---|---|
| January | 5.67 | 0.04 |
| February | 1.73 | 2.13 |
| March | 0.83 | 0.83 |
| April | 0.00 | 0.32 |
| May | 0.32 | 0.12 |
| June | 0.00 | 0.00 |
| July | 0.08 | 0.36 |
| August | 4.45 | 2.92 |
| September | 0.39 | 0.94 |
| **Total** | **13.47 in.** | **7.66 in.** |

Table 4. Plant available water(in.) in the upper 60 in. of the soil profile and the percent of total plant available water for each treatment at the time of the initial post-plant irrigation.
Irrigation Timing Experiment. Marana, Az.

**1993**

| Treatment | Plant Available Water (in.) | % Total |
|---|---|---|
| T1 (6/04) | 6.5 | 86 |
| T2 (6/18) | 4.5 | 59 |
| T3 (6/28) | 2.7 | 35 |

**1994**

| Treatment | Plant Available Water (in.) | % Total |
|---|---|---|
| T1 (5/29) | 6.2 | 81 |
| T2 (6/10) | 4.9 | 65 |
| T3 (6/25) | 2.1 | 28 |

Table 5. Total water use (in.) per measured soil layer (in.) at the time of the initial post-plant irrigation for T1, T2, and T3. Irrigation Timing Experiment. Marana, Az.

| | | 1993 | |
|---|---|---|---|
| Depth(in.) | T1 6/08¶(900)§ | T2 6/18¶(1224)§ | T3 6/29¶(1477)§ |
| 6 | 0.39 | 0.41 | 0.63 |
| 10 | 0.45 | 0.71 | 0.86 |
| 20 | 0.23 | 0.70 | 0.90 |
| 30 | 0.01 | 0.69 | 0.93 |
| 40 | 0.12 | 0.44 | 0.91 |
| 50 | 0 | 0.31 | 0.54 |
| 60 | 0 | 0.23 | 0.14 |
| **Total** | **1.2** | **3.49** | **4.91** |
| | | **1994** | |
| Depth(in.) | T1 5/29¶(711)§ | T2 6/10¶(1020)§ | T3 6/25¶(1417)§ |
| 6 | 0.44 | 0.47 | 0.57 |
| 10 | 0.60 | 0.74 | 1.02 |
| 20 | 0.23 | 0.52 | 1.09 |
| 30 | 0.11 | 0.28 | 1.15 |
| 40 | 0.26 | 0.40 | 0.94 |
| 50 | 0 | 0.31 | 0.53 |
| 60 | 0 | 0.20 | 0.21 |
| **Total** | **1.64** | **2.92** | **5.54** |

¶ Date of initial post-plant irrigation
§ HUAP on date of T1, T2, and T3

Table 6. Yield (lbs. lint/acre) for T1, T2, and T3. Irrigation Timing Experiment. Marana AZ.

| | 1993 | 1994 |
|---|---|---|
| Treatment | | |
| 1 | 1112 a* | 1082 a |
| 2 | 1095 a | 1035 a |
| 3 | 977 b | 964 a |
| $LSD_{0.05}$ | 52 | NS |
| OSL[¶] | 0.0014 | 0.0981 |
| CV(%)[§] | 2.82 | 6.15 |

¶ OSL Observed Significance Level
§ CV Coefficient of Variation
* Means followed by same letter are not significantly different

