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# Performance evaluation of urban turf irrigation smartphone app

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ABSTRACT

Data and technology are available to support a real-time irrigation smartphone app for turf that would result in more efficient irrigation scheduling which is needed to reduce water volumes applied and increase irrigation water conservation. Objectives were to (1) develop a turf irrigation smartphone app for warm season turf that would generate real-time irrigation schedules for users to program automatic timers and (2) evaluate app performance in regards to turf quality and water volumes applied with a field plot study. A smartphone app was developed and tested in a plot study in Homestead, Florida, USA, from December 2013 to November 2014. Study treatments included different irrigation scheduling methods: time-based schedule, smartphone app, and two on-site evapotranspiration (ET) controllers. Results indicated that the app and ET controllers resulted in significantly lower irrigation depths compared to the time-based treatment, ranging in water savings from 42% to 57%. The difference among the app and ET controllers was how rainfall was integrated into the schedule. Use of the seasonal water conservation model in the smartphone app is recommended to compensate for the lack of on-site rainfall measurements in the generated irrigation schedule.



## 1. Introduction

Urban irrigation accounts for 30–70% of residential per capita water use (FDEP, 2002). Haley et al. (2007) reported similar findings for Central Florida where 65% of total water used was for irrigation. Automated irrigation systems that are not adjusted based on weather conditions or seasonal fluctuations in plant water requirements have contributed to greater water volumes being applied on urban landscapes, resulting in a lower irrigation water use efficiency. Numerous studies have shown that water savings can be obtained with better irrigation practices which include use of rain sensors, soil water sensors (SWS), and evapotranspiration (ET) controllers to manage irrigation systems (e.g., Cárdenas-Lailhacar et al., 2008; McCready et al., 2009; Cárdenas-Lailhacar and Dukes, 2010). The premise behind these technologies is that irrigation schedules are modified based on rainfall, soil water content (i.e., SWS based), or weather conditions (i.e., ET-based). While implementation of rainfall sensors with automated irrigation systems is required by law in some states (e.g., California, Florida, Texas), they result in lower water savings (7–49%) compared to SWS (11–95%) and ET (20–79%) based irrigation scheduling methods (Dobbs et al., 2014). Thus, water conservation efforts in urban systems have shown greater savings with SWS based and ET based irrigation systems.

Soil water sensor based and ET controller irrigation systems are often referred to as "Smart" irrigation systems. Typical soil water sensor based irrigation systems in landscapes require a SWS that is connected to an automatic controller; information on soil water content is received and evaluated by the controller (Dukes, 2012). The SWS information is used to allow or not allow a scheduled irrigation event to occur. Likewise, ET controllers require installation of weather sensors, acquisition of real-time weather data and/or historical ET data with site specific information to determine and execute an irrigation schedule (Dukes, 2012). Both systems require the installation of equipment and knowledge on how to operate and maintain the equipment. These technologies improve irrigation by provided an irrigation schedule based on measured soil water content or weather parameters as compared to using a more static irrigation schedule. While the smart irrigation technologies provide efficient irrigation schedules and typically conserve water

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while maintaining plant health, there are limitations to their implementation. Smart irrigation systems have a greater initial investment cost and may require some training to setup or program as compare to a regular automatic irrigation controller.

The difference in using ET methods, as compared to SWS, to schedule irrigation is that weather data parameters (such as temperature, solar radiation, wind speed, and relative humidity which are used to estimate ET) are available in real-time – and are generally free and accessible. This is particularly true in the United States where data are often available on state and national levels. The primary limitations to using the data for irrigation are knowledge on accessing the data and applying it to a specific purpose. Another limitation is that while ET may be estimated fairly accurately using state and national weather stations for a specific location, rainfall estimates will likely be less accurate due to convection weather events, particularly in the southeastern United States (Boybeyi and Raman, 1992; Bosch et al., 1999). Rainfall and ET are the components of the water balance needed to develop the most accurate irrigation schedules using weather data.

