Importance of ET Controller Program Settings on Water Conservation Potential

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A Tribute to the Career of Terry Howell, Sr.

Abstract. *In unincorporated Orange County, Florida, 57% to 62% of single-family residential homes were found to regularly over-irrigate, resulting in the need to find better ways to schedule automatic irrigation. The objective of this research was to evaluate the effects of programming for identical virtual landscapes to further explore the water savings potential of evapotranspiration (ET) controllers. As a virtual test, three Rain Bird ET controllers were studied: the ESP-SMT controller with two firmware options (original and an updated), and the ESP-SMTe, a replacement product for the ESP-SMT. Irrigation was scheduled for a virtual central Florida landscape by altering possible program settings of plant type, microclimate, soil type, and density that relate directly to parameters used in the soil water balance. The ESP-SMTe consistently applied similar amounts of irrigation to the ESP-SMT with updated firmware, indicating that controller updates were minor between the two models. The settings were optimized for Florida landscapes by selecting a heavier soil type, increasing the shade, and selecting a medium stand for a custom plant type, resulting in reductions in irrigation application. The ESP-SMTe and ESP-SMT with updated firmware were different from the ESP-SMT with original firmware, where newer models applied more water despite identical settings, averaging 12 to 21 mm more per month than the original firmware. Additionally, all of the controllers were unable to fully account for rainfall throughout the test resulting in a minimum of 51% in over-irrigation compared to the gross irrigation requirement (GIR). Increasing the accuracy of rainfall accounting would be extremely beneficial to overall water conservation and efficiency. In a separate, independent ET controller study, there was a large discrepancy in irrigation application among multiple brands programmed to irrigate the same virtual landscape. This further shows the importance of understanding the algorithms behind the program settings.*

Keywords. *Conservation, Irrigation requirements, Landscape, Programming, Smart controller.*

Florida is currently ranked as the third most populous state with an average increase in population of 803 new residents per day, estimated from July 2013 to July 2014 (U.S. Census Bureau, 2014). Central Florida continues to be faced with positive population growth combined with limitations to available groundwater resources. When increasing pumping capacity to address population growth is not an option, increasing water conservation and efficiency becomes a top priority of utilities.

Targeting efficiency in automatic irrigation has become increasingly important with estimates of over half of total household water use going toward landscape irrigation (Haley et al., 2007; Devitt et al., 2008). Specifically for Orange County Utilities (unincorporated Orange County, Fla.), 57% to 62% of single-family residential homes were regularly over-irrigating compared to calculated landscape irrigation requirements (Romero and Dukes, 2014). Finding better ways to schedule automatic irrigation has become a high priority as the installation of automatic irrigation systems continues to be standard practice.

A technological method for scheduling irrigation is a smart controller that can adjust or override irrigation based on weather or soil conditions (Dukes, 2012). Currently, there are two commercially-available products designated as smart controllers. Weather-based irrigation controllers, or evapotranspiration (ET) controllers, typically use weather information, user-selected program settings, and proprietary algorithms to determine the irrigation schedule instead of relying on manually selected runtimes. Soil moisture sensor (SMS) controllers bypass irrigation events when the measured soil moisture is greater than a user set threshold. More detailed descriptions of smart controller functionality and performance can be found in Davis et al. (2009), McCready et al. (2009), Davis and Dukes (2010), McCready and Dukes (2010), and Cardenas-Lailhacar and Dukes (2012).

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To address the growing public water demands in Orange County, a study was conducted to determine the water conservation potential of smart controllers implemented on residential landscapes of excessive irrigators (Davis and Dukes, 2015a; 2015b). All single-family homes within the Orange County Utilities service area were evaluated for over-irrigation tendencies by comparing estimated irrigation application from billing data and parcel information to the calculated gross irrigation requirement (GIR) as a monthly landscape irrigation ratio (LIR) using the methods described in Romero and Dukes (2014). Once the 167 participants were selected for the study, they were re-evaluated with site-specific information and were found to have excessive irrigation patterns, averaging 6 to 8 times the GIR (Davis and Dukes, 2015a), thus confirming the methodology for selecting high outdoor water users.

A portion of the Orange County smart controller study (Davis and Dukes, 2015a; 2015b) focuses on differences in irrigation application based on the program settings supplied to the ET controllers by the contractor or recommended optimized settings based on previous UF-IFAS work. Davis and Dukes (2015b) showed that the ET controller with contractor settings typically applied less irrigation per week than the comparison group with no smart technology, depending on season. An additional decrease in average weekly irrigation application resulted when the ET controller was programmed with optimized settings. However, it is unclear how the differences in these program settings helped to reduce irrigation application. The objective of this research was to evaluate the effects of irrigation application by changing ET controller program selections for identical virtual landscapes as a way to further explore their water savings potential.

Materials and Methods

A total of three independent studies were conducted as a part of this evaluation: (a) central Florida smart controller study, (b) virtual test of Rain Bird ET controllers, and (c) independent virtual test of multiple brands. The central Florida smart controller study, as was discussed in the introduction and in Davis and Dukes (2015a; 2015b), was a field study conducted in Orange County, Florida, with single-family homes using smart technologies. The virtual test of Rain Bird ET controllers was conducted as a portion of the field study to further evaluate program settings of the controllers (and is the focus of this article). The independent virtual test of multiple brands was conducted as part of a completely separate study conducted in conjunction with a manufacturer to evaluate product brands irrigating a single virtual landscape scenario.

Virtual Test of Rain Bird ET Controllers

In a virtual test, four ET controllers were installed at an outdoor testing site located on the University of Florida main campus in Gainesville, Florida (fig. 1). Three controllers were the ESP-SMT (Rain Bird Corporation, Azusa, Calif.) and one controller was the ESP-SMTe (Rain Bird Corporation, Azusa, Calif.); all controllers and program selections were chosen to represent variations of the treatments implemented in the central Florida smart controller study (Davis and Dukes, 2014a; 2015b) (fig. 2).

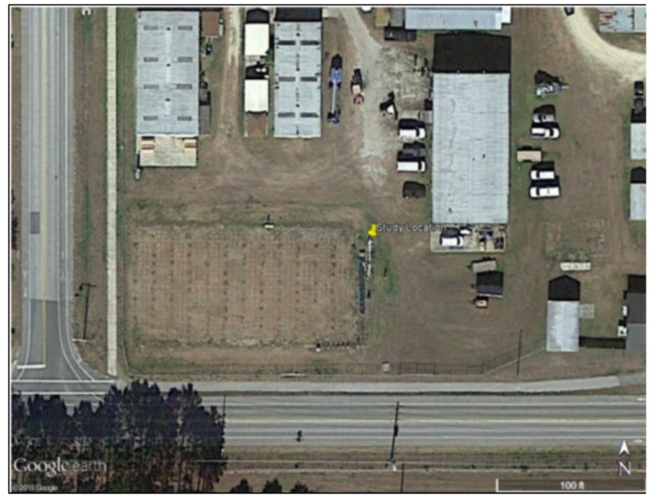

Figure 1. Four Rain Bird ET controllers were installed on the University of Florida campus located at the corner of Hull Road (south) and Museum Road (west).

