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# Evaluation and Demonstration of Evapotranspiration-Based Irrigation Controllers

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## *Abstract*

Irrigation systems need to become more efficient to minimize the use of limited water resources while maintaining landscapes of acceptable quality to consumers. This manuscript gives a preliminary report on the evaluation of three commercially available evapotranspiration (ET) based controllers in residential landscaped plots with respect to irrigation application and landscape quality compared to a homeowner irrigation schedule. The irrigation treatments were as follows: T1, Weathermatic Smart Line Series controller; T2, Toro Intelli-sense; T3, ETwater Smart Controller 100; T4, a time-based treatment; and T5, 60% of T4. This paper reports preliminary results from May 25, 2006 to November 30, 2006. T1 overestimated ETo by 32%, but applied less water than all other treatments during the summer season. Water savings occurred even though ETo was overestimated due to an underestimation of the crop coefficient for warm season turfgrass [0.85 in Allen et al. (1998)] programmed into the controller (0.60) and due to frequent irrigation event bypass during the rainy summer season. The Weathermatic controller applied 11% and 14% less water than the theoretical gross irrigation requirement during the summer and fall seasons, respectively. The Toro Intelli-sense controller applied 126 mm in the fall, which was 40% less than theoretical requirements, and had the most accurate ETo of all the controllers. The ETwater controller overestimated ETo by 7% and applied 63% more irrigation water than was required theoretically. During this preliminary testing, the ET controllers did not result in turf quality below acceptable levels.

## *Introduction*

Florida homeowners who utilize automatic timers for irrigation currently apply 47% more water for landscape irrigation than homeowners without automatic irrigation systems (Mayer et al., 1999). Also, Florida ranks first for the largest net gain in population and fourth in overall population in the United States from April 1, 2000 through July 1, 2006 (USCB, 2006). As a result, irrigation systems will need to become more efficient to minimize the use of increasingly limited water resources while maintaining landscapes of acceptable quality to consumers.

Commercially available irrigation controllers that use evapotranspiration (ET) data to apply the proper amount of irrigation water to a landscape are being used in western states. However, this technology has not been tested in a humid region such as Florida. Therefore, this study was designed to evaluate commercially available ET controllers relative to a homeowner irrigation schedule under Florida conditions. Potential irrigation savings are described by Berg et al. (2001) as the difference between actual outdoor water applied and what should have been applied taking weather into account. Water savings should not be at the expense of landscape quality.

Crop or plant ET (ETc) is the evaporation from the soil surface and the transpiration through plant canopies (Irmak and Haman, 2003). It is part of a balanced energy budget that exchanges energy for outgoing water at the surface of the plant. The components of the budget are net radiation primarily from solar radiation, various heat fluxes, and other climatic conditions. ETc can be calculated from reference ET (ETo) determined from the ASCE standardized reference ET equation (Allen et al., 2005) and a crop coefficient (Kc) which is based on the type of plant material, production environment, and maturity.

ET-based controllers are irrigation scheduling devices that consider weather-based parameters when determining irrigation events. Depending on the manufacturer, each controller functions differently but typically can be programmed with various conditions specific to the landscape. These conditions could include soil type, plant type, root depth, sun and shade, etc. There are three main types of controllers as follows: standalone, signal-based, and historical ET-based (USDOI, 2004).

Standalone controllers use sensors to measure weather parameters and then calculate ET based on these parameters. The sensors collect data readings anywhere from every second to every fifteen minutes, but ET used for irrigation purposes is the daily total. Onsite sensors could include: temperature, solar radiation, ET gauge, or even a full weather station (Riley, 2005).

Signal-based controllers utilize cellular or paging technology to receive ETo data. Weather data is gathered from publicly available weather stations near the controller location. ETo is calculated and sent to the controller directly. Depending on the manufacturer, the ET data can be from an average of multiple weather stations in the area or from a single weather station.

Historical-based controllers rely on historical ET information for the area. Typically, monthly historical ET is downloaded to the controller by the manufacturer or installer. This is not as efficient as other methods because it does not take into account actual changes in the weather. Attachments, such as temperature sensors, can be added to adjust monthly ET to daily ET. For example, if there is an unusually rainy or dry month, the controller will adjust for that difference from historical values.

The objective of this study was to evaluate landscape quality and the amount of irrigation applied by three commercially available ET-based controllers in residential landscape plots compared to a typical homeowner irrigation schedule under Florida conditions. This manuscript reports preliminary data from an ongoing project.

## *Materials and Methods*

This study was conducted at the University of Florida Gulf Coast Research and Education Center (GCREC) in Wimauma, Florida. There are a total of twenty 7.62 m x 12.2 m plots with 3.05 m buffer zones between plots (Fig.1). To represent a typical residential landscape, the plots consist of 65% St. Augustinegrass (*Stenotaphrum secundatum*) and 35% mixed ornamentals. The ornamentals are as follows: Cape Plumbago (*Plumbago auriculata)*, Crape Myrtle (*Lagerstroemia indica* 'Natchez'), Gold Mound Lantana (*Lantana camara* 'Gold Mound'), Big Blue Liriope (*Liriope muscari* 'Big Blue'), and Indian Hawthorne (*Raphiolepis indica*).

A shed houses the controllers and a manifold table that supports a flow meter and solenoid valve for each plot. The flow meters (11.4 cm V100 w/ Pulse Output, AMCO Water Metering Systems, Ocala, FL) are used to monitor irrigation water application. They are connected to five SDM-SW8A switch closure input modules (Campbell Scientific, Logan, UT) that in turn connect to a CR-10X data logger (Campbell Scientific, Logan, UT) for monitoring switch closures every 18.9 liters from the water meters. The data were also collected manually on a bi-weekly basis. Each plot contains an irrigation zone for the turfgrass and mixed ornamentals.

Irrigation sprinklers specified for the turfgrass portion of the plot consist of Rain Bird (Glendora, CA) 1806 15 cm pop up spray bodies that have Rain Bird R13-18 black rotary nozzles (Fig. 2). In each plot, there are four sprinklers with a 180 degree arc (R13-18H) and a center sprinkler with a 360 degree arc (R13-18F).

Time domain reflectometry (TDR) probes (Campbell Scientific, Inc., Logan, UT) were buried in turfgrass and mixed ornamental areas of each plot to monitor soil moisture in the 10 cm to 18 cm depth representing the root zone of St. Augustinegrass and the upper root zone of ornamentals. All plant material was delivered on March 20, 2006 and planted by March 22, 2006. Initially, water was applied for 30 minutes everyday to every zone during the first 60 days of establishment. Irrigation treatments were initiated on May 22, 2006.

The type of soil located at the project site was mapped as Zolfo fine sand (USDA SCS, 1989). According to the survey, Zolfo series is a sandy, siliceous, hyperthermic Grossarenic Entic Haplohumods, somewhat poorly drained. The field capacity (FC) and permanent wilting point (PWP) for Zolfo fine sand was determined from laboratory samples to be 13% and 3% (all soil moisture values here presented on a volumetric basis), respectively (Carlisle et al., 1985).

