Irrigation Association Smart Water Application Technologies (SWAT) scores and water conservation potential

Consuelo C. Romero, Ph.D.
Agricultural and Biological Engineering Department, University of Florida,
PO Box 110570, Gainesville, FL.

Michael D. Dukes, Ph.D., P.E., C.I.D.
Agricultural and Biological Engineering Department, University of Florida,
PO Box 110570, Gainesville, FL.

Mary S. McCready, M.S.
Florida Yards and Neighborhoods Program, Miami-Dade Extension, IFAS Extension,
University of Florida, 18710 SW 288 St. Homestead, FL.

Abstract. *The Irrigation Association (IA) Smart Water Application Technologies (SWAT) program was developed to test irrigation controllers to ensure they are able to respond to climate demand or to other feedback from the irrigated system such as soil moisture. Irrigation controllers are tested to gauge their response to climate factors and or soil moisture relative to conventional irrigation theory. Although the SWAT testing process serves as a benchmark to ensure that controllers can respond to changes in climatic or soil moisture conditions, an assessment has not been performed linking SWAT testing controllers to water conservation potential. The objectives of this study were to compare SWAT scores of irrigation adequacy and scheduling efficiency to water conservation potential of controllers tested under field conditions. It was found that generally, irrigation scheduling efficiency decreased as rainfall increased and the irrigation adequacy increased. High scores were not absolutely necessary to guarantee good turf quality. In addition, high scores did not guarantee high levels of water conservation. Thus, the SWAT protocol testing does screen controllers for their ability to adjust relative to irrigated landscape conditions; however, it does not guarantee water conservation.*

Keywords: scheduling efficiency, irrigation adequacy, SWAT, smart water application technology, water conservation.

1. Introduction

The development of Smart Water Application Technologies (SWAT) was initiated in 2002 by water purveyors who wanted to improve residential irrigation water scheduling. Later in 2005, studies reported in the California Water Plan Update, indicated water savings of 17% through the adoption of controllers automatically adjusted to reflect daily changes in ET (Huck and Zoldoske, 2006). SWAT is a national initiative coordinated through the Irrigation Association to achieve exceptional landscape water use efficiency through the application of irrigation technology. The SWAT protocol provides a procedure to evaluate the efficacy of irrigation system controllers that use either climatological or soil moisture data as a basis for scheduling irrigations. This evaluation is accomplished by creating a virtual landscape subjected to representative environments (zones) to evaluate the ability of individual controllers to adequately and efficiently irrigate that landscape. A soil moisture balance is performed by each zone as a standard procedure to test the controller's performance, and deficit and surplus for each zone calculated. The total accumulated deficit over time is a measure of the adequacy. Irrigation adequacy represents how well irrigation met the needs of the plant material. It has been suggested that if this value is above 80%, acceptable vegetation quality will be maintained (SWAT, 2008). On the other hand, the accumulated surplus of applied water over time is a measure of the scheduling efficiency. Although not clearly defined, it has been suggested that a scheduling efficiency score of at least 95% be required for controllers to ensure irrigation is efficient.

1.1 Irrigation controllers

Smart controllers measure depletion of available plant soil moisture in order to operate an irrigation system, replenishing water as needed while minimizing excess water use (IA, 2007). They also must recognize rainfall and its water contribution to the root zone in the irrigation schedule (Huck and Zoldoske, 2006). Examples of the various types of controllers include: historic ET, which uses historical ETo data from a table stored in the controller; on-site sensor, which uses one or more sensors to calculate ETo using and approximate method; real-time ET (real-time ETo is transmitted to the controller daily and it is usually determined using a form of the Penman equation); on-site weather station (central control), which is a controller or a computer connected to an on-site weather station equipped with sensors that record most of the parameters for use in calculating ETo with a form of the Penman equation (IA, 2007); controllers that use rainfall and temperature sensors; and soil moisture sensors, that can provide closed-loop feedback to time-based system controller, allowing controllers to recognize soil moisture levels and terminate irrigation events when soil moisture reaches predetermined levels (Huck and Zoldoske, 2006).

1.2 Testing of controllers for water conservation

Proper installation and programming of each of the technologies is essential element to balancing water conservation and acceptable turf quality (McCready et al., 2009). Evapotranspiration-based (ET) irrigation controllers that are designed to irrigate based on calculated ET needs of the crop. Results of a study evaluating three brands of ET controllers in residential landscaped plots compared to a homeowner irrigation schedule showed consistent water savings with two of the brands (from 14% to 40%). The treatments of this study, carried out in Florida, did not result in turf quality below acceptable levels (Davis et al., 2009). Another study carried out in Florida showed water savings between 25% and 62% when testing two brands of ET controllers on irrigated St. Augustinegrass (McCready et al., 2009).

Rain sensor (RS) controllers are small devices wired to the irrigation system controller designed to interrupt time clock scheduled irrigation cycles after a certain amount of rainfall occurs, conserving water while preventing irrigation (Dukes and Haman, 2002a). A study comparing bermudagrass plots under a completely time-based scheduling system with and without a rain sensor showed that the treatment without-rain-sensor used 45% more water than the with-rain-sensor treatment (Cardenas-Lailhacar et al., 2005). Another study testing rain sensors showed water savings of 7% to 30% when using rain sensor systems compared to historical net irrigation requirement, under dry to normal rainfall conditions, without reducing turf quality below acceptable limits (McCready et al., 2009).

Soil moisture sensor (SMS) irrigation controllers are designed to allow or bypass timed irrigation events (Dukes, 2005), providing a maximum water use efficiency by maintaining soil moisture at optimum levels (Cardenas-Lailhacar et al., 2005). Soil moisture sensor based irrigation control may offer some advantages over the climate based control technology. There are just few studies testing these SMS controllers. One is a study using soil moisture sensors to control residential irrigation systems in Colorado resulted in water saving of 27% compared to the theoretical water requirement calculated by a water balance (Qualls et al., 2001). Another study was carried out under Florida conditions during two 5-month periods, one in 2004 and the other in 2005, were three commercially available SMS controllers were tested on bermudagrass (*Cynodon dactylon* L.; Cardenas-Lailhacar et al., 2008). They reported water savings ranging from 69% to 92% during normal to rainy conditions for three of four controllers tested. Results for the 5-month period in 2004 only showed irrigation water saving from 46% to 88%. The turf quality was not affected, mainly because bermudagrass is known as a more drought-tolerant grass compared to other species (Cardenas-Lailhacar et al., 2005).Water savings were also reported by McCready et al. (2009) when using SMS controllers on St. Augustinegrass (*Stenotaphrum secundatum* (Walter) Kuntze) irrigation plots during dry conditions in Florida. Water savings ranged from 11% to 53% compared to a time based irrigation schedule developed based on the historical net irrigation requirement, and turf quality was above the acceptable limits.

The California Department of Water Resources funded two large programs in southern and northern California to improve urban irrigation efficiency and reduce runoff thorough the installation of smart controllers (Mayer et al., 2009). This study compared a single year of pre-installation data against a single year of post-installation data. The impact of 3,112 smart controllers installed at 2,294 sites at both sides showed that overall, outdoor water use was reduced by an average of 47.3 kgal per site (-6.1% of average outdoor use), a statistically significant reduction at the 95% confidence level. Seven of eight controller brands included in the analysis saved water on average; however the water savings associated with brand was not statistically significant. In addition, seven of the eight controller brands included in this study have published SWAT test results and all of the published SWAT scores were above 95% for adequacy. According to these results, it seems that the SWAT testing protocol may be used to predict a reasonable field performance, but not guarantee water savings.

The objective of this study was to compare SWAT scores of irrigation adequacy and scheduling efficiency to water conservation potential of controllers tested under field conditions.

2. Materials and Methods

2.1 Site description

The study was performed at the Plant Science Research and Education Unit in Citra, Florida. There were four treatment periods: 22 April 2006 to 30 June 2006 (S06), 23 September 2006 to 15 December 2006 (F06), 1 May 2007 to 31 August 2007 (S07) and 1 September 2007 to 30 November 2007 (F07). As described in McCready et al., (2009), the experimental area consisted of 72 plots (18.2 m^2 each) of 'Floratam' St. Augustinegrass (*Stenotaphrum secundatum*). Four Toro 570 Series (The Toro Company, Bloomington, MN.) quarter circle pop-up spray heads with a measured application rate of 50 mm h^{-1} irrigated the plots. Irrigation time clocks were used for scheduling all of the treatments except where a time-based controller was not necessary. Plot maintenance was according to local recommendations to maintain good quality during the growing season. Full details of the site layout and experimental procedures can be found at Shedd (2008) and McCready et al. (2009).

2.2 Data collection

Irrigation water applied was monitored using flow meters on each plot as described by McCready et al. (2009). Weather data parameters (rainfall, incoming solar radiation, relative humidity, air temperature and wind speed) were collected from an automated weather station (Campbell Scientific, Logan, UT) within 900 m of the experimental site (McCready et al., 2009). The ASCE standardized method (Allen et al., 2005) was used to calculate ETo. Monthly values of locally determined Kc were specified for a warm season turfgrass (Jia et al., 2009).

2.3 Experimental design

Table 1 shows all the experimental treatments evaluated for this study. A commercially available soil moisture sensor controller, Acclima Digital TDT RS500 (Acclima Inc., Meridian, ID.) was tested. Two different volumetric moisture content (VWC) thresholds were used in the testing, 7% and 10%. The soil moisture sensor (SMS) treatments had a sensor buried in the experimental plots to control irrigation. ET controllers included the Toro Intelli-Sense (The Toro Company, Bloomington, MN.) The Toro Intelli-Sense controller (TORO) calculates irrigation runtime and the frequency of irrigation events. Rain sensor (RS) treatments, using the Mini-Click rain sensor

(Hunter Industries Inc., San Marcos, CA), were set at several day of the week frequencies and threshold depths: 1 d/wk, 6 mm threshold; 2 d/wk, 6 mm threshold; and 7 d/wk, 3 mm threshold. There were two comparison treatments: a time-based treatment without a rain sensor (WOS) and a time based treatment with a rain sensor set at 6 mm and an irrigation depth equal to 60% of the possible depth scheduled for WOS and the other RS treatments (DWRS).

