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WATER USE COMPARISON OF LONG AND MEDIUM MATURITY COTTON IN THE SAN JOAQUIN VALLEY

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Abstract

The San Joaquin Valley produces upwards of 100,000 ha or 85 to 90 percent of the U.S. Pima cotton, *Gossypium barbadense,* crop. Although it typically produces lower yields than the Upland *Gossypium hirsutum* cultivar, the Pima cultivar has extra-long staple cotton, which is prized for its high quality, and the cultivar is adapted for most cotton producing regions of the world. The active vegetative growth period of commonly grown Pima cultivars exceeds that of Upland by 10 to 21 days, while a similar extension of the fruit maturity period has been observed. We studied the extended vegetative growth period to observe any influence on seasonal crop water use patterns. During this three-year study we made plant canopy measurements and monitored crop evapotranspiration (ET_c) throughout the growing season in grower fields. While similar water management approaches were employed between fields each year of the study, year-to-year differences in grower water management practices appear to have influenced annual differences in ET_c. Increases in ET_c were observed for Pima cotton both early and again late in the season; however, midseason water use rates did not differ. The frequency and volume of irrigation water applied was at least as important to seasonal crop water use as climate variation.

Introduction

Sharing water resources in the highly populated state of California is difficult when seeking a balance of issues related to urban, environmental, and agricultural needs. Recent state and federal legislation enacted has reduced agricultural deliveries to many water districts serving agricultural interests in the San Joaquin Valley where a wide variety of crops are grown. The San Joaquin Valley produces more than 350,000 ha of cotton annually and is recognized as a world leader in high quality cotton fiber. Since the early 1990's, Pima cotton *Gossypium barbadense,* has been grown with relative success with San Joaquin Valley cotton growers producing between 85 and 90% of the national crop. Pima cotton is known as a full-season cotton with indeterminate plant growth and an extended period of fruit set during the season. Because of the expense and scarcity of water for San Joaquin Valley crops, water and farm managers need to better understand water use patterns for each of these cotton types. To obtain the information, a three year study was conducted to compare crop evapotranspiration (ET_c) and crop coefficient (K_c) values for the two cultivars using the surface renewal (SR) and soil water depletion (SWD) methods. The results are discussed in this paper.

Materials and Methods

Studies were conducted during the 2000, 2001, and 2002 growth season in cotton fields located 16 and 8 km south of Five Points, California. The dormant soil type in the region is panoche clay loam with instruments located in large scale grass fields during the 2000 and 2001 season while 2002 data were collected at the University of California's West Side Research and Extension Center. Planting dates range from early March 29 to April 24. During each year, one field was planted to *Gossypium hirsutum* (Upland) cotton and the adjacent field to *Gossypium barbadense* (Pima) cotton.

The SR method to measure sensible heat flux density (H) was first proposed by Paw U and Brunet (1991) and later refined for field applications by Snyder et al. (1996) and Spano et al. (1997). The SR method uses fine-wire thermocouples to measure high frequency temperature fluctuations. Then H is determined using a structure function to identify ramp-like characteristics in the temperature traces. The method is explained in Paw U et al. (1995), Snyder et al. (1996) and Spano et al. (1997). The SR estimates of H were calibrated against 1-dimensional sonic anemometer measurements taken during several one week periods. When combined with measurements of net radiation (R_n) and soil heat flux density (G), the latent heat flux density (LE) was estimated using the energy balance equation:

$$LE = R_n - G - H \tag{1}$$

where E is the water vapor flux density in kg m^{-2} s^{-1} and L is the latent heat of vaporization ($L \approx 2.45 \times 10^6$ J kg^{-1}), so all variables in Eq. 1 are expressed in W m^{-2}. Dividing LE in W m^{-2} by L in J kg^{-1} gives an estimate of ET_c in mm.