The use of smart irrigation systems based on SWS and ET has not been widely implemented for residential turf irrigation. This is likely due to the cost of implementing the system, the time investment of finding equipment and contractors, lack of knowledge on how to properly operate the system, and apathy of some sectors of the population. An alternative approach is to provide users with an irrigation schedule specific to their system that is updated based on real-time information but does not rely on on-site instrumentation thus reducing initial costs and setup time. ET-based irrigation scheduling models offer this potential and have been widely developed for agricultural crops. For the past several years these types of models have been available via web-based interface but their adoption has been limited for a variety of reasons but primarily because they are data intensive and require the user to interact with them on a regular basis. Similar models have also been developed for irrigating turf for the homeowner and other public entities. These models have even lower adoption rates than agricultural models. The overall goal of the work reported here was to develop a novel ET-based irrigation scheduling tool for warm season turf that requires minimal interaction from the end-user, is delivered to the user via a smartphone platform, and outperforms many other irrigation scheduling tools. Our specific objectives were to (1) develop a turf irrigation smartphone app for warm season turf that would generate real-time irrigation schedules for users to program automatic timers and (2) evaluate app performance in regards to turf quality and water volumes applied with a field plot study.

## 2. Methods

### 2.1. Turf irrigation smartphone app

The turf irrigation app was designed to calculate irrigation schedules or the time an irrigation system should operate given minimum user inputs and real-time weather data. Default values are available for most inputs but users have the option to modify these based on their knowledge of the irrigation system. The app framework includes input screens that are organized by system and zone where system represents a particular irrigation system/controller and the zones refer to the zones within that particular system. Typically, landscape irrigation systems are divided into zones where each zone should represent a particular plant type(s) with similar water requirements. The turf app currently includes cool season turf, warm season turf, annual flowers woody plants and herbaceous perennials for wet and dry environments and desert plants. The app allows 10 systems with up to 10 zones each.

**Table 1**
Field capacity (FC) and wilting point (WP) by soil type (Zotarelli et al., 2010).

| Soil type | FC | WP |
|---|---|---|
| Sand | 0.08 | 0.02 |
| Sandy loam | 0.16 | 0.06 |
| Loam | 0.26 | 0.08 |
| Silt loam | 0.31 | 0.10 |
| Clay loam | 0.34 | 0.14 |
| Clay | 0.37 | 0.16 |

The system input screen requires identification of the location (latitude and longitude using a movable pin and the user's current location), naming of the system, and identification of soil type and root depth. Soil type and root depth selections provide information that is used in the irrigation calculations. Specifically, soil type is assigned field capacity values (Table 1). Root depth has a default value of 12 in (30.5 cm; note all values in the app are in English units as preferred by the end user).

The zone input screen is specific to each zone. Inputs include a description (or name), sprinkler type, rate, area, week events (or days to irrigate), and water conservation mode. The sprinkler types are associated with a default irrigation rate (in/h) which is adjustable by the user. The different sprinkler types are micro, spray, multi-stream spray, gear driven rotors, and impact with default rates of 0.5 in/h (1.27 cm/h) for all systems except spray which is 1.5 in/h (3.81 cm/h) (Fig. 1). Irrigation rates can be determined using a catch can approach for each zone; otherwise, default values for each sprinkler type can be assumed. The area value input by the user is used to calculate gallons of water saved using the app as compared to a standard 2-day-a-week irrigation practice of 0.75 in (1.91 cm) per event. The user must also select the days of the week on which irrigation will occur. For many locations, this would be designated based on local irrigation restrictions. We recommend no more than three days a week being selected for irrigation.

The water conservation mode was added as research has shown that warm season turf may not need to be irrigated to field capacity but rather may have sufficient water when irrigated at a deficit (Lu et al., 2013). The three options are normal, seasonal water conservation, and annual water conservation (Fig. 1). Normal refers to an irrigation schedulebased on refilling the soil profile to field capacity. Thus, "normal mode" includes no deficit irrigation. The seasonal water conservation option results in a reduction in irrigation by 25% when rainfall exceeds ET for the previous 15 days. The annual water conservation option provides an irrigation schedule with a 25% deficit from field capacity year-round (see Fig. 2).

Considering the user inputs, irrigation schedules are generated using real-time weather data from Florida Automated Weather Network (FAWN) and the Georgia Environmental Monitoring Network (GAEMN). Thus, the smartphone app is currently applicable to Florida and Georgia. Temperature, solar radiation, relative humidity, and wind speed with the FAO Penman Monteith equation (Allen et al., 1998) are used to generate a daily reference ET (ETo). Reference ET is modified to crop ET (ETc) using crop coefficients (Kc; Table 2). The app defines this relationship as:

$$\mathrm{ET}_c = K_c \mathrm{ET}_o \quad (1)$$

Irrigation schedules are calculated considering user input and real-time weather data. The irrigation schedule generated is based on average crop ET for the previous 5 days. This value is translated into minutes of irrigation time considering the irrigation rate input by the user. The app alerts the user if the information provided results in an irrigation schedule that exceeds soil water holding capacity. The app will not generate a schedule where an irrigation event would exceed soil water holding capacity. Every 15 days, a