Two ESP-SMT controllers were installed with factory-packaged components thus utilizing the original version of firmware (2009-2010). It was found in Davis et al. (2009) that replications of ET controllers of the same model, and firmware, had identical performance since the scheduling algorithms are identical. The third ESP-SMT was installed with a panel that utilized updated firmware released in 2011.

The ESP-SMTe is the current model of ET controller offered by the Rain Bird Corporation. Some of the product features of both the ESP-SMT and ESP-SMTe are available in product literature, including a few of the differences between the models, but most algorithms are proprietary and unknown. The most obvious differences were the removal of density selections when the plant type is a turfgrass material, slight modifications to crop coefficient values, and the removal of efficiency factors.

Figure 2. Three ESP-SMT and one ESP-SMTe were programmed to schedule irrigation for multiple configurations of landscape settings possible in central Florida. Each controller had an independent rain gauge (fourth gauge not pictured).

Table 1. Program settings for zones running on the Rain Bird ESP-SMT controllers with the original firmware.

Panel[a]	Zone	Application Rate (mm/h)	Efficiency	Crop Coefficient (K_C)	Root Zone (mm)	Microclimate	Soil Type	Density
A	1	41	1	0.6	203	25% Shade	Loamy Sand	Dense
A	2	41	1	0.6	203	25% Shade	Sandy Loam	Dense
A	3	41	0.65	WT[b]	76	Full Sun	Sand	Dense
A	4	41	0.65	WT	76	Full Sun	Loamy Sand	Dense
A	5	41	0.65	0.6	203	25% Shade	Loamy Sand	Dense
A	6	41	0.65	0.6	203	Full Sun	Loamy Sand	Dense
A	7	41	1	0.6	203	25% Shade	Loamy Sand	Medium
A	8	41	1	0.6	203	25% Shade	Sand	Dense
B	1	41	0.65	CT[c]	76	Full Sun	Loamy Sand	Dense
B	2	41	0.65	CT	76	Full Sun	Sand	Dense
B	3	41	0.65	WT	76	Full Sun	Loamy Sand	Medium
B	4	41	1	0.6	203	25% Shade	Loam	Dense
B	5	41	1	0.6	203	50% Shade	Loamy Sand	Dense
B	6	41	1	0.6	203	75% Shade	Loamy Sand	Dense
B	7	41	1	0.6	203	Full Sun	Loamy Sand	Dense

[a] Two controllers having the same firmware were used to program all 15 zones.

[b] WT represents warm season turfgrass as the plant type settings with crop coefficients selected for Bermudagrass in the SWAT testing protocol (Irrigation Association, 2008).

[c] CT represents cool season turfgrass as the plant type settings with crop coefficients selected for Tall Fescue in the SWAT testing protocol (Irrigation Association, 2008).

A total of 28 zones were programmed on the three ESP-SMT controllers with 15 zones using the original firmware and 13 zones using the updated firmware (tables 1-2). The ESP-SMTe was programmed with 18 zones that replicated settings of zones on the ESP-SMT for direct comparison (table 3). Program settings for each zone varied by a single variable to determine the effect of monthly irrigation application as a result of that variable. Variables included plant type, microclimate, soil type, and density.

The controllers were installed in an outdoor location to maintain proper functionality of the weather-based devices, such as taking accurate measurements of temperature and rainfall, but they were not associated with physical irrigation systems or turfgrass plots. Instead, all 46 zones were wired to a series of circuit panels connected to a field laptop personal computer running an executable program coded in Visual Basic (fig. 3). When a zone was activated by the controller, a timestamp was generated to signify the start of the electrical signal. Another timestamp occurred when the electrical signal disappeared, indicating that the zone deactivated. Accuracy of the timestamps fell within two seconds. The timestamp data was output to a text file that was periodically downloaded from the computer. Manual irrigation data was transcribed from all four controllers during the study period to verify results provided by the data logging system. Gross irrigation was calculated from the timestamps using the application rates programmed for the corresponding zones.

As a comparison, the gross irrigation requirement (GIR) was calculated to provide an estimate of theoretical irrigation needs using a soil water balance, similar to the functionality of an ET controller. In a virtual test such as this, there are no measured irrigation depths for comparison; thus, the GIR was considered to be a benchmark for evaluating ET controller performance. The GIR was calculated by multiplying the net irrigation water requirement (IWR_{net}) by an efficiency factor, which was identical to the value programmed into the controllers. The IWR_{net} is the amount of irrigation required to replenish available water holding capacity (AWC) of the soil, or the maximum depth of water that can be stored after gravitational drainage (Irrigation Association, 2005). The IWR_{net} was determined from mass conservation of soil water content (Irrigation Association, 2005):

$$IWR_{net} = PWR - R_e \quad (1)$$

Table 2. Program settings for zones running on the Rain Bird ESP-SMT controller with the updated firmware.

Zone	Application Rate (mm/h)	Efficiency	Crop Coefficient (K_C)	Root Zone (mm)	Microclimate	Soil Type	Density
1	41	1	WT[a]	76	Full Sun	Sand	Medium
2	11	1	WT	76	Full Sun	Sand	Medium
3	41	1	CT[b]	76	Full Sun	Sand	Medium
4	41	1	WT	76	Full Sun	Loamy Sand	Medium
5	41	1	WT	76	Full Sun	Sandy Loam	Medium
6	41	1	WT	76	25% Shade	Loamy Sand	Medium
7	41	1	WT	76	50% Shade	Loamy Sand	Medium
8	41	1	WT	76	75% Shade	Loamy Sand	Medium
9	41	1	0.6	203	25% Shade	Loamy Sand	Dense
10	41	1	0.6	203	25% Shade	Loamy Sand	Medium
11	41	1	0.6	203	Full Sun	Sand	Medium
12	41	1	WT	76	Full Sun	Loam	Medium
13	41	1	WT	76	Full Sun	Sand	Dense

[a] WT represents warm season turfgrass as the plant type settings with crop coefficients selected for Bermudagrass in the SWAT testing protocol (Irrigation Association, 2008).

[b] CT represents cool season turfgrass as the plant type settings with crop coefficients selected for Tall Fescue in the SWAT testing protocol (Irrigation Association, 2008).

Table 3. Program settings for zones running on the Rain Bird ESP-SMTe controller.