Net radiation (R_n) was measured with a Q7.2 radiometer from REBS, Inc. mounted at about 1 m above the maximum canopy height. Soil heat flux density was measured at 0.04 m depth using heat flux plates (HMT3 from REBS, Inc) and averaging soil temperature sensors (TCAV from Campbell Scientific, Inc.) buried at 0.02 m deep to measure changes in store soil heat above the flux plates. High frequency temperature was measured using 76.2 µm diameter type-T fine-wire thermocouples (FW3 from Campbell Scientific, Inc.). For calibration, H was measured with a 1-dimensional sonic anemometer (CA27 from Campbell Scientific, Inc.).

The SR data were collected at 4 Hz, and time lags of 0.25 and 0.50 seconds were used with the structure function (Van Atta, 1977) to determine the temperature ramp amplitude and inverse ramp frequency. Then, H was calculated as

$$H = \alpha \rho C_p \left(\frac{a}{l+s} \right) z \tag{3}$$

The factor a is the mean ramp amplitude, l+s is the inverse ramp frequency, z is the measurement height above the ground, □ is the air density, C_p is the air heat capacity at constant pressure, and □ is a coefficient to correct for uneven heating of the air under the measurement height. In this experiment, □ was determined as the slope of a linear regression through the origin of H measured with a sonic anemometer versus H calculated using equation 3 and □ =1.0. Half hour values for LE were calculated as the residual in the energy balance equation (Eq. 1). The hourly average LE was calculated as the average of two half hour periods and it was divided by L to convert to mm h^{-1} of crop evapotranspiration (ET_c). The hourly ET_c values were summed over 24 hours to obtain daily ET_c.

Soil moisture depletion (SWD) measurements using a standard neutron scatter approach were used to estimate ET_c near the SR stations. At each of the two SR stations, seven neutron probe access tubes were installed to a depth of 2.4 meters and were calibrated using a range of soil moisture levels throughout the season to develop a standard calibration relationship between probe count and measured volumetric soil moisture. Readings were taken at 0.3 m intervals on a weekly basis unless irrigation was in progress. In the case of irrigation events, measurements were taken one to two days prior to the irrigation event and then again two to four days after the irrigation event once field capacity was again reached.

ET_c values were determined from SWD measurements using a volume balance approach. Water loss from the full soil profile was summed between soil moisture measurement dates to estimate the cumulative loss. The mean daily water loss was found by dividing by the number of days in the period. Crop water loss during irrigation events was assumed to be intermediate between the water loss during the period prior to irrigation and the water loss period immediately following the irrigation. Prior to the first measurements, soil water losses were estimated as 0.25 ET_o.

Crop coefficient (K_c) values were determined from ET_c estimates as:

$$K_c = \frac{ET_c}{ET_o} \tag{2}$$

where ET_o was estimated using the standardized EWRI-ASCE hourly Penman-Monteith equation (Walter et al., 2000) and data from the West Side Field Station near Five Points.

Results and Discussion

Figure 1 shows the daily ET_c calculations for both varieties during the 2001 season. Measurements started on May 19, so the ET_c values before that date were estimated using ET_c and a fixed K_c = 0.25, which was estimated from data in both seasons. Note that the ET_c was unseasonably high during May 2001. After measurements started, the ET_c values were higher for Pima until mid-August. The higher ET_c for Pima during the rapid growth phase was most likely due to the earlier planting date. Then the Pima ET_c dropped to quite low values during September and early August. During September, the Upland ET_c values remained considerably higher than Pima. It is believed that the Pima ET_c dropped due to water stress that hastened the onset of senescence. Visually, the Pima variety was clearly stressed, with wilting and a sparse canopy during the late season. The Upland variety was tall, dense and showed no signs of water stress.

In 2000, Pima developed quicker and had a denser canopy than Upland. As in 2001, Pima had higher ET_c rates during rapid growth and midseason in 2000. In the 2000 season, however, the ET_c for Pima did not drop as much during September 2000 (Figure 3) as it did in 2001 (Figure 2). It is believed that a high water table in 2000 led to a dense Pima canopy and high ET_c late in the season, whereas no water table and stopping irrigation too early led to lower Pima ET_c during late season in 2001.