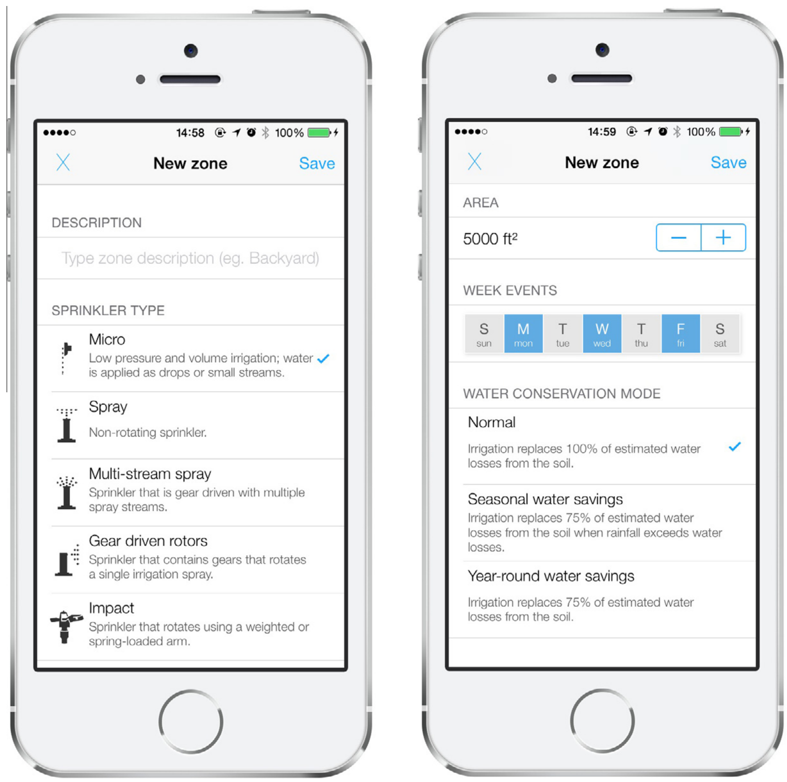


**Fig. 1.** Screenshots of turf app showing sprinkler type and water conservation mode selection screens.

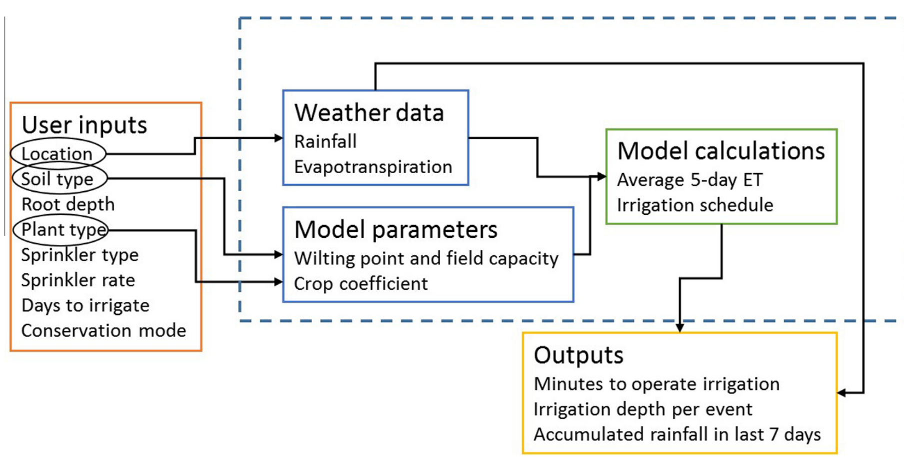


**Fig. 2.** A schematic of the app model with inputs and outputs, the dashed line encompasses the app internal components.

new irrigation schedule is sent to the user via a notification. Notifications are sent prior to the 15 day period if the previous 5 day average ET varies more than 50% from the 5 day average ET used in the previously sent irrigation schedule (see Fig. 3).

Dormancy of the crop is also considered in the turf smartphone app. Dormancy in warm season turf is assumed to occur if three or more days within the previous five days had an average temperature less than 16 °C. When this occurs, the user is sent this alert, "Temperatures in your area suggest that grass is dormant. Irrigation is likely not needed unless there is a prolonged period of no precipitation."