Zone	Application Rate (mm/h)	Efficiency	Crop Coefficient (K_C)	Root Zone (mm)	Microclimate	Soil Type	Density
1	41	1	WT[a]	76	Full Sun	Sand	NA[b]
2	11	1	WT	76	Full Sun	Sand	NA
3	41	1	CT[c]	76	Full Sun	Sand	NA
4	41	1	WT	76	Full Sun	Loamy Sand	NA
5	41	1	WT	76	Full Sun	Sandy Loam	NA
6	41	1	WT	76	25% Shade	Loamy Sand	NA
7	41	1	WT	76	50% Shade	Loamy Sand	NA
8	41	1	WT	76	75% Shade	Loamy Sand	NA
9	41	1	0.6	203	25% Shade	Loamy Sand	Dense
10	41	1	0.6	203	25% Shade	Loamy Sand	Medium
11	41	1	0.6	203	Full Sun	Sand	Medium
12	41	1	WT	76	Full Sun	Loam	NA
13	41	1	WT	76	Full Sun	Sand	NA
14	41	1	0.6	203	25% Shade	Loamy Sand	Medium
15	41	1	0.6	203	25% Shade	Loamy Sand	Medium
16	41	1	WT	203	25% Shade	Loamy Sand	NA
17	41	1	WT	203	25% Shade	Loamy Sand	NA
18	41	1	WT	203	25% Shade	Loamy Sand	NA

[a] WT represents warm season turfgrass as the plant type settings with crop coefficients selected for Bermudagrass in the SWAT testing protocol (Irrigation Association, 2008).
[b] Density is not an applicable setting when warm season turfgrass or cool season turfgrass settings are selected.
[c] CT represents cool season turfgrass as the plant type settings with crop coefficients selected for Tall Fescue in the SWAT testing protocol (Irrigation Association, 2008).

The PWR is the plant water requirement (mm) and R_e is effective rainfall (mm). The IWR_{net} was accumulated daily, but was applied only when the soil water level fell below management allowable depletion (MAD), calculated as 50% of AWC (Irrigation Association, 2005). The AWC was selected to represent the two main soil types in Orange County, 43 mm for flatwoods soils, characterized as poorly to moderately drained sands, and 24 mm for uplands soils, characterized as excessively to moderately drained sands, based on a root zone depth of 305 mm for turfgrass (Davis and Dukes, 2015a). Deep percolation and surface runoff can be considered negligible with proper design and management of the irrigation system. Since this was a virtual test, it was assumed that the irrigation system would have been designed and maintained properly thus avoiding the need for estimating the parameters.

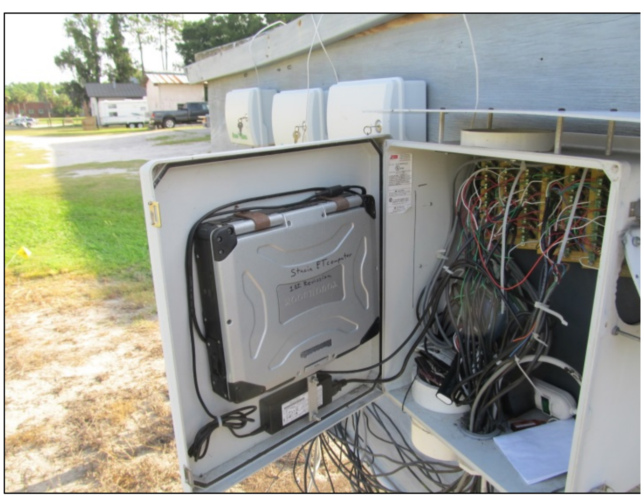

Figure 3. All four ET controllers were wired to circuit boards connected to a laptop running a Visual Basic program that records timestamps of irrigation events. This test was virtual, thus the controllers did not control physical irrigation systems.

The PWR is the amount of water necessary to maintain healthy plant material (Irrigation Association, 2005) and was calculated as the plant-specific evapotranspiration (ET_C) by taking into account plant characteristics using coefficients specific to the crop (K_C), microclimate (K_{MC}), and density (K_D).

$$PWR = K_C * K_{MC} * K_D * ET_O \quad (2)$$

Reference evapotranspiration (ET_O) is the estimated evapotranspiration of a short reference crop assumed to be a dense, well-watered, cool-season turfgrass maintained at a 0.12 m height. The ET_O was calculated by the American Society of Civil Engineers – Environmental and Water Resources Institute (ASCE-EWRI) standardized ET equation (ASCE, 2005). This equation used temperature, relative humidity, solar radiation, and wind speed collected from a weather station located on-site and maintained by the UF-IFAS research team from April 2012 through August 2013. Rainfall depths were also collected at this weather station. When data from this station was unavailable (Sept. 2013-Oct. 2014), the data was substituted from the weather station located 1.5 km away. As a comparison to the weather conditions during the study period, historical ET_O and rainfall were estimated from 37 years of weather data collected from the National Weather Service weather station located at the Gainesville Regional Airport, approximately 10 km from the test site. Historical ET_O was calculated using the ASCE-EWRI standardized ET equation.

The K_C values are ratios of average ET_C to average ET_O. These values incorporate distinguishing characteristics of the specific crop to the reference crop such as crop height, crop-soil surface resistance, and albedo of the crop-soil surface (Allen, 2000). The K_C values selected for these studies were updated monthly for warm season turfgrass located in central Florida with values of 0.45 (Dec.-Feb.), 0.60 (Nov.), 0.65 (Mar.), 0.70 (Jul., Aug., Oct.), 0.75 (Jun., Sep.), 0.80 (Apr.), and 0.90 (May) (Jia et al., 2009). For the

GIR, the microclimate and density coefficients were selected as 1 for turfgrass in a full sun setting.

Effective rainfall was limited to the portion of total daily rainfall that caused the soil water level to maximize AWC after PWR was taken into account. Rainfall that exceeded AWC was considered unavailable to the plant material due to surface runoff or deep percolation.

All values representing the parameters in the GIR were selected based on the best available scientific information for a virtual central Florida landscape. These same values would be used for developing an irrigation schedule for any turfgrass-based landscape in that region. Though calculations are mostly proprietary and not fully known, ET controllers are typically designed to estimate the numeric values required to calculate IWR_{net} by using general program descriptions (e.g., plant type, soil type, microclimate, density). These descriptions help a homeowner or irrigation professional to select the most applicable settings for their landscape without knowing parameters like K_C or AWC.

The plant type setting affects the frequency of irrigation based on selections of the K_C (eq. 2) and the root depth. Both warm and cool season turfgrass selections have K_C values that vary by month, but average 0.6 and 0.8, respectively. The root depth setting determines the AWC, thus determining the amount of ET_C that can occur before irrigation is necessary. The default root depths within the controller program settings for both types of turfgrasses were 76 mm. Since a majority of landscapes were dominated by turfgrass in the central Florida smart controller study, other plant types were not explored in this virtual test.

The setting of microclimate, also referred to as the shade factor, affects the frequency of irrigation events by adjusting the PWR (eq. 2). Increasing the amount of shade results in decreasing ET_O and ultimately a decrease in frequency of irrigation events. Specifically for the Rain Bird controllers, it can be selected as full shade, 75% shade, 50% shade, 25% shade, and full sun resulting in K_{MC} values that range from 0.56 to 1.0 for turfgrasses. In this virtual test, full shade was not evaluated due to its rare occurrence in central Florida landscapes.