Neutron probe depletion estimates show rapidly increasing ET_c values shortly after the 20th of June (Figure 3), and high values were maintained mid-July through mid-August before declining values were observed. In both the SR and SWD methods it was clear that ET_c declined at a faster pace in the Pima in comparison to the Upland cotton. This is likely evidence that soil water storage was declining at a faster rate in the Pima site due to an earlier irrigation termination date, a more restricted root zone, or a combination of the two factors. By September 12, both methods showed ET_c at levels at 1 to 3 mm per day in the Pima while the Upland site maintained a 4 to 5 mm per day water loss.

Both varieties had lower K_c values than are typically reported in the literature from California. This was especially true for the SR method (Figures 4-6). For example, DWR Bulletin 113-3 (1975) reports midseason K_c values as high as 1.31 for cotton. In the three years of experimentation, we rarely observed midseason $K_c > 1.10$ for either variety (Figures 4-6). The exception was for Pima during 2001, which showed higher Kc values immediately following irrigation that again dropped to $K_c < 1.00$ within a few days after irrigation (Figure 5). The *Kc* developed using SWD measurements found peak values in the 1.05 to 1.15 range with an average peak value of 1.1 (Figure 6), again well below Bulletin 113-3 values but slightly higher than the SR estimates.

Because the Pima field had a sparse canopy mid- and late-season during 2001, the wetted soil surface received considerable solar radiation during midseason. It also had a high net radiation immediately following irrigation. Crop coefficient values near 1.00 to 1.05 have also been observed using lysimeter measurements in Davis (T.C. Hsiao, personal communication).

Estimates of ET_c by both SR and SWD methods were similar with season total evapotranspiration similar for each approach (Figure 7). SWD measurements were lower than SR determinations early and late in the season, with mid-season crop ET estimates slightly higher than averages developed by the SR method. SWD errors caused by low neutron attenuation near the soil surface and moisture migration from the subsurface soil may explain low estimates early and late season, while drainage following irrigation events may be responsible for over-estimation of ET_c midseason. Both methods, however, did show similar trends throughout the season with similar cumulative total ET_c at season's end.

Regardless of the method used to estimate ET_c and K_c values for Pima and Upland cultivars, cumulative differences exist between the two species, though data peaks remained similar. The greatest likelihood for K_c to exceed 1.0 was between July 4 and August 10 with Upland estimates near 1.0 and Pima values slightly higher depending on the irrigation regime used. Peak K_c's for Pima rarely exceeded 1.0 in 2001.

Late-season water management practices by Pima cotton can have a particularly strong influence on the K_c and ET_c. Our data suggest late-season water management strategies greatly influence how the crop uses water, and while this may be useful in seasons in which a late-season crop set may contribute significantly to yield, reductions in late-season irrigation practices could be used some years without significant reductions in yield or quality.