The ASCE standardized reference evapotranspiration equation was used to calculate ETo (Allen et al., 2005) as seen below.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T+273}(e_s - e_a)u_2}{\Delta + \gamma(1 + C_d u_2)} \tag{1}$$

Variables in this equation are defined as net radiation, $R_n$ (MJ/m$^2$/day); heat flux, G (MJ/m$^2$/day); vapor pressure, $\Delta$ (kPa/°C), $e_s$ (kPa), $e_a$ (kPa); temperature, T (°C); and wind speed, $u_2$ (m/s). The psychrometric constant, $\gamma$ (kPa/°C), can be obtained from the measured mean atmospheric pressure (Allen et al., 2005). Also, the standard reference crop is grass for Florida (Irmak and Haman, 2003). This results in constants $C_n$ and $C_d$ as 900 and 0.34, respectively (Allen et al., 2005).

Controllers that use just temperature or solar radiation sensors do not use the ASCE standardized ET equation to calculate ET. An example is the Hargreaves equation as follows:

$$ET_0 = 0.0023 R_A TD^{1/2}(T + 17.8) \tag{2}$$

where $R_A$ (MJ/m$^2$/day) is extraterrestrial radiation, TD (°C) is the difference between the mean monthly maximum temperature and the mean monthly minimum temperature, and T (°C) is the ambient air temperature (Jenson et al., 1990). This equation does not use all of the parameters that the ASCE standardized equation uses. Instead, it relies on solar radiation calculated from extraterrestrial radiation found in tables based on the site latitude (27°N for this site) and locally collected temperature information.

Plant ET can be calculated for a specific plant material by applying a crop coefficient (Kc), using the following equation:

$$ET_C = K_C * ET_0 \tag{3}$$

A daily soil water balance was used to calculate the theoretical turfgrass irrigation requirements for comparison with actual irrigation water applied. The balance is defined as:

$$\Delta S = Pe + I - ETc - D - RO = 0 \tag{4}$$

where $\Delta S$ (mm) is the change in soil water storage within the root zone, Pe (mm) is effective rainfall, I (mm) is irrigation depth, ETc (mm) is crop evapotranspiration, D (mm) is drainage, and RO (mm) is surface runoff (Fangmeier et al., 2006). Due to the flat topography and relatively high permeability on site (USDA SCS, 1989), it was assumed that there is negligible surface runoff and irrigation is scheduled so that, ideally, there is negligible drainage. The change in storage can also be considered negligible when considered on a weekly basis. These assumptions reduce equation 4 to the equation used to calculate the irrigation depth required:

$$I = ETc - Pe \tag{5}$$

Effective rainfall is the amount of rainfall that is stored in the root zone. The remainder of rainfall is considered runoff or drainage below the root zone. Rainfall that caused the soil water content to exceed field capacity was assumed to drain out of the root zone. The amount of water held in the root zone and available to the plant is called available water, AW. Available water (mm) was calculated from soil parameters using the equation:

$$AW = \frac{(FC - PWP) * RZ}{100} \tag{6}$$

where FC is the field capacity ($cm^3$ of water/$cm^3$ of soil), PWP is the permanent wilting point ($cm^3$ of water/$cm^3$ of soil), and RZ (mm) is the root zone depth (Irrigation Association, 2005). To prevent plant stress, available water should not be allowed to reach the PWP before irrigation is scheduled; irrigation should be applied when the water level drops by a percentage known as the maximum allowable depletion (MAD), chosen as 50% for warm season turfgrass (Allen et al., 1998). The amount of water allowed to be used before irrigation is required is called readily available water, RAW (mm), and is calculated using the following equation (Irrigation Association, 2005):

$$RAW = AW * MAD \tag{7}$$

The net irrigation depth to be applied is determined from the change in soil water level occurring due to ETc loss and effective rainfall. However, the theoretical gross irrigation depth is necessary to compare to the amount of water applied by the treatments. The gross irrigation depth is calculated from an efficiency factor ultimately determined from the low quarter distribution uniformity ($DU_{lq}$) of the system. The average low quarter distribution uniformity was assumed to be 67% for rotator sprinkler nozzles from Solomon et al. (2006) due to the unavailability of site-specific information. The low half distribution uniformity ($DU_{lh}$) was calculated using the equation:

$$DU_{lh} = 38.6 + 0.614 * DU_{lq} \tag{8}$$

which is then used to calculate the efficiency factor (E) using the equation:

$$E = \frac{100}{DU_{lh}} \tag{9}$$

The gross irrigation is calculated by multiplying the net irrigation depth by the efficiency factor, determined from (8) and (9) to be 1.25 (Irrigation Association, 2005).

Five treatments were established, T1 through T5, replicated four times for a total of twenty plots in a completely randomized block design (Fig. 1). The irrigation treatments are as follows: T1, Smart Line Series controller (Weathermatic, Inc., Dallas, TX); T2, Intelli-sense (Toro Company, Inc., Riverside, CA) formerly known as the Hydropoint WeatherTRAK; T3, Smart Controller 100 (ETwater Systems LCC, Corte Madera, CA); T4, a time-based treatment determined by UF-IFAS recommendations (Dukes and Haman, 2002); T5, a time-based treatment that is 60% of T4. All treatments utilized rain sensors set at a 6 mm threshold and operate under typical water restrictions consisting of irrigation windows of two days per week.

The Weathermatic controller, T1, is a standalone controller because it utilizes an onsite weather monitor to collect ambient air temperature used to calculate ETo by the Hargreaves equation (Samani, 2000). The Toro, T2, and ETwater, T3, controllers are signal-based. Climate parameters such as temperature, relative humidity, wind speed, and solar radiation are collected from public weather stations and ETo is calculated. The Toro controller uses paging technology while the ETwater uses cellular technology to deliver the ETo to the controllers. Both manufacturers utilize the weather data to calculate ETo using the ASCE standardized reference ET equation (Allen et al., 2005). Each controller applies a manufacturer-programmed crop coefficient, chosen by specifying the plant material setting, to the calculated ETo to get ETc. The crop coefficients associated with the Weathermatic controller are known to be 0.60 for both turfgrass and mixed-ornamentals while the crop coefficients from Toro and ETwater were not provided. An irrigation depth to be applied is calculated as well as an associated runtime based on the user-defined application rate and plant needs. Table 1 depicts the user-defined program settings specific to this study.

T4 is a time-based treatment where the irrigation depth was determined by month from 60% of historical ET specific to south Florida (Dukes and Haman, 2002). T5 is considered a deficit treatment and only applies 60% of the irrigation depth calculated from T4. Application depths and runtimes are shown in Table 2.