The soil type setting is used to determine the AWC, soil intake rate, allowable surface accumulation, and maximum allowable depletion value. For these particular models of ET controllers, the available selections are sand, loamy sand, sandy loam, loam, clay loam, silty clay, and clay. As the setting is adjusted from sand toward clay loam, the irrigation frequency decreases while the irrigation runtimes increase due to an estimated increase in AWC. Additionally, there is an increase in the number of cycles and a decrease in the runtime length per cycle in the heavier soils. Silty clay and clay soils are expected to have an increased frequency in irrigation events due to smaller maximum allowable depletion values of 40% and 35%, respectively, compared to 50% for all other soil types. In Florida, the lighter soils are most dominant thus only the selections of sand, loamy sand, sandy loam, and loam were evaluated.

Plant density refers to the amount of leaf area of the plant material as opposed to exposed soil area. The plant density factor (K_D) affects the frequency of irrigation events where a decrease in density results in a decrease in PWR (eq. 2). For these specific controllers, the available selections for density are sparse (large proportion of exposed soil), medium (average amount of exposed soil), and dense (large proportion of plant material). According to manufacturer literature, plant density is not a factor in turfgrass. However, a custom plant type, which was used to represent turfgrass in the central Florida smart controller study, was assumed as a non-turfgrass material and is subject to the density factors of 1.2 for dense and 1.0 for medium stands for all three models.

Monthly irrigation application scheduled by the controllers was analyzed from April 2012 through October 2014 using Statistical Analysis System software version 9.4 (SAS; Cary, NC). Zones 5-8 on Panel A, zones 4-7 on Panel B, and zones 11-13 on the controller with updated firmware were not implemented until June 2012, thus their data was unavailable until July 2012. Additionally, data was only recorded for the ESP-SMTe from September 2013 through October 2014. Comparisons of irrigation application were determined using the general linear model procedure (PROC GLM) with treatment differences ascertained from the least mean squares (LSMEANS) analysis assuming a significance level of 5% (α=0.05).

Independent Virtual Test of Multiple Brands

An independent virtual test was conducted over one irrigation season in 2010 to evaluate ET controller performance of multiple brands programmed to irrigate the same virtual landscape. Installation and data collection for these controllers were conducted using the same methodology previously described. The five brands tested in this virtual test were: A) Intelli-Sense (The Toro Company, Riverside, Calif.), B) SL1600 (Weathermatic, Garland, Tex.), C) Solar Sync (Hunter Industries, San Marcos, Calif.), D) ET System (Hunter Industries, San Marcos, Calif.), and E) ESP-SMT. All five brands were programmed for a virtual landscape described as bermudagrass in full sun on sand at a 0% slope. One brand of controller was replicated so that one device received optimized program settings using manufacturer suggestions such as custom sprinkler type, increased root zone depth, and daily water windows. The other device was restricted to two days per week and programmed solely using the landscape description. The other four brands of controllers were also programmed using the restricted settings. An irrigation timer with a fixed weekly schedule was installed for comparison to the ET controllers, also programmed under a restricted twice per week schedule using runtimes determined from monthly historical GIR. Results were presented anonymously with brand labels of R, W, X, Y, and Z.

Results and Discussion

Historical monthly ET_O ranged from 60 mm (January) to 178 mm (May) when considering 37 years as the historical average (fig. 4). The ET_O during the study period followed

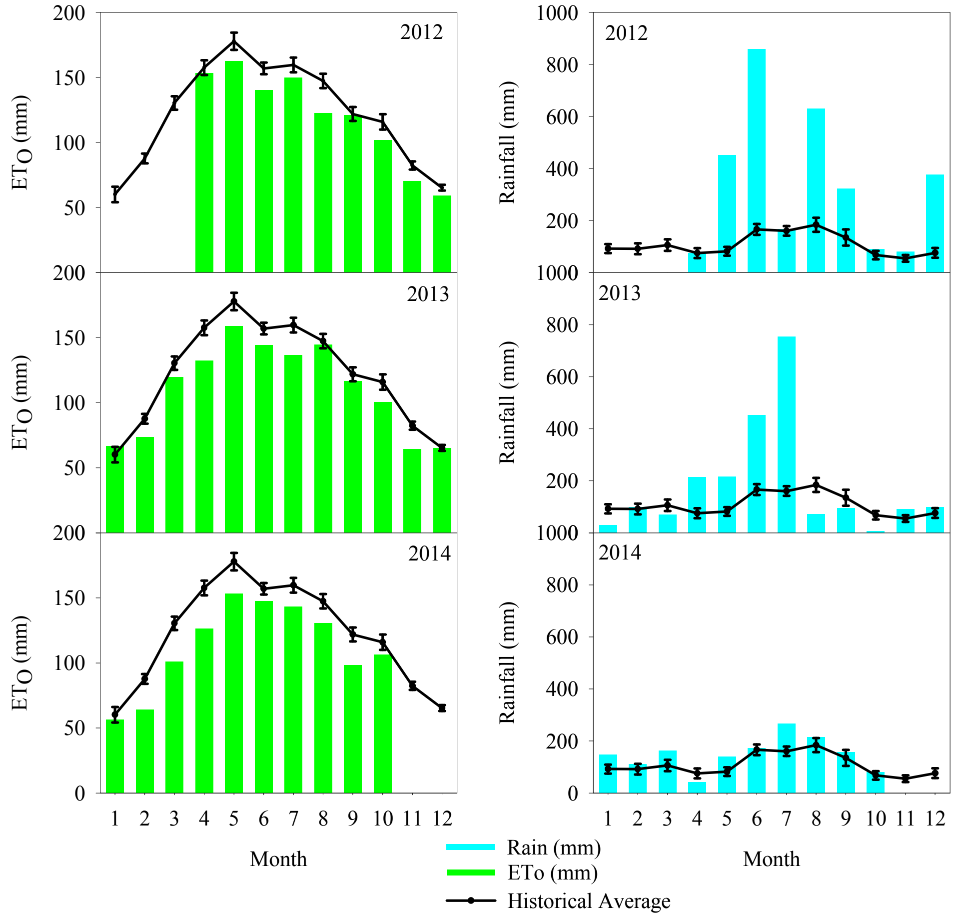

Figure 4. Monthly ET_O and rainfall during the study period was compared to the historical average ET_O and rainfall determined from 37 years of weather data collected from the weather station located at the Gainesville Regional Airport in Gainesville, Fla. The error bars represent the 95% confidence interval based on standard error.

the trend of the historical average, usually falling below the mean. Weather station data was checked for quality using the procedures described by ASCE (2005).

There was a total of 6,882 mm of rainfall occurring over the 31 months at the test site. A large amount of rainfall occurring in 2012 that were attributed to the following verified storm events:

- Tropical storm Beryl on 27-31 May 2012 (363 mm),
- Tropical storm Debbie on 24-26 June 2012 (653 mm),
- Unnamed storm on 19-21 August 2012 (343 mm),
- Hurricane Isaac on 26-29 August 2012 (126 mm),
- Unnamed storm on 10 December 2012 (183 mm).