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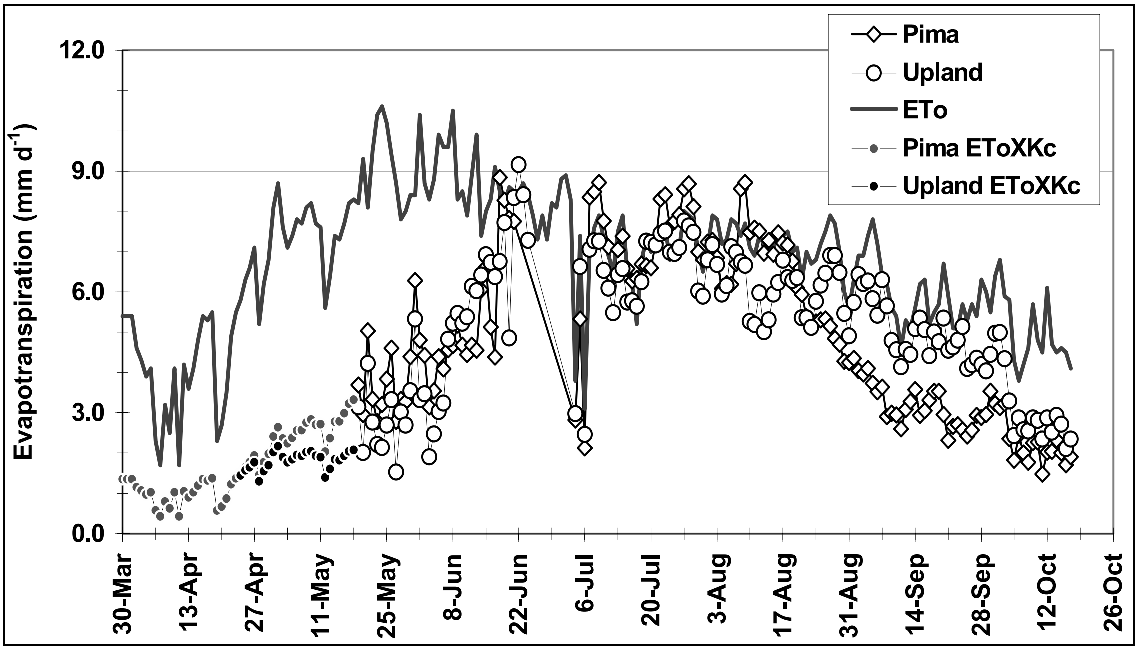

Figure 1. Daily ET_c and ET_o during the 2001 season from SR measurements. ET_c was calculated from ET_o and estimated K_c values before May 19.

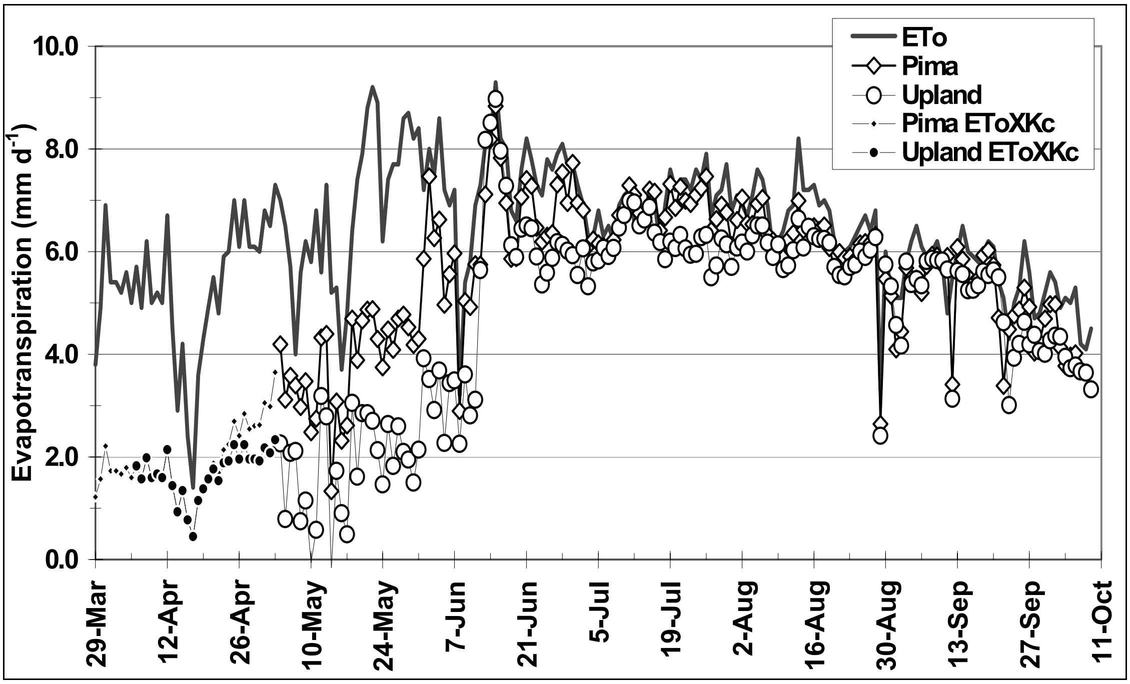

Figure 2. Daily ET_c and ET_o during the 2000 season from SR measurements. Daily ET_c was calculated from ET_o and K_c values before May 5.