Data collection includes: climate data at fifteen minute intervals such as wind speed, solar radiation, temperature, relative humidity, and rainfall depth from a Florida Automated Weather Network (FAWN) weather station located onsite; irrigation water applied per plot from totalizing flow meters; soil moisture content from TDR probes; and plant quality measurements. The Weathermatic controller stores the weather data it uses to calculate ETo in the controller, allowing recalculation of the values. ETo information for T1, the Weathermatic controller, was collected from the commencement of treatments at the end of May 2006 through November 30, 2006. ETo values sent to the Toro controller was provided by the manufacturer from August 13 through October 31, 2006. ETo values sent to the ETwater controller was provided by the manufacturer from August 4 through October 4, 2006. Comparisons of ETo was made for all controllers during time periods where data were collected for every controller. The Toro Intelli-sense was not installed until August 8, 2006; the ET comparison begins on August 11, 2006. Data was unavailable from ETwater from August 17, 2006 through August 28, 2006 as well as September 18, 2006 through September 22, 2006. The Toro controller also had missing ETo data on August 12, 2006 and September 4, 2006.

Turfgrass quality is measured monthly using the National Turfgrass Evaluation Program (NTEP) standards (Morris and Shearman, 2006). The turfgrass is rated on a scale from 1 to 9 where 1 represents dead turfgrass or bare ground, 9 represents an ideal turfgrass, and 5 is considered to be the minimum acceptable quality for a residential setting. Each rating is determined by examining aspects of color, density, uniformity, texture, and disease or environmental stress. SAS statistical software (SAS Institute, Inc., Cary, NC) was used for all statistical analysis, utilizing the General Linear Model (GLM) procedure and assuming a 95% confidence interval. Means separation was conducted using Duncan's Multiple Range test.

## ***Results and Discussion***

Two seasons of data were collected during 2006: summer represented as June, July, and August; fall represented as September, October, and November. The Toro Intelli-sense, T2, was not installed until August 12, 2006. Thus, only the Weathermatic and ETwater controllers were compared to the time-based treatments for the summer. Also, the ETwater (T3) controller ceased functioning on August 23, 2006 due to a circuit panel malfunction on the controller. In the fall, the Weathermatic and the Intellisense were compared to the time-based treatments.

The volumetric water content rarely dropped below 10%. This is an acceptable range because to the minimum soil moisture content should be keep no lower than 50% of the available water, or 8% for this site. Maintaining volumetric water content below 8% would cause the plants to become unnecessarily stressed. The plots had high water content due to plentiful rainfall from June 10, 2006 to September 21, 2006.

Thirty year historical rainfall averages were calculated from total monthly precipitation data collected by the National Oceanic and Atmospheric Administration (NOAA, 2005) from 1975 through 2005. The closest NOAA weather station from the project site that collected this information was located approximately 28 km away, in Parrish, FL. All months received less rain than historical averages except for the month of July which had almost twice the historical average (Fig. 3). Overall, both seasons were drier than average with a total of 869 mm of rainfall from May 25, 2006 through November 30, 2006 with approximately 205 mm of effective rainfall (Fig. 4) as calculated by equations 4-7.

During July and August, the time-based treatment (T4) applied significantly ($P<0.0001$) more water than any other treatment at 239 mm (Table 3). Part of the reason for this trend is that this treatment (T4) along with the deficit time-based treatment (T5) had a nonfunctional rain sensor until August 25. The trend in turf quality tended to be better in this treatment but the turfgrass quality was only significantly higher than the ETwater controller that applied 174 mm over the same time period. The Weathermatic controller applied the least amount of irrigation, 95 mm, during this time period and all treatments had at least acceptable turfgrass quality.

In the fall, T1 applied significantly more water (182 mm) than the other treatments ($P<0.0001$). Turf quality was significantly better and at least at acceptable levels (>5) on the Weathermatic and the Intellisense controller treatments compared to the time-based treatments T4 and T5, which had average turf quality ratings of 4.8 and 4.3, respectively. The time-based treatments had reduced quality averages due to a scheduling error in October where very little irrigation was programmed, coupled with almost no rainfall during the same time period. Consequently, disease and pests further reduced the turf quality. However, by the end of the fall season turf quality was at least acceptable on all treatments.

Figure 5 shows the ETo delivered to or estimated by the controllers compared to the ASCE standardized method. The Weathermatic, T1, calculated the highest amount of ETo (174 mm) of any of the controllers, overestimating ETo by 32%. However, this treatment applied the least amount of water for the summer season and less than the calculated irrigation requirement for the fall season. This difference is due to an underestimation of Kc for warm season turfgrass [0.85 in Allen et al. (1998)] programmed into the controller (0.60) and also due to seven bypassed irrigation events by the rain switch on the Weathermatic controller. T2, Toro, overestimated ETo by 2% which is the closest estimation by any of the controllers. The ETwater controller, T3, overestimated ETo by 7% when directly comparing the treatments, calculating ETo to be 141 mm compared to 131 mm calculated by the ASCE method.

Figures 6 and 7 show the theoretical irrigation requirement and actual irrigation applied to each treatment along with effective rainfall for each season. T1 applied 189 mm during the summer season and 182 mm over the fall season, applying less than the theoretical requirement by 11% and 14%, respectively. T2 began irrigating independently by August 12, 2006 and applied 44% less (126 mm) than the theoretical requirement. One reason T1 and T2 applied less than the theoretical requirement is because the irrigation efficiency setting in the controller was not changed from the default 100% (T1) or set at 95% (T2). However, the theoretical calculation of irrigation required used 80% efficiency (E = 1.25) resulting in more water required than 100% efficiency. The ETwater controller, T3, applied 63% more than the theoretical irrigation requirement (344 mm) during the summer season despite the fact that efficiency in this controller was set at 95%. T4 exceeded the theoretical requirement the most by applying 74% (369 mm) more water than required during the summer, but applied 25% (159 mm) less than the theoretical requirement during the fall. Over-irrigation during the summer was a result of the non-functional rain sensor mentioned earlier. Results from the fall indicated that this treatment, except for an error in the irrigation schedule for October, applied a reasonable amount of water to maintain turfgrass quality. The time-based deficit treatment, T5, applied 16% (245 mm) more than the theoretical requirement during the summer due to the same nonfunctional rain sensor that affected T4. Similar to T4, T5 resulted in 52% (101 mm) less irrigation than the theoretical requirement during the fall.