Above average rainfall occurred in June and July of 2013 resulting in elevated rainfall totals for these months. In June, there were 11 rainfall events greater than 25 mm but less than 110 mm. Likewise, there were 16 rainfall events meeting this criteria in July. Historically, the rainy season falls within June through September, thus frequent rainfall during these months is normal. It is probable that the accuracy of the rain gauge was compromised due to the nature of the rainfall events, which can be for short durations of high intensity in this region (Habib et al., 2001; Ciach, 2003). However, any rainfall totals greater than the AWC are considered as runoff or deep percolation. Thus, it is more important to measure when the rainfall event occurred rather than accurately determining the depth of events greater than 25 mm for this virtual test.

Plant Type

There is an option in the ET controller settings for selecting a custom plant type instead of a pre-programmed plant type that allows for the selection of one K_C value, no longer changing on a monthly basis, and a user-specified root depth. In the central Florida smart controller study, the optimized setting for turfgrass was the custom plant type with a K_C of 0.6 to represent warm season turfgrass (Gibeault et al., 1989; Allen et al., 1998) and a root depth of 203 mm. Though a monthly K_C would have been preferable, there was not an option on the controller to keep the monthly K_C values while increasing the root depth. It was determined to be more important to increase the AWC, allowing for more storage of irrigation or rainfall, instead of slightly increasing or decreasing the estimate of ET_C by month using monthly crop coefficients.

Over the entire 31 month study period, irrigation application for the cool season turfgrass was not different from the custom plant type using the original firmware, averaging 71 and 72 mm, respectively (table 4). Given that the settings for the custom plant type were selected to

Table 4. Comparison of varying plant type settings for the Rain Bird ESP-SMT controllers averaged over 31 months.

Variable Setting Description	Crop Coefficients (K_C)	Root Zone Depth (mm)	Original Firmware Irrigation Application[a] (mm/month)	Updated Firmware Irrigation Application[b] (mm/month)
Cool season turfgrass	Varies monthly	76	71 *a*	82 *a*
Warm season turfgrass	Varies monthly	76	52 *b*	69 *b*
Custom	0.6	203	72 *a*	69 *b*

[a] Statistical significance is represented by letters within the column. Identical settings were full sun, loamy sand, and dense stand.
[b] Statistical significance is represented by letters within the column. Identical settings were full sun, sand, and medium stand.

Table 5. Comparison of varying plant type settings for the Rain Bird ESP-SMT controllers and the ESP-SMTe controller over 14 months.

Variable Setting Description	Crop Coefficients (K_C)	Root Zone Depth (mm)	Original Firmware Irrigation Application[a] (mm/month)	Updated Firmware Irrigation Application[b] (mm/month)	ESP-SMTe Irrigation Application[c] (mm/month)
Cool season turfgrass	Varies monthly	76	65 *a*	85 *a*	88 *a*
Warm season turfgrass	Varies monthly	76	44 *b*	69 *b*	70 *b*
Custom	0.6	203	69 *a*	74 *b*	69 *b*

[a] Statistical significance is represented by letters within the column. Identical settings were full sun, loamy sand, and dense stand.
[b] Statistical significance is represented by letters within the column. Identical settings were full sun, sand, and medium stand.
[c] Statistical significance is represented by letters within the column. Identical settings were full sun, sand, and medium stand.

represent a warm-season turfgrass, the lack of difference between the results for these two plant types was unexpected. However, the warm season turfgrass setting on the original firmware resulted in less irrigation application and was different from the other settings, averaging 52 mm. The results on the updated firmware, however, showed that the cool season turfgrass setting applied the most irrigation, averaging 82 mm, and was different from the warm season turfgrass and custom plant type, both applying 69 mm of irrigation. The results for the updated firmware showed that the custom plant type, representing a warm-season turfgrass, was not different in monthly irrigation application from the warm-season turfgrass setting.

When considering only the period when the ESP-SMTe controller was active, the pattern in differences for irrigation application based on plant type for both ESP-SMT controllers were the same (table 5). The ESP-SMTe applied 88 mm of irrigation for the cool season turfgrass setting. The cool season turfgrass setting was different from both warm season turfgrass and the custom plant type for the ESP-SMTe, applying 70 and 69 mm, respectively.

Though the Florida climate cannot support cool season turfgrasses as a perennial crop, it was included in the analysis because this default setting was found frequently on the controllers programmed by the contractor in the central Florida smart controller study. When the controllers were initially installed with the original firmware, the default setting of cool season turfgrass would not have resulted in increased irrigation compared to the custom settings. However, there would have been an increase in irrigation application as a result of the cool season turfgrass setting on the updated firmware. Also, there was an increase from a cool season turfgrass setting if the ESP-SMTe was used. There was no improvement by using the custom setting over the warm season turfgrass setting in the newer models. However, the ability to further optimize the program with a variable K_C for the custom plant type, reflecting true evapotranspiration estimates in Florida, may have further reduced irrigation application compared to both turfgrass settings.

MICROCLIMATE

Over the 31 month study period, both controllers with different firmware had differences between all four microclimates with monthly average irrigation application ranging from 38 to 78 mm for the original firmware and 46 to 77 mm for the updated firmware (table 6). This pattern was also observed for all three controllers evaluated over the 14 month period, with irrigation application by the ESP-SMTe ranging from 39 to 68 mm (table 7). This indicates that increasing the amount of shade would effectively reduce irrigation application of the zone for all controller models.

SOIL TYPE

It was expected to see a decreasing pattern in irrigation application from sand to loam due to a larger AWC

Table 6. Comparisons of various program settings for microclimate, soil type, and density settings for each panel over 31 months.

Variable Setting Description[a]	Original Firmware Irrigation Application (mm/month)	Updated Firmware Irrigation Application (mm/month)
Microclimate[b]		
Full Sun	78 *a*	77 *a*
25% Shade	63 *b*	66 *b*
50% Shade	56 *c*	54 *c*
75% Shade	38 *d*	46 *d*
Soil Type[c]		
Sand	68 *a*	75 *ab*
Loamy Sand	63 *ab*	77 *a*
Sandy Loam	59 *b*	70 *bc*
Loam	61 *b*	67 *c*
Density and Identical Settings		
Dense Custom[d]	65 *b*	82 *a*
Medium Custom	50 *c*	66 *b*
Dense Turfgrass[e]	55 *c*	96 *a*
Medium Turfgrass	57 *c*	74 *b*

[a] Statistical significance is specific to within each column and category for microclimate and soil type due to differences in settings other than the variable. Significance for density is specific to the category only.
[b] Identical settings for the original firmware were custom plant type (K_C = 0.6, root depth = 203 mm), loamy sand, and dense stand. Identical settings for the updated firmware were warm season turfgrass, loamy sand, and medium stand.
[c] Identical settings for the updated firmware were custom plant type (K_C = 0.6, root depth = 203 mm), 25% shade, and dense stand. Identical settings for the updated firmware were warm season turfgrass, full sun, and medium stand.
[d] Identical settings for both firmware were custom plant type (K_C = 0.6, root depth = 203 mm), 25% shade, and loamy sand.
[e] Identical settings for both firmware were warm season turfgrass, full sun, and loamy sand.

