Soil Moisture-Based Irrigation Controller
Final Test Report

Submitted to:

EPA WaterSense Program

By:

Michael D. Dukes, Ph.D., P.E.

University of Florida

Institute of Food and Agricultural Sciences

Agricultural and Biological Engineering Department

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Introduction

The University of Florida, Agricultural and Biological Engineering Department under the direction of Dr. Michael Dukes performed testing of soil moisture-based irrigation controllers as part of the American Society of Agricultural and Biological Engineers (ASABE) committee work for X633, Testing Soil Moisture Sensors for Landscape Irrigation. Testing occurred January – July 2019 and was funded in part by the Metropolitan Water District of Southern California Innovation Conservation Program.

The purpose of the testing was as follows:

1. Verify the test procedure under lab conditions.
2. Determine precision of soil moisture sensor irrigation controllers (SMS controllers) under two soil types and two added water salinity levels.

Key test questions included:

1. What is the precision of SMS controllers?
2. How does SMS controller response vary across moisture levels?
3. Do readings change at 0 hr vs. 24 hr?
4. What is the SMS controller precision after freezing?

Procedure

The test procedure was performed based on the latest version of the draft standard from the ASABE X633 committee. A total of four commercially available SMS controllers were tested and randomly labeled as brands A-D. Two test media mixes are specified that represent two soil types, moderately coarse and moderately fine. In addition, two added water salinity levels are specified <0.2 dS/m and 3 dS/m. For each test media and each salinity level, SMS controllers are tested at three soil moisture levels (i.e. water depletion levels). These levels are determined as a percentage depletion from field capacity (FC) and are 20%, 40% and 60% depletion where 0% depletion is FC and 100% depletion is air dry.

Test Media Preparation

The test consists of two test media mixes that are created from 60F silica sand, 325 silica flour, and sodium bentonite (Fig. 1). The test media mixes are created as follows based on proportions by weight and the following measured textures:

Coarse media: 6:2:2 (63% sand, 16% silt, 21% clay)
Fine media: 1:1:1 (40% sand, 29% silt, 31% clay)

The coarse and fine test media mixes emulate a sandy loam soil and clay loam soil (Fig. 2), respectively. Air dry components were mixed together in proportions by weight given above.

Once dry components are mixed, the three water depletion levels were determined as follows for 20%, 40% and 60% depletion, respectively:

Coarse media (FC = 20% by vol.): 16%, 12%, 8%
Fine media (FC = 32% by vol.): 25.6%, 19.2%, 12.8%

Test Apparatus

Containers were selected with dimensions that allow installation of three sensors with enough space to prevent interference between the sensors or the edges of the containers. The volume level of the container that includes the depth for sensor burial was marked and target volume was determined by liquid (Fig. 3). The dry mass of media required was calculated from the target bulk densities of 1.4 g/cc and 1.3 g/cc for the coarse and fine media, respectively as specified by the X633 committee. The applicable sensors volumes were determined via liquid displacement and subtracted from the container volume to calculate the dry media weight required for packing to achieve the target bulk density.

Once the test media were prepared, as specified by the X633 draft standard, the moist test media was packed carefully in the container in layers as specified by the X633 draft standard (Fig. 3). Once the container was packed to a depth of sensor placement, the sensors are placed in the container and moist media is carefully packed around the sensors (Fig. 4) to ensure no air gap around the sensors. Finally, moist media was packed to the final volume that results in the target test bulk densities. The test containers were covered and sealed to prevent evaporation. The test containers were weighed to ensure the target soil and water added is achieved within 1% of the calculated amount and that evaporative losses do not occur during testing (Fig. 5).

The sensors were configured to a 24VAC power source. In this testing the power source consisted of an ordinary irrigation controller (Fig. 6).

Data Collection

All sensors have readings collected in the air and then fully submersed in water to establish the full reading range and ensure functionality. A sensor reading, if applicable, and irrigation enabled and disabled readings were taken immediately after the containers were packed and sealed at the 0 hr time. Another set of readings were taken 24 hr later. The 0 and 24 hr readings were taken since the draft X633 standard specifies that sensors shall be allowed to acclimate for a period of time specified by the manufacturer before a reading is taken. In this testing several sensors could be read immediately while one required 24 hrs to acclimate. The containers were weighed again to ensure no loss of water.

The X633 test procedure calls for a freeze test where the 40% depletion on the 0 dS/m fine media test container is placed in a freezer at -18 C for 72 hrs and then it is removed and allowed to thaw to pre-freeze temperature for 24 hrs. Readings are collected from the three sensors pre and post freeze. In addition to the X633 specified freeze test, the freeze test was also conducted on the coarse media with 3 dS/m water added salinity at 40% depletion.

Data Analysis

Data for each media mix, water added salinity, and depletion level were analyzed in terms of the precision of the three test sensors in each of those scenarios. Data were collected for sensor reading (if available), and irrigation enabled and disabled readings. Precision was determined by the average deviation from the mean as follows:

$$Avg\ Deviation = \frac{\sum_{i=1}^{n}|\bar{x}-x_i|}{n} \qquad [1]$$

Where: $\bar{x}$, mean of n sensor readings
x_i, sensor i reading
n, number of sensors in a test, 3

The Avg Deviation was normalized to the Relative Average Deviation (RAD) resulting in a percentage measure independent of individual sensor units as follows:

$$Relative\ Avg\ Deviation = \frac{Avg\ Deviation}{\bar{x}} \qquad [2]$$

In addition, the coefficient of determination was computed for the best fit line through the average of the three sensor readings at each water depletion level. The slope of that line was also determined.