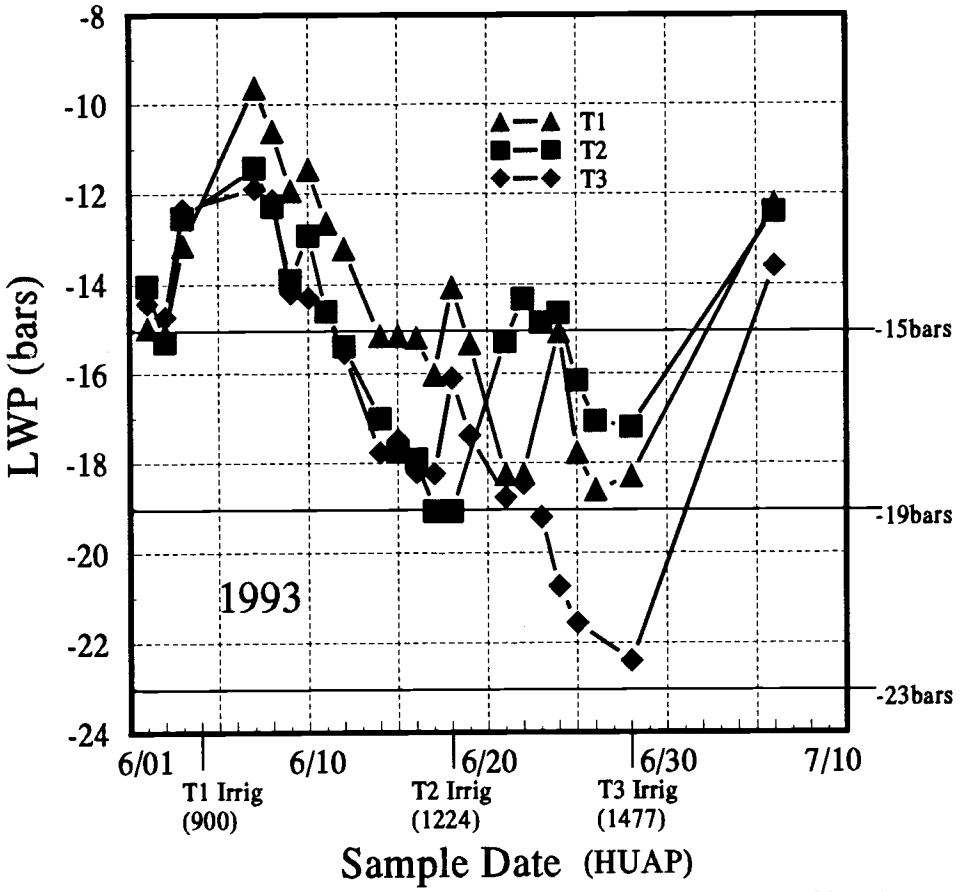


Figure 1. Mean values of LWP for T1(-15bars), T2(-19bars), and T3(-23bars) from 1 June until 9 July. Irrigation Timing Experiment Marana AZ.

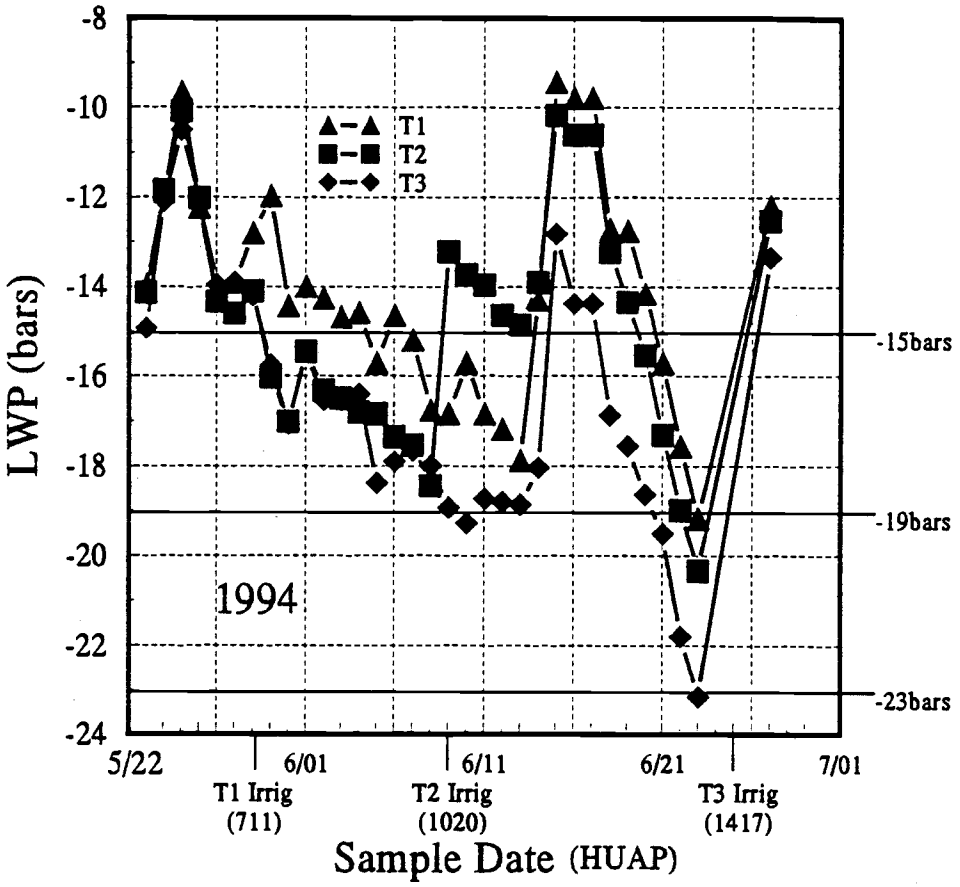


Figure 2. Mean LWP values for T1(-15bars), T2(-19bars), and T3(-23bars) from 23 May until 30 June. Irrigation Timing Experiment Marana AZ.