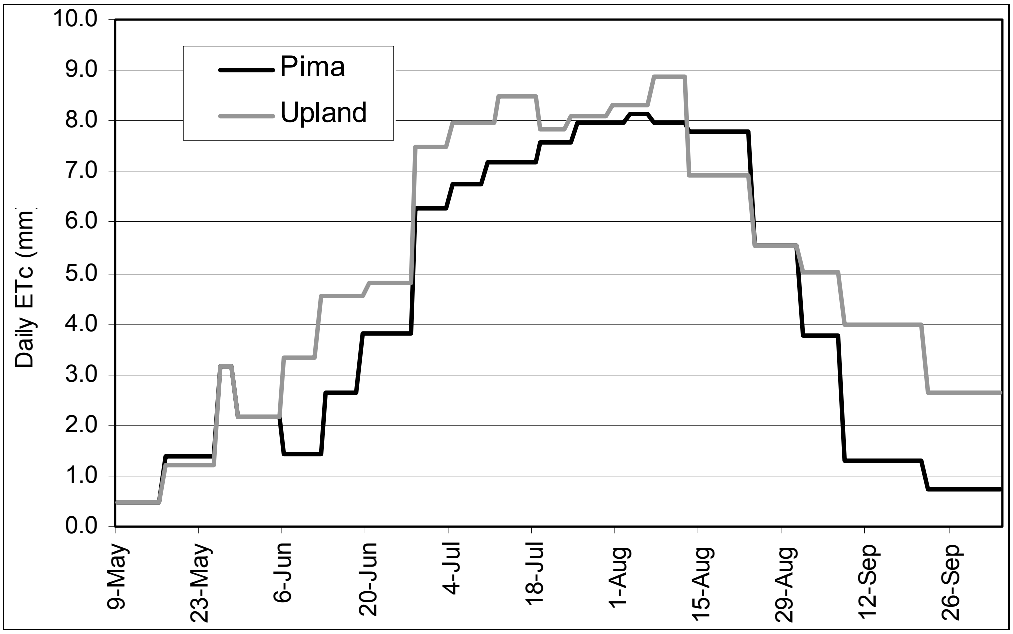

Figure 3. Plot of Daily ET_c for Pima and Upland cotton varieties from neutron probe data during the 2001 season.

