SOIL MOISTURE SENSOR IRRIGATION CONTROLLERS AND RECLAIMED WATER;
PART II: RESIDENTIAL EVALUATION

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emerging technologies for sustainable irrigation

A Tribute to the Career of
Terry Howell, Sr.

ABSTRACT. *Water savings potential of soil moisture sensor irrigation control technologies have not been reported in homes irrigating with reclaimed water (RW). The main objective of this research was to evaluate the performance and water conservation potential of a soil moisture sensor system (SMS) in homes that used RW as their source for irrigation, as compared to homes with irrigation timers only, or to homes with educational materials and/or rain sensors. Secondary objectives were to: a) estimate the water depth applied by the different technologies compared to a theoretical requirement (calculated using a daily soil water balance), and b) estimate the effects of local watering restrictions on the amount of RW used by homeowners. In the vicinity of Palm Harbor, Florida, a total of 64 homes supplied with reclaimed water for irrigation (with an average salinity of 0.7 dS/m) were selected for this study. Dedicated irrigation flowmeters were installed in every home. The 64 homes were divided in 4 treatments with 16 homes each. Treatments were: MO (monitored only), SMS, rain sensor, and rain sensor plus educational materials. The SMS treatment was the only group of homes significantly different to MO, reducing the average number of irrigation events per week (1.7 vs. 2.7 events/week, respectively), decreasing the depth of the weekly irrigation (22 vs. 42 mm, respectively), and applying 44% less water, over the 32 months of data collection. These results indicate that the tested SMS can save a significant amount of RW, compared to the other methods/technologies investigated. Even when all treatments over-irrigated most of the time, SMS irrigated most properly, compared to a theoretical requirement. Finally, under severe dry weather conditions, the local watering restrictions promoted a more efficient use of the RW.*

Keywords. *Irrigation scheduling, Irrigation water, Potable water, Reclaimed water, Rain sensor, Soil moisture sensor, Turf quality, Turfgrass, Water use.*

Smart irrigation controllers such as soil moisture sensor systems (SMSs) have proven that they can save significant amounts of water in controlled turfgrass plots under normal/wet weather and, even, under dry weather conditions. These water savings have been achieved without a decline in the turfgrass quality (Cardenas-Lailhacar et al., 2008, 2010; McCready et al., 2009; Cardenas-Lailhacar and Dukes, 2012; Grabow et al., 2013). Haley and Dukes (2012) reported that the homes with an SMS in the same area as this study, applied 65% less water than the homes without sensor feedback. These savings were achieved despite the lower than normal precipitation during the 26-month study, and without a detrimental effect to the turfgrass quality.

Different projects outside of Florida have also tested SMSs under residential settings. In an early study in Utah, Allen (1997) reported that residences with an SMS applied 10% less water compared to the control group. Likewise, in North Carolina, Nautiyal et al. (2014) reported that the SMS group applied 42% less water than the homes in the control group, again, without detriment to the turfgrass quality.

To assess the amount of over- or under-irrigation, some studies have compared the water applied by homes equipped with an SMS to a theoretical irrigation requirement, as established by a daily soil water balance. In Colorado, Qualls et al. (2001) installed granular matrix SMSs in residences, which resulted in 27% less water applied than the theoretical requirement. In Pinellas County, Florida, homes equipped with an SMS appeared to drastically under-irrigate; however, turf quality was not different than the other treatments that irrigated in greater quantity and frequency (Haley and Dukes, 2012). In

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Orange County, Florida, properties decreased by 44% their historical to gross irrigation requirement ratio after installing an SMS (Davis and Dukes, 2015).

All the previous studies have been performed with potable water, but no study has reported the performance of SMSs under reclaimed water (RW) irrigation. Florida and California are the highest RW users in the United States, with 2.5 and 2.2 Mm^3/day, respectively, followed by Texas with just 0.1 Mm^3/day. However, Florida more than doubles California when considering the per capita use, with 140 versus 61 l/day/person, respectively, and is more than 27 times higher than the 5 l/day/person of RW use in Texas (WateReuse Association, 2008; FL-DEP, 2014).

In many municipalities of Florida where water supplies are limited, RW is being increasingly used for irrigation purposes. In Florida, the main users of RW in 2005 were 201,465 residences, followed by 572 parks, 462 golf courses, and 251 schools (FL-DEP, 2014). All the residences using RW in Florida have an automatic irrigation system to justify the cost of the initial connection. It has been reported, though, that automatic irrigation systems use on average 47% more potable water than non-automatic systems in the United States (Mayer et al., 1999). In Florida, most of the residences have no dedicated flowmeter installed to measure the volume of RW used through time; thus, a low fixed cost per month is charged to homeowners, independently of their consumption. Therefore, it is difficult to estimate the water used by individual homeowners irrigating with RW.

Over time, RW has become a limited resource in certain municipalities of Florida and, therefore, some restrictions to its use have been ordered. In Pinellas County (where this study took place), a water ordinance states that watering is not allowed between 10 A.M. and 4 P.M. Moreover, under normal weather conditions, homeowners are asked to voluntarily irrigate a maximum of 3 days/week. During dry weather conditions, a rule of 2 days/week is decreed, and under severe drought conditions (a recurrent phenomenon in Florida), the water is delivered to entire neighborhoods just 2 days/week (PCU, 2014).