FAWN and GAEMN stations do not adequately represent the spatial variability of rainfall in Florida and Georgia. Thus, we do not include rainfall in the irrigation calculation for developing the schedule. The app does, however, send notifications to users when rainfall has occurred at the weather station registered as closest to their irrigation system and when rainfall is forecasted to occur with over 60% probability for their irrigation system location. Forecast data used is from the National Weather Service (2014).

The smartphone app was developed using native programming languages and tools for each platform: Objective C, xCode and iOS SDK for iOS; Java, Eclipse and Android SDK for android available at https://developer.apple.com/ios/ and https://developer.android.com/ respectively. The app programming follows the MVC (Model-view-controller) software architecture pattern in both platforms. The weather data from different sources (FAWN, GAEMN and NWS) are obtained using PHP (Hypertext Preprocessor) Web Services which return the data for the requests made by the apps in JSON (JavaScript Object Notation) format.

**Table 2**
Crop coefficients (Kc) used in the smartphone app calculations.

| Month | Kc North Florida[a] | Kc Central Florida[b] | Kc South Florida[c] | IA[d] Kc Georgia |
|---|---|---|---|---|
| January | 0.35 | 0.45 | 0.71 | 0.52 |
| February | 0.35 | 0.45 | 0.79 | 0.64 |
| March | 0.55 | 0.65 | 0.78 | 0.70 |
| April | 0.80 | 0.80 | 0.86 | 0.73 |
| May | 0.90 | 0.90 | 0.99 | 0.73 |
| June | 0.75 | 0.75 | 0.86 | 0.71 |
| July | 0.70 | 0.70 | 0.86 | 0.69 |
| August | 0.70 | 0.70 | 0.90 | 0.67 |
| September | 0.75 | 0.75 | 0.87 | 0.64 |
| October | 0.70 | 0.70 | 0.86 | 0.60 |
| November | 0.60 | 0.60 | 0.84 | 0.57 |
| December | 0.45 | 0.45 | 0.71 | 0.53 |

[a] Jia et al. (2009).
[b] Davis and Dukes (2010).
[c] Romero and Dukes (2011).
[d] Irrigation Association (2008).

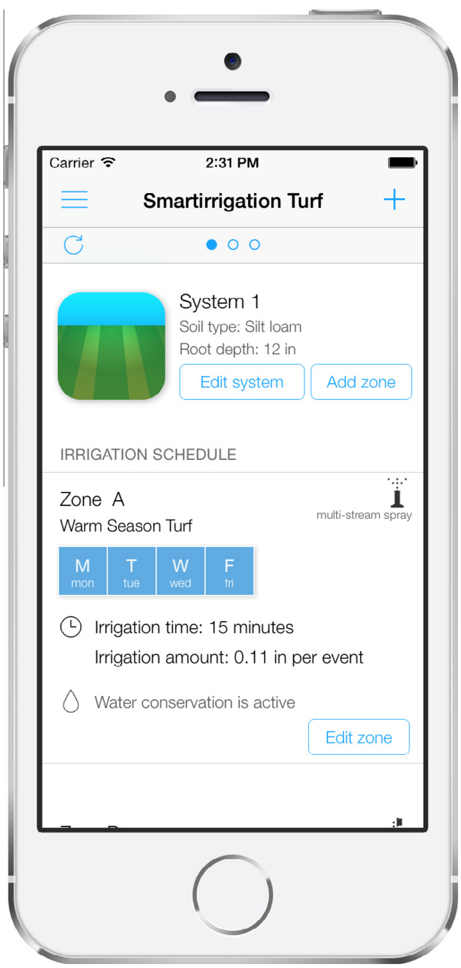


**Fig. 3.** Screenshot of turf app showing irrigation schedule output.

An UNIX based server is used to store using a MySql database and process data for the app, the operating system Crontab program automates calculations required to address daily changes in estimated water demands for each system registered by Smartirrigation Turf app users as to send recommendations of schedule changes via push notifications using APNS (Apple Push Notification Service) and GCM (Google Cloud Messaging) services.

A diagram of interaction between client (app), server and automated weather stations covering the complete system operation is shown in Fig. 4.