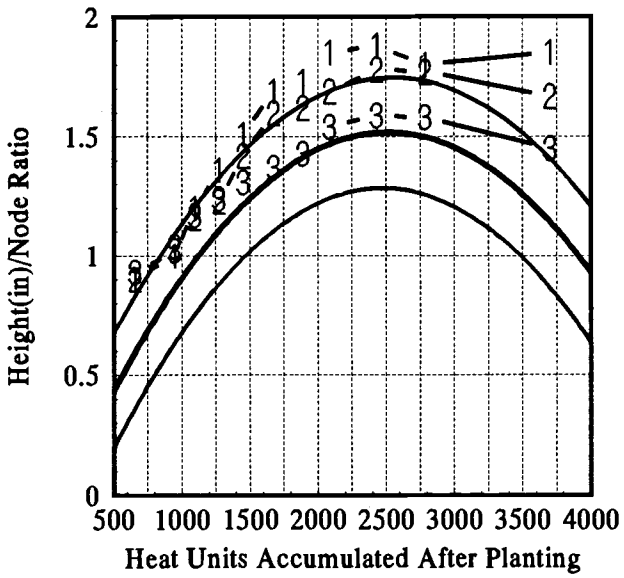


Figure 3. Height/Node ratios vs. HUAP 1993
T1(1), T2(2), and T3(3)
Irrigation Timing Experiment Marana AZ.

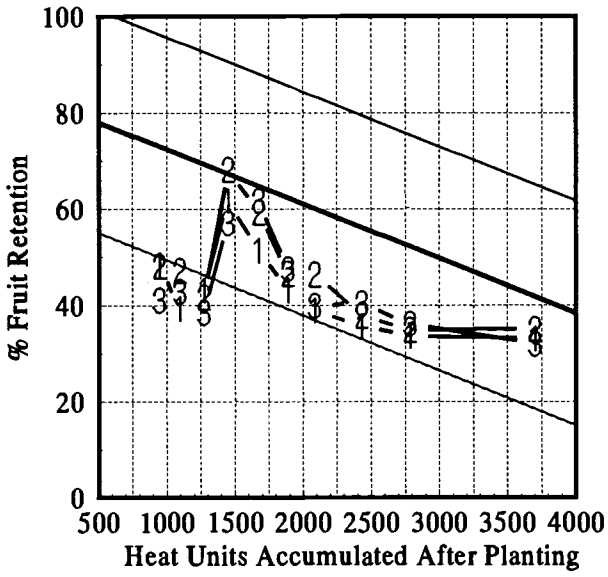


Figure 4. Fruit Retention vs. HUAP 1993
T1(1), T2(2), and T3(3)
Irrigation Timing Experiment Marana AZ.

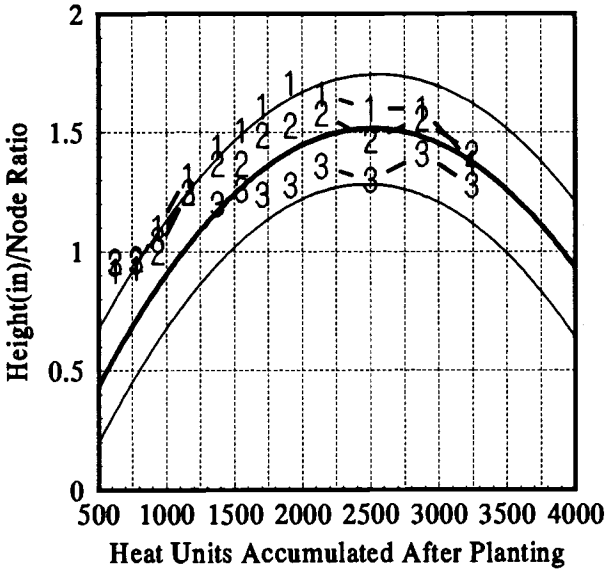


Figure 5. Height/Node ratios vs. HUAP 1994
T1(1), T2(2), and T3(3)
Irrigation Timing Experiment Marana AZ.

