Evaluation of Sensor Based Residential Irrigation Water Application on Homes in Florida

Melissa B. Haley[1] and Michael D. Dukes[2]

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Abstract

The objective of this project was to determine if an automatic residential irrigation system with soil moisture sensor irrigation controllers could reduce irrigation water application while maintaining acceptable turfgrass quality. Research was conducted on cooperating homes (n=59) in Pinellas County, FL. Experimental treatments evaluated were (1) automatic time based irrigation set and operated by the cooperator, (2) an automatic timer with the integration of a soil moisture sensor, (3) an automatic timer with a rain sensor, and (4) an automatic timer with a rain sensor along with educational materials including a recommended run time schedule given to the cooperator. Continuous irrigation water use, quarterly turf quality ratings, and weather data were collected for the homes over a 26-month period. In addition to elapsed weekly irrigation water use, hourly use was recorded and the fraction of total household use (indoor vs. outdoor) was calculated. The total cumulative savings were calculated compared to the meter only treatment. The soil moisture sensor treatment yielded the greatest savings; with 65% cumulative less water applied for irrigation than the meter only treatment. Although the rain sensor plus educational materials treatment initially showed substantial savings the saving were not as great during the second year of data collection, the total average irrigation savings was 45%. Lastly, the rain sensor treatment yielded a 14% savings over the meter only treatment. These savings trends are similar to what has been found in plot studies.

Introduction

The Florida climate consists of dry and warm weather in spring and fall, coupled with frequent rain events in summer months (NOAA 2003). With these environmental conditions occurring in areas of mostly sandy soil, which has a low water holding capacity, irrigation is often used to supplement rainfall to maintain high quality landscapes. Therefore, automatic in-ground irrigation is common in Florida. Of all new home construction within the United States, more than 15% occurred in Florida from 2005-2006 (USCB 2007). Further, the majority of new homes are sold with automatic in-ground irrigation systems (TBW 2005; Whitcomb 2005). Homes with automatic irrigation systems have been reported to have higher water use compared to manual irrigation or hose-end sprinklers (Mayer et al. 1999).

According to initial plot study results in Florida, soil moisture sensor system controlled irrigation represents a technology that could lead to substantial savings in irrigation water use while maintaining acceptable turf quality, even during dry weather conditions (Cardenas-Lailhacar et al. 2008). The project described here expands the testing of this technology into existing residential irrigation systems as a means to validate the plot study results.

[1] Graduate Research Assistant, Agricultural and Biological Engineering Dept., University of Florida, Gainesville, FL 32611, tel: (352) 871-3523, email: mbhaley@ufl.edu
[2] Associate Professor, Agricultural and Biological Engineering Dept., University of Florida, Gainesville, FL 32611, tel: (352) 392-1864, email: mddukes@ufl.edu

The objectives of this study were to quantify irrigation water use and to evaluate turf quality differences between: 1) a time-based irrigation system with a soil moisture sensor system, 2) a time-based irrigation system with a rain sensor, and 3) a time-based irrigation system with rain sensor as well as distributed educational materials. All of these experimental treatments consisted of technology or irrigation scheduling intervention and were compared to homes with minimal intervention during the same data collection period.

Materials and Methods

The homes included in this research project were located in the City of Palm Harbor, Pinellas County, Florida within the Pinellas Anclotte Basin of the Southwest Florida Water Management District, SWFWMD (Figure 1). Residential cooperators with automatic in-ground irrigation systems using potable water were recruited. All cooperating homes had a pre-existing automatic irrigation system and time-based controller. Additionally at each home, a positive displacement irrigation sub-meter was installed as well as supplementary equipment (rain sensor or soil moisture sensor) as needed based on participating home treatment type.