Figure 1. Mixing media components (credit Bernard Cardenas UF/IFAS)

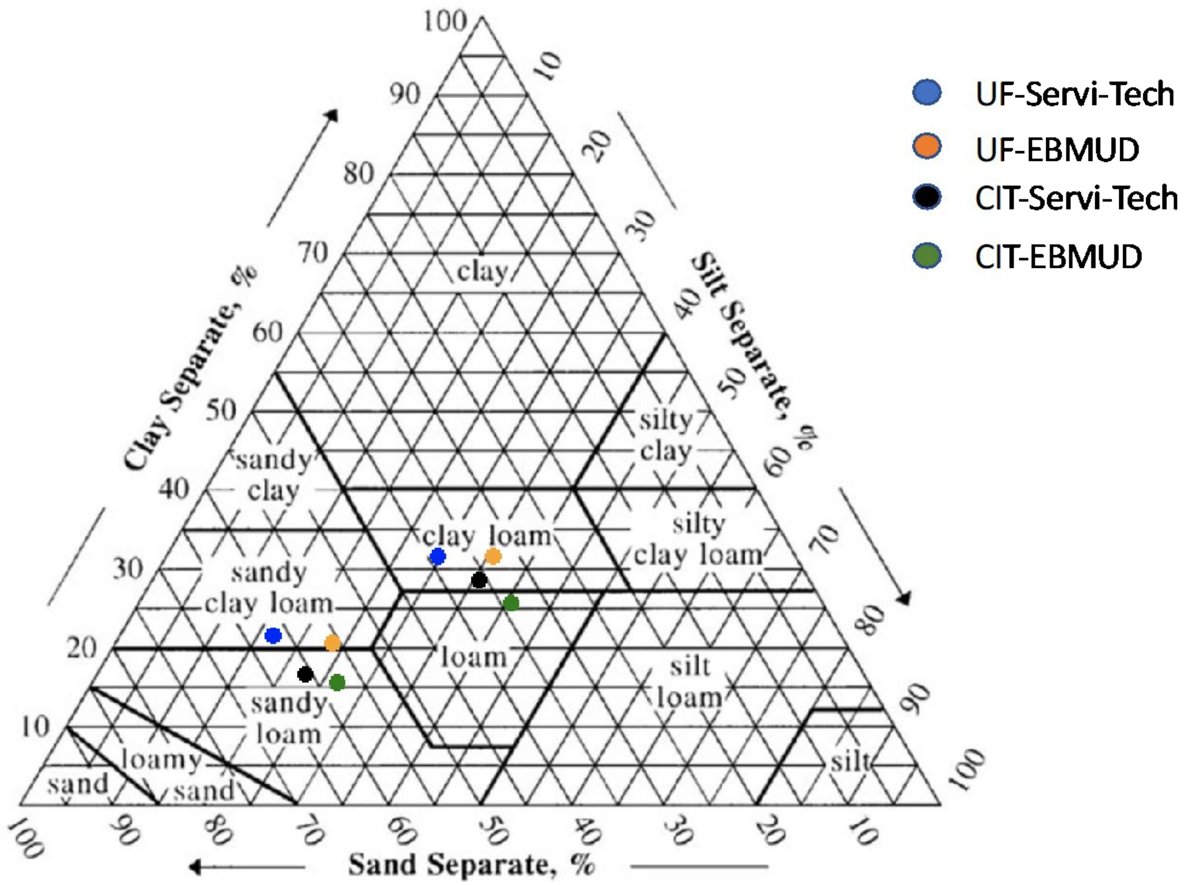

Figure 2.Textural triangle showing test media equivalent soil texture across two mixing labs and two analysis labs.

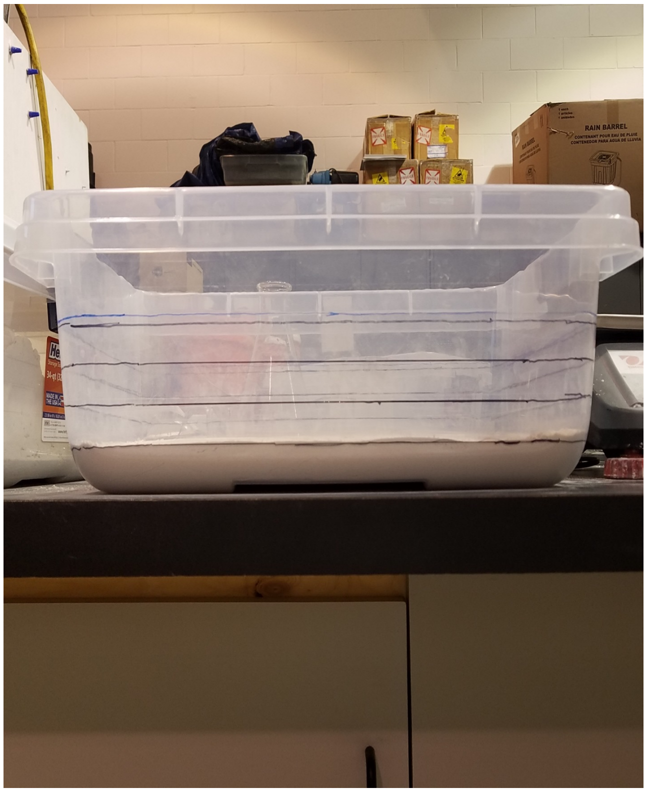

Figure 3. Packing media mixture (credit Bernard Cardenas UF/IFAS)

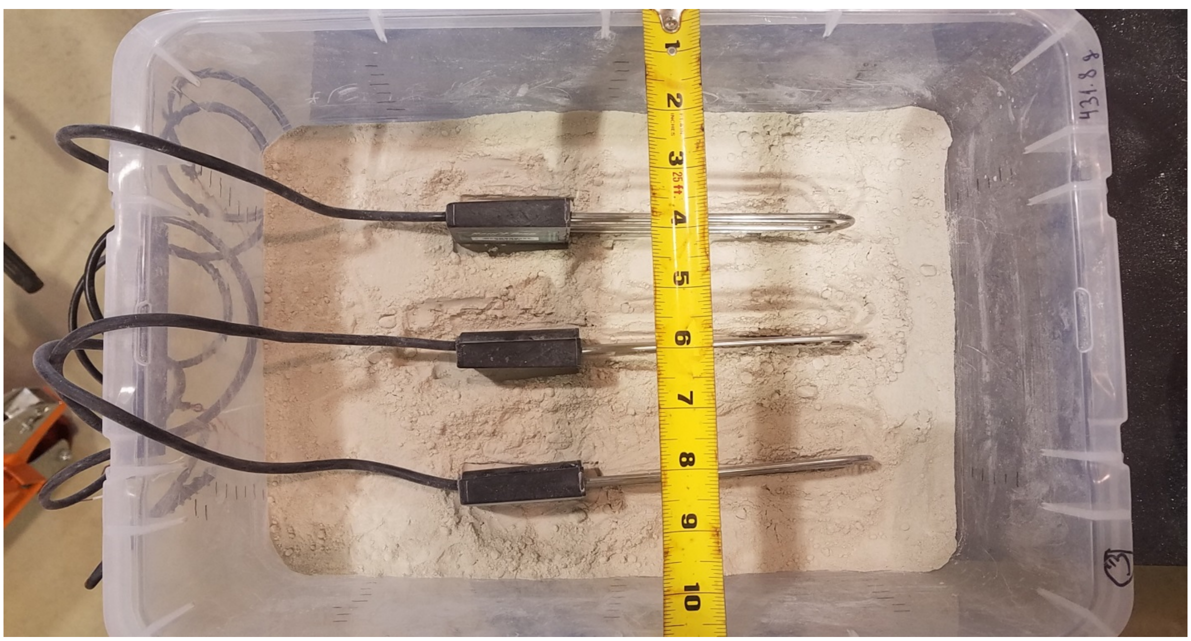

Figure 4. Installation of sensor mechanisms during packing (credit Bernard Cardenas UF/IFAS)

Figure 5. Packed test containers sealed and weighed (credit Bernard Cardenas UF/IFAS)

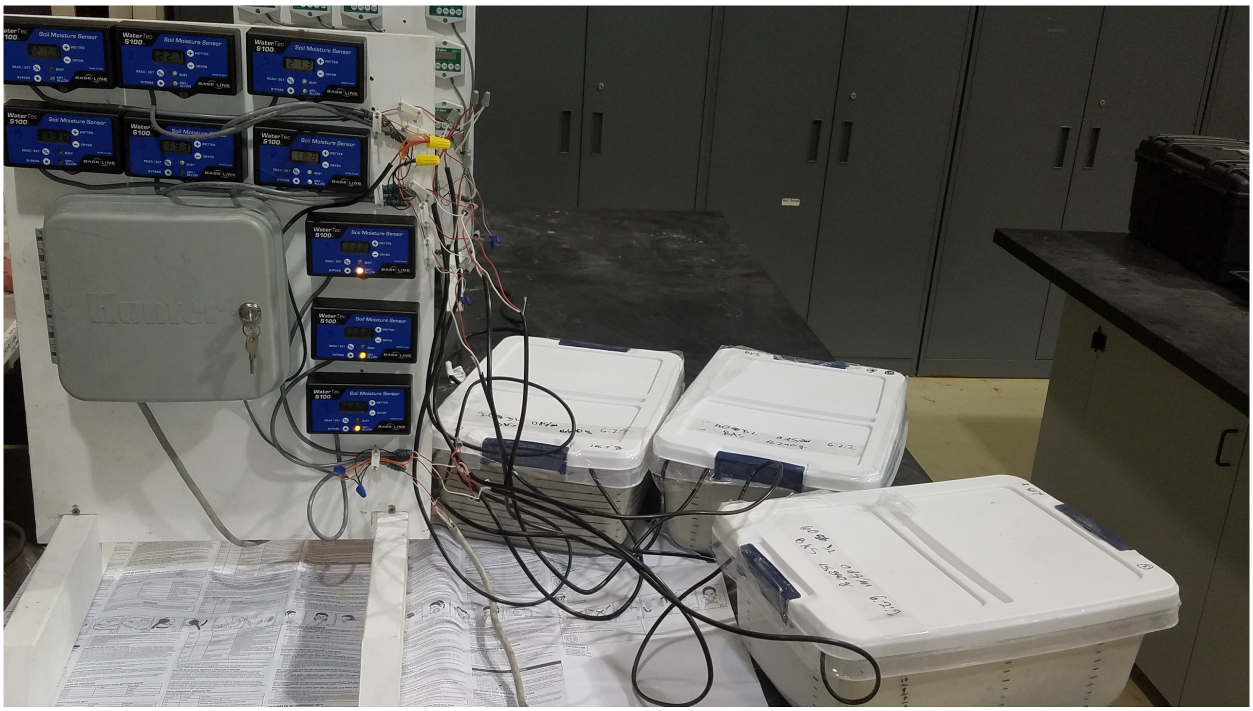

Figure 6. Testing of SMS controllers powered by an irrigation controller (credit Bernard Cardenas UF/IFAS)

Results and Discussion

Test Under Lab Conditions

Mixing of air dry test media by weight was a straight forward if not messy process that requires proper personal protective equipment. Packing carefully is essential to achieving the proper target bulk density. Since the theoretical weight of the container, moist soil and sensors is known, it is also straightforward to determine actual weight comparison to the theoretical. In this testing the theoretical weight diverged from the actual packed weight from 0% to 1% and averaged 0.3% across all tests. The actual weight diverged from the theoretical due to small losses of media during packing.

The test matrix is shown in Table 1 with the four brands tested across media type and salinity level. Controller D (tests 4, 8, 12, 16) was not able to be successfully tested since the algorithm used by this controller does not directly fit the X633 draft standard and, as a result, irrigation was never disabled. The 0 hr readings were not possible on brand C due to the necessary equilibration period of this brand.

SMS Controller R^2 & Slope

The coefficients of determination (R^2) are shown in Figs. 7-8 for R^2. The R^2 value ranged from 0.61 to 1.00 with all but three values above 0.90. There was no obvious trend across media type or water salinity except for a decline in the 24 hr irrigation disabled R^2 across the fine media 3 dS/m tests; however, all of these R^2 values still exceeded 0.80. These relatively high R^2 values indicate that the best fit line explains the majority and, in most cases, nearly all the deviation in the results.

The absolute value of the slope of the best fit line through the average of the three sensor readings at each water depletion level is shown in Figs. 9-10. Generally, slope values of irrigation enable and disable readings were very low, <0.5. Similar to the R^2 values, the absolute value of the slope did not show obvious trends across media nor across water added salinity.

SMS Controller Precision

As described earlier, the RAD was calculated as a measure of precision for each of the 16 test conditions across four brands, two test media and two water added salinities. Each of these 16 test combinations had three replicate sensors in a test container. The calculated RAD was determined across the three sensors' response for irrigation enabled and irrigation disabled except where not applicable (brand C) or not possible (brand D) as described earlier. The values are shown in Figs. 11-12. All of the RAD values were less than 8% for irrigation enabled and less than 12% for irrigation disabled with the majority of values less than 6%. Similar to the R^2 and slope, obvious trends across media type or water added salinity were not apparent. Finally, when both irrigation enabled and disabled RAD values for 0 and 24 hr periods were averaged together, all values were less than 10% (Fig. 13).

Freeze Test

As with the precision testing, three brands were successfully tested in the freeze test. The fourth brand was unable to be tested for precision as described earlier. However, all four brands functioned (i.e. enabled and disabled irrigation) before and after the freeze test. The RAD ranged from 0 to 7.1% before the freeze test and 0% to 14.0% across the three brands tested and across both irrigation enable and disable readings. For one brand, there was a trend for both irrigation enable and disable RAD to be larger after the freeze test than before the test. There was no other obvious trend in precision of irrigation enable vs. disable.

Additionally, two brands were tested with the coarse medium and 3 dS/m water. Pre-freeze RAD compared to post-freeze RAD was nearly identical. In addition, average RAD across the two brands and both enable and disable readings was 4.1%.

Summary and Conclusions

In summary, four brands of SMS controllers were tested for their relative precision of three sensors in two different constructed media (coarse and fine), with two added water salinity levels (0 and 3 dS/m) across three water depletion levels. Precision was calculated from both irrigation enable and irrigation disable readings. In addition, the SMS brands were tested for function and precision after being frozen. Three of the SMS brands were successfully tested in the precision tests. The fourth brand was unable to be tested since its mode of operation does not allow testing according to the current test procedure. It is anticipated that a slight adjustment to the test procedure could be made to accommodate this SMS brand. Manufacturers can provide specific instructions for testing such as the acclimation period for the sensors.

Across the tested brands, media types and salinity levels the precision was relatively high with the irrigation enable and disable relative average deviation values ranging from 0.5% to 10.9%, and when averaged, these values were 3.1%. These results indicate that these SMS brands, when subjected to repeated similar conditions, have a high likelihood of repeatable results.

Table 1. Testing matrix

Test	Brand	Soil	Salinity
1	A	Coarse	0 dS/m
2	B		
3	C		
4	D		
5	A	Fine	0 dS/m
6	B		
7	C		
8	D		
9	A	Coarse	3 dS/m
10	B		
11	C		
12	D		
13	A	Fine	3 dS/m
14	B		
15	C		
16	D		

Table 2. Freeze test Relative Average Deviation (RAD)

	Pre-Freeze RAD		Post-Freeze RAD	
Brand	**Enable**	**Disable**	**Enable**	**Disable**
A	3.8%	7.1%	3.0%	3.9%
B	1.4%	1.4%	13.9%	14.0%
C	0.0%	0.0%	0.0%	0.0%
D	N/D	N/D	N/D	N/D

Note: N/D = not able to be determined

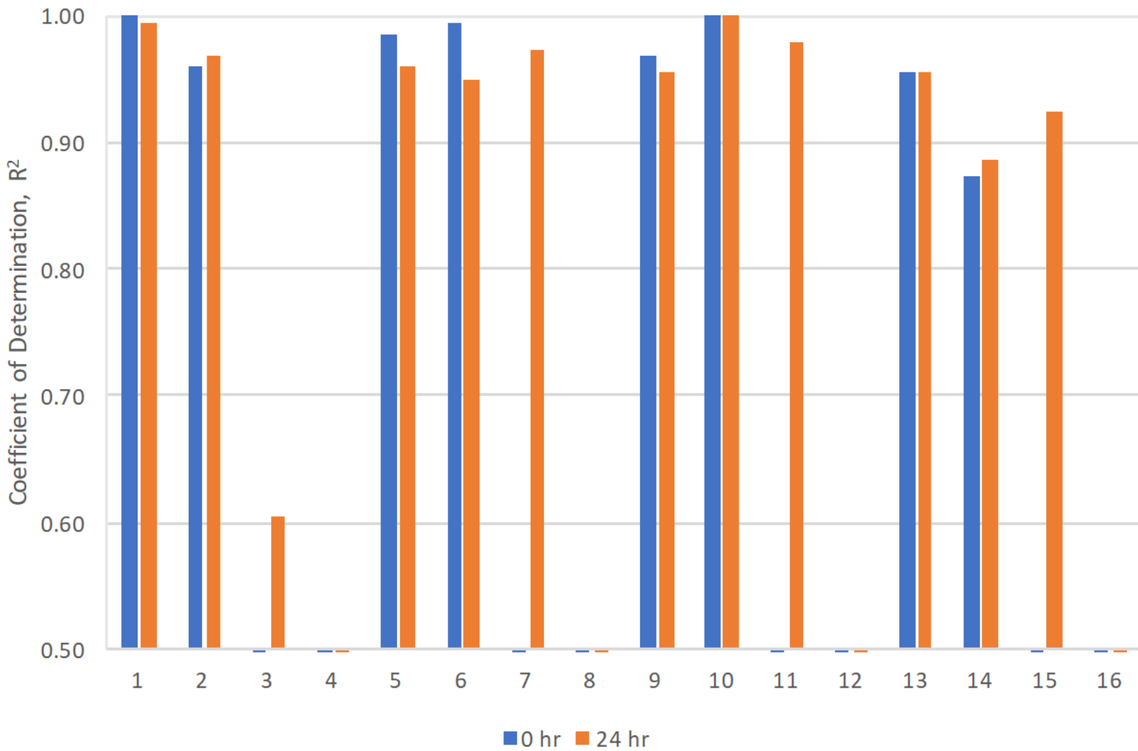

Figure 7. Average regression coefficient of determination irrigation enabled

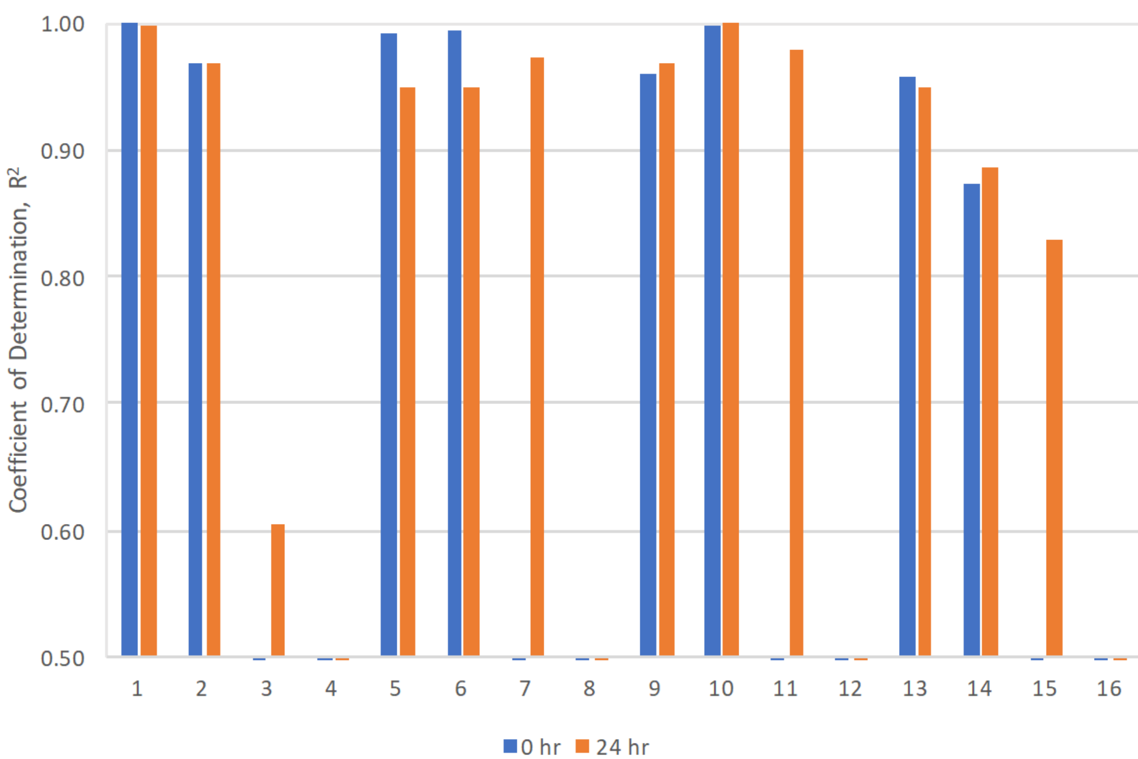

Figure 8. Average regression coefficient of determination irrigation disabled

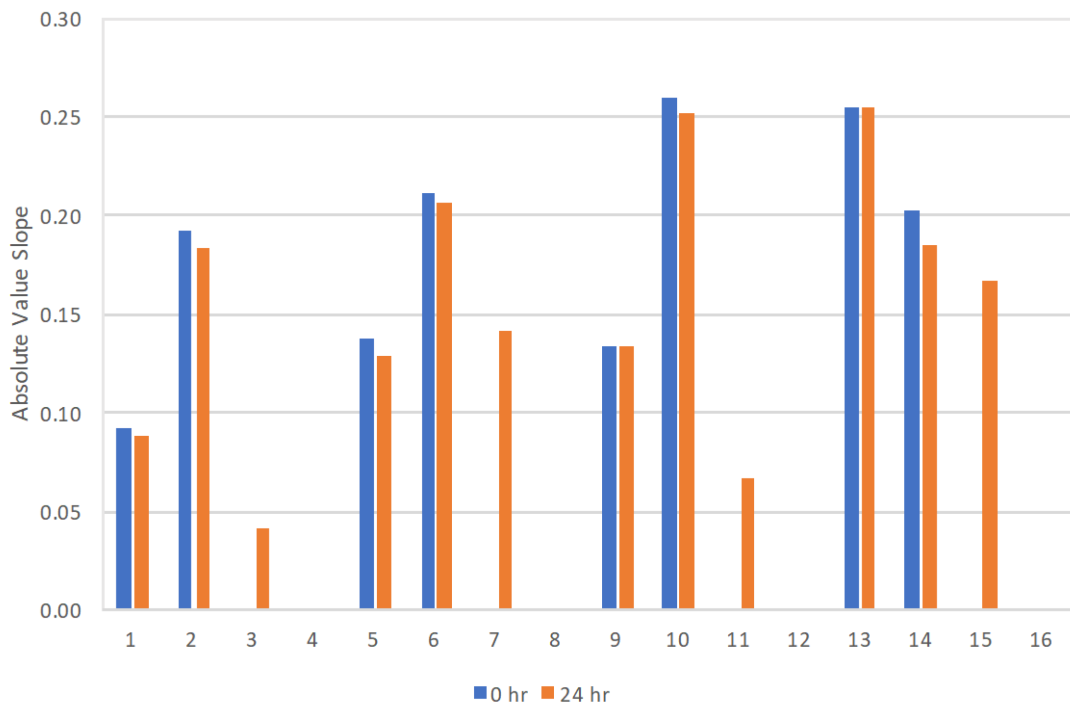

Figure 9. Absolute value of slope of regression line across water depletion levels and irrigation enabled values

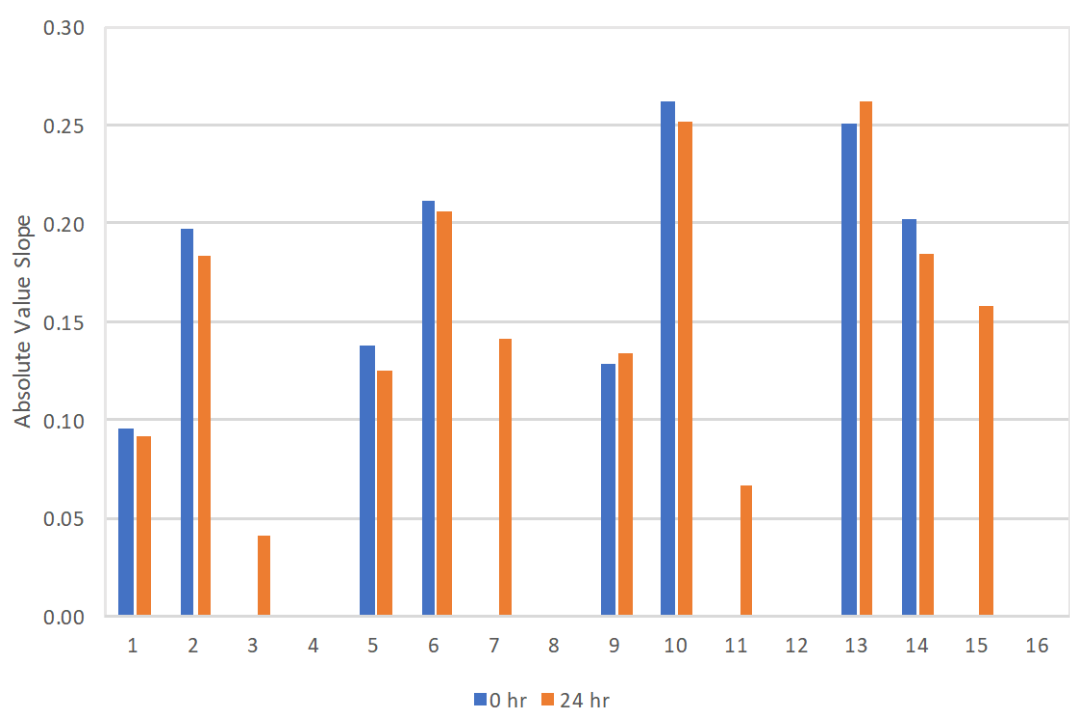

Figure 10. Absolute value of slope of regression line across water depletion levels and irrigation disabled values

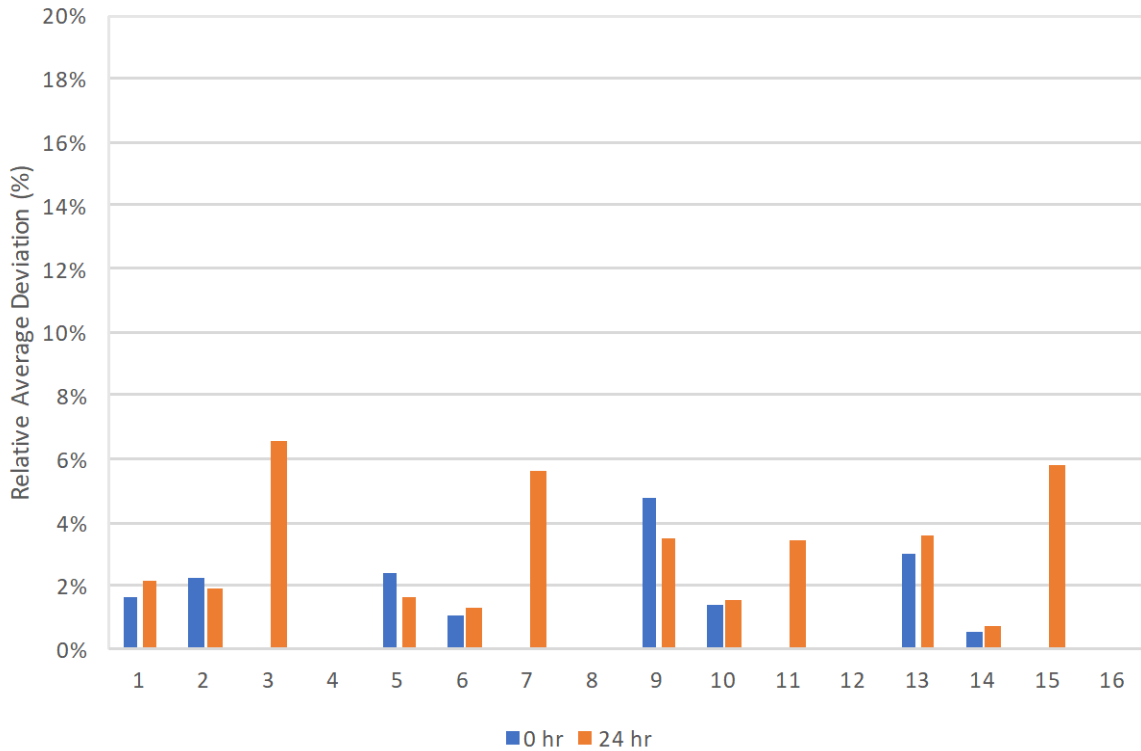

Figure 11. Average relative average deviation irrigation enabled

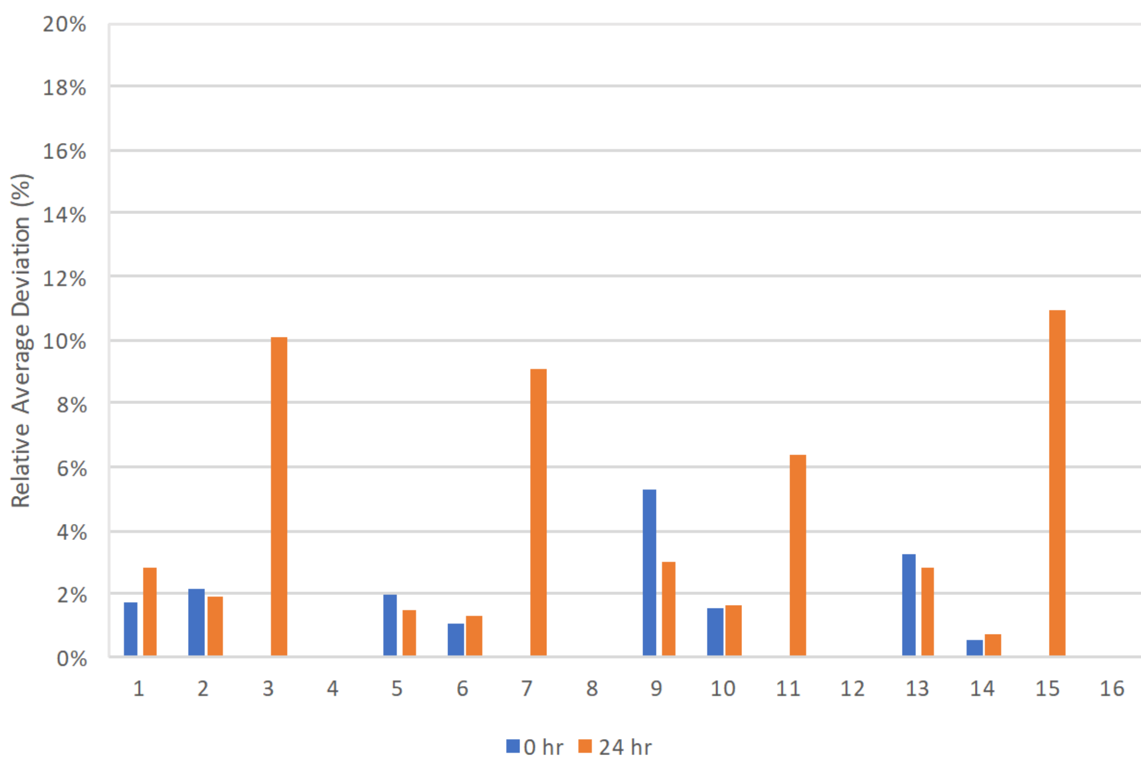

Figure 12. Average relative average deviation irrigation disabled

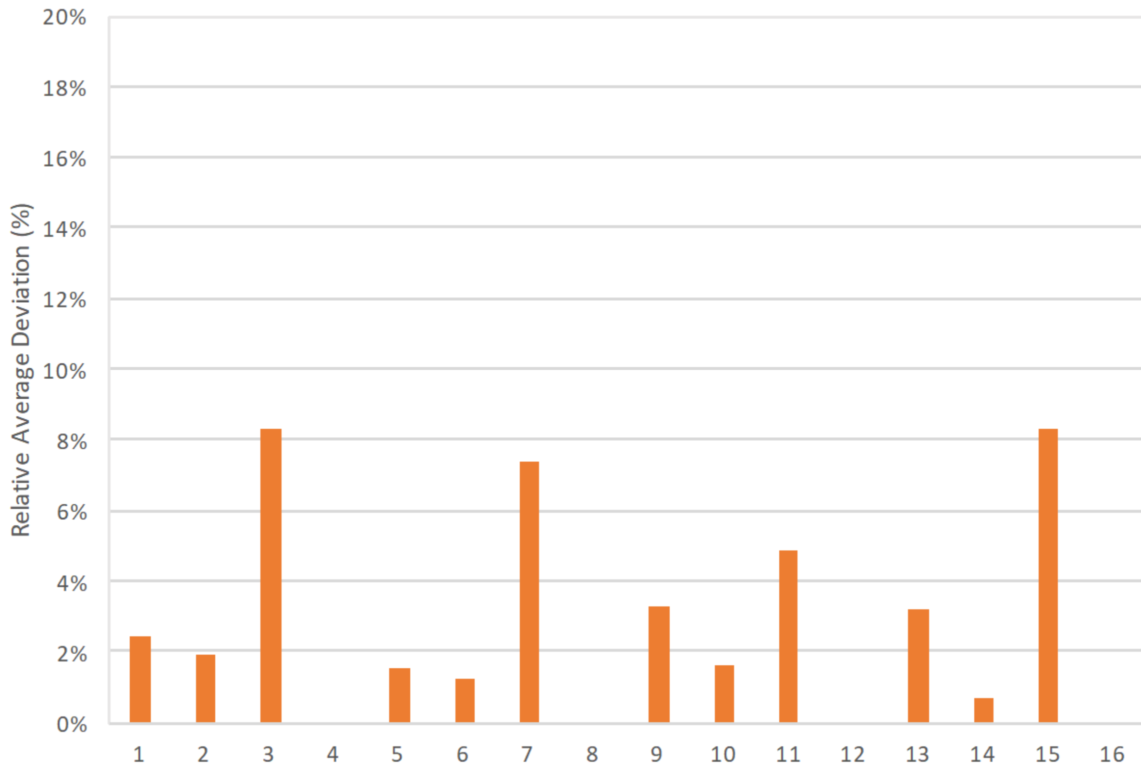

Figure 13. Average relative average deviation across irrigation enabled and disabled