Table 7. Comparisons of various program settings for microclimate, soil type, and density settings for each panel over 14 months.

Variable Setting Description[a]	Original Firmware Irrigation Application (mm/month)	Updated Firmware Irrigation Application (mm/month)	ESP-SMTe Irrigation Application (mm/month)
Microclimate[b]			
Full Sun	74 *a*	71 *a*	68 *a*
25% Shade	59 *b*	62 *b*	56 *b*
50% Shade	50 *c*	51 *c*	47 *c*
75% Shade	36 *d*	42 *d*	39 *d*
Soil Type[c]			
Sand	61 *a*	75 *a*	70 *a*
Loamy Sand	59 *ab*	71 *a*	67 *ab*
Sandy Loam	54 *bc*	63 *b*	61 *bc*
Loam	52 *c*	63 *b*	57 *c*
Density and Identical Settings			
Dense Custom[d]	61 *b*	79 *a*	74 *a*
Medium Custom	41 *d*	62 *b*	53 *c*
Dense Turfgrass[e]	49 *B*	75 *A*	75 *A*
Medium Turfgrass	52 *B*	74 *A*	71 *A*

[a] Statistical significance is specific to within each column and category for microclimate and soil type due to differences in settings other than the variable. Significance for density is specific to the category only.

[b] Identical settings for the original firmware were custom plant type (K_C = 0.6, root depth = 203 mm), loamy sand, and dense stand. Identical settings for the updated firmware and ESP-SMTe were warm season turfgrass, loamy sand, and medium stand.

[c] Identical settings for the updated firmware were custom plant type (K_C = 0.6, root depth = 203 mm), 25% shade, and dense stand. Identical settings for the updated firmware and ESP-SMTe were warm season turfgrass, full sun, and medium stand.

[d] Identical settings for all controllers were custom plant type (K_C = 0.6, root depth = 203 mm), 25% shade, and loamy sand.

[e] Identical settings for all controllers were warm season turfgrass, full sun, and loamy sand.

allowing for more effective rainfall throughout the rainy periods. However, this was not seen over the 31 month period for either firmware option. Irrigation application for the ET controller with original firmware ranged from 59 mm for the sandy loam to 68 mm for the sand setting with no difference between loamy sand, sandy loam, and loam averages (table 6). For the updated firmware, there was no difference by changing the soil type from sand (75 mm) to loamy sand (77 mm) and no difference from sandy loam (70 mm) to loam (67 mm).

Over the 14 month period, there was a clearer decreasing pattern for the original firmware with irrigation ranging from 52 mm for the loam soil type to 61 mm for the sand soil type (table 7). There was no difference in average irrigation application by adjusting the soil type by one setting such as sand to loamy sand. The same pattern occurred with the ESP-SMTe with average irrigation application ranging from 57 to 70 mm for loam and sand, respectively. For the ET controller with updated firmware, there was no difference between the sand and loamy sand settings, applying 75 and 71 mm, respectively. There was also no difference between sandy loam and loam settings, both averaging 63 mm. There was, however, a difference between the two sets of settings with a decrease in average irrigation application for the heavier soils.

Density and Identical Settings

Both controllers reduced average irrigation application as a result of a medium setting compared to the dense setting for the custom plant type over the 31 month period (table 6). Because identical settings were used for all controllers evaluated for density differences, results can also be evaluated across controllers by plant type. Irrigation application ranged from 50 mm for the medium setting on the original firmware to 82 mm for the dense setting on the updated firmware for the custom plant setting. Thus, irrigation increased by 64% when the settings changed to dense using the updated firmware compared with the medium setting on the original firmware. The increase in irrigation application when changing the density factor from medium to dense was 30% and 37% for the original and updated firmware, respectively, despite an increased factor of only 20%. The updated firmware scheduled more irrigation than the original firmware for both density settings, thus contradicting the goal of water conservation.

According to the manufacturer, program settings of turfgrass were not supposed to be affected by the density setting. This was true for the original firmware with no differences in the two density options, averaging 57 and 55 mm for medium and dense settings, respectively (table 6). However, there was a difference in irrigation application for the updated firmware, averaging 96 mm for the dense setting and 74 mm for the medium setting. Just as with the custom plant type, the updated firmware had increased irrigation application compared to the original firmware.

When evaluating the 14 month period for all three controllers, there was a difference between density settings for the custom plant type (table 7). Irrigation application ranged from 41 mm (original) to 62 mm (updated) for the medium setting and 61 mm (original) to 79 mm (updated) for the dense setting. More irrigation occurred for the dense setting with the custom plant type than for the medium setting on all controllers. Just as in the 31 month period, irrigation application for the updated firmware was different from the original firmware, resulting in an increase in irrigation when settings were identical. There was no difference in irrigation application between the ESP-SMTe and the updated firmware.

As the manufacturer had stated, density was not considered for turfgrass during the 14 month period for any of the controllers (table 7). Similar to the results using the custom plant type, the original firmware, applying 49 mm (dense) to 52 mm (medium), was different from the other evaluated controllers, but there was no difference between the updated firmware, applying 74 mm (medium) and 75 mm (dense), and the ESP-SMTe, applying 71 mm (medium) to 75 mm (dense). These results also show that there was no difference between the updated firmware and the ESP-SMTe, but the original firmware applied less irrigation.

There were some results that were unexpected with the clearest example occurring with the difference in average irrigation application as a result of the density setting in turfgrass for the updated firmware (table 6). The manual recordings of the controller logs sometimes varied from the data logger output by small amounts due to measurement accuracy. The logger records to the second whereas the logs on the ET controller record to the closest minute. When controller data was substituted for logger data during periods when the logger data was unavailable, the differences were compounded for each month due to frequent and short irrigation events at high application rates. For example, a 2.7 min runtime at an application rate of 51 mm/h could be recorded by the controller as 3 min resulting in 11% error in irrigation application for one event. The accuracy of the data logger was verified in the lab. Thus, it is unknown whether the controller intended an irrigation event of 2.7 min and recorded as a whole number in the log or if the controller was inaccurate in timing a 3 min runtime.

In both periods of evaluation, irrigation application for the custom plant type was affected by the default density setting when compared to the warm season turfgrass setting (tables 4-5). The default setting for density was dense for the original firmware and medium for the updated firmware resulting in a higher density factor for a custom plant type with a dense stand (1.2) compared to warm season turfgrass on the original firmware (1.0), but was the same as warm season turfgrass on the updated firmware (1.0). This difference contributed to the increase in average irrigation application for the original firmware that did not occur for the updated firmware.