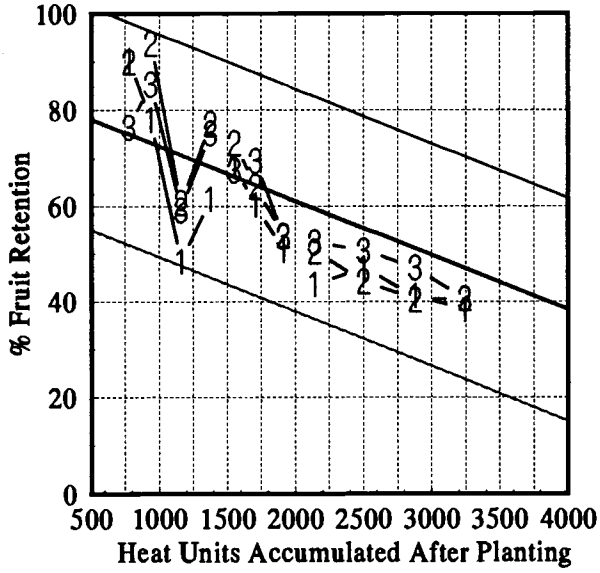


Figure 6. Fruit Retention vs. HUAP 1994
T1(1), T2(2), and T3(3)
Irrigation Timing Experiment Marana AZ.

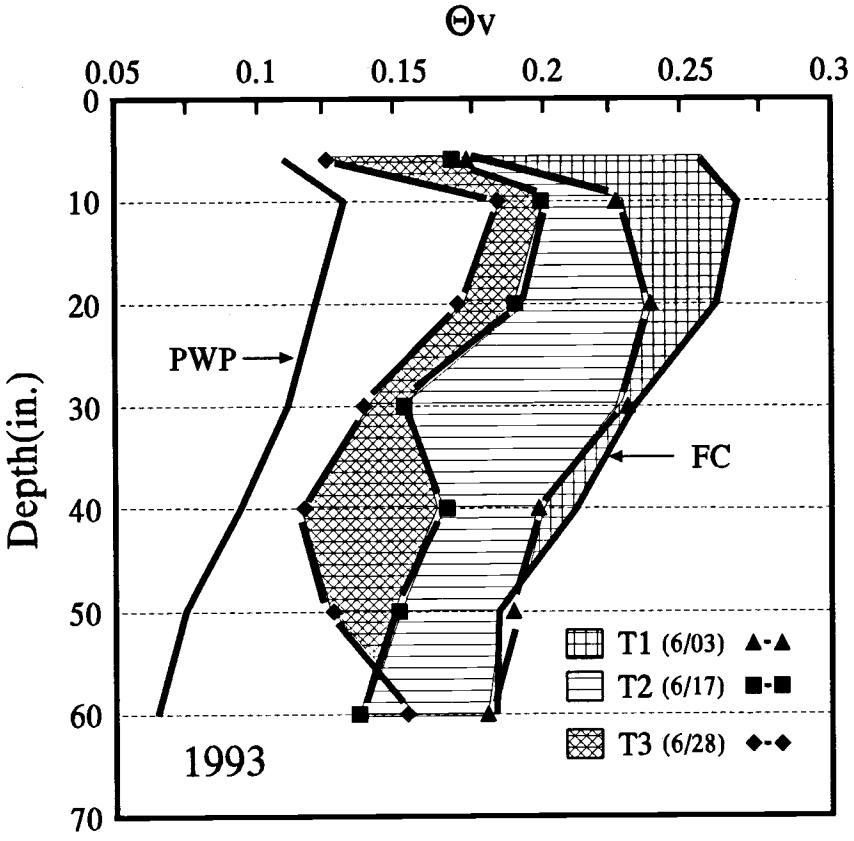


Figure 7. Plant available water and extraction patterns in the upper 60 in. of the soil profile at the initial post-plant irrigation for T1(6/03), T2(6/17), and T3(6/28). Irrigation Timing Experiment Marana AZ.