## *Preliminary Summary & Conclusions*

The Weathermatic controller overestimated ETo more than other ET controllers, but applied less water than all other treatments during the summer season and more water than all other treatments in the fall season; however, still reduced irrigation compared to the theoretical irrigation requirement. The difference can be attributed to the Weathermatic controller applying a Kc that is lower than the other controllers, using 0.60 compared to Allen et al. (1998) using 0.85 for warm season turfgrass. The Kc value is not provided by the other manufacturers. The Toro controller had the most accurate cumulative ETo value and saved water relative to the theoretical requirement during the fall season. The ETwater controller had a cumulative ETo value 7% higher than the standardized estimate. The ETwater controller had reduced turf quality relative to the time-based treatments in the summer but still above an acceptable level. The deficit time schedule had turf quality that was significantly lower than the Weathermatic and Toro controllers in the fall. T1, the Weathermatic controller, applied 11% and 14% less than theoretical irrigation requirements in both seasons, while the rest of the treatments applied more than the theoretical requirement during the summer by 63% (T3), 74% (T4), and 16% (T5) and less than the theoretical requirement during the fall by 40% (T2), 25% (T4), and 52% (T5). These initial results show that ET controllers have the potential to reduce water application relative to time-based schedules while maintaining acceptable turf quality.

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**Table 1. ET controller program settings.**

| | T1 – Weathermatic | T2 – Toro | T3 – ETwater |
|---|---|---|---|
| **Soil Type** | Sandy | Sandy | Sandy |
| **Plant Type** | Warm Season Turfgrass | Warm Season Turfgrass | Warm Season Turfgrass |
| **Sprinkler Type** | 0.6 in/hr | 0.61 in/hr | 0.61 in/hr |
| **Slope** | 0° | 0° | 0° |
| **Shade** | NA[*] | Sunny All Day | Sunny All Day |
| **Root Depth** | NA | 6 in | 6 in |
| **Efficiency** | 100% | 95% | 95% |
| **Zip Code** | 33598 | NA | NA |
| **Latitude** | 27°N | NA | NA |

[*] NA represents parameters that were not specifically applicable for the controller

**Table 2. Calculated irrigation depths applied twice weekly and associated runtimes per irrigation event for T4, time-based, and T5, 60% deficit time-based.**

| Month | T4 Irrigation Depth (mm) | T4 Runtime (min) | T5 Irrigation Depth (mm) | T5 Runtime (min) |
|---|---|---|---|---|
| **January** | 6 | 23 | 4 | 14 |
| **February** | 6 | 24 | 4 | 15 |
| **March** | 9 | 35 | 5 | 21 |
| **April** | 10 | 37 | 6 | 22 |
| **May** | 9 | 34 | 5 | 20 |
| **June** | 8 | 31 | 5 | 19 |
| **July** | 12 | 48 | 7 | 29 |
| **August** | 14 | 53 | 8 | 32 |
| **September** | 8 | 31 | 5 | 19 |
| **October** | 3 | 32 | 2 | 19 |
| **November** | 8 | 33 | 55 | 20 |
| **December** | 7 | 29 | 4 | 17 |

**Table 3. Total average water applied and average turf quality measurements for the summer season (July 1, 2006 through August 31, 2006) and fall season (September 1, 2006 through November 30, 2006).**

| | | Summer | | Fall | |
|---|---|---|---|---|---|
| Controller | Treatment | Total Irrigation Applied (mm) | Turf Quality | Total Irrigation Applied (mm) | Turf Quality |
| Weathermatic | 1 | 95 *d*[*] | 5.5 *ab* | 182 *a* | 5.3 *a* |
| Toro | 2 | NA | NA | 126 *c* | 5.0 *a* |
| ETwater | 3 | 174 *b* | 5.3 *b* | NA | NA |
| Time-based | 4 | 239 *a* | 6.3 *a* | 159 *b* | 4.8 *ab* |
| 60% Time-based | 5 | 142 *c* | 6.0 *ab* | 101 *d* | 4.3 *b* |
| Effective Rain (mm) | | 150 | | 60 | |
| Turfgrass ETc (mm) | | 191 | | 220 | |

[*] Nnumbers with different letters in columns indicated differences at the 95% confidence level using Duncan's Multiple Range Test.

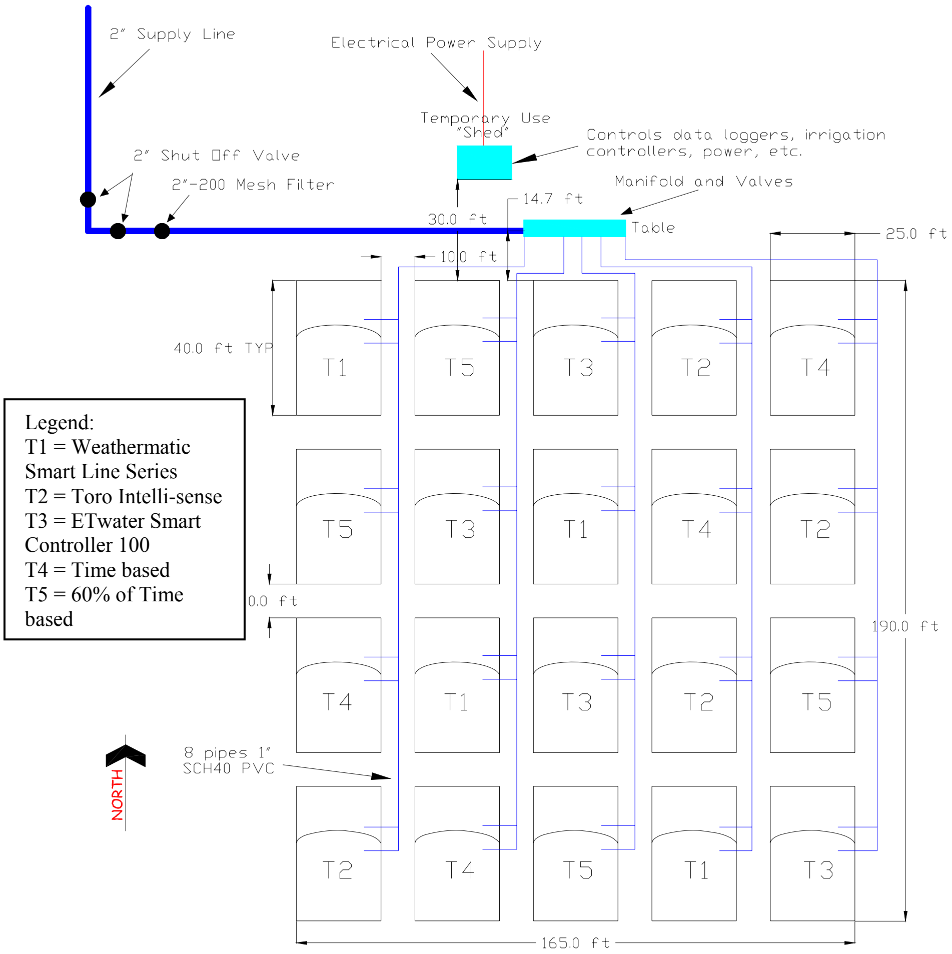
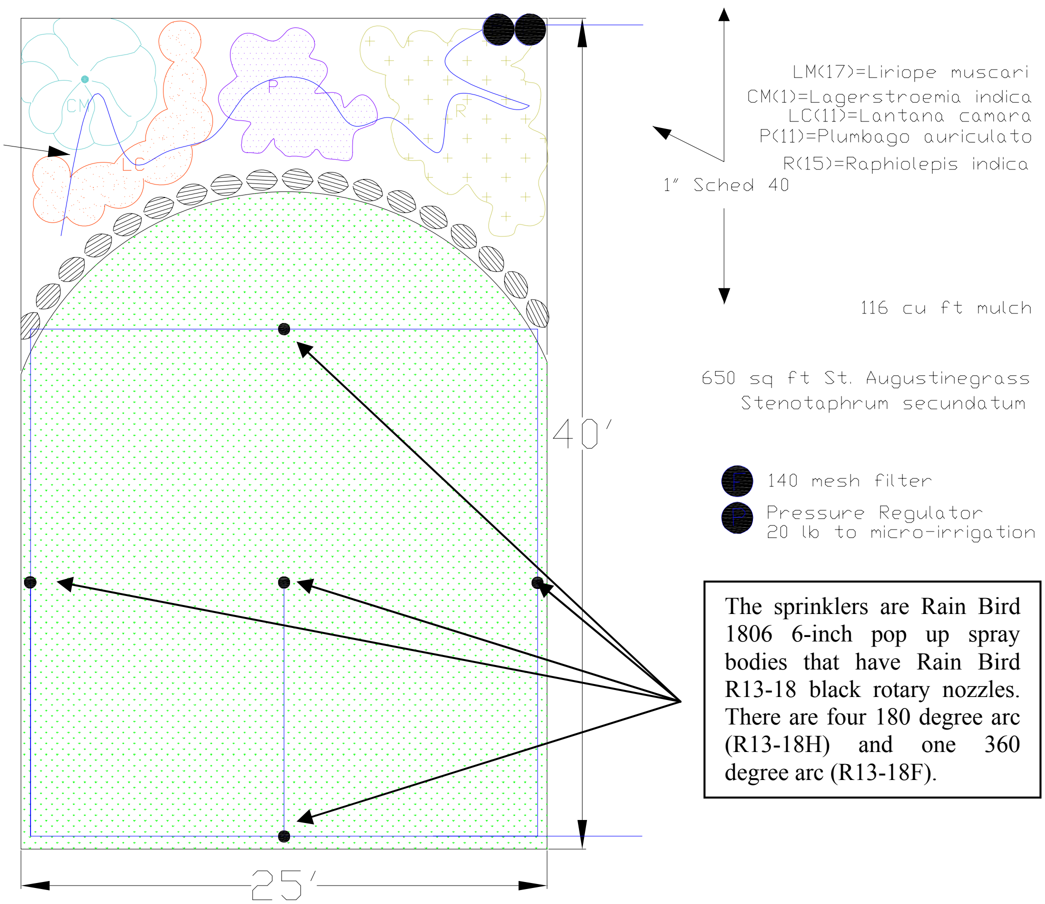