Compared to potable water, RW may contain higher levels of salt; mainly in coastal communities of Florida, due to infiltration into the distribution system from salty coastal groundwater and/or from inflow from salty coastal storm surges. Cardenas-Lailhacar and Dukes (2015) reported that a higher level of salt can interfere with the operation and readings of some types of SMSs. The main objective of this research was to evaluate the performance and water conservation potential of an SMS in homes that used RW as their source for irrigation, as compared to homes with irrigation timers only, or to homes with educational materials and/or rain sensors. Secondary objectives were to: a) estimate the water depth applied by the different technologies compared to a theoretical requirement (calculated using a daily soil water balance), and b) estimate the effects of local watering restrictions on the amount of RW used by homeowners.

MATERIALS AND METHODS

RECRUIT COOPERATING HOMES

A total of 64 homes were required to volunteer for this study. Pinellas County Utilities (PCU) sent to the Institute of Food and Agricultural Sciences of the University of Florida (UF-IFAS) the list of home addresses in Pinellas County that were already connected to RW. From that list, UF-IFAS preselected homes in developments or subdivisions that were in the vicinity of Palm Harbor—where a study of SMSs installed in homes irrigating with potable water was already performed by Haley and Dukes (2012). The RW delivered to these homes had an average electrical conductivity of 0.7 dS/m (Bob Peacock, 2008, PCU, personal communication), which is classified as medium-high according to the U.S. Salinity Laboratory (1969).

A letter was generated and sent to the preselected homes, inviting them to be part of this research project. The letter was sent to a total of 640 homes and contained basic information about the research project. If they were interested in participating, they were invited to a UF-IFAS website. On this website, after a brief introduction about the project, they were prompted to read an Informed Consent, where relevant details of the project were explained. If they agreed with the terms, they could continue by clicking on a link accepting their participation and entering basic information regarding their irrigation system, practices, and contact info.

A total of 98 people completed the process, which represented a 15% response to the sent letters. This response was slightly higher than the 11% response reported by Davis and Dukes (2015) in a similar study carried out in Orange County, Florida. Most of the respondents perceived themselves as low irrigators compared to their neighbors.

A total of 92 homes were then visited and their irrigation systems evaluated. A copy of the completed and written evaluation was given to the homeowners. The main objectives of these evaluations were to check if the homes met the project requirements, if there were some repairs homeowners would need to do before the project initiation, and to measure the irrigated area.

The law in Florida requires, in all automatic irrigation systems, a device that inhibits or interrupts operation during periods of sufficient moisture [Florida Statutes, Chapter 373.62]. However, only 4 out of the 92 houses visited had a rain sensor previously installed and, of those, only 1 was functional. None of the visited properties had an SMS previously installed.

During the visits, seven properties were discarded; mainly because their irrigation systems needed major repairs or the homeowners did not live on the property. From the remaining homes, 64 were selected for the study. All of these houses met the project requirements: the owners lived in the home, the properties had well established St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] with a minimum acceptable or higher turfgrass quality, a properly working in-ground automatic irrigation system, were using RW as their irrigation source, were located in the vicinity of Palm Harbor, and were clustered in four residential developments or subdivisions. In each subdivision, four treatments were implemented. The homes were randomly assigned to one of the treatments, with a similar amount of replications (properties) per treatment in a particular location (subdivision).

INSTRUMENTATION AND TREATMENTS

On every selected home, a dedicated flowmeter (C700, Elster AMCO Water, Inc., Ocala, Fla.) was installed to measure the amount of RW used for irrigation. A datalogger that was part of an automatic meter reading (AMR) system (Datamatic Inc., Plano, Tex.) was affixed to every installed flowmeter to record, at hourly intervals, the frequency and amount of RW used per irrigation cycle. A hand-held device (Roadrunner, Datamatic Inc., Plano, Tex.) was used to program the AMRs and to download the data from the AMRs.

The homes were split into 4 treatments, with 16 replicates (homes) each, as follows: a) MO: homes that were monitored only (for control/comparison purposes) which had no additional equipment other than the irrigation timer, b) SMS: homes with an additional SMS, c) RS: homes with an additional rain sensor, and d) EDU: homes with an additional rain sensor, and where the homeowners received educational materials with instructions on adjusting their irrigation timers, seasonally. These materials were customized considering their irrigation system and area under irrigation.

The Digital TDT system from Acclima Inc. (Meridian, Idaho) was installed on the homes assigned with the SMS treatment. This SMS was chosen due to the negligible effect of different salinities and temperatures on a lab evaluation testing—in contrast with two other SMSs tested—(Cardenas-Lailhacar and Dukes, 2015), to their good performance during a field plot evaluation (Cardenas-Lailhacar and Dukes, 2016), and because SMS-probes might degrade under RW with variable salinity over time. Therefore, this SMS appeared to be the best option to ensure a reliable product during the entire study (32 months). The rain sensor used was the wireless RS1000 (Irritrol, Riverside, Calif.); which was previously evaluated by UF-IFAS (Meeks et al., 2012). This rain sensor gave more location options to the contractor compared to the typical wired rain sensors.