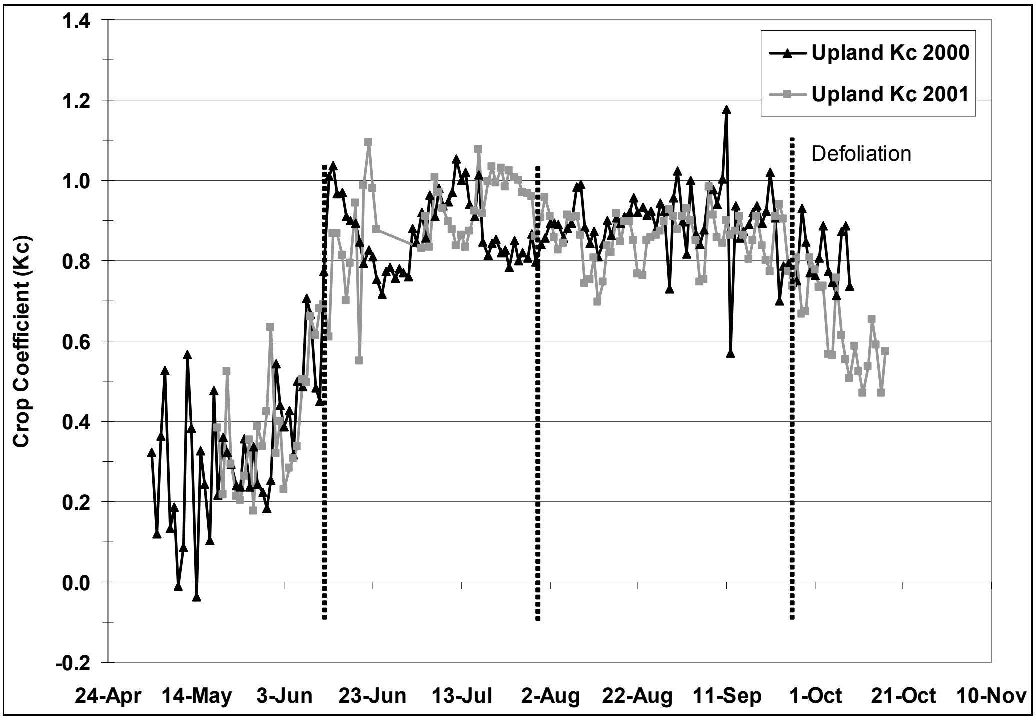

Figure 4. Crop coefficient (K_c) values for Upland variety in both 2000 and 2001 seasons.

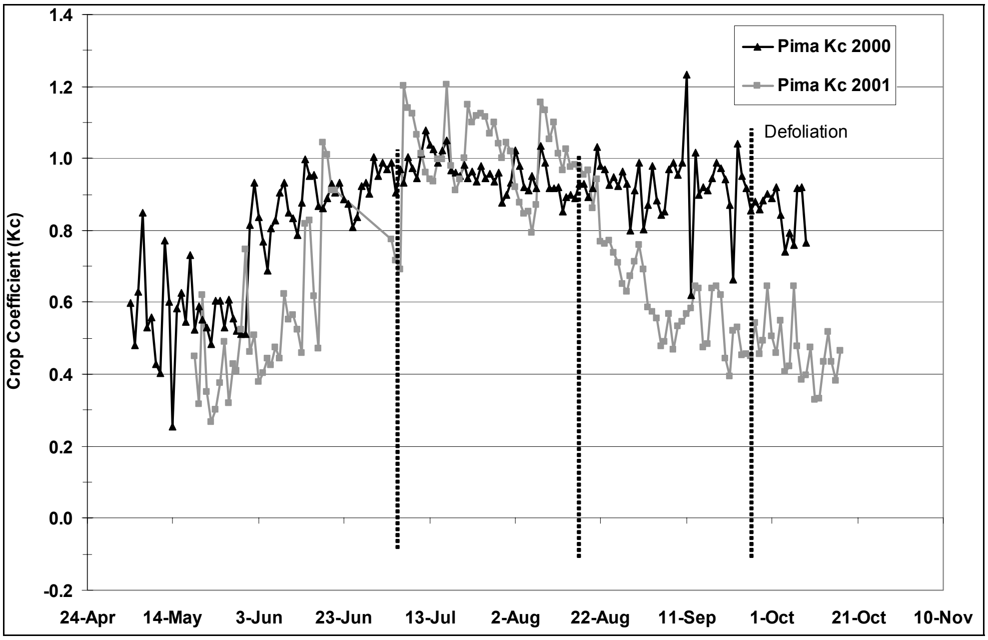

Figure 5. Crop coefficient (K_c) values for Pima variety during 2000 and 2001 seasons from SR measurements.