Comparison to Field Study Results

Two of the treatments in the central Florida smart controller study involved the comparison of the contractor-installed settings, determined to be default settings from when the controller initially receives power, and optimized settings selected by UF-IFAS that were specific to the landscape. All participants with ESP-SMT controllers in central Florida smart controller study utilized faceplate panels with the updated firmware. Generally, the changes made by UF-IFAS consisted of increasing the AWC through soil and plant types, decreasing the microclimate factor, selecting an appropriate sprinkler application rate and efficiency combination most closely representing the system in the field, and restricting irrigation events to three days per week instead of everyday. The cooperators that received the optimized programming also received an additional opportunity for learning about the ET controller through a one-on-one interaction to discuss its operation and ask questions.

Results from the central Florida smart controller study showed that the optimized programming reduced irrigation application compared to ET controllers with contractor defaults after 22 months of evaluation (Davis and Dukes, 2015b). However, none of the treatments performed with high efficiency in all seasons and neither of the ET controller treatments were able to maintain irrigation within the expected achievable to high efficiency range. In some cases, the ET controllers with default settings were unable to reduce irrigation from the comparison group (Davis and Dukes, 2015b), shown to over-irrigate by 6 to 8 times the GIR (Davis and Dukes, 2015a).

Over the 31 month controller virtual test in Gainesville, the default settings for the updated firmware applied 97 mm of irrigation, resulting in a difference from the optimized settings of the same firmware, applying 67 mm (table 8). However, the optimized settings for the original firmware resulted in more irrigation on average than the default settings, applying 65 and 53 mm, respectively, resulting in a difference. There was no difference between the firmware options when using the custom plant type.

Similar patterns occurred during the 14 month period where the default settings on the updated firmware applied the most irrigation, averaging 75 mm, with the optimized settings resulting in a reduction in irrigation application, averaging 62 mm (table 9). Once again, the original firmware had the opposite result where the optimized settings applied more irrigation than the default settings on the original firmware, averaging 61 mm and 41 mm, respectively. There was no difference in irrigation application for the default settings on the ESP-SMTe (75 mm) and the updated firmware. There was a difference in optimized settings, applying 52 mm, compared to the

Table 8. Comparison of irrigation application over a 31 month period for the default contractor settings and optimized program settings used during educational trainings that was typically implemented in the central Florida smart controller study.

Representative Soil Type	Settings	Panel	Plant Type	Micro-climate	Soil Type	Density	Irrigation Application (mm/month)[a]
Sand	Default	Original	Warm turfgrass	Full Sun	Sand	Dense	53 *c*
Sand	Optimized	Original	Custom	25% Shade	Loamy Sand	Dense	65 *b*
Sand	Default	Updated	Warm turfgrass	Full Sun	Sand	Dense	97 *a*
Sand	Optimized	Updated	Custom	25% Shade	Loamy Sand	Medium	67 *b*

[a] Statistical significance is represented by letters within the column.

Table 9. Comparison of irrigation application over a 14 month period for the default contractor settings and optimized program settings used during educational trainings that were typically implemented in the central Florida smart controller study.

Representative Soil Type	Settings	Panel	Plant Type	Micro-climate	Soil Type	Density	Irrigation Application (mm/month)[a]
Sand	Default	Original	Warm turfgrass	Full Sun	Sand	Dense	41 *d*
Sand	Optimized	Original	Custom	25% Shade	Loamy Sand	Dense	61 *b*
Sand	Default	Updated	Warm turfgrass	Full Sun	Sand	Dense	75 *a*
Sand	Optimized	Updated	Custom	25% Shade	Loamy Sand	Medium	62 *b*
Sand	Default	ESP-SMTe	Warm turfgrass	Full Sun	Sand	NA	75 *a*
Sand	Optimized	ESP-SMTe	Custom	25% Shade	Loamy Sand	Medium	52 *c*

[a] Statistical significance is represented by letters within the column.

default settings on the ESP-SMTe. There was also a difference between optimized settings of the ESP-SMTe and updated firmware indicating that the newest model of controller would be more water conservative if program settings were optimized.

All three ET controllers continued to apply more irrigation than required compared to the GIR for irrigation using a soil water balance (fig. 5). During periods of frequent rainfall, the GIR resulted in little to no irrigation (October to February 2014 and May to September 2014), totaling 502 mm of irrigation over 14 months. However, all three controllers continued to apply irrigation during those periods resulting in much higher cumulative totals than the recommendation. For the default programming, the updated firmware and the ESP-SMTe cumulatively applied 1,039 and 1,020 mm, respectively, both resulting in an increase of over 100%. The ESP-SMTe and the original firmware over-irrigated by 51%, totaling 760 mm, whereas the updated firmware over-irrigated by 71%, totaling 860 mm, for the optimized settings. It is clear that rainfall was a factor in overall irrigation application for these controllers.

Rain Bird provided new ET controller faceplate panels for all cooperators in the central Florida smart controller study after 29% of unsolicited cooperator feedback was concerning irrigation occurring too soon after rainfall events. Based on personal communication with Rain Bird representatives, there were two potential reasons for this issue. First, the algorithms associated with the incorporation of rainfall into the irrigation schedule required an update resulting in the need for updated firmware. In the original firmware, rainfall was not taken into account until the daily update occurring at midnight. This resulted in irrigation applied on the same day as rainfall even if the water window was scheduled after the rainfall event. The second reason is that the design of the debris screen covering the rain gauge can divert unsteady rainfall away from the tipping bucket thus recording less rainfall than actually occurred. This could be an error if rainfall totaled less than AWC.

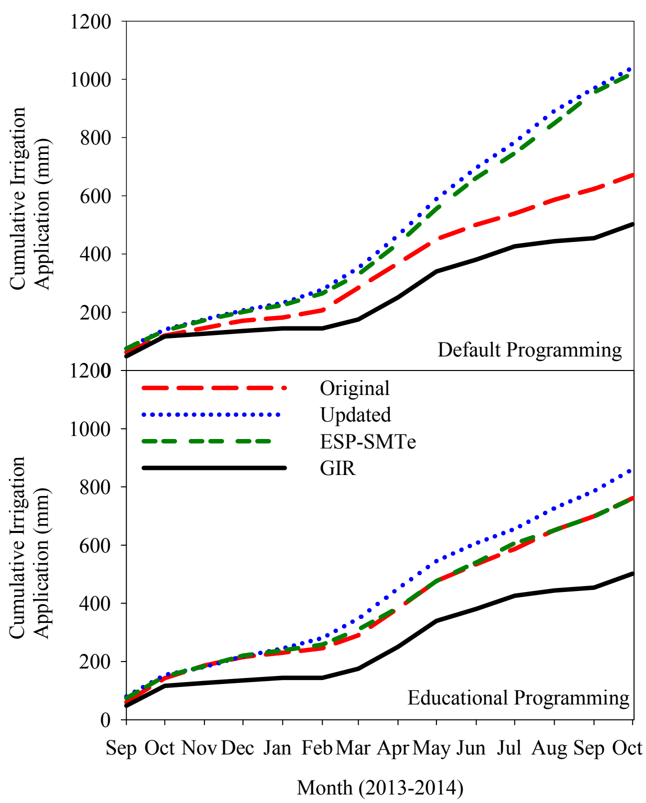

Figure 5. Cumulative irrigation application for all three controllers using default and optimized program settings compared to the GIR determined using a soil water balance (eq. 1).