The same irrigation contractor from the Haley and Dukes (2012) study was hired to install all the irrigation equipment. However, the location of the RSs and SMSs units were previously determined in situ by UF-IFAS personnel. During installation, the rain sensors were set at a threshold of 6 mm (¼ in). The SMS probes were buried in a representative zone on each treatment home, following UF-IFAS recommendations (UF-IFAS, 2007). The thresholds of the different SMSs were set individually following the "automatic turn on threshold method", described in the product's manual.

The cost of SMSs for residential use has dropped around 60% to 70% during the last 10 years. At the beginning of this project, the cost of the Acclima Digital TDT was around $200, and $90 for the Irritrol wireless rain sensor. At present, the cost has declined to around $100 for the Acclima Digital TDT and $60 for the Irritrol wireless rain sensor. In addition, a contractor would likely charge around $150-$200 for installation. Under field plot conditions, Acclima Digital TDT models have performed maintenance-free for more than 5 years, and Irritrol wireless rain sensor only needed battery replacement after three years.

After all of these irrigation control technologies and methodologies (treatments) were installed and implemented, data from the AMRs were downloaded bimonthly. A manual reading of the flowmeters was taken at the same time to assure that the AMRs were functioning properly.

During the irrigation system evaluations, the irrigated area was measured. Aerial pictures of the properties were printed from the web before the visit. After turning the automatic irrigation system on, only the areas being irrigated were considered and measured.

The turfgrass quality of each home was also rated during the irrigation system evaluation, as a baseline comparison, to estimate potential turfgrass quality decline based on irrigation reduction. The turfgrass quality was visually assessed and rated using a scale from 1 (dead) to 9 (dense, dark green, uniform), following the National Turfgrass Evaluation Procedures (Morris and Shearman, 1998). A rating of 5 was considered the minimum acceptable turf quality for a homeowner. All ratings were carried out by the same person during the AMR downloading.

WEATHER DATA

Four weather stations that were described and set up in Palm Harbor by Haley and Dukes (2012) were maintained in this study. All the weather stations were within 4 km of one another, and each was within a 1 km radius of the surrounding homes. At each station, measurements were taken every 15 min and included air temperature, relative humidity, wind speed, wind direction, solar radiation, barometric pressure, and soil heat flux. Rainfall was recorded continuously by a tipping bucket rain gauge. Data were recorded by a CR10X datalogger (Campbell Scientific Inc., Logan, Utah). Daily averages, maximum, and minimum values were used to calculate the standardized reference evapotranspiration rate, following the ASCE-EWRI methodology (Allen et al., 2005).

SOIL WATER BALANCE

To estimate the amount of over- or under-irrigation of treatment irrigation means, a theoretical irrigation requirement was calculated. Evapotranspiration for the landscape was calculated as (Allen et al., 2005):

$$ET_L = ET_o \times K_L \quad (1)$$

where

ET_L = overall estimated landscape evapotranspiration (mm/day);

ET_o = reference evapotranspiration for short vegetation (mm/day); and

K_L = landscape coefficient (eq. 2).

$$K_L = (Kc_{turfgrass} \times A_{turfgrass}) + (Kc_{ornamental} \times A_{ornamental}) \quad (2)$$

where

Kc = crop coefficient for either turfgrass or ornamental plantings; and

A = turfgrass or ornamental planting area (%).

The warm season turfgrass $Kc_{turfgrass}$ coefficients were interpolated between values calculated for Citra, Florida and Ft. Lauderdale, Florida since the study location is in between these two regions (Jia et al., 2009). The Ft. Lauderdale values were determined by Jia et al. (2009) based on turfgrass consumptive use data from Stewart and Mills (1967). These values ranged between 0.45 (in December, January, and February) to 0.90 (in May). The *in situ* measured irrigated areas were averaged per treatment. However, the irrigation requirement of established ornamental areas was considered negligible (Scheiber et al., 2008; Moore et al., 2009; Shober et al., 2009; Wiese et al., 2009).

The theoretical irrigation water requirement was calculated using a daily soil water balance (Dukes, 2007)

$$I_{calc} = ET_L - P_{gross} + RO + D \quad (3)$$

where

I_{calc} = calculated net irrigation requirement (mm/day);

P_{gross} = total rainfall (mm/day);

RO = surface runoff (mm/day); and

D = drainage below the root zone from excess rainfall (mm/day).