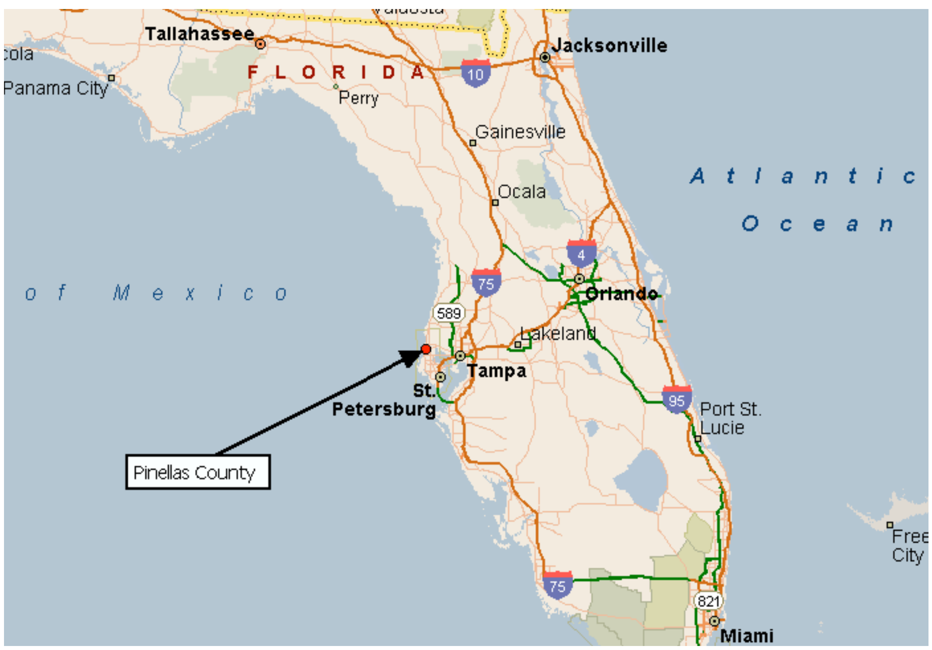

Figure 1. Map of the Florida, including location of data collection (Pinellas County).

The homes were divided into four experimental treatments. Treatment classification refers to the method or technology used for irrigation control.

- Treatment one, T1, homes had an Acclima TDT RS-500 soil moisture sensor system (SMS) set at the 10% (volumetric water content) threshold, coupled with the timer-based irrigation controller.
- Treatment two, T2, homes had a mini-click rain sensor (RS) added to the timer-based irrigation controller.

- Treatment three, T3, homes were a comparison group and did not have any control technology other than the existing time clock common to all homes. This treatment is referred to hereafter as meter only (MO).
- Treatment four, T4, homes had a mini-click rain sensor added to the timer-based irrigation system as well as educational materials (EDU).

Research personnel programmed the SMS controller threshold setting, but the homeowner programmed the irrigation time clock. Only in the T4 (EDU) group was an attempt made to explicitly encourage homeowners to set their irrigation timers according to recommended settings after the initial treatment implementation. It is important to note that the MO homes did not have rain sensors.

The primary component of the educational materials included a customized irrigation run time card and documents explaining outdoor water conservation. The run time card is based on the home's specific system design, zone layout, and application rates. This card provides the homeowner with system run times for each season and each irrigation zone. The laminated card was fastened to the controller box. It was hypothesized that the card would make it easy for homeowners to set the correct time on their timer to irrigate a particular irrigation zone.

Four weather stations were setup in Palm Harbor. The stations were relatively close to each other, within 4 km (2.5 miles), and all had a grass reference surface. Each weather station was within a 1 km (0.6 miles) radius of the surrounding homes for the given location. As common with most urban weather stations, the stations were surrounded by different obstacles and encountered different fetch distances. Practical efforts were made to minimize obstructions near the weather stations and the stations were representative of weather data in urban area.

Prior to data collection, an irrigation system evaluation was conducted at each home. During this evaluation any required maintenance resulting from broken heads and/or leaks was noted. Any maintenance that would compromise the irrigation uniformity test was fixed before the testing began. In extreme cases it was recommended that the homeowner fix deficiencies before they could become part of the study. Meter data was used to determine the application rate (depth/time) for each zone on all of the irrigation systems. This information was later utilized when creating the runtime cards for the EDU treatment. An estimation of system low-quarter distribution uniformity (DU_{lq}) was calculated by performing a catch-can test following the Mobile Irrigation Lab Handbook guidelines for Florida (Mickler 1996). Irrigated area was determined based on the Pinellas County property appraisal public records (www.pcpao.org), Pinellas County public GIS records (www.gis.pinellas.org), and the actual irrigation areas were measured at the site visits to homes. The aerial estimated irrigated area was then compared to the calculated irrigated area from the property appraisal information (Haley and Dukes 2007).