**Figure 1: Plot layout and controller treatments.**



The sprinklers are Rain Bird 1806 6-inch pop up spray bodies that have Rain Bird R13-18 black rotary nozzles. There are four 180 degree arc (R13-18H) and one 360 degree arc (R13-18F).

**Figure 2: Schematic of plot irrigation design**

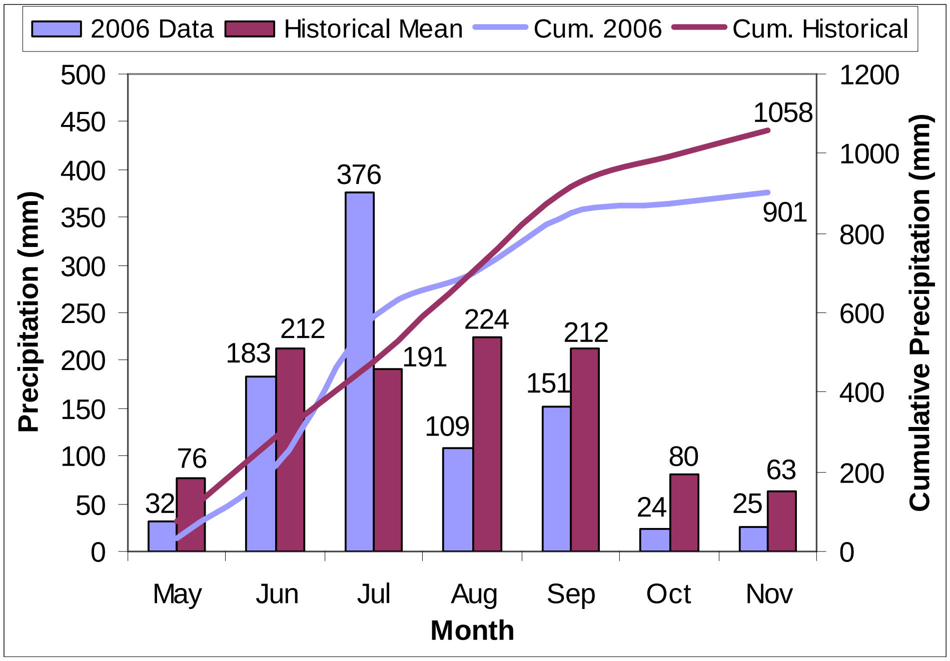


**Figure 3: Comparison of total monthly rainfall from 2006 and historical monthly average rainfall from May through November.**