## *2.2. Plot study*

A plot study was initiated to evaluate the app performance at the University of Florida Institute of Food and Agricultural Sciences, Tropical Research and Education Center in Homestead, Florida (latitude: 25°30′24″N longitude: 80°29′57″N). South Florida is characterized by a sub-tropical climate with dry and wet seasons; warm season grasses grow year-round at the study site location. Plots consisted of 20.9 $m^2$ with 0.61 m buffers between plots. Plots had established St. Augustine grass (*Paspalum notatum*) with a quarter-circle pop-up irrigation head in each corner (four per plot) with matched precipitation (MP) rotator nozzles (Hunter Industries, Inc., San Marcos, CA, USA). Average irrigation rate from catch can tests was 10 mm/h (0.4 in/h). Water volumes applied were measured for each plot using DLJ multi-jet water meters (Daniel L. Jerman Co., Hackensack, NJ, USA). Volumes were recorded manually after each irrigation event for each treatment replicate (i.e., total of 16 water meters as there were four replicates). The experiment consisted of four treatments (T1–T4: automatic timer, automatic timer with smartphone app irrigation schedule, automatic timer with ET controller 1, and automatic timer with ET controller 2, respectively) arranged in a randomized block design. All treatments followed the local watering restrictions of two days a week, Sunday and Thursday. Automatic timer treatment where scheduled to irrigate 19 mm (0.75 in) per event based on catch can rates. Data were collected from December 2013 to November 2014. An Onset Rain Gauge (tipping bucket style; Cape Cod, MA) was installed for measuring rainfall at the study site.

The automatic timer with app treatment irrigation schedule was modified according to the schedule submitted by the app. This included the minutes to operate the system, and rainfall and forecast notifications. The app inputs selected were sandy loam, 102 mm (4 in) root depth, multi-stream spray sprinkler type, 10 mm/h (0.4 in/h), 464.5 $m^2$ (5000 $ft^2$) area, and normal mode for water conservation. The inputs have minimum and maximum values assigned for inputs which is why the 102 mm root depth was selected (i.e., this is the minimum root depth allowed in the app).

Two ET controllers were used in this study as two different treatments. ET controller 1 treatment (i.e., treatment 3) was a Rain Bird ESP EMTe (Rain Bird Inc., Tucson, AZ). Irrigation was halted for one full day if over 10 mm (0.4 in) of rain was measured for ET controller 1. ET controller 1 also features an irrigation function that allowed the setting of the maximum allowed depletion before irrigation would occur; this was set to 45% of plant available water or 4 mm (0.16 in). The Rain Bird controller included real-time measurement of temperature and effective rainfall (Rain Bird, 2013). ET controller 2 treatment (treatment 4) was a Hunter ET System. The Hunter ET controller (Hunter Industries, San Marcus, CA) had a small weather station with real-time measurement of rain gauge, solar radiation, air temperature, and relative humidity. Both ET controllers used some form of the Penman Monteith equation (Monteith, 1965) to calculate reference ET and allowed for customization of crop coefficients such that both ET controller treatments and the app treatment used the same crop coefficient (i.e., South Florida, Table 2). Both controllers were programmed to irrigate on Sunday and Thursday (ET controller 1 at 3:30 am; ET controller 2 at 5:30 am). Remaining input parameters for the ET controllers were selected as close as possible to site conditions (Table 3). ET controllers determined irrigation schedules (or run times) based on an internal algorithm that considered water losses