Household water consumption, both total household and water used for irrigation only was recorded by flow meter readings. The irrigation water use for the homes was calculated as a depth of water applied (mm or inches) by dividing the volume usage (m^3 or gal) by the irrigated area (m^2 or ft^2) of the home. From July 2006 through April 2007, PCU personnel recorded the weekly elapsed water meter readings manually. Beginning in April 2007, dataloggers were attached onto the irrigation meters to collect actual water use frequency. The dataloggers are part of an automatic meter reading/recording (AMR) technology for data collection using a meter interface unit which attaches to the existing irrigation water meter.

In addition to water use data collection, turf quality ratings were collected seasonally as a benchmark measure of minimum acceptability for each treatment regime. Initial turf quality ratings were taken for each home during the irrigation evaluations, as a baseline standard of comparison for each home. It should be noted that the assessment of turfgrass is a subjective process following the National Turfgrass Evaluation Procedures (Shearman and Morris 1998).

Data analysis was performed using Statistical Analysis System (SAS) software (SAS 2004). The four experimental treatments were replicated at least three times in each of four locations for a minimum of 48 sites. Several treatments had more than three replications for a total of 59 homes in the study group.

Results

Data collection on all of the homes commenced on July 2006 and ended December 2008, with treatments assigned by November 2006 for a total of 26 months. During this period the rainfall was 17% less (1,043 mm) than the historical norm (1,259 mm). A total of 15 of 26 months during the study had less than normal rainfall. August through December 2008 was a continuous dry period.

Over the course of the study, it was observed that the cooperating homes had relatively low water use characteristics. As part of a concurrent study in Pinellas County, response to a mail-out survey was received from 272 homes (including 45 these homes) regarding their irrigating practices. Sixty-nine percent of the these homes reported that they did "consider their irrigation practices to be very water conserving" (Haley and Dukes 2008).

Irrigation application was influenced by the season of the year, as shown in Table 1. The highest water use occurred in the spring months with an average of 56 mm/month applied, compared to the other months with an average of 41 mm/month. The spring months had the highest irrigation demand due to the relatively high evaporative demand as well as low rainfall.

Different irrigation amounts were observed on the treatments depending on study year. Table 2 gives the irrigation application for each treatment for the full study years of 2007 and 2008. In 2007, the SMS and EDU treatments used significantly less irrigation (28 mm/month averaged) compared to the MO and RS treatments (70 mm/month averaged). In contrast, the SMS treatment used the least irrigation in 2008 compared to the other treatments at 19 mm/month. The other irrigation control technologies/strategies used similar amounts of 44 to 54 mm/month (Table 2). Thus, even though the fall of 2008 was dry and resulted in increased irrigation in all treatments (Figure 2), the SMS control systems resulted in significant savings during the rainy summer months as well as intermittent rain in the fall.

Mean cumulative irrigation application for each treatment, over the 26-month data collection period is presented in Figure 2. This figure shows the actual irrigation depth applied by each treatment group, where the recorded volumes were normalized over the irrigated areas. The total cumulative savings were calculated compared to the meter only treatment. The SMS treatment yielded the greatest savings; with 65% less water applied (554 mm) for irrigation than the MO treatment (1,584 mm). Although the EDU treatment initially showed substantial savings, over the 26-month study period the total irrigation savings was 45% with 864 mm applied across the study period. Lastly, the RS treatment yielded a 14% savings over the MO treatment with 1,366 mm applied.

Table 1. Mean monthly irrigation application by treatment for all homes for all study years by season.

Season[Z]	Overall					
	I_{actual}[Y] (mm[W]/month)	N[X] (#)	Range (mm/month)	Median (mm/month)	Std Dev (mm/month)	CV (%)
Spring	56[U]	322	0-950	33	88	154
Summer	37	253	0-264	18	49	133
Fall	45	339	0-572	22	66	146
Winter	40	394	0-577	27	51	127

Note: Uppercase superscript letters indicate footnotes.
[Z] Seasons defined as: spring, March, April, May; summer, June, July, August; fall, September, October, November; winter, December, January, February.
[Y] Monthly average irrigation applied.
[X] N = number of observations in the comparison.
[W] Conversion: 1 inch = 25.4 mm

Table 2. Mean monthly irrigation application by treatment for all homes for years 2007 - 2008.

Treatment[Z]	2007					
	I_{actual}[Y] (mm[W]/month)	N[X] (#)	Range (mm/month)	Median (mm/month)	Std Dev (mm/month)	CV (%)
SMS	27	92	0-309	11	46	165
RS	65	123	0-950	44	119	149
MO	75	122	0-775	38	96	158
EDU	28	101	0-166	22	46	103
	2008					
Treatment	I_{actual} (mm/month)	N (#)	Range (mm/month)	Median (mm/month)	Std (mm/month)	CV (%)
SMS	19	151	0-317	10	60	189
RS	44	137	0-198	39	44	101
MO	54	126	0-241	35	59	109
EDU	47	149	0-372	27	60	130

Note: Uppercase superscript letters indicate footnotes.
[Z] Treatments are: SMS, time-based controller plus soil moisture sensor system; RS, time-based controller plus rain sensor; MO, time-based controller only; EDU, time-based controller plus rain sensor and educational materials.
[Y] Monthly average irrigation applied.
[X] N = number of observations in the comparison.
[W] Conversion: 1 inch = 25.4 mm

These results were similar to what was found in the preliminary plot study. During frequent rainfall conditions, soil moisture sensor savings averaged 72% and during dry weather conditions, savings averaged 28 to 54% (Cardenas-Lailhacar et al. 2008, McCready et al. 2009).

Likewise the rain-sensor treatment resulted in 34% less water applied than the without-rain-sensor treatment during wet weather conditions, and between 13% and 24% during the dry seasons (Cardenas-Lailhacar and Dukes 2008).

Initially it appeared that the EDU treatment was as effective as the SMS treatment, then over time acted more similarly to the RS treatment. Table 2 illustrates similar irrigation between EDU and SMS in 2007 followed by higher irrigation on EDU homes in 2008. A steady increase in the consumptive use of the EDU treatment can be observed beginning in the fall of 2007 (Figure 2). This trend coincides with when the irrigation schedule should have been readjusted back to the lower fall runtime.

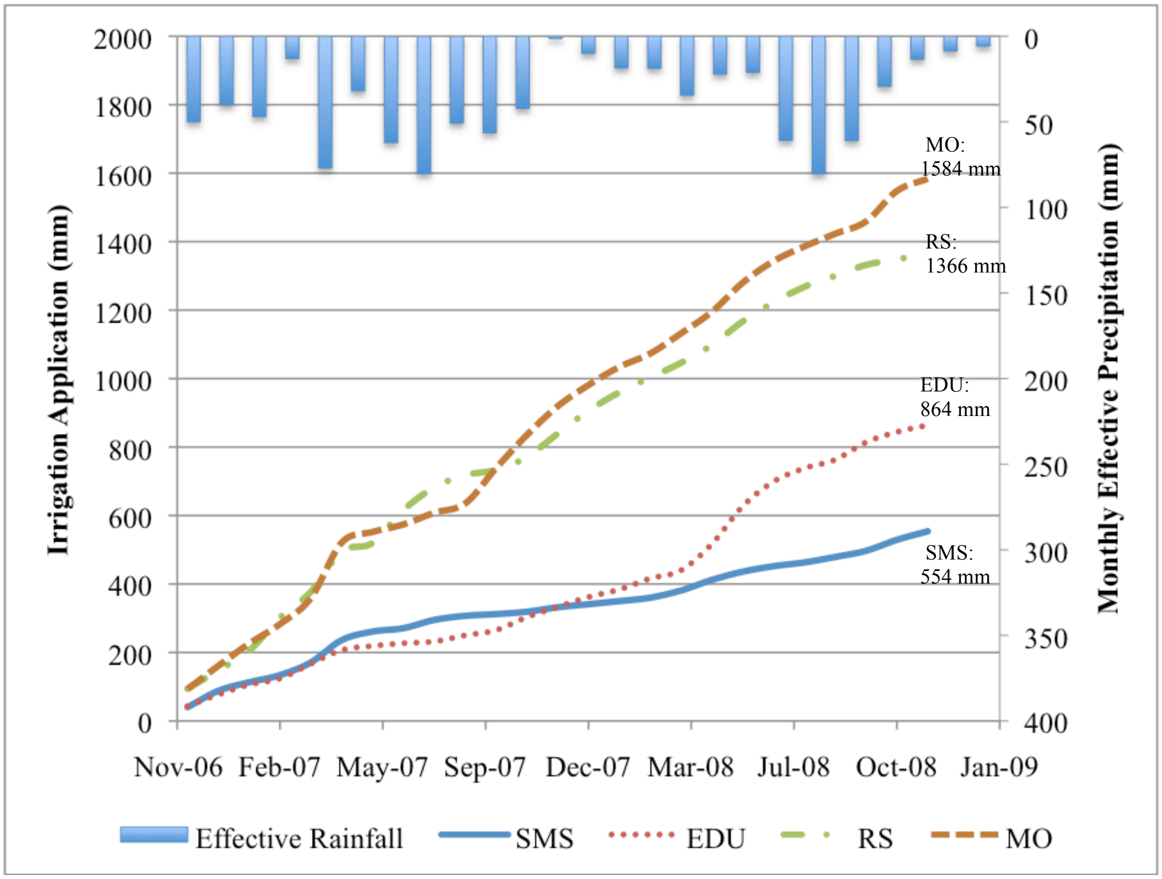

Figure 2. Cumulative irrigation application over the entire data collection period.

Irrigation frequency was determined from the AMR data in addition to volume of water use. Table 3 presents the average monthly number of irrigation events by treatment and season. Analysis of these data yielded an interaction between treatment and location. On average the SMS treatment resulted in 2 events per month, with EDU averaging 4 events, and the RS and MO treatments both with a mean of 5 events per month. Four events per month would agree with the one-day per week watering restriction for the study area.

Table 3 also displays the number of events per season. Since the AMRs were installed during late spring 2007, there was not sufficient data during the spring season to calculate the number of irrigation events, consequently this analysis commenced with summer 2007. The number of irrigation events is shown by season within each year. However, the significant difference between the number of irrigation events and each season only occurred during 2008.

Table 3. Number of irrigation events per month, for the AMR irrigation meter data from study homes during the collection period June 2007 – Dec 2008.

			Number of Irrigation Events					
			I_{actual}[Z] (#[X]/ month)	N[Y] (#)	Range (#/ month)	Median (#/ month)	Std Dev (#/ month)	CV (%)
Treatment[W]	SMS		2.1	185	0-11	1	2.8	136
	RS		4.7	195	0-22	4	5.6	114
	MO		5.2	173	0-29	4	6.5	125
	EDU		3.6	187	0-20	3	4.1	113
Season[V] by Year	2007	Spring	—[U]	—	—	—	—	—
		Summer	2.1	32	0-21	1	4.3	210
		Fall	4.5	81	0-29	3	6.7	153
		Winter	4.1	46	0-21	3	4.9	137
	2008	Spring	5.6	144	0-29	5	5.6	109
		Summer	4.1	138	0-26	3	5.0	135
		Fall	2.8	117	0-20	2	3.6	143
		Winter	3.5	138	0-29	3	4.7[T]	151

Note: Uppercase superscript letters indicate footnotes.
[Z] Monthly average number of irrigation events applied.
[Y] N = number of observations in the comparison.
[X] Conversion: 1 inch = 25.4 mm
[W] Treatments are: SMS, time-based controller plus soil moisture sensor system; RS, time-based controller plus rain sensor; MO, time-based controller only; EDU, time-based controller plus rain sensor and educational materials.
[V] Seasons defined as: spring, March, April, May; summer, June, July, August; fall, September, October, November; winter, December, January, February.
[U] AMRs installed during late Spring 2007.
[T] Winter of 2008 consisted of December 2008 and January 2009 only.

Figures 3 though 6 display examples of the actual water use as collected from the AMR dataloggers for individual homes during a 70-day period. These graphs can visually demonstrate the effectiveness of the sensor functionality. It is important to note that these graphs are depicting individual home examples and not the average of all homes in the treatment. Figure 3 depicts a MO home that is not in compliance with the once per week watering restriction as where Figure 4 depicts a MO home that is in compliance with the local watering restriction. Figure 5 illustrates a home with a functioning rain sensor. It can be seen that although the home is not in compliance with the 1-day per week watering ordinance, the sensor is effectively reducing irrigation events. Finally, Figure 6 presents the water use frequency of a home with a soil moisture sensor.

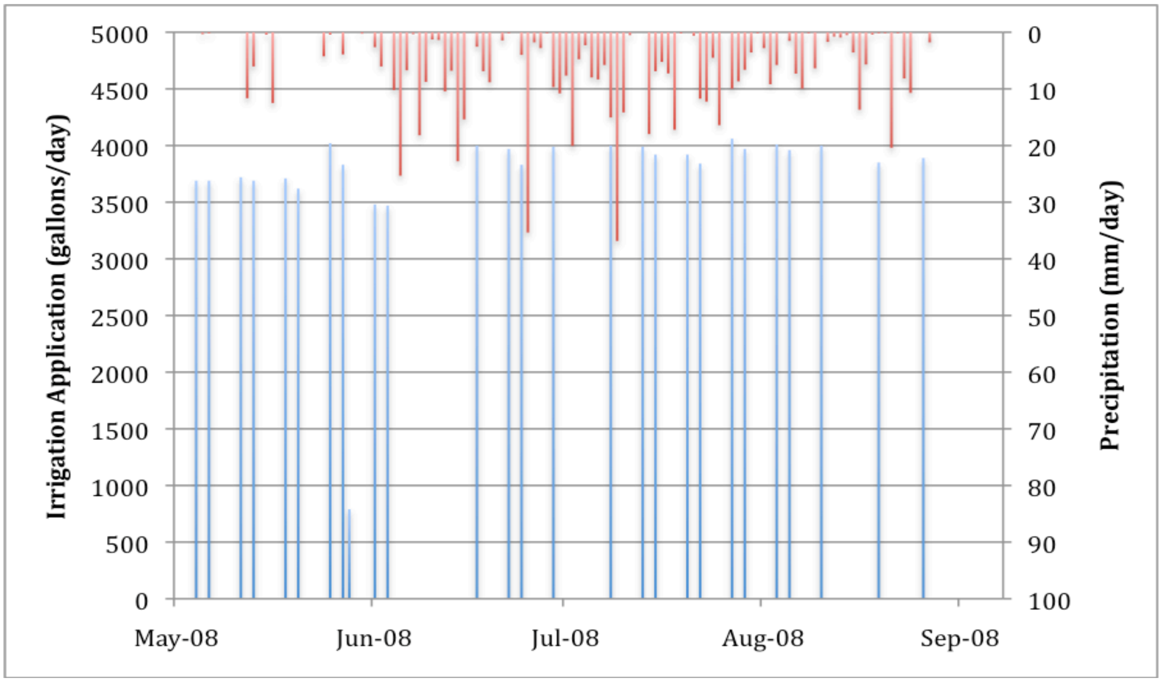

Figure 3. Irrigation frequency of a MO home not in compliance with the 1-day per week ordinace. Blue columns denote irrigation application (gallons/day). Red cloums denote precipitation (mm/day).