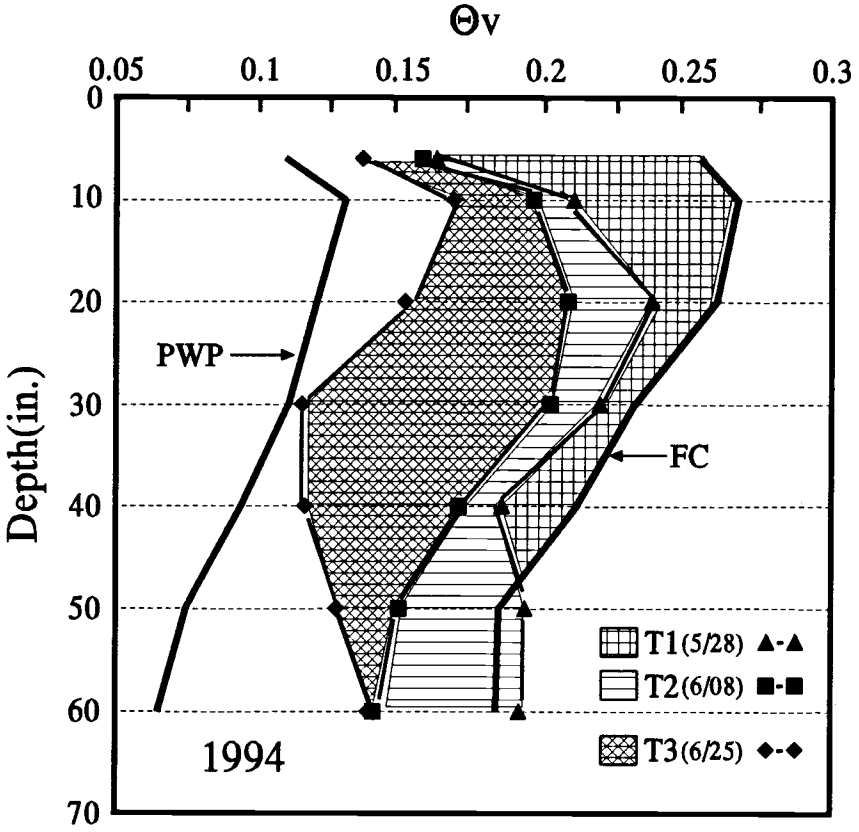


Figure 8. Plant available water and extraction patterns in the upper 60 in. of the soil profile at the initial post-plant irrigation for T1(5/28), T2(6/08), and T3(6/25). Irrigation Timing Experiment Marana AZ.

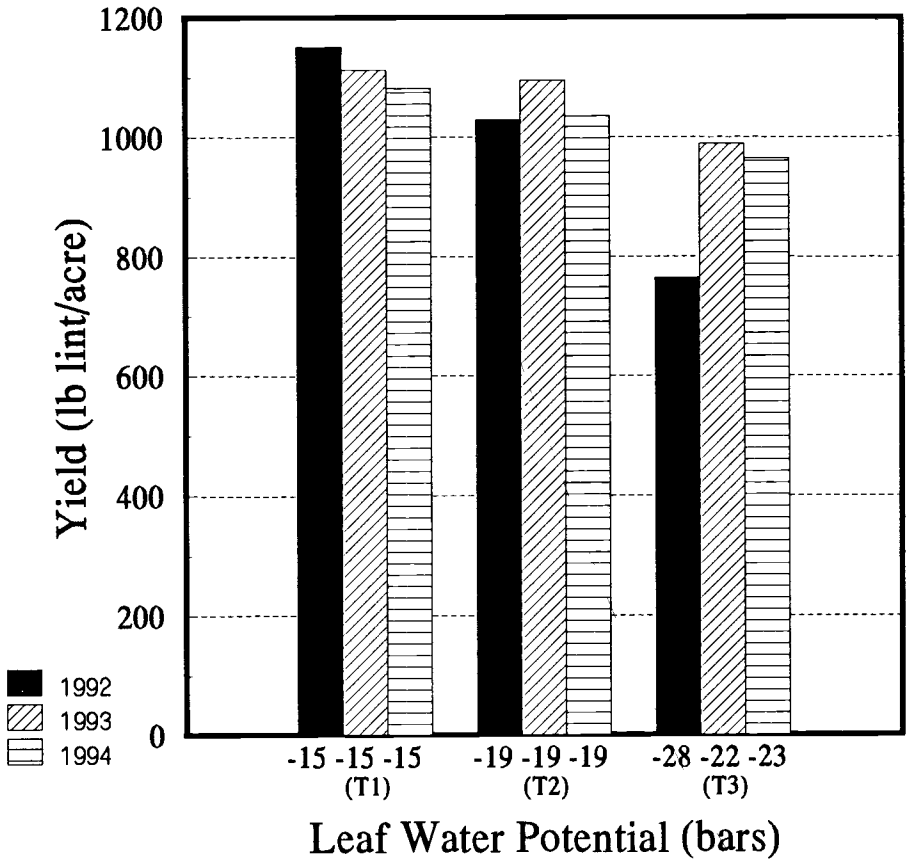


Figure 9. Lint yield vs. measured LWP values
1992 (Brown et al.), 1993, and 1994
Irrigation Timing Experiment Marana,AZ