# Soil Moisture Sensor Performance in Turfgrass Plots Irrigated with Reclaimed Water

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**Abstract.** *The use of soil moisture sensor systems (SMSs) in turfgrass plots irrigated with reclaimed water (RW) has not been studied. RW can contain more salts than potable water; which might affect SMS readings. The objectives of this experiment were to: a) analyze the behavior consistency of SMS replicates within a brand, b) quantify the potential irrigation water savings of 4 SMS brands, and c) compare the different brands against each other. The experimental area was located in Gainesville, Florida. Four quarter-circle pop-up sprinklers irrigated 60 plots (3.66 x 3.66 m each) covered with St. Augustinegrass (Stenotaphrum secundatum [Walt.] Kuntze). Treatments included a time-based without-sensor (WOS) and four SMS-based treatments; brands: Aquaspy, Baseline, Dynamax, and Acclima (AQU, BAS, DYN, and ACL, respectively). Replicates from AQU were the only ones with significant different behavior within a brand. The irrigation water savings compared to WOS averaged 45, 61, 61, and 68% for AQU, BAS, DYN, and ACL respectively.All SMSs tested responded properly to soil water conditions and might be a useful tool for conserving water on turf irrigated with reclaimed wastewater.*

**Keywords.** Reclaimed water, soil moisture sensor, turfgrass quality, water savings.

## Introduction

The dry and warm weather during spring and fall in Florida, and the sporadic large rain events in the summer, coupled with the low water holding capacity of its prevalent sandy soils, make irrigation indispensable for high quality landscapes desired by homeowners (Baum et al., 2005; NOAA, 2003). In Florida, turfgrass represents the largest cultivated crop, which is irrigated with reclaimed water (RW) in several municipalities.

Of the commercially available soil moisture sensor systems (SMSs) for residential use, the most common type is known as an “add-on” device. These SMSs consist of a probe to be inserted in the root zone of the turf area and a controller to be connected to the time clock, or timer, of an automated irrigation system. On the controller, the user can set a soil water content threshold. Then, depending on the soil water content at the programmed start time, the SMS will allow or bypass that scheduled irrigation cycle, depending if it is drier or wetter than the threshold, respectively.

Under turfgrass plots conditions, irrigation systems receiving feedback from SMSs have saved potable water compared to typical time-based irrigation systems (Cardenas-Lailhacar et al., 2008 and 2010; McCready et al., 2009; Grabow et al., 2013). This technology has also demonstrated potable water savings in homeowner settings (Grabow et al., 2010; Haley and Dukes, 2011). In these studies, the reported overall turfgrass quality was above minimum acceptable, regardless of the water savings.

The use of SMSs in turfgrass plots irrigated with RW has not been reported. Most of the SMSs marketed for landscape irrigation respond to electromagnetic properties of the soil, more specifically, to the dielectric permittivity. Compared to potable water, RW can contain more salts, which may alter the dielectric permittivity of the soil and, hence, affect the readings of SMSs when measuring the soil water content.

This research was carried out on turfgrass plots irrigated with RW. The objectives were to: a) analyze the behavior consistency of SMS replicates within a brand, b) quantify the potential irrigation water savings of 4 SMS brands, and c) compare the different brands against each other.

## Materials and Methods

The experiment was installed at the Agricultural and Biological Department facilities, University of Florida, Gainesville, Florida; on Arredondo fine sand (loamy, siliceous, semiactive, hyperthermic Grossarenic Paleudults) (USDA, 2013). Sixty plots were covered with St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze), cultivar Floratam. Each plot was 3.66 m X 3.66 m and sprinkler irrigated by four quarter-circle, 15 cm pop-up spray heads (Rain Bird sprinklers 1800 series, 12Q nozzles; Rain Bird International, Inc., Glendora, Calif.). The RW used for irrigation came from the University of Florida Water Reclamation Facility; and had an average electrical conductivity (a measurement of water salinity) of 0.75 dS/m, which is classified as medium-high according to the U.S. Salinity Laboratory (1969).

Four commercially available SMSs were selected for evaluation: Acclima Digital TDT (Acclima Inc., Meridian, ID), Aquaspy (AquaSpy Inc., CA), Baseline biSensor (Baseline Inc., ID), and Dynamax SM200 (Dynamax Inc., TX), coded as ACL. AQU, BAS, and DYN, respectively (Table

1). Each SMS probe was positioned in the center of a different plot, with the midpoint of their sensing portion buried at a depth of 8 cm, in the top 7 – 10 cm of the soil, where most of the roots were present.

The plots containing a sensor for irrigation control were saturated and allowed to drain for 24 hours, to reach field capacity. Then, SMS readings were taken and the thresholds were set individually on each controller. The following procedure was conducted to determine the individual set points (all units in percentage of volumetric water content, except for MAD):

$$\text{FC} - \text{PWP} = \text{AW} \tag{1}$$

$$\text{Threshold Set Point} = [(1\text{-MAD}) \times \text{AW}] + \text{PWP} \tag{2}$$

where: FC = Field capacity, PWP = permanent wilting point (in this case, 4% was considered to be the PWP), AW = available water, and MAD = maximum allowable depletion (in this case, a factor of 0.3–equivalent to 30%–was considered).

### *Treatments*

Two basic types of treatments were defined: SMS-based treatments, and time-based treatments (Table 1). Within the time-based treatments, and to simulate requirements imposed on homeowners by Florida Statutes (Chapter 373.62), two time-based treatments were connected to a same rain sensor: with-rain-sensor (WRS) and deficit-with-rain-sensor (DWRS). The rain sensor (Mini-click II, Hunter Industries, Inc., San Marcos, CA) was set at a 6 mm rainfall threshold. A without-sensor treatment (WOS) was also included, in order to simulate common homeowner irrigation systems with an absent or non-functional rain sensor or SMS; and was the main comparison treatment. The SMS-based treatments were replicated three times. Every treatment /replicate were controlling the irrigation of four plots each, in a completely randomized design.