To determine the amount of irrigation required, the upper and lower boundaries were determined using the soil water-holding capacity of the soil. The upper boundary is referred as field capacity (FC) and is the amount of water that the soil can hold after gravitational drainage. The amount of rainfall considered effective (P_e) was the depth of rain that fell until FC was reached. Additional rainfall was considered excess, and resulted in RO or D. The lower boundary is the maximum allowable depletion (MAD), a water level between FC and permanent wilting point (PWP); where PWP is the point where plants can no longer extract water from the root zone (IA, 2005). Based on the soil survey data for urban land in Pinellas County (USDA, 2006), the FC was taken as 10% and the permanent wilting point as 3%, resulting in a 7% available water content (USDA, 2006). For St. Augustinegrass, the root zone was assumed to be 20 cm (Shedd, 2008) and MAD was assumed to be 50% of the available water content (Allen et al., 2005).

Once the soil hydraulic properties were used to define the upper limit of water storage, I_{calc} was determined assuming ideal irrigation conditions such that D and RO were zero for the theoretical irrigation estimate. Equation 3 simplifies to estimate net irrigation requirement:

$$I_{calc} = ET_L - P_e \quad (4)$$

When the amount of soil water at the beginning of the day was at or below the lower boundary (MAD), the net amount of irrigation (I_{calc}) to reach the upper boundary (FC) was calculated. Finally, the gross irrigation requirement (GIR) was estimated by dividing I_{calc} by an estimated irrigation efficiency. A 60% irrigation efficiency was assumed for a typical residential irrigation system.

DATA ANALYSIS

The number of irrigation events per week, the irrigation depth per event and per week, and the cumulative irrigation depth (total water use) per treatment were calculated. Statistical analyses for irrigation and turfgrass quality data were performed using SAS (2008) with the general linear model procedure (proc GLM). Analysis of variance was used to determine treatment effects, and Duncan's multiple range test was used to identify mean treatment differences. Differences were considered significant at a confidence level of 95% or higher ($p \leq 0.05$).

RESULTS AND DISCUSSION

The homes were fully implemented with the irrigation equipment by January 2011. The data collection began on February 2011 and ended on September 2013, for a total of 32 months.

IRRIGATION APPLICATION

All the treatments tended to apply a similar depth of water per irrigation event, which ranged between 14.1 and 15.4 mm (table 1). Therefore, differences in cumulative water application between the treatments (if any) were not a consequence of one treatment applying consistently more water per irrigation event, but a result of the irrigation control of the different methods/technologies tested. The usual recommendation for this area is to apply around 19 mm per irrigation event to replenish the soil with water (Dukes, 2014). Therefore, none of the treatments appeared to be applying water at rates that would be wasted through run-off or deep percolation. However, if the frequency of irrigation is too high, over-irrigation may occur.

From the AMR data, not only the volume of water applied per irrigation event was determined, but also the irrigation frequency. Table 1 shows that treatments MO, RS, and EDU averaged significantly more irrigation events per week (between 2.3 and 2.7) than treatment SMS (1.7 irrigation events per week). The number of irrigation events per week for treatments MO, RS, and EDU, was close to the regular RW use recommendation of 3 days per week for PCU customers during the normal season (PCU, 2014). However, water restrictions and, afterwards, water

Table 1. Average irrigation applied per event, number of irrigation events per week, and irrigation depth per week, by treatment.

Treatment[a]	Depth per Event (mm)	Events per Week (No.)	Depth per Week (mm)
MO	15.4 ns[b]	2.7 a[c]	42 a
RS	15.4 ns	2.4 a	37 a
EDU	14.4 ns	2.3 a	33 a
SMS	14.1 ns	1.7 b	24 b

[a] Treatments are: MO, timer only; RS, timer plus rain sensor; EDU, timer plus rain sensor plus educational materials; SMS, timer plus soil moisture sensor system.

[b] ns = No significant difference.

[c] Different letters within a column indicate statistical difference at P<0.05 (Duncan's multiple range test).

delivery of 2 days/week were in effect over 25% of the time of the study, and during months of usual irrigation. This may explain, in part, the averages below 3 irrigation events per week that homeowners were theoretically allowed for most of the time of this study. Furthermore, during the recruiting process, 53% of the cooperators reported manually shutting down the system for some days after a large rain event, and 10% said that they turned off the system for more than one month of the year.

The greater number of irrigation events per week for treatments MO, RS, and EDU, resulted in a significantly higher depth of irrigation applied per week by these treatments (table 1). The averages ranged between 33 and 42 mm/week, compared to treatment SMS, which averaged 24 mm/week. The irrigation depth per week follows a very similar trend compared to the number of irrigation events per week. This indicates that the differences in the amount of water applied by the treatments was mainly a result of the different technologies bypassing irrigation events, compared to treatment MO.

ACTUAL VS. GROSS IRRIGATION REQUIREMENT

Average monthly irrigation application was compared to the monthly GIR, calculated through a daily soil water balance, to determine over- or under-irrigation of the treatments (figs. 1-4). Over the course of this study, and compared to a historical normal for this region (NOAA, 2003), the precipitation average was 65% less from November 2011 through May 2012, and 60% below from November 2012 through February 2013. Conversely, rainfall was more than two times the historical normal in June 2012 and from April through July 2013.

Most of the time, the calculated GIR remained at or below 50 mm per month (fig. 1). During the months of December to February of each year, however, monthly GIR values ≤25 mm were obtained. These low GIR values indicated that a low irrigation depth was required during those months. Likewise, during the months of August of each year, as well as June 2012 and July 2013, GIR values also ≤25 mm were calculated, due to the relatively high rainfall during those months.

Conversely, the calculated GIR was ≥50 mm during three periods over the course of the study: April to June 2011, March to May 2012, and April to May 2013; including peaks during the month of May of each of these years, with 140, 121, and 99 mm of GIR, respectively. This concurs with historical normal weather during these seasons of the year, when high temperatures are coupled with low precipitation rates on this region (NOAA, 2003). As a result of these dry weather conditions, decreasing amounts of available RW remained at PCU facilities during these time periods. Therefore, water restrictions were put in effect and, afterwards, RW was delivered by PCU only twice per week during the months of April to June of 2011, March to May 2012, and May to June of 2013.

The effects of this RW delivery procedure by PCU on each treatment can be seen in figures 1-4. Treatments MO, RS, and EDU resulted in drastic reductions in water applications throughout these periods. The SMS treatment also did, but at a lower rate. During periods of no rainfall, treatments MO, RS, and EDU had no irrigation bypass, which explains the similar level of reduction in their irrigation application. Conversely, treatment SMS could still override some scheduled irrigation events during the dry periods, if the soil water content was above the bypass threshold set point. This may explain the lower impact of the water restrictions in the water application rate on homes equipped with an SMS. After hydrologic conditions recovered and water restrictions were lifted and RW normally delivered, a tendency to increase the water use was observed, mainly on treatments MO, RS, and EDU.

In spite of the technologies/methods investigated in this

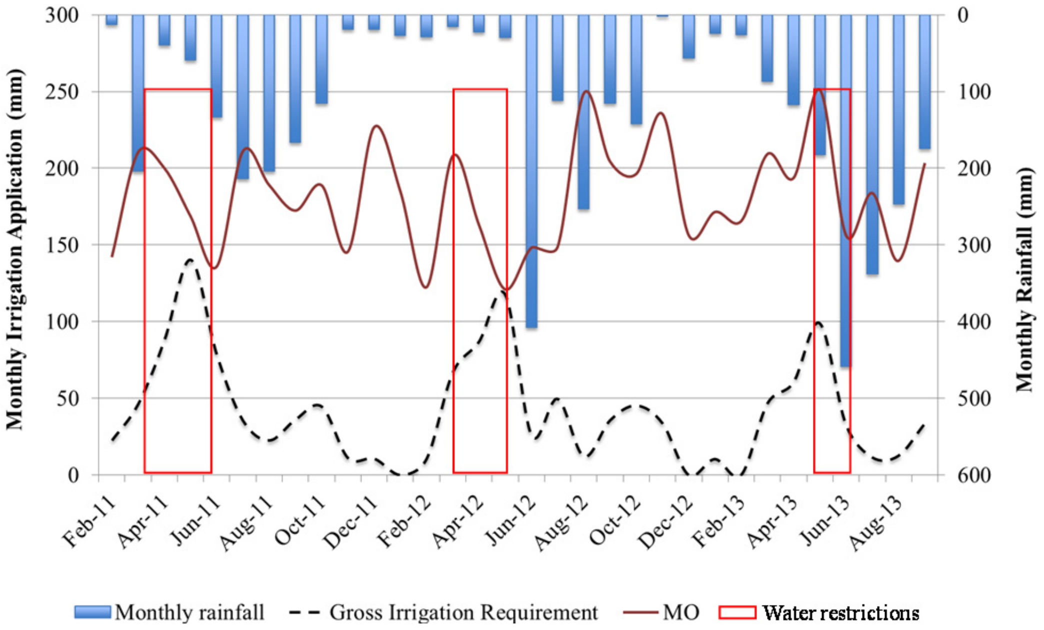

Figure 1. Monthly irrigation application for MO treatment compared to a calculated gross irrigation requirement based on a daily soil water balance model. Water restrictions were imposed during the time-frame encompassed in the red rectangles.

study (SMS, RS, and EDU) and the water restrictions implemented by PCU to save water, all irrigation treatments over-irrigated most of the time (figs. 1-4). Treatment MO applied the same amount of water as the calculated GIR only in May 2012 (fig. 1). This lower application, however, was mainly due to the water delivery procedure applied by PCU mentioned above. Treatments RS (fig. 2) and EDU (fig. 3) also over-irrigated most of the time, with only 3 months (out of the 32-month testing period) where these treatments were close or slightly below the GIR. However, this was due mainly, again, to the water restrictions implemented by PCU. Apart from the aforementioned exceptions, MO, RS, and EDU consistently over-irrigated the rest of the time, applying between 3.5 to 4.4 times the calculated GIR; even though most of the cooperators considered themselves low irrigation water users compared to their neighbors.

SMS was the treatment that most times applied a depth of irrigation close to the estimated need; as it was during the periods between May to October 2011, March to June 2012, and May to June 2013 (fig. 4). Part of these periods concurred with the water restrictions implemented by PCU. The rest of the time, SMS also over-irrigated, but at a lower proportion than the other treatments, applying on average

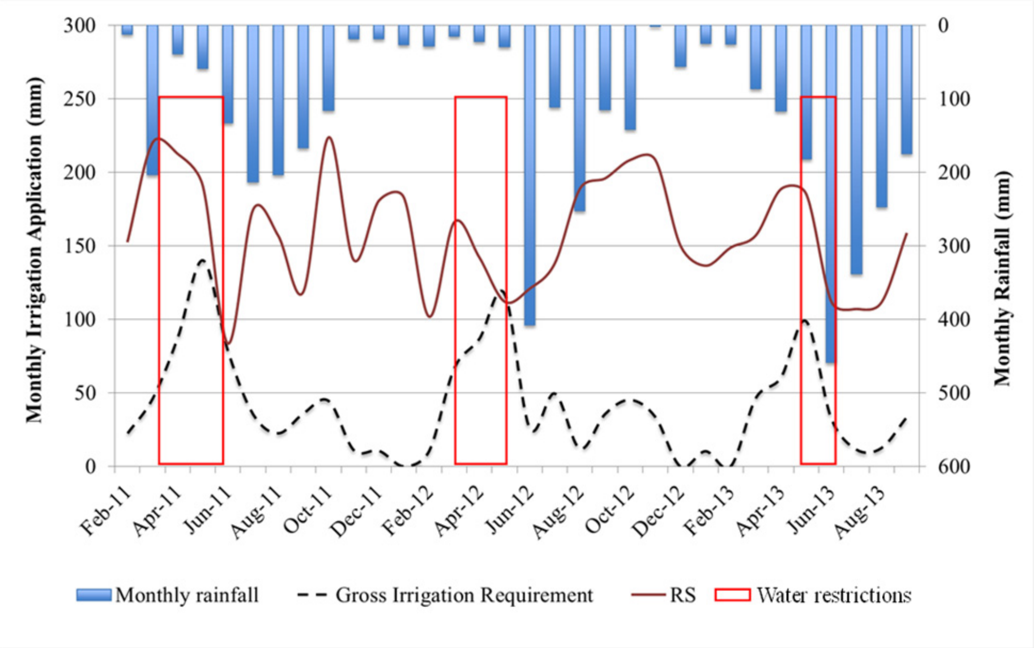

Figure 2. Monthly irrigation application for RS treatment compared to a calculated gross irrigation requirement based on a daily soil water balance model. Water restrictions were imposed during the time-frame encompassed in the red rectangles.

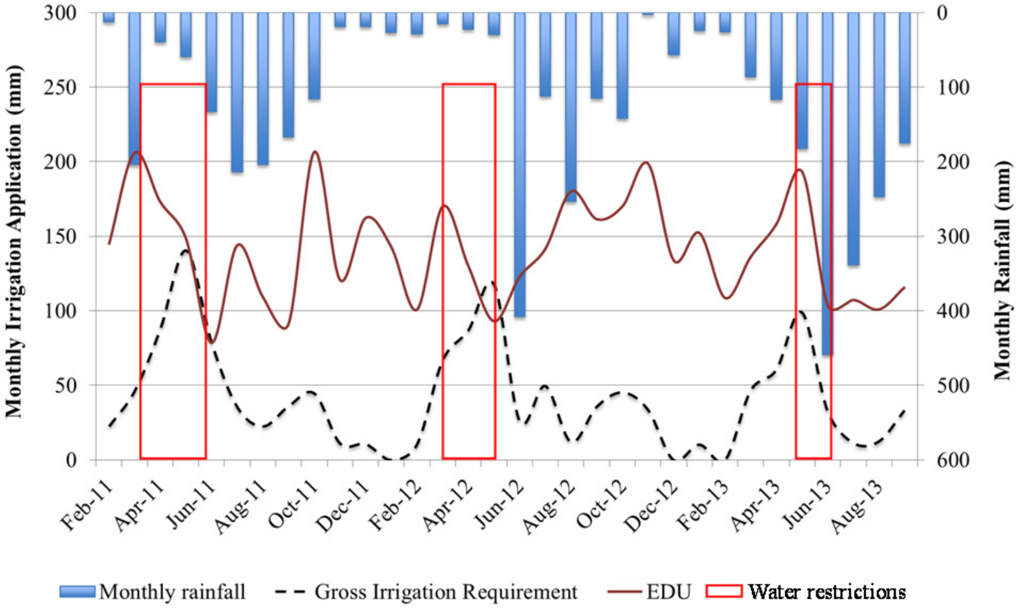

Figure 3. Monthly irrigation application for EDU treatment compared to a calculated gross irrigation requirement based on a daily soil water balance model. Water restrictions were imposed during the time-frame encompassed in the red rectangles.

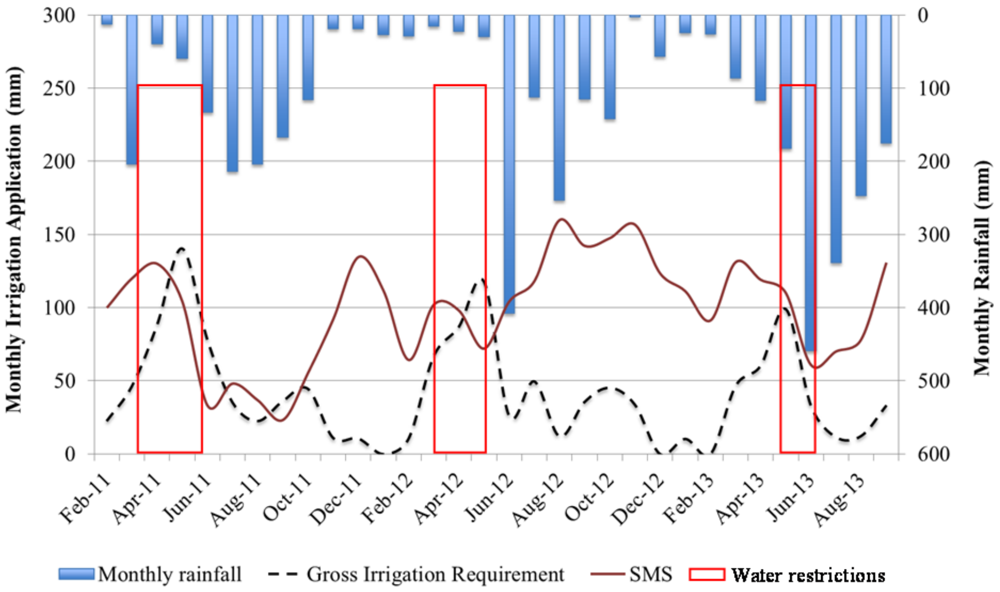

Figure 4. Monthly irrigation application for SMS treatment compared to a calculated gross irrigation requirement based on a daily soil water balance model. Water restrictions were imposed during the time-frame encompassed in the red rectangles

2.5 times more water than the GIR. Therefore, the homes with an SMS were the group that, on average, irrigated most efficiently; even when there is still room to improve their irrigation application depth. In a similar study carried out in Orange County, Florida, homes equipped with an SMS resulted in 2.85 times more water applied than a calculated GIR, but a 44% decrease in water application compared to their historical to GIR ratio.

The SMS homes had a tendency to increase the difference between the GIR and the actual irrigation depth after June 2012 (fig. 4). When analyzing the irrigation data from individual residences, it was apparent that some homeowners disconnected their SMS system for some periods and, in some cases, permanently after a certain point. However, as part of the experimental design, no or minimal contact was maintained with the homeowners after selecting them for the study; so as not to interfere with their irrigation practices and, thus, to obtain the most representative results possible. A longer period of data collection could elucidate the use of these devices by homeowners.

WATER SAVINGS

The cumulative depths of water applied over the 32-month data collection period by treatments MO, RS, and EDU were 5858, 5143, and 4612 mm, respectively. These water depths were not statistically different from each other at the 95% confidence level, but significantly different from SMS (fig. 5). The average proportion of 12% of water

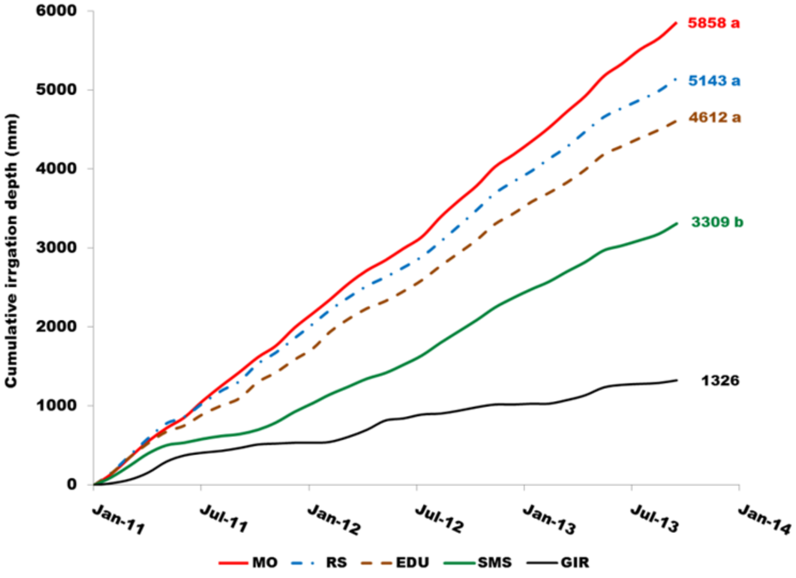

Figure 5. Cumulative mean irrigation by treatment, with statistical comparisons, vs. calculated GIR. Different letters after cumulative irrigation depth indicate statistical difference at P<0.05 (Duncan's multiple range test).

savings of treatment RS compared to MO is consistent with a previous study carried out in homes of this area by Haley and Dukes (2012). In that study, a 14% water savings was reported,and was also not significantly different than homes without an RS.

Even when the EDU treatment showed a tendency to save more water than MO (21%) and nine percentile points more than RS, none of these treatments were statistically different from each other at the 95% confidence level. Similar results were reported by Haley and Dukes (2012) where their EDU treatment achieved 24% of water savings compared to MO but, likewise, those treatments were not statistically different at the 95% confidence level. The EDU treatment, however, was significantly different from MO or RS at the 90% confidence level. Thus, periodic reminders to homeowners to adjust their timers could promote a behavior change, with a positive effect in water savings over time. As further support for this idea, RS and EDU had a similar trend of cumulative water applied over time (fig. 5), but EDU was always lower than RS after the fifth month of the start of the study.

In this study, SMS applied a cumulative mean irrigation of 3309 mm versus 5858 mm applied by MO (fig. 5). Therefore, SMSs saved an average of 44% of the water applied by the homes with no additional irrigation technology other than the irrigation timer, MO. In the study carried out by Haley and Dukes (2012), the homes equipped with an SMS applied 65% less water than the MO group, over 26 months. Likewise, in Orange County, Florida, Davis and Dukes (2015) reported a 63% decrease of water applied by properties equipped with an SMS, compared to their 8-year historical average.

Properties equipped with an SMS applied 36% and 28% less water than RS and EDU, respectively. This reveals that SMSs can save a significant amount of water in homes irrigating with RW, even when compared to the other methods/technologies tested.

There is still room to achieve a more efficient irrigation using these devices, when compared to a theoretical GIR (figs. 4-5). Nevertheless, because most of the residences have no dedicated flowmeter, homeowners have no reference to estimate variations on their monthly RW use and, consequently, to avoid overirrigation. In addition, as PCU charges a fixed cost per month (US$18), it seems that homeowners have no economic incentive to conserve water. Finally, it appears that the watering policies implemented by PCU promoted a more efficient use of the RW: the average amount of water applied by the different treatments decreased substantially and was closer to the calculated GIR during the watering restriction periods (figs. 1-4).

TURFGRASS QUALITY

Throughout the data collection period, no significant differences in average site turfgrass quality ratings were detected between homes based on treatment group. On average, turfgrass quality was always above the minimum acceptable (i.e., >5); even when some cooperating homes occasionally received less than minimally acceptable turf quality ratings (i.e., <5), while some other homes were rated as exceptional quality (i.e., 8-9). Cooperators mentioned no complaints regarding their turfgrass quality as affected by irrigation treatment during the study time-frame. Water restrictions imposed by PCU did not decrease the turfgrass quality, compared to pre-restriction periods, due to water applications in general above the calculated GIR (figs. 1-4).

CONCLUSIONS

The vast majority of the residences irrigating with RW in the Palm Harbor area have no dedicated irrigation flowmeter. Therefore, it is difficult for PCU to measure the impact of their watering restriction strategies. These results may help PCU and other RW utilities to estimate the real impact of these restrictions, at an individual residence level. In this study, the watering restrictions promoted a more efficient use of the RW, as the average amount of water applied by the different treatments decreased substantially, and was closer to the calculated GIR during the watering restriction periods.

All implemented treatments over-irrigated, ranging from 2.5 times (SMS) to 4.4 times (MO) more than the calculated GIR. Despite some homeowners disconnecting their SMS for some periods, or permanently after a certain point, the homes equipped with an SMS were the group that on average irrigated most properly; even when there is still room to improve their irrigation application. Therefore, there is a substantial opportunity not just to conserve but, at the same time, to make better use of the RW, which may allow connecting more houses to the RW system. This could, as a consequence, save an important amount of potable water currently destined for irrigation purposes.

The SMS treatment was the only group of homes significantly different from the comparison treatment, MO; reducing the average number of irrigation events per week (1.7 vs. 2.7 events/week, respectively), decreasing the depth of the weekly irrigation (22 vs. 42 mm, respectively) and reducing the total cumulative irrigation depth (3309 vs. 5858 mm, respectively). Consequently, the SMS treatment applied 44% less water compared to the MO group, over 32 months of data collection.

These results demonstrate that the tested SMS can save a significant amount of water in homes irrigating with RW, even when compared to the other methods/technologies investigated (RS and EDU). Adding a rain sensor or a rain sensor plus educational materials, instead of an SMS, did not result in significantly lower irrigation amounts.

These results concur with those yielded in previous studies irrigating with potable water, under controlled plots and in residential settings in Florida. Consequently, the tested SMS may improve proper irrigation, promote water conservation, and reduce the environmental and economic impacts of over-irrigating landscapes; not only under potable but also reclaimed water irrigation. A study with a higher number of homes and for a longer period of data collection is needed to reinforce trends observed in this study. Such a study could increase acceptance of SMSs by homeowners.

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ABBREVIATIONS

AMR = Automatic meter reader/recorder
EDU = Educational materials + rain sensor treatment
IFAS = Institute of Food and Agricultural Science
GIR = gross irrigation requirement
MO = Metered only treatment
RW = Reclaimed water
RS = Rain sensor treatment
SMS = Soil moisture sensor system, or SMS treatment
UF = University of Florida