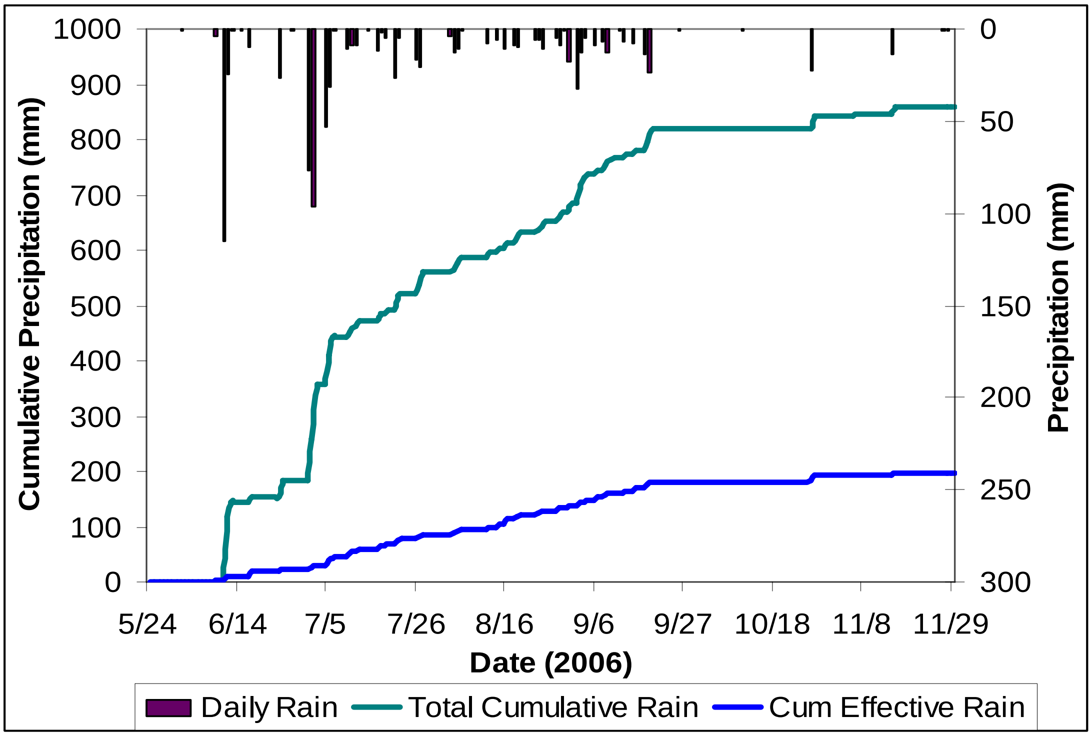


**Figure 4: Comparison of cumulative rainfall, cumulative effective precipitation, and daily precipitation events in 2006.**

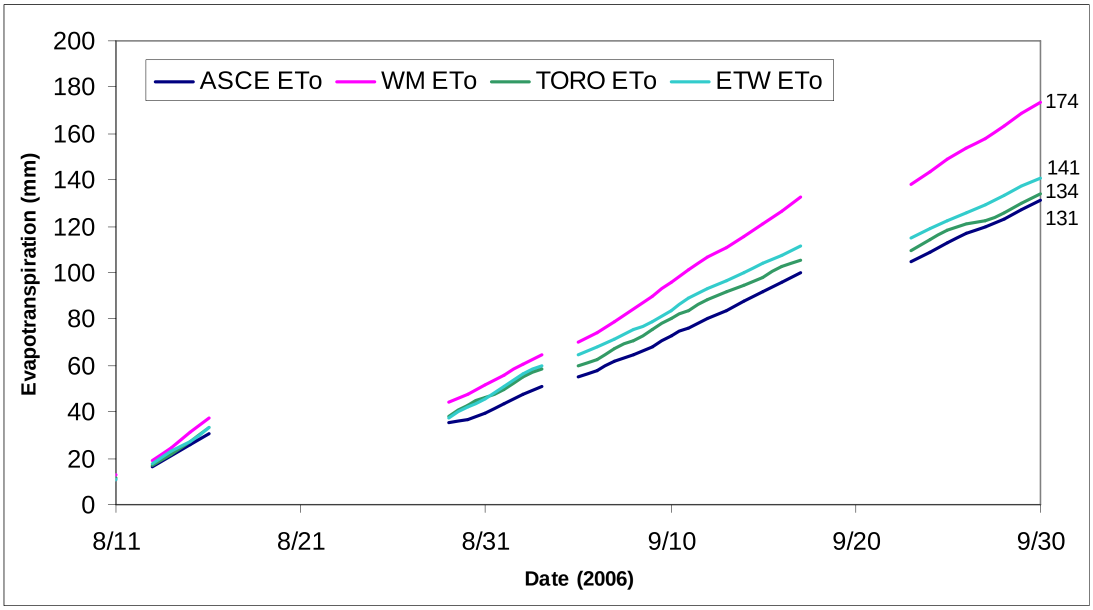


**Figure 5: Comparison of cumulative ETo from August 11, 2006 through September 30, 2006.**

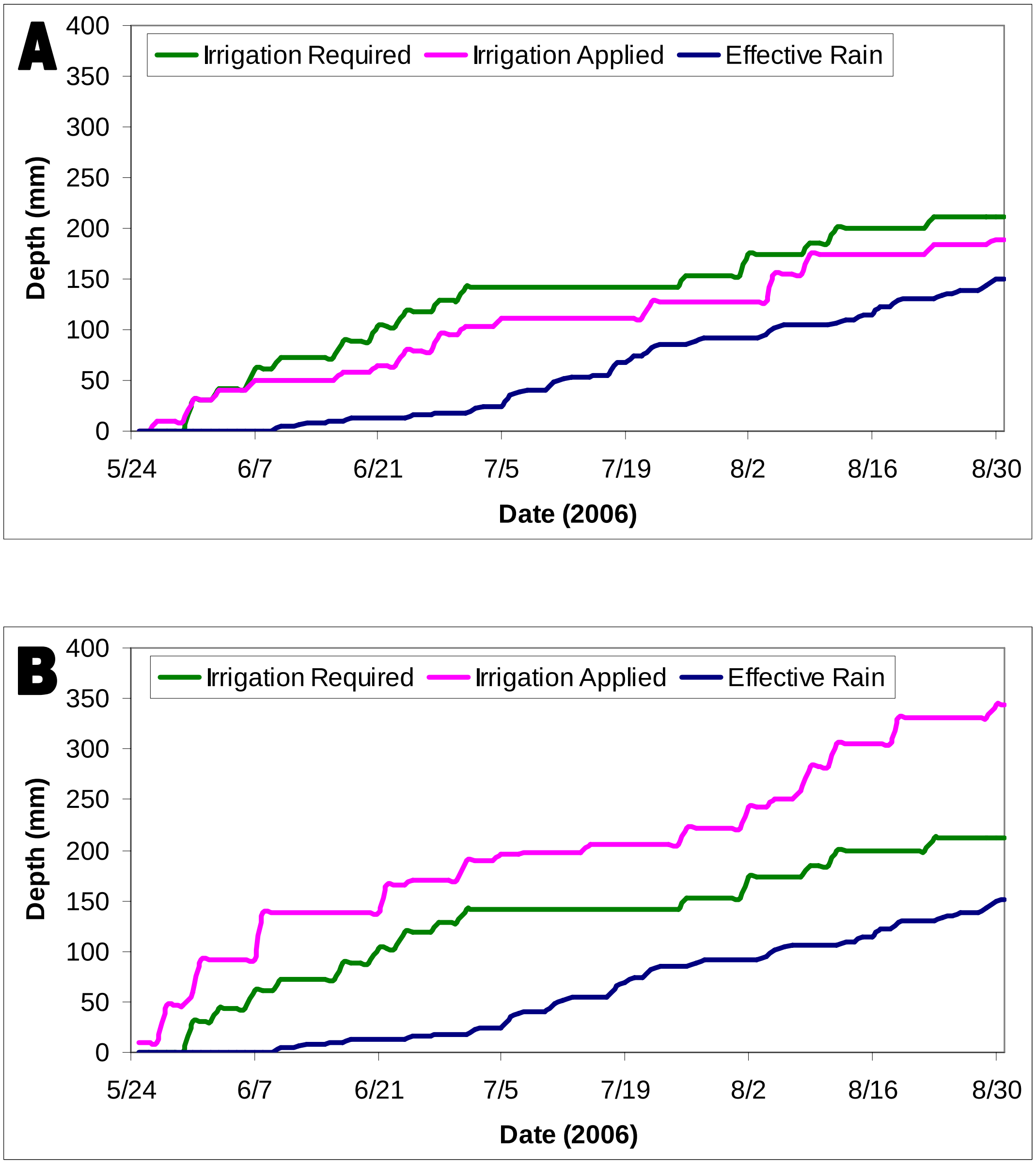
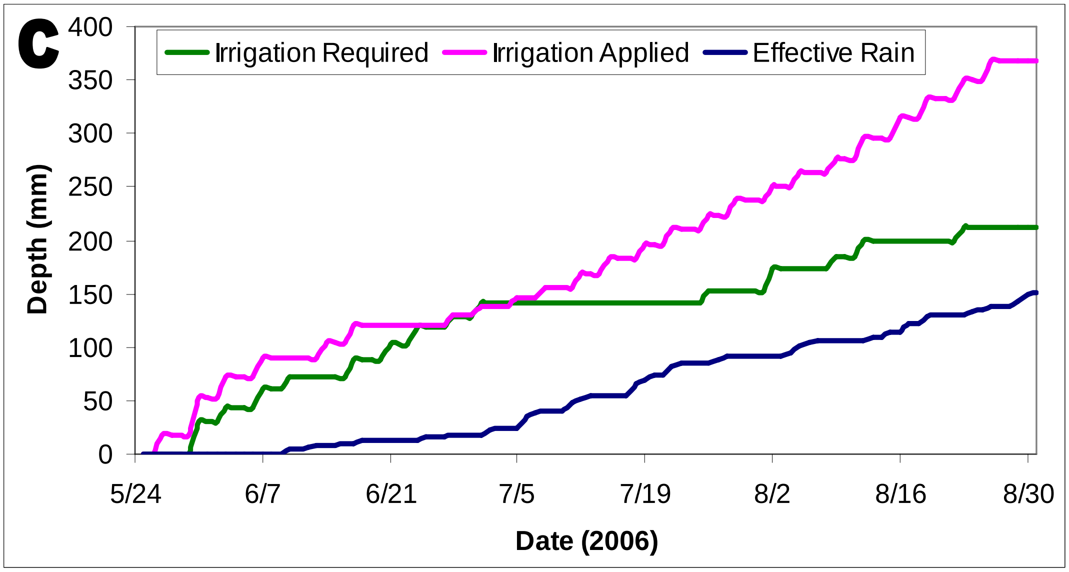


**Figure 6-1: Graphs representing the theoretical cumulative gross irrigation depth (assuming irrigation efficiency = 80%) required according to the soil water balance, irrigation applied, and effective rainfall during the summer season for: (A) T1, Weathermatic; (B) T3, ETwater.**



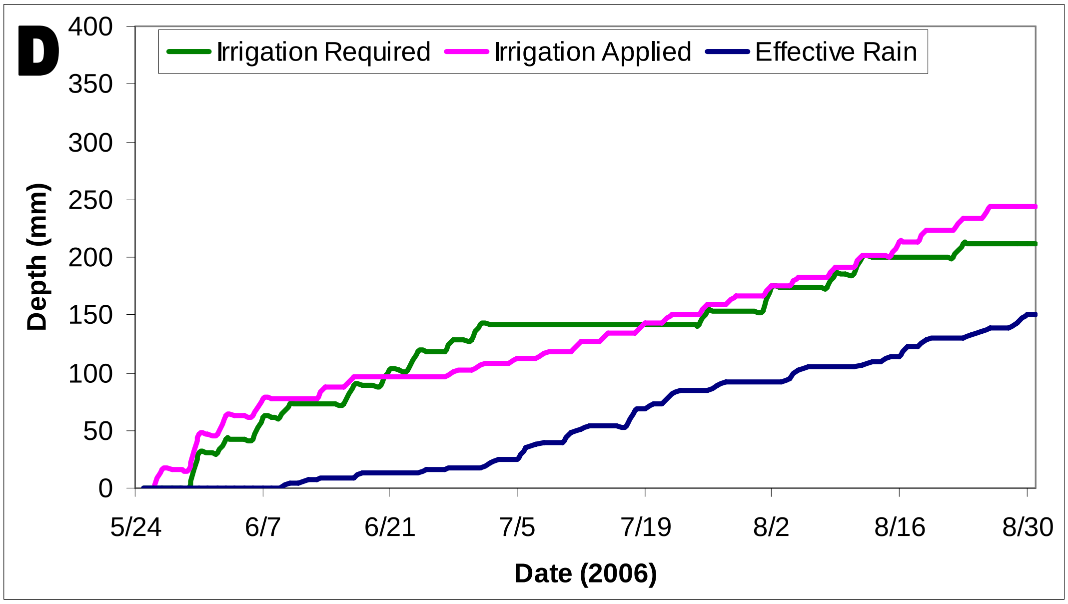


**Figure 6-2: Graphs representing the theoretical cumulative gross irrigation depth (assuming irrigation efficiency = 80%) required according to the soil water balance, irrigation applied, and effective rainfall during the summer season for: (C) T4, time-based; (D) T5, 60% Time-based.**

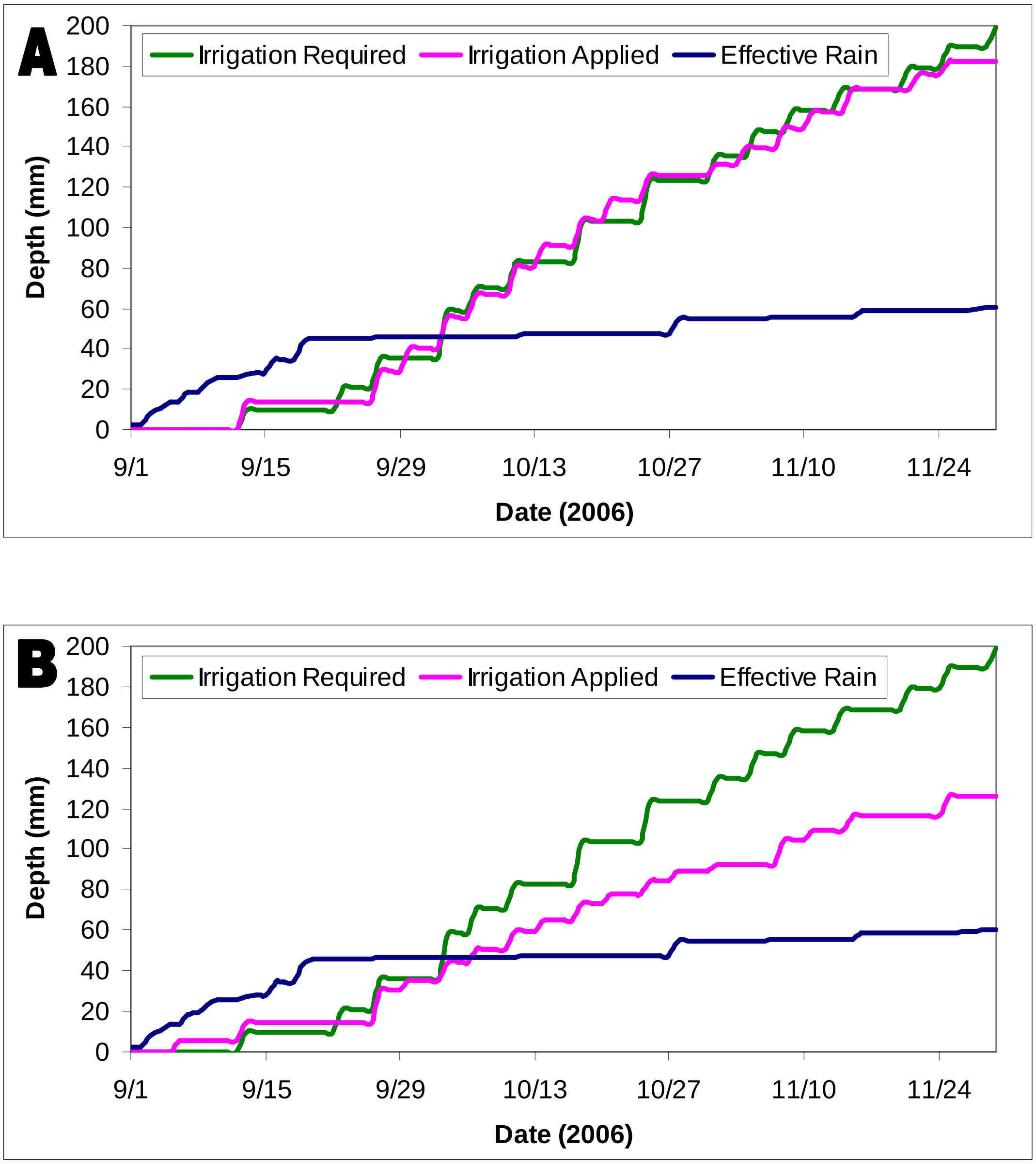
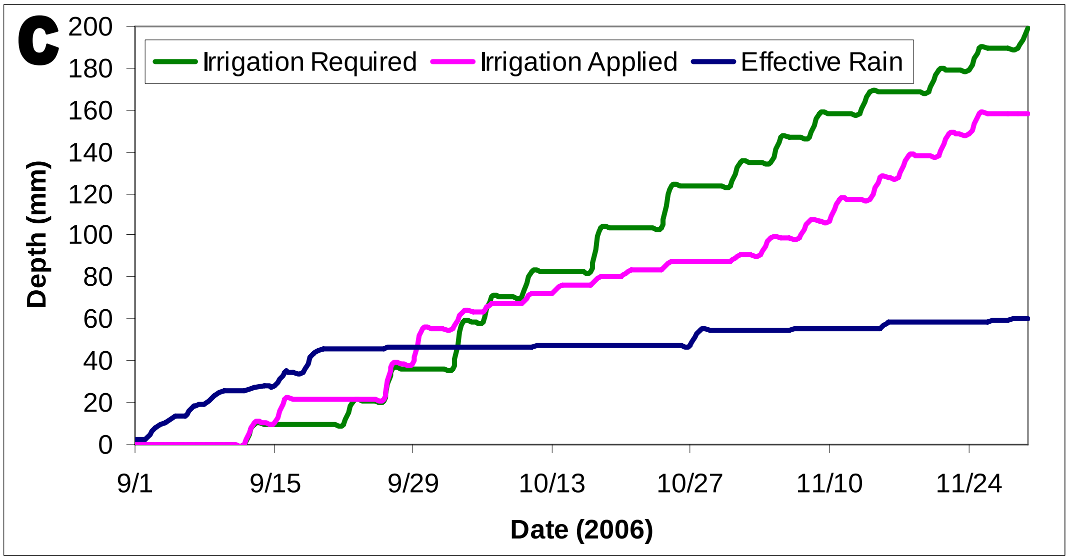


**Figure 7-1: Graphs representing the theoretical cumulative gross irrigation depth (assuming irrigation efficiency = 80%) required according to the soil water balance, irrigation actually applied, and effective rainfall during the fall season for: (A) T1, Weathermatic; (B) T2, Toro.**



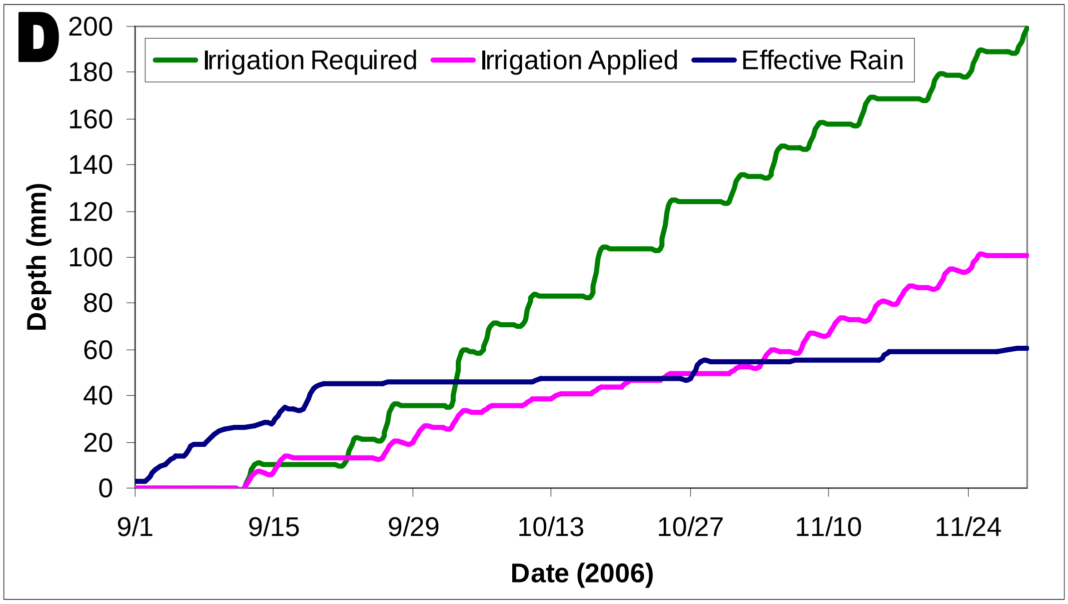


**Figure 7-2: Graphs representing the theoretical cumulative gross irrigation depth (assuming irrigation efficiency = 80%) required according to the soil water balance, irrigation actually applied, and effective rainfall during the fall season for: (C) T4, time-based; (D) T5, 60% Time-based.**