The same total application depth per week was divided over the possible number of irrigation days per week. Every treatment except for the TORO and the DWRS had the same possible total depth or irrigation application. The monthly irrigation schedule was based on local recommendations (Dukes and Haman, 2002b). Turfgrass quality evaluations were made using the National Turfgrass Evaluation Program (NTEP) procedures (Shearman and Morris, 1998), with details provided by McCready et al. (2009).

Table 1: Summary of irrigation controllers experimental treatment codes and descriptions (after McCready, 2009).

Treatment code	Irrigation frequency (d/wk)	Treatment description
Soil moisture sensor controller		
AC7	2	Acclima set at 7% VWC[1]
AC10	2	Acclima set at 10% VWC
ET controller		
TORO	2	Toro Intelli-Sense
Rain sensors and time-based irrigation		
RS1-6mm	1	Rain sensor set at 6 mm rainfall threshold
RS2-6mm	2	Rain sensor set at 6 mm rainfall threshold
RS7-3mm	7	Rain sensor set at 3 mm rainfall threshold
DWRS	2	Reduced irrigation schedule (60% of RS2-6 mm)

[1] VWC= volumetric water content.

2.4 SWAT ‘inspired’ water balance approach

A daily soil water balance (Dukes, 2007) was performed for the 2006 and 2007 testing periods. The actual water applied was input into this daily soil water balance along with ET and rainfall to determine the daily soil water level. These theoretical values were compared to the irrigation applied with the SMS, RS and ET systems in order to determine the irrigation adequacy and scheduling efficiency of water application. Direct runoff and soak runoff were neglected since they are not relevant due to the sandy soils with high infiltration rates. These two parameters are included, however, in the SWAT protocol (SWAT, 2008). The soil water balance equation was represented as follows:

$$D_{r,i} = D_{r,i-1} - (P - RO)_i - I_i - CR_i + ET_{c,i} + DP_i$$

where $D_{r,i}$ is depletion of water from the root zone at the end of the day (mm), $D_{r,i-1}$ is depletion of water from the root zone at the end of the previous day (mm), P_i is precipitation (mm), RO_i is runoff from the soil surface (mm), I_i is irrigation depth applied (mm), CR_i is capillary rise from the groundwater table (mm), $ET_{c,i}$ is crop evapotranspiration (mm) and DP_i is deep percolation (mm). For this study, RO and CR were considered negligible due to the low slope inclination of the experimental site, the depth of the water table (more than 5 m deep) and the sandy soil texture. Any water applied in excess of field capacity is considered to contribute to DP. A root zone depth of 30 cm was used since this is the most frequent root depth found for warm-season grasses (Doss et al., 1960; Peacock and Dudeck, 1985). ET_c was calculated by multiplying ET_o (ASCE standardized method, Allen et al., 2005) and monthly K_c values specified for warm-season turfgrasses (Jia et al., 2009). The irrigation schedule used for the RS and SMS treatments was based on a system efficiency of 60%, whereas 95% efficiency was used for the TORO controller. Thus calculated gross irrigation was determined from these efficiency values. The depth of available water (AW) was calculated using the following equation (Cassel and Nielsen, 1986):

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

where FC is field capacity (cm^3 of water per cm^3 of soil), PWP is permanent wilting point (cm^3 of water per cm^3 of soil), RZ is root zone depth (mm). The depth of RAW is calculated using the following equation (IA, 2005):

$$RAW = MAD * AW$$

A MAD (maximum allowed depletion) factor of 50% established for turfgrass has been suggested by Allen et al., 1998. To account for the decrease in crop transpiration when the soil moisture was below MAD, the adjusted $ET_{c,adj.)}$ was calculated using a water stress coefficient (Ks) as described in Allen et al. (1998).

Irrigation adequacy (%) refers to whether or not the irrigation applied is sufficient for plant needs (SWAT, 2008) and was calculated as follows:

$$Irrig.\,adequacy = \left[\frac{ETc, adj - Deficit}{ETc, adj}\right] * 100$$

where deficit was calculated as the water that was needed by the plant and was not readily available. Scheduling efficiency is a measure of how well irrigation depths were applied while preventing runoff and deep percolation and was calculated using the following equation (SWAT, 2009):

$$Scheduling\ efficiency = \left[\frac{Net\ irrig. - Irrig.\,losses}{Net\ irrig.}\right] * 100$$

where irrigation losses (mm) are the amount of water applied that exceeded the FC of the soil, leading to runoff or deep percolation. Since runoff was assumed to be zero under this condition, any over irrigation was assumed to lead to drainage below the root zone.

Both scores (irrigation adequacy and scheduling efficiency) were calculated for running totals of 30-day periods. These scores were only calculated if rainfall totaled at least 10.2 mm and ETo was at least 63.5 mm during the testing period to be considered a valid value (SWAT, 2008). Water savings were calculated between each controller treatment water use and the WOS (without a sensor) schedule, that was as a baseline for comparison purposes.

3. Results and discussion

3.1 Adequacy scores versus water savings

Considering all controller treatments, there was no correlation between water savings and irrigation adequacy scores (R=0.0979) (Figure 1, Table 2). There was not a clear correlation between increased water savings and higher scores since there are high scores associated with low water savings. When analyzing by individual controller treatments, correlations showed positive higher values, reaching maximum R values for AC7 (R = 0.7862) and for DWRS (R = 0.7254). This would mean that the higher the adequacy score, the higher the water savings value, when in theory the expected relationship would be a direct but negative correlation (higher water saving occurring when adequacy scores are lower). However, a negative direct correlation was observed when all the treatments were analyzed by season treatments F07 and S07 (R= -0.5639 and -0.5498, respectively). The highest overall water savings were seen during F07, which received the greatest amount of rainfall during the four treatment periods (McCready et al, 2009).

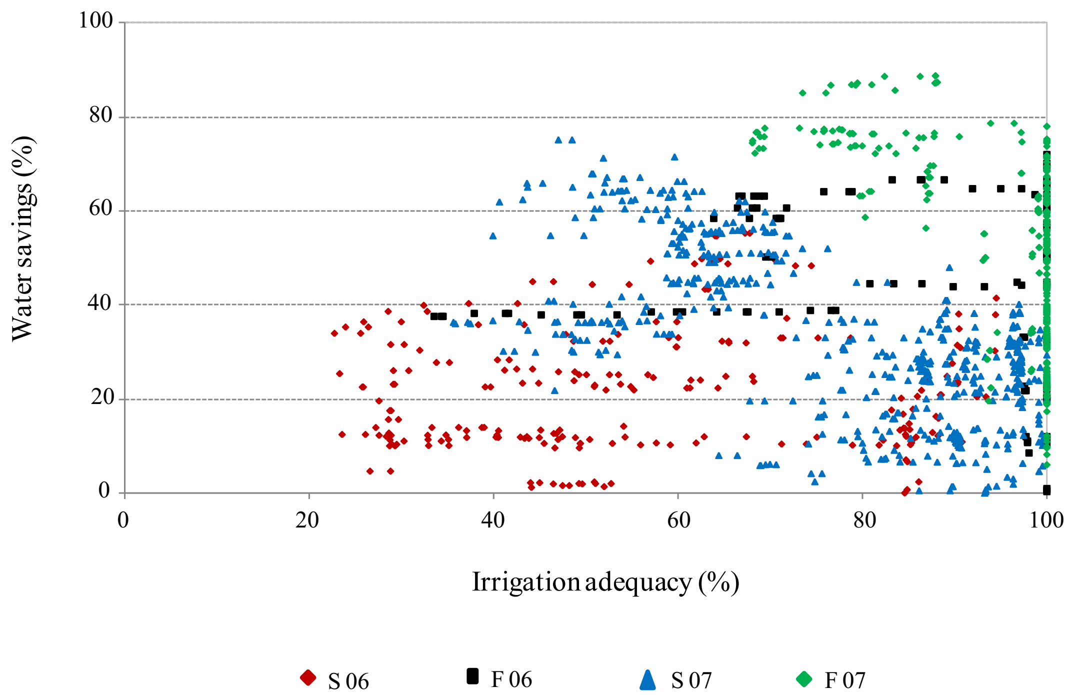

Figure 1: Water savings versus irrigation adequacy by seasons. S06 = spring 2006, F06 = fall 2006, S07 = spring 2007, and F07 = fall 2007.

Table 2: Correlation coefficients from multiple correlation analysis considering all treatments and by controller treatments.

Treatments		Gross irrigation	Water savings	Irrigation adequacy	Scheduling efficiency	Turf quality	30-day rainfall
	G. irrigation[1]	1					
	W. savings	-0.7549	1				
	I. adequacy	-0.02869	0.0979	1			
ALL	S. efficiency	-0.0883	0.0043	-0.3171	1		
	T.quality	-0.0375	0.1954	0.3906	0.1720	1	
	30-d rainfall	-0.2179	0.2896	0.3164	-0.4247	-0.0502	1
	G. irrigation	1					
	W. savings	-0.9271	1				
AC7	I. adequacy	-0.7337	0.7862	1			
	S. efficiency	0.3041	-0.2664	-0.4642	1		
	T.quality	-0.4510	0.6384	0.2519	0.1287	1	
	30-d rainfall	-0.3247	0.3388	0.6607	-0.8529	-0.0811	1
	G. irrigation	1					
	W. savings	-0.8685	1				
AC10	I. adequacy	-0.4295	0.4885	1			
	S. efficiency	-0.3881	-0.0559	-0.1594	1		
	T.quality	-0.3463	0.3997	0.6023	0.0176	1	
	30-d rainfall	-0.1894	0.2711	0.3399	-0.7683	-0.7683	1
	G. irrigation	1					
	W. savings	-0.9612	1				
TORO	I. adequacy	-0.0734	0.1412	1			
	S. efficiency	-0.5067	0.4703	-0.4178	1		
	T.quality	-0.3692	0.3250	0.1157	-0.2649	1	
	30-d rainfall	-0.1872	0.2219	0.2735	-0.2903	0.0899	1
	G. irrigation	1					
	W. savings	-0.8358	1				
RS1-6mm	I. adequacy	-0.3107	0.4368	1			
	S. efficiency	0.2146	-0.2606	-0.4443	1		
	T.quality	0.1409	0.0634	0.5807	0.1837	1	
	30-d rainfall	-0.4011	0.5542	0.3793	-0.2594	-0.0441	1
	G. irrigation	1					
	W. savings	-0.6008	1				
RS2-6mm	I. adequacy	-0.2047	0.2724	1			
	S. efficiency	0.4720	-0.4566	-0.4932	1		
	T.quality	0.2542	0.2737	0.2334	0.1073	1	
	30-d rainfall	-0.1813	0.4435	0.3357	-0.4682	-0.0779	1
	G. irrigation	1					
	W. savings	-0.7446	1				
RS7-3mm	I. adequacy	-0.2697	0.5265	1			
	S. efficiency	0.6989	-0.6225	-0.5782	1		
	T.quality	0.0647	0.3077	0.8709	-0.3478	1	
	30-d rainfall	-0.3459	0.4374	0.3821	-0.2066	0.1537	1
	G. irrigation	1					
	W. savings	-0.6566	1				
DWRS	I. adequacy	-0.7602	0.7254	1			
	S. efficiency	0.1564	-0.1499	-0.0896	1		
	T.quality	-0.0442	0.3835	0.2240	0.4935	1	
	30-d rainfall	-0.3388	0.5442	0.4665	-0.3348	-0.1609	1

[1]G. irrigation= gross irrigation, w.savings = water savings, i.adequacy = irrigation adequacy, s. efficiency = scheduling efficiency, t. quality = turfquality, 30-d rainfall = 30-day rainfall.

3.2 Scheduling efficiency versus water savings

The expected positive and direct correlation between water savings and scheduling efficiency was not observed when all treatments were considered together (R value was 0.0043; Figure 2, Table 2). When evaluating each controller treatment, correlation values were negative, especially with the three rain sensor treatments, except with the TORO controller, that showed an R value of 0.4703. Rain sensors may not take into account rainfall perfectly, which led to lower scheduling efficiency. As with the irrigation adequacy scores, there were high score values associated with both, high and low water savings (Figure 2, Table 2). But when all controller treatments were evaluated by season, F06, S07 and F07 showed positive correlations, although the R values were low (R=0.3292, 0.3163 and 0.3342, respectively).

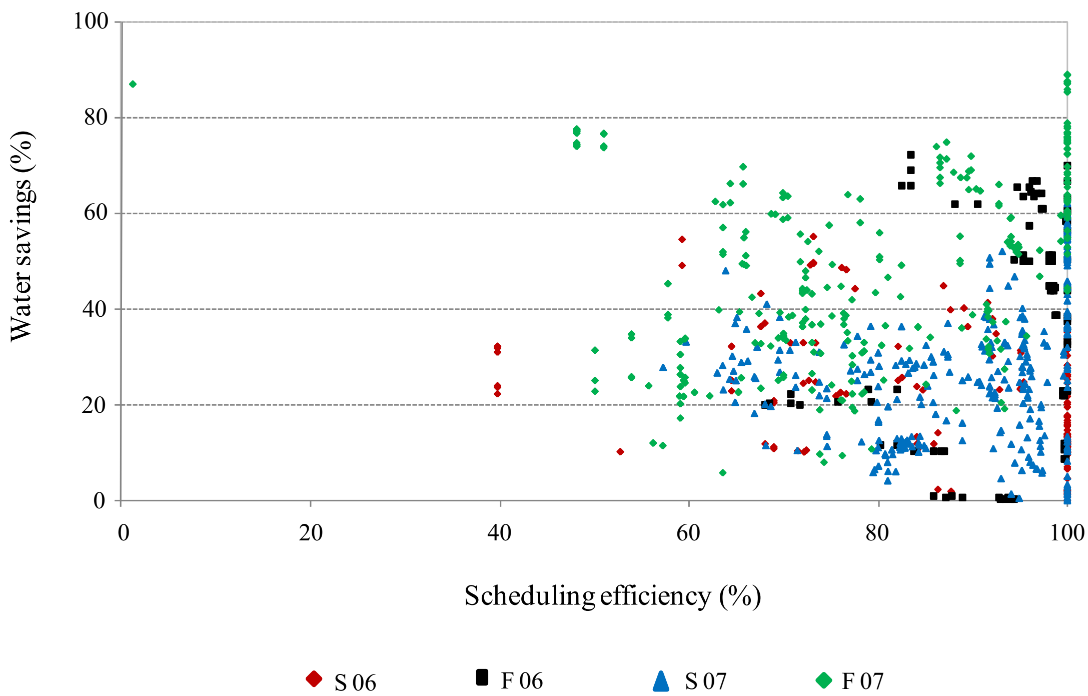

Figure 2: Water savings versus scheduling efficiency by seasons. S06 = spring 2006, F06 = fall 2006, S07 = spring 2007, and F07 = fall 2007.

3.3 Turf quality versus SWAT scores

Turf quality values from 4.0 to 8.0 were related to a range of irrigation adequacy scores that ranged from 20 to 100%, showing an R=0.3905 (Figure 3a, Table 2). Considering all controller treatments, the correlation was positive, with an R = 0.3905. In some cases, irrigation adequacy was very low (30%) and turf quality was still acceptable (7.0). On the other hand, there were cases were irrigation adequacy was higher than 80% and turf quality included a 4.0 rating. The RS7-3mm controller treatment showed the highest correlation with irrigation adequacy (R=0.8709), showing adequacy scores from 80 to 100% correlated with turf quality of 6.0 and 7.0, respectively. This treatment was followed by AC10 (R=0.6023), which showed lower adequacy scores from 40% to 100% correlated with turf quality from 5.0 to 7.0. The rest of controller treatments showed positive low correlation values (R < 0.5; Table 2). Considering all treatments by season, F07 showed the highest correlation with irrigation adequacy (R=0.6194). This treatment period showed acceptable turf quality rating (5.0) even in then non-irrigated plots, because of frequent rainfall.

Scheduling efficiency scores for all treatments showed a positive but low correlation with turf quality ratings (R=0.1720; Figure 3b; Table 2). Scheduling efficiency would not be expected to increase turf quality but it is important to note that did not decrease turf quality. Scheduling efficiency ranged from 40% to 100% for turf quality ratings ranging from 4.0 to 8.0. Analyzing every controller showed no correlation at all. Analyzing by season treatment, only S06 and F06 showed positive correlations with R=0.5137 and R=0.5735, respectively (Table 3). These two seasons were relatively dry and all the technologies tested managed to reduce water application (McCready et al., 2009), meaning a high efficiency of irrigation while turf quality was still acceptable.

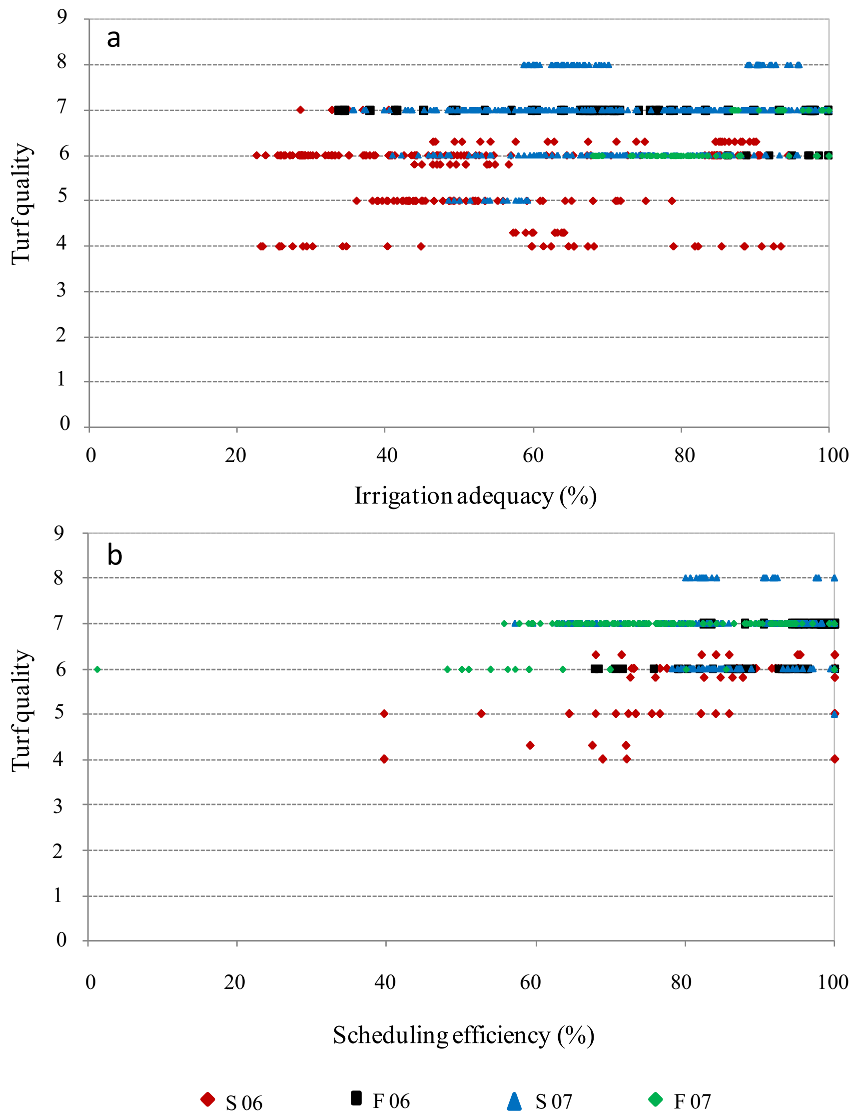

Figure 3: Turf quality versus irrigation adequacy (a) and scheduling efficiency (b) across seasons. S06 = spring 2006, F06 = fall 2006, S07 = spring 2007, and F07 = fall 2007.

3.4 Rainfall amount and SWAT scores

There was a positive correlation between 30-day period rainfall and irrigation adequacy when all the controller treatments were analyzed (R=0.3164; Figure 4a; Table 2), which means the higher the cumulative rainfall, the lower the irrigation input, and the higher the irrigation adequacy. The only controller treatment showing the highest correlation was treatment AC7, with an R= 0.6607. The rest of the controller treatments showed correlation values lower than 0.5 (Table 2). When the correlation analysis was done by season treatment, S06 was the only treatment showing a positive correlation with an R=0.5328, while the remaining treatments did not show any correlations at all (Table 3). Relationship between the 30-day period rainfall and scheduling efficiency show an inverse correlation when all treatments were considered (R= -0.4247, Figure 4b). This would mean that for a higher cumulative rainfall amount, a lower irrigation application corresponded. Scheduling efficiency tended to decreased because of timing of rainfall during the soil water balance. In the soil water balance, the rainfall occurs before irrigation, causing drainage to occur from irrigation. The analysis by seasonal treatment showed no correlation between cumulative rainfall and scheduling efficiency.

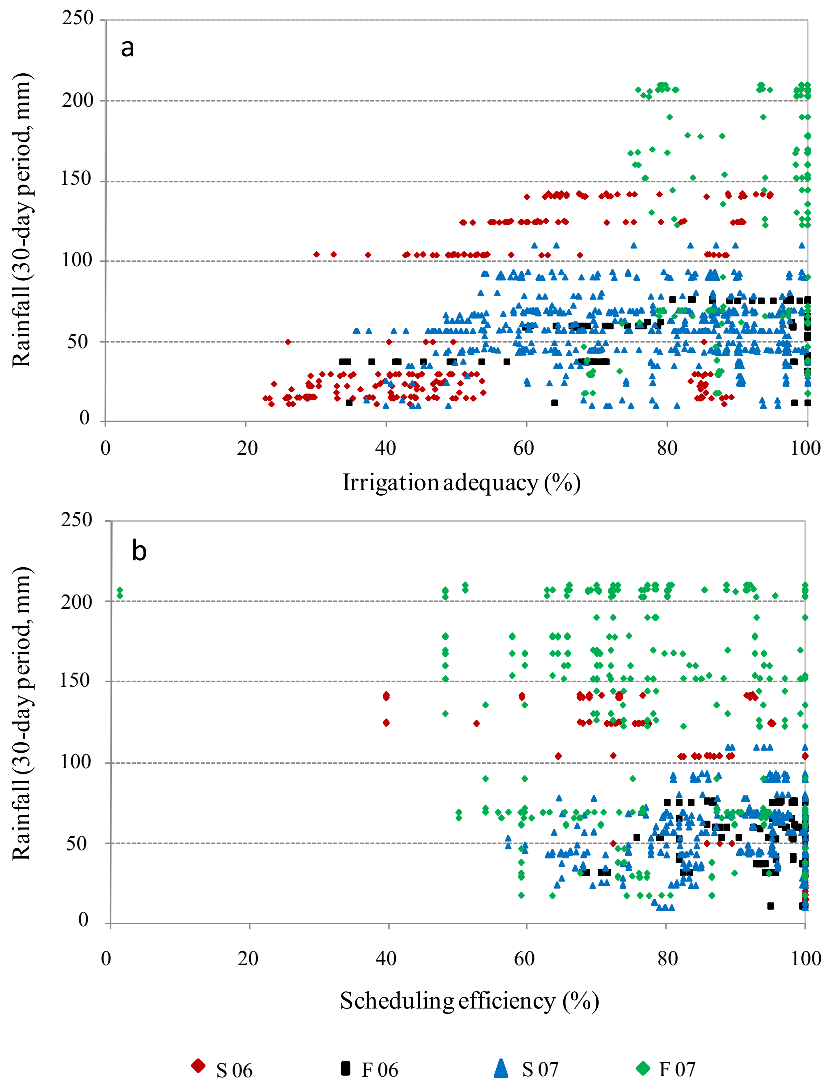

Figure 4: Thirty day cumulative rainfall versus irrigation adequacy (a) and scheduling efficiency (b) across seasons. S06 = spring 2006, F06 = fall 2006, S07 = spring 2007, and F07 = fall 2007.

Table 3: Correlation coefficients from multiple correlation analysis (analysis by season).

Treatments		Gross irrigation	Water savings	Irrigation adequacy	Scheduling efficiency	Turf quality	30-day rainfall
	G. irrigation	1					
	W. savings	-0.8571	1				
	I. adequacy	0.0869	0.1364	1			
S06	S. efficiency	0.1639	-0.4446	-0.3016	1		
	T.quality	0.0682	-0.1919	0.0071	0.5137	1	
	30-d rainfall	-0.2379	0.5841	0.5328	-0.8009	-0.2905	1
	G. irrigation	1					
	W. savings	-0.7977	1				
F06	I. adequacy	-0.0441	-0.2214	1			
	S. efficiency	-0.1422	0.3292	-0.3492	1		
	T.quality	-0.3917	0.5346	-0.3781	0.5735	1	
	30-d rainfall	-0.1882	0.0093	0.1507	0.0801	-0.2543	1
	G. irrigation	1					
	W. savings	-0.7945	1				
S07	I. adequacy	0.5356	-0.5498	1			
	S. efficiency	-0.5316	0.3163	-0.4717	1		
	T.quality	-0.2064	0.1377	0.2069	0.02744	1	
	30-d rainfall	-0.0844	-0.0348	-0.0050	0.1706	-0.3401	1
	G. irrigation	1					
	W. savings	-0.8701	1				
F07	I. adequacy	0.6253	-0.5639	1			
	S. efficiency	-0.3292	0.3342	-0.0002	1		
	T.quality	0.3349	-0.2455	0.6194	0.3126	1	
	30-d rainfall	0.1911	0.0105	0.0681	-0.2132	0.0665	1

[1]G. irrigation= gross irrigation, w.savings = water savings, i.adequacy = irrigation adequacy, s. efficiency = scheduling efficiency, t. quality = turfquality, 30-d rainfall = 30-day rainfall.

3.5 Testing SWAT scores in time

In terms of SWAT testing, controller will (almost) get good scores if testing occurs for a long enough time period. We analyzed the temporal average considering one season (S06), two seasons (S06+F06) and so on, of irrigation adequacy and scheduling efficiency. The results showed that the average irrigation adequacy increased when more evaluations were considered (Figure 5a). This trend was observed for all the controller treatments. However, this trend was not observed for scheduling efficiency (Figure 5b). Scores were high or low for at least some 30 day period. Since the variability is high we would propose that multiple 30 day periods need to be used for evaluating controllers

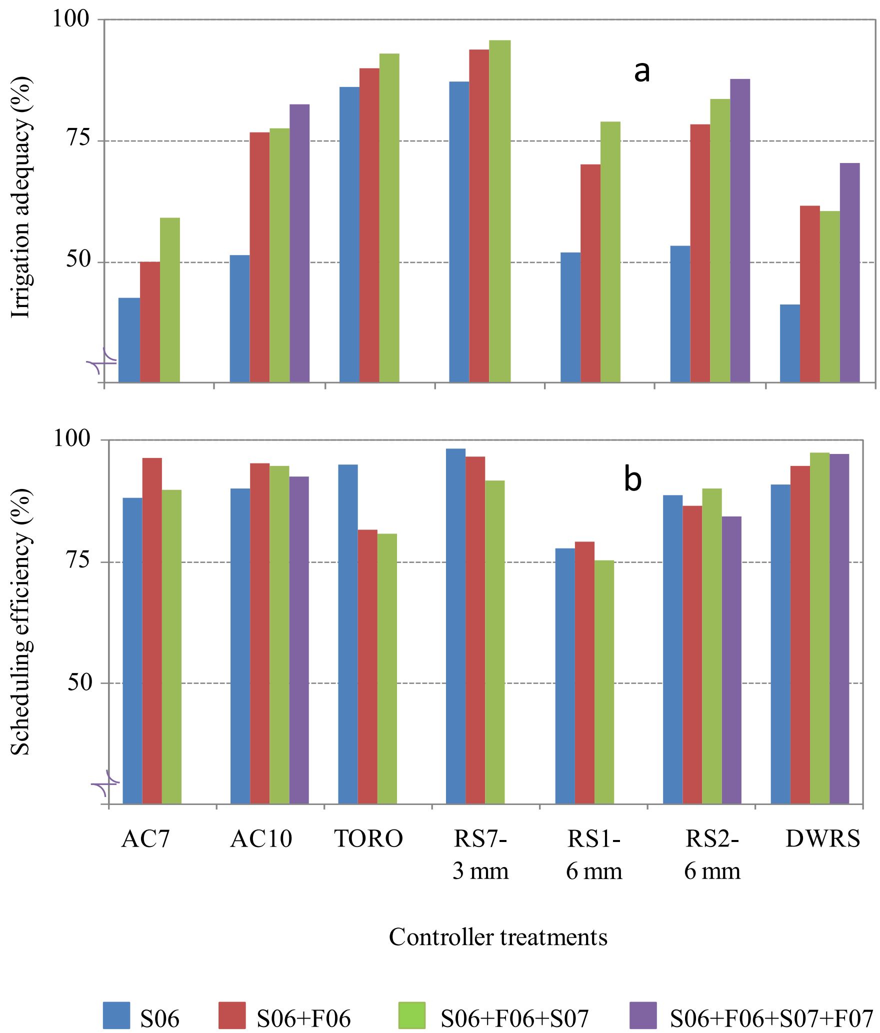

Figure 5: Effect of long-term evaluation irrigation controllers on irrigation adequacy and scheduling efficiency. S06 = spring 2006, F06 = fall 2006, S07 = spring 2007, and F07 = fall 2007.

4. Conclusions

There is a not a clear trend for water conservation with either higher scheduling efficiency or higher irrigation adequacy scores evaluated under field conditions. Also, turf quality remained acceptable (5.0) even when adequacy scores were as low as 30%. In SO6 the general trend was that as efficiency increased, water savings decreased, which was the opposite of the other testing periods. There were some cases where irrigation efficiency reached low values (around 50%) but high water savings (75%) during F07 under treatment AC7. These results indicate that the values used in the SWAT analysis soil water balance need to be verified against field data, particularly for irrigation adequacy. There was a positive correlation between 30-day period rainfall and irrigation adequacy but negative with scheduling efficiency. Thus, the overall indication is that rainfall during the testing period can contribute to increased adequacy scores and decreased scheduling efficiency scores, indicating that the controllers tested here did not perfectly account for rainfall or the soil balance does not perfectly capture the actual conditions. In all cases, less gross irrigation led to increased water savings.

As described by Mayer et al. (2009), the SWAT testing protocol was not designed as a way to assess water savings, but rather is a method to try and ensure controllers apply the right amount of water based on current ET formulation. If water efficiency or irrigation adequacy are the primary goal of the testing regime, then a conservation-oriented testing criteria perhaps derived from the current SWAT protocol should be considered. Historical water use compared to estimated irrigation need of a site with a new smart controller may be one of the most important things to determination of water savings. Future testing should evaluate the SWAT protocol analysis against field installations and to develop optimized programming for various technologies to promote water conservation.

5. References

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