When considering the low AWC and rainy climate common to Florida, the inaccuracies of measuring rainfall can be a large error in scheduling irrigation. The AWC for the sand soils used to calculate the GIR was 24 mm resulting in 12 mm of plant available water when considering a maximum allowable depletion of 50%. Thus, any rainfall event totaling 6 mm or more should result in delaying irrigation for at least one day. There were 346 rainfall events occurring over the 31 month period. Of these events, 49% were less than 6 mm, 13% were between 6 and 13 mm, 15% were between 13 and 25 mm, and 23% totaled more than 25 mm. Out of the 346 opportunities for irrigation to be delayed due to rainfall, there were only 57 instances where all events on both ESP-SMT controllers, regardless of firmware, refrained from irrigation. When considering only the updated firmware that takes rainfall into account on a sub-daily basis, a total of 62 rainfall events resulted in no irrigation with 73% of skipped irrigation events attributable to rainfall events greater than 6 mm. It is likely that the debris screen was the main source of error in accounting for rainfall due to so few rainfall events occurring during the water window and the few differences in the skipped irrigation events between the original and updated firmwares.

Two additional settings were factored into the optimized settings that could not be considered in this test. The sprinkler type setting selects the application rate to convert the calculated irrigation requirement to a runtime. In central Florida, the landscapes are flat and the utility provides good pressure in the 414 to 552 kPa range at the edge of the residential property. Thus, application rates were measured with frequent rates of 51 mm/h for spray nozzles and 25 mm/h for rotors, the two dominant sprinkler types (Davis and Dukes, 2012). However, the default rates are 41 and 11 mm/h, respectively, resulting in a longer runtime than required and over-irrigation. Restriction of the allowable irrigation days was not evaluated in this virtual test as well. This is a controller setting and not a zone setting thus it could not be evaluated with only one controller per model.

Independent Virtual Test of Multiple Brands

According to the GIR, there was 494 mm of irrigation required for this landscape despite 558 mm of rainfall occurring from 1 April 2010 through 1 September 2010 (fig. 6). The timer using the historical GIR schedule resulted in an overall cumulative total similar to the GIR, totaling 470 mm. However, all six ET controllers applied very different amounts of irrigation throughout this period, ranging from 17 to 620 mm, despite irrigating the same virtual landscape.

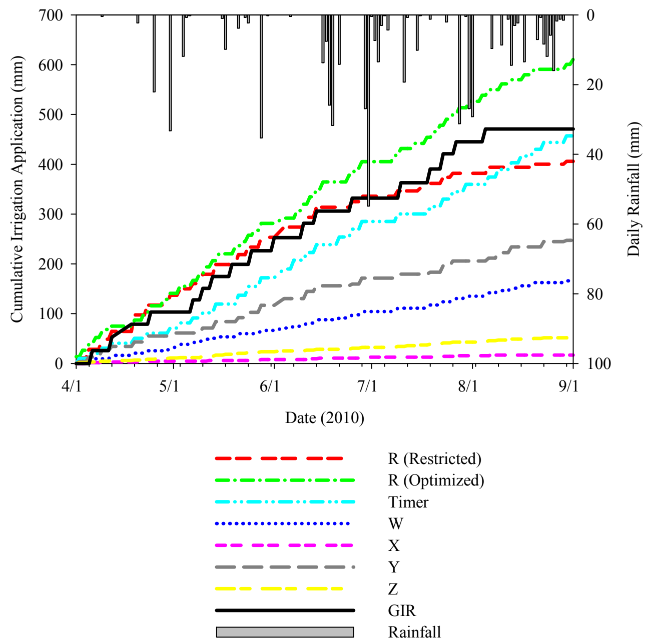

Figure 6. Cumulative irrigation was compared among five brands of ET controllers (labeled R, W, X, Y, and Z), an irrigation timer with a rain sensor, and the GIR determined using a soil water balance (eq. 1) for a landscape description of bermudagrass on a sand in full sun.

The optimized settings of the R controller resulted in increased irrigation application compared to the R controller with restricted settings, which included water windows occurring two days per week and the use of landscape descriptions for program settings. The program setting optimization in this independent virtual test corresponded to the results for the ESP-SMT controllers with the original firmware, but contradicted the results of the ESP-SMT controllers with the updated firmware (table 6). Additionally, the other four ET controllers of varying brands had highly variable irrigation schedules despite irrigating the same virtual landscape. Thus, it is important to have knowledge concerning the algorithms and values associated with the settings as well as the way the controller uses those values based on both the brand and model of ET controller to irrigate efficiently. The effect of the program settings on the irrigation schedule would be beneficial to the professional installer in effort to maximize the water conservation potential of the technology.

Conclusion

The newest Rain Bird ET controller, the ESP-SMTe, consistently applied similar amounts of irrigation as the ESP-SMT with updated firmware, indicating that controller updates were minor between the two models. Plant types specific to central Florida were not a factor in irrigation application. However, selecting a heavier soil type, increasing the shade, and selecting a medium stand when a custom plant type was chosen resulted in reductions in irrigation application. These two controllers were different from the ESP-SMT with original firmware since the newer models applied more irrigation with identical programming.

The optimized settings on both newer models, selected as a combination of custom plant type, heavier soil type, increased shade, and medium stand, resulted in a reduction in irrigation application compared to the default values. Combining these custom settings with accurate sprinkler application rates and restricted irrigation days could produce an even larger reduction. As a result, these custom setting selections continue to be the UF-IFAS recommended optimized settings for the Rain Bird ET controllers. However, an independent virtual test showed that selecting settings using a single landscape description (e.g., irrigation of St. Augustinegrass with spray heads on sand) resulted in highly variable irrigation totals, ranging from 17 to 620 mm, when evaluating multiple brands of ET controllers over an irrigation season. Thus, recommended settings cannot be generalized, making them specific to the ET controller brand and model. Despite the commitment of considerable time and effort, it is recommended that the user of the ET controller become familiar with the brand and model by observing the irrigation schedules after installation and adjusting the program settings to meet the needs of the landscape. Until manufacturers accept the benefits of increased technological adoption by end users from providing the algorithms behind the program settings, it would be advantageous to consult an irrigation professional or knowledgeable extension personnel to help with this process.

The accurate measurement and incorporation of rainfall into irrigation scheduling in Florida's humid climate is extremely important due to frequent and variable rainfall events. However, these controllers were unable to fully account for rainfall throughout the virtual test. This can easily cause over-irrigation of 51-100%+ above the GIR. Increasing the accuracy of rainfall accounting would be extremely beneficial to overall water conservation and efficiency. Adjusting options for settings to allow for tailored irrigation schedules, such as being able to automatically adjust crop coefficients when increasing the root depth would also contribute to improved efficiency.

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