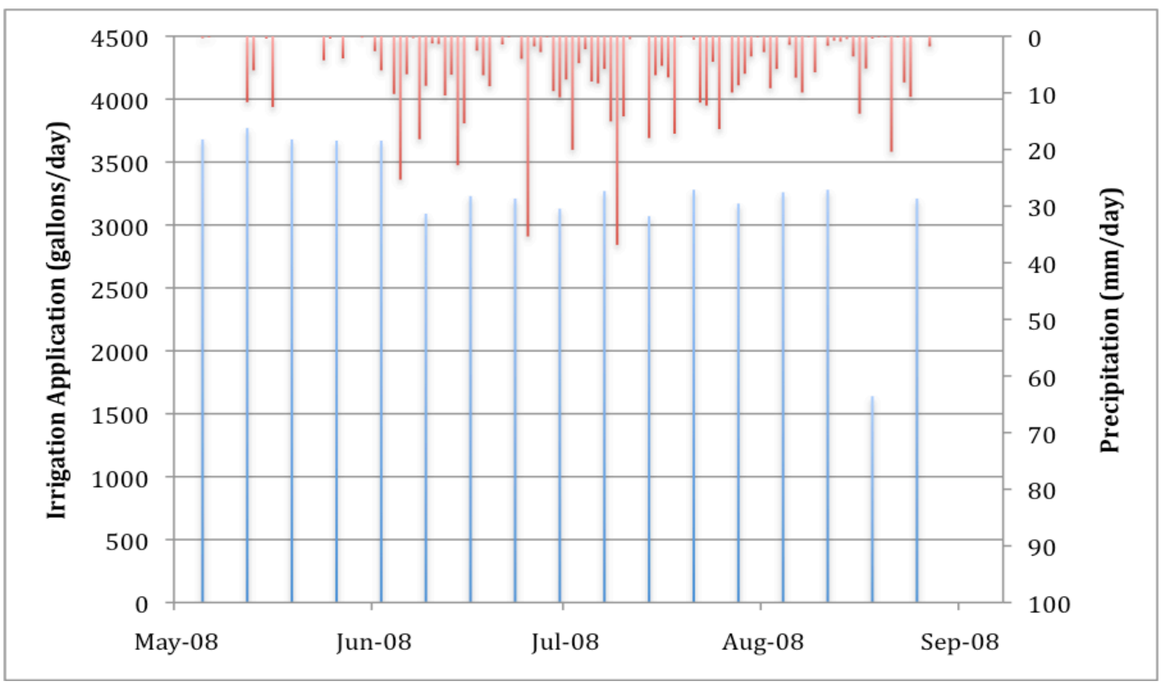

Figure 4. Irrigation frequency of a MO home in compliance with the 1-day per week ordinace. Blue columns denote irrigation application (gallons/day). Red cloums denote precipitation (mm/day).

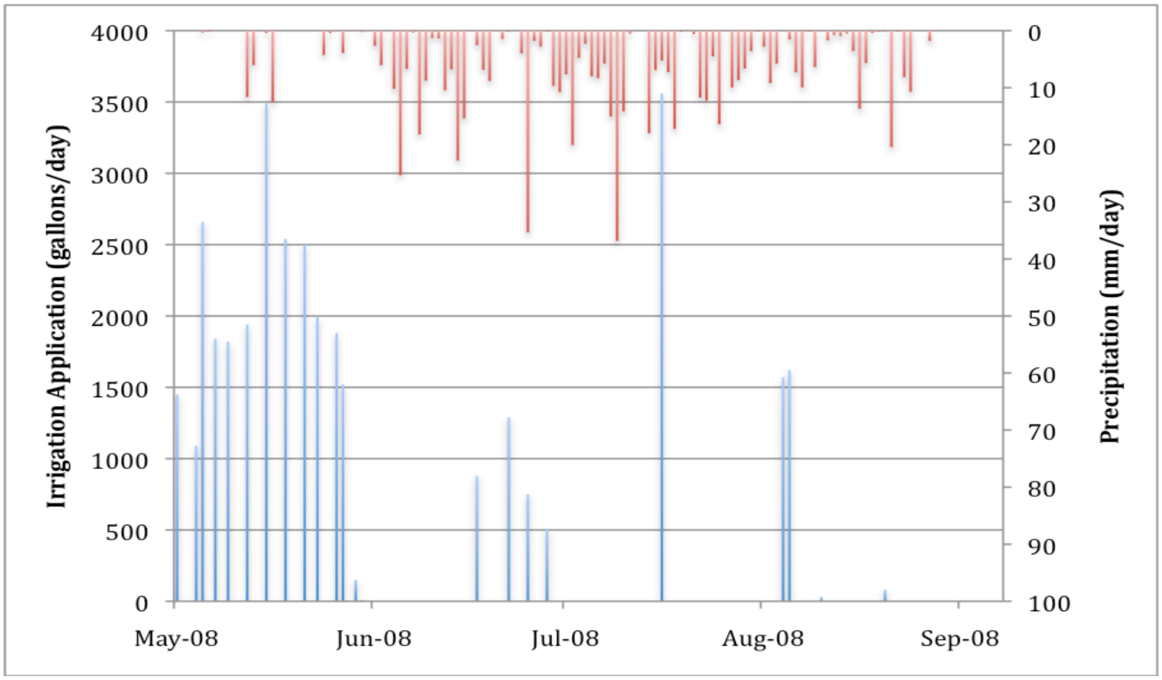

Figure 5. Irrigation frequency of a home with a rain sensor. Blue columns denote irrigation application (gallons/day). Red cloums denote precipitation (mm/day).

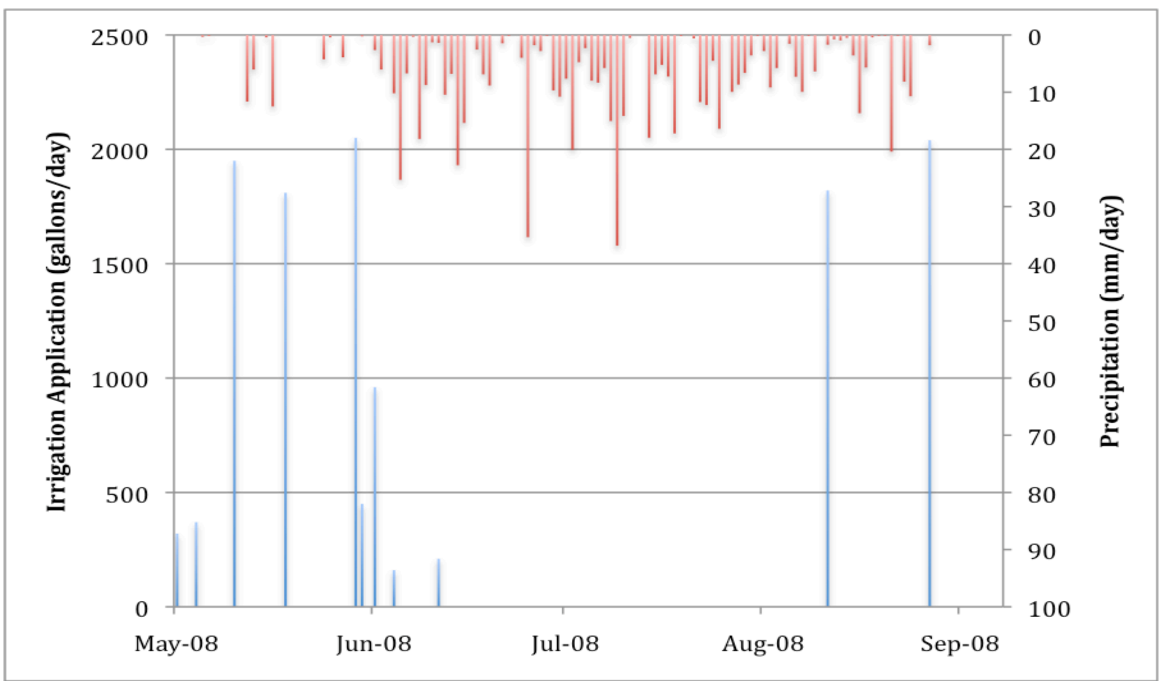

Figure 6. Irrigation frequency of a home with a soil moisture sensor. Blue columns denote irrigation application (gallons/day). Red cloums denote precipitation (mm/day).

Summary and Conclusions

The goal of this study was to quantify irrigation water use between the time-based irrigation system compared to treatments with a soil moisture sensor and controller, rain sensor, and rain sensor along with educational materials advising time clock setting. To determine the treatment effects, the total cumulative savings were compared to the meter only treatment. The soil moisture sensor treatment yielded the greatest savings with 65% of the meter only treatment. Although the educational materials treatment initially showed significant savings similar to soil moisture sensor controllers, over the 26 months, the final irrigation savings was 45%. Lastly, the rain sensor treatment yielded a 14% savings over the meter only treatment. These savings could result a reduction of water consumption up to 262, 189, and 42 gallons per day for the SMS, EDU, and RS respectively compared to homes with no sensor interaction.

Throughout the data collection period, precipitation was 17% less than historical norm. In light of the less than normal precipitation, the soil moisture sensor homes bypassed unneeded irrigation events during rainy as well as dry times with intermittent rainfall, with an average of only 2 irrigation events per month. All other treatments had at least one home more than 20 irrigation events over the course of a month, with a mean of 4-5 events per month. Thus, the soil moisture sensor systems limited the number of irrigation events, where the maximum number of monthly events was 11 versus the 29 events of the meter only treatment. Further, the number of irrigation events by the SMS homes that were half to a third less than the other study homes. Therefore, the soil moisture sensor system controllers can respond as a regulator for irrigation time clock programming that does not correspond to changing weather conditions.

Acknowledgments

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