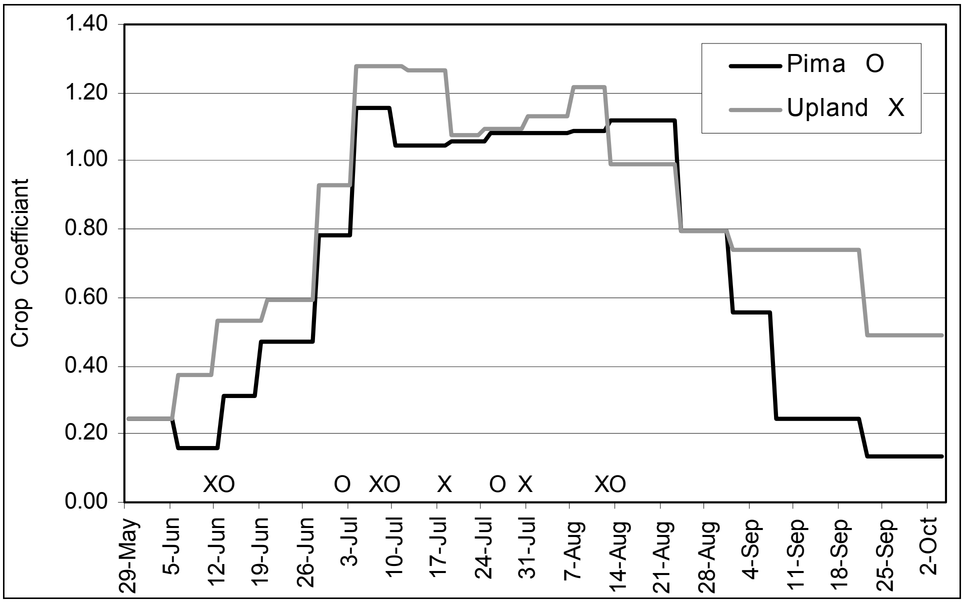

Figure 6. Crop coefficient (K_c) curves for Pima and Upland varieties in the 2001 season from neutron probe data. ‘O’ indicates Pima irrigations, ‘X’ indicates Upland irrigations.

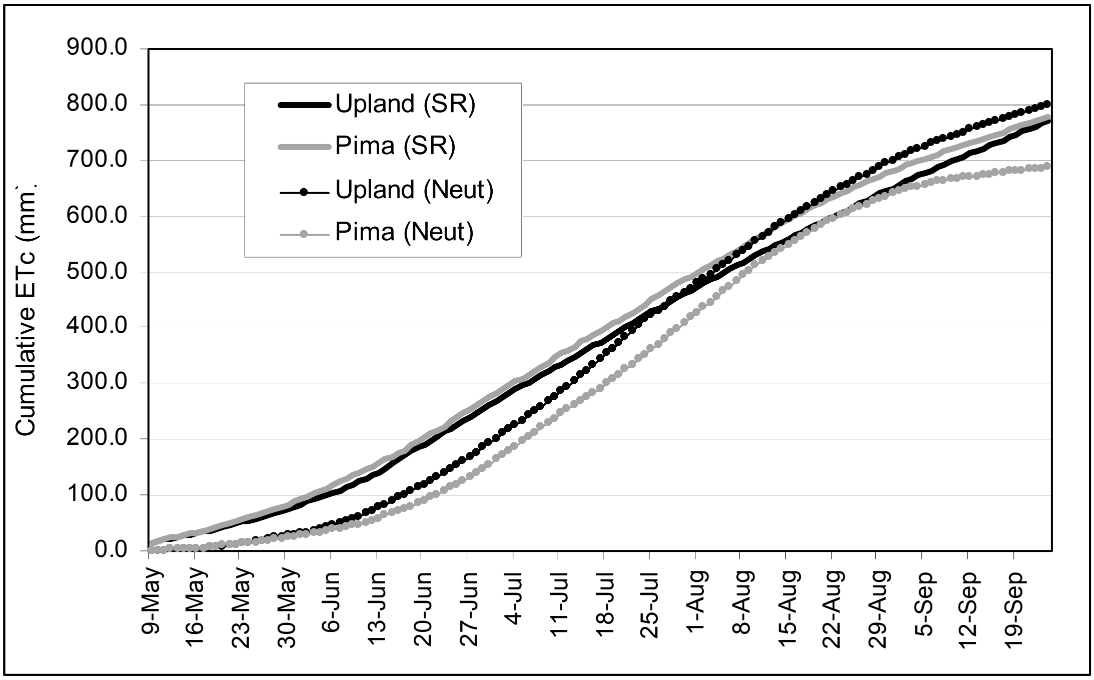

Figure 7. Cumulative (ET_c) average from the 2001 and 2002 seasons for Pima and Upland varieties. Surface Renewal (SR) and Neutron Probe (Neut) data are shown for comparison.