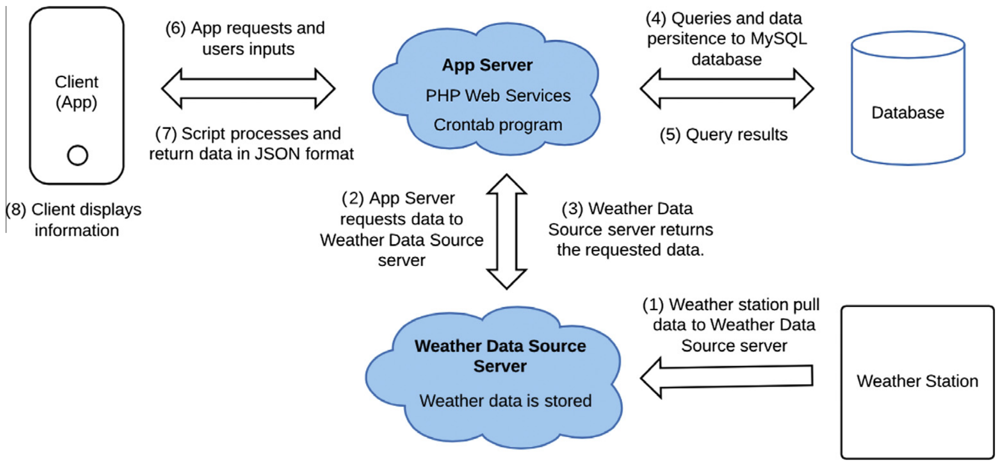


**Fig. 4.** Diagram of interaction among client, server and automated weather stations.

**Table 3**
Information used in programming the ET controllers.

| Input description | ET controller 1 | ET controller 2 |
|---|---|---|
| Wind speed | Monthly averages | Annual average value |
| Relative humidity | Monthly averages | Measured by sensor |
| Soil type | Sandy loam | Sandy loam |
| Sun exposure | Full | Full |
| Irrigation rate[a] | 0.46 in/h | 0.42 in/h |
| Slope | 0–2% | 0% |
| Rooting depth | 3 in | |
| Crop type | Warm season grass | St Augustine grass |
| Sprinkler type | Rotary nozzles | Custom |

[a] The irrigation rate used was measured in the four plots and averaged for each treatment.

through ET and water gains by effective rainfall. Thus, the amount of irrigation applied varied by irrigation event depending on the accumulated difference between ET and effective rainfall.

The proximity of the study site to the FAWN station (<1 km) used by the smartphone app suggested that ET at the study site would be similar to that at the FAWN station. Reference ET was compared using data from FAWN to generate FAO Penman Monteith and that reported by ET controller 1 (which provided a weather log of daily reference ET values). ET controller 2 displayed crop ET but personnel was not available to record this information on a daily basis and a record was not stored in the controller.

The turf app and ET controllers were dependent on ET and rainfall to develop irrigation schedules. Rainfall was included in the schedule differently by each treatment (Table 4). Rain depths collected at the study site were used to evaluate the accuracy of the notifications sent by the app and the functionality of the ET controllers. Rainfall from the on-site tipping bucket was also compared to that reported by ET controller 1.

Treatments were compared in terms of water volumes applied per event. Statistics were performed using either a one-way analysis of variance (ANOVA) (parametric; normally distributed data) or Kruskal–Wallis one way ANOVA on ranks (nonparametric; non-normally distributed data). Steel–Dwass–Critchlow–Fligner procedure was used to identify significant differences among treatments ($p < 0.05$).

Turf plots were evaluated for quality using a survey form. Turfgrass quality was evaluated on a scale from 1 (worst) to 9 (best) in regards to genetic color, turfgrass density, percent living ground cover, and texture. A survey was conducted at the end (December 2014) and turf grass was uniform at the beginning of the study.

## 3. Results and discussion

Irrigation amounts applied were primarily dependent upon ET for treatments 2, 3, and 4. FAWN data (from Homestead, FL approximately <1 km from study site) were used by the app to calculation FAO Penman Monteith reference ET which was converted to crop ET using the monthly crop coefficient to generate an irrigation schedule (treatment 2). ET controller 1 (treatment 3) also reported ETo in its weather output feature. Insufficient data were recorded from ET controller 2 (treatment 4) for comparison. The reference ET values used for treatments 2 and 3 were compared with historical averages (Table 5). The ETo demand for the study period was very similar to the historical trend for the site.

Results showed some variability between FAWN and the ET controller ETo values which could be attributed to differences in the measured values used in the calculations. ET controller 1 uses historical averages for relative humidity and wind speed while the FAWN based estimate (and smartphone app) uses real-time measured values for these two parameters. If irrigation were based solely on accumulated ETo (not including rainfall or site restrictions), the difference in depth applied would be 77 mm (or 6%). Rutland and Dukes (2014) also reported that an ET controller that

**Table 4**
Methods used to integrate rainfall into irrigation schedules.

| Treatment 1<br>Automatic timer | Treatment 2<br>Smartphone app irrigation schedule | Treatment 3<br>ET controller 1 | Treatment 4<br>ET controller 2 |
|---|---|---|---|
| No action for rainfall; irrigate as scheduled | • Notifications of rainfall events 24 h prior to a scheduled irrigation event<br>• Notification if there is over a 60% probability of rainfall on the day of a scheduled irrigation event | • Rainfall setting that indicates a hold on irrigation for 24 h after receiving 0.4 in rain<br>• Requirement of 55% depletion of plant available water before irrigating<br>• Controller subtracts effective rain from the demand measured as crop ET when developing the irrigation schedule | • Rain sensor pauses irrigation if rainfall is detected; resumes after rainfall ends if needed to fill deficit<br>• Controller subtracts effective rain from the demand measured as crop ET when developing the irrigation schedule |

**Table 5**
Florida Automated Weather Network (FAWN) historical averages, FAWN study period, and ET controller 1 reference evapotranspiration (ETo) data.

| Month | FAWN historical average (mm)[a] | FAWN study period (mm)[b] | ET controller 1 (mm)[b] |
|---|---|---|---|
| December 2013 | 72 | 63 | 73 |
| January 2014 | 82 | 61 | 72 |
| February 2014 | 114 | 87 | 88 |
| March 2014 | 131 | 120 | 119 |
| April 2014 | 144 | 139 | 141 |
| May 2014 | 129 | 154 | 143 |
| June 2014 | 129 | 119 | 140 |
| July 2014 | 126 | 123 | 146 |
| August 2014 | 107 | 132 | 141 |
| September 2014 | 102 | 104 | 112 |
| October 2014 | 78 | 103 | 107 |
| November 2014 | 69 | 78 | 78 |
| Total | 1284 | 1283 | 1360 |

[a] FAWN weather parameters were used to calculate FAO PM ET from 2008 to 2014 for historical averages and from December 2013 to November 2014 for the study period.
[b] The study period was December 2013 to November 2014.

used only site temperature measurements over predicted reference ET from 9 to 15% for the site location.

Rainfall measured at the study site is reported with historical averages, FAWN rainfall data, and rainfall recorded by ET controller 1 (Table 6). The FAWN and site rainfall values were more similar than that measured by ET controller 1. ET controller 1 had lower rainfall measurements for most months. Review of the data suggested that the ET controller 1 did not record rainfall for some events. However, when rainfall was recorded the difference from measured was on average 10%.

Irrigation depths applied resulted in significant water savings with the smartphone app and ET controller treatments (Table 7); irrigation water savings ranged from 42% to 57% compared to the time based schedule. Others have reported water savings using ET controllers (Devitt et al., 2008; McCready et al., 2009; Davis and Dukes, 2014). Dobbs et al. (2014) conducted a field study at the same location with bahiagrass and reported a 70% water savings using an ET controller with a similar time-based rate. The variation between water savings reported by Dobbs et al. (2014) and that measured in this study are likely due to differences in weather conditions, turf type, and ET controller used. Thus, irrigation scheduling with an ET controller will result in different savings depending on the application, technology used, and weather conditions.

The turf smartphone app irrigation schedule was similar to the ET controllers with savings always significantly greater than the time-based treatment with varying similarities to the two ET controllers. One difference observed between the app and ET controller schedules was found in the seasonal comparisons where both ET controllers had a greater irrigation rate during the dry season while the app had a greater irrigation rate during the wet season. Both ET controllers included a measurement device for rainfall which was included in the irrigation schedule generated while the app relied on the user to turn on and off the irrigation based on notifications. During the study period 7 notifications were received from the app indicating a rainfall event had occurred within 24 h of a scheduled irrigation event and 10 notifications were received that the probability of rainfall on a scheduled irrigation day was over 60%. Of these events, the system was turned off 7 times. Rainfall was received on 8 of the 10 dates for which it was predicted to occur. Failure to turn the system off was due to lack of available personnel near the system. ET controller 1 and ET controller 2 also did not irrigate on some scheduled days with 3 and 8 irrigation events not occurring for each system, respectively. The dates for irrigation events being bypassed by a controller or the app varied. If irrigation for the app treatment had been turned off, the average irrigation volume would still have been 10 mm however wet season average would have been 11 mm (Table 7).

Results showed that ET controller 1 reported a greater ETo and a lower rainfall for the study period as compared to site measurements; however, ET controller 1 (treatment 3) applied less irrigation than the other ET-based treatments. This suggests that an

**Table 6**
Florida Automated Weather Network (FAWN) historical averages, FAWN study period, and ET controller 1 rainfall data.

| Month | FAWN historical average (mm)[a] | FAWN study period (mm)[a,b] | ET controller 1 (mm)[b] | Rainfall at site (mm) |
|---|---|---|---|---|
| December 2013 | 38 | 57 | 44 | 60 |
| January 2014 | 37 | 76 | 83 | 85 |
| February 2014 | 47 | 63 | 11 | 70 |
| March 2014 | 48 | 53 | 37 | 53 |
| April 2014 | 88 | 38 | 6 | 41 |
| May 2014 | 148 | 94 | 95 | 96 |
| June 2014 | 190 | 251 | 197 | 251 |
| July 2014 | 179 | 261 | 210 | 260 |
| August 2014 | 237 | 105 | 101 | 84 |
| September 2014 | 182 | 130 | 112 | 112 |
| October 2014 | 115 | 85 | 54 | 96 |
| November 2014 | 59 | 39 | 51 | 50 |
| Total | 1369 | 1251 | 1000 | 1268 |

[a] FAWN rainfall data historical average from 2008 to 2014 with FAWN study period from December 2013 to November 2014.
[b] The study period was December 2013 to November 2014.

**Table 7**
Irrigation water depths applied (mm) per treatment and season with significant differences.

| Treatment | All data | | Dry season | | Wet season | |
|---|---|---|---|---|---|---|
| | Total | Avg/event | Total | Avg/event | Total | Avg/event |
| Time based | 2109 | 20a | 1031 | 20a | 1078 | 21a |
| App | 1086 | 10bc | 467 | 9b | 619 | 12c |
| ET controller 1 | 898 | 9b | 460 | 9b | 438 | 8b |
| ET controller 2 | 1222 | 12c | 696 | 13c | 525 | 10bc |

Significant differences are identified different letters ($\alpha = 0.05$).

internal calculation that includes rainfall results in the lower schedule for ET controller 1 as the app does not directly include rainfall and this information was not recorded for ET controller 2. Note that overall, the irrigation depths applied were not significantly different for the app and ET controller 1 for all data and dry season data. The difference observed during wet season may be due to the different methods of integrating rainfall into the irrigation schedule for these two treatments. ET controller 2 also showed significant water savings as compared to the time based treatment and was statistically similar to ET controller 1 during wet season. This similarity may be due to both ET controllers having an on-site tipping bucket style measurement which was included in the irrigation schedule.

Overall the smartphone app performed similar to that of the ET controllers and provides an alternative for users where an ET controller is not a viable option. One limitation of the app is the exclusion of site-specific rainfall. Another limitation is that the app is not directly connected to the automatic irrigation controller so the user must manually implement a schedule change at the controller. As was noted in this study, this is not always possible. Thus, some notifications for bypassing irrigation events due to predicted or measured rainfall may not be implemented in the irrigation schedule by the user. Direct operation of the automatic controller by the app would likely improve water savings. The seasonal water conservation option on the app would provide some incorporation of rainfall into the schedule. For our study, using this feature would have resulted in a reduction in irrigation to 989 mm from 1086 mm with seasonal totals of 568 mm for wet season and 421 mm for dry season. Thus, the lack of on-site rainfall data can be minimized by using the seasonal water conservation mode in the smartphone app.

Turf grass quality per plot was evaluated and compared using a value scale from 1 to 9 among treatments for genetic color, turf grass density, percent living ground cover, and texture with no significant differences were observed. For all characteristics evaluated and all treatments, variability was low with average values ranging from 7.8 to 8.4. This finding supports the use of lower irrigation amounts to maintain turf grass quality using weather-based approaches such as the turf app and ET controllers.

## 4. Conclusions

A smartphone app was developed for generating site-specific irrigation schedules using real-time weather data and an ET based approach. The app offers the convenience of alerting users when irrigation changes are needed using real-time and forecast weather data. Since these recommendations are sent via push notifications, users are informed when changes are necessary providing useful interaction without overburdening with information.

A plot study showed that the app-based schedules were similar to that of an on-site ET controller. Significant differences (water savings) were observed between the ET controllers and the app as compared to that of a time-based schedule. Water savings using the app was 48% as compared to the time-based schedule. While the app treatment total irrigation depth was greater during wet season than the ET controller 1 treatment depth, if the seasonal water savings option had been used there would have been a 51 mm reduction in irrigation applied.

Results support the use of the app technology for scheduling irrigation to better reflect plant water needs while maintaining plant quality as compared to a time-based schedule. Limitations of the app in regards to including rainfall in the schedule can be minimized by using the seasonal water conservation setting which reduces the irrigation schedule when rainfall exceeds ETc.

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