All irrigation cycles were programmed on two ESP-6Si, and three ESP-4Si timers (Rain Bird International, Inc., Glendora, CA), and set to start at 0600 h, with the purpose of diminishing wind drift and decreasing evaporation. Treatments were set to run 3 days per week (to mimic homes—as part of a companion study—using RW as its irrigation source in Pinellas Co. which are allowed to irrigate 3 days per week [PCU, 2010]). All treatments were programmed to run for the same amount of time; except for treatment DWRS which was programmed to run for just 60% of this schedule. Therefore, differences in water application among treatments was the result of sensors bypassing scheduled irrigation cycles. All the runtimes were adjusted monthly, to replace 100% of the historical ET-based irrigation schedule recommended for the Gainesville area by Dukes and Haman (2002).

### *Data collection*

Date, time, and amount of irrigation applied to each plot was continually recorded through pulse-type positive displacement flowmeters (PSMT 20mm x 190mm, Amco Water Metering Systems, Inc., Ocala, FL) that were connected to nine AM16/32 multiplexers (Campbell Scientific, Logan, UT), which were hooked up to a CR 10X model datalogger (Campbell Scientific, Logan, UT).

Weather data were collected by an automated weather station (Campbell Scientific, Logan, UT), located within 1 m of the experimental site. Measurements made every 15 minutes included minimum and maximum air temperatures, relative humidity, wind speed and direction, and solar radiation. Rainfall was recorded continuously by a tipping bucket rain gauge on the weather station and a nearby manual rain gauge.

Turfgrass quality was visually assessed and rated using a scale of 1 to 9 where 1 represents brown, dormant turf, and 9 represents the best quality (Shearman and Morris, 1998). A rating of 5 was considered to be the minimum acceptable turf quality for a homeowner.

Data presented in this publication represent the first season of an ongoing experiment, and were obtained from 17 August through 23 November 2010. Data analysis was performed using the general linear model (GLM) function of the Statistical Analysis System software (SAS, 2008). Analysis of variance was used to determine treatment differences and Duncan's Multiple Range Test was used to identify mean differences. Differences were considered significant at a confidence level of 95% or higher ($p \leq 0.05$).

## Results and Discussion

### *Rainfall*

During the research time-frame, two different and defined rainfall conditions occurred (Figure 1). From 17 August to 29 September (44 days) the number, frequency, and depth of rainfall events were considered adequate for irrigation purposes and, compared to historical records, estimated as a normal to wet weather condition. Conversely, from 30 September until the end of this experiment on 23 November (55 days) only 10 mm of rain fell (compared to 110 mm of a normal year), including more than a month with no rain at all (Figure 1). Therefore, this second period was considered very dry.

### *Turfgrass*

During the normal to wet weather conditions, no significant differences in turfgrass qualities were found between the treatments, which were all rated as ≥ 6 (data not shown). During the dry period, the St. Augustinegrass suffered an unrelenting quality decline. Turf specialists diagnosed a massive infestation of take-all root rot (*Gaeumannomyces graminis var. graminis*)—which had no chemical control—possibly due to the weather conditions. The turfgrass quality was not considered for analysis during this dry period, because was not a result of the different irrigation treatments.

### *Irrigation bypass proportion*

Every treatment was programmed to run a total of 42 irrigation cycles during this study. Table 2 shows the number and proportion of the scheduled irrigation cycles (SICs) that were bypassed by the different treatments, as well as the average proportion bypassed by the different SMS brands and replications. The time-based treatment without sensor feedback (WOS) was programmed to run independently of the weather and/or soil moisture conditions, so no (0%) SIC was bypassed. The two time-based treatments that were receiving feedback from the same rain sensor (WRS and DWRS) bypassed 21% of the SICs. Conversely, 55% of the SICs were bypassed on average by the SMS-based treatments.

Regarding the different SMS brands, on average, AQU bypassed the least amount of SICs, with an average of 44%, followed by DYN and BAS, with 56% and 58%, respectively. Brand ACL bypassed the greatest amount of SICs, with an average of 63%. The majority of the irrigation cycles bypassed by the SMS-based treatments occurred during the rainy period; verifying that the tested SMSs worked properly under reclaimed wastewater conditions, with variable results. In addition, all SMS-replicates bypassed more SICs compared to the treatments with rain sensor feedback; which is consistent with previous findings (Cardenas-Lailhacar et al., 2008 and 2010).

***Irrigation application***

The cumulative irrigation through time allowed by the time-based treatments is shown in Figure 2, and by the SMS-based treatments is shown in Figures 3 through 6. All of these treatments are compared to the reference treatment (WOS), which applied a total of 461 mm.

Figure 2 shows that, as designed, treatment WOS applied a cumulative irrigation of 461 mm. The two treatments connected to the same rain sensor, WRS and DWRS, applied 340 and 223 mm, respectively; representing 26 and 52% of water savings compared to WOS, respectively. These water savings were achieved as a result of the bypassed irrigation cycles only during the rainy period (from the beginning of the experiment until 29 September). After 29 September no scheduled irrigation cycle was bypassed by the rain sensor due to the absence of rain events close or greater than 6 mm (threshold set on the rain sensor). Treatment DWRS applied 66% of the total water applied by WRS, which was close to the target of 60%. These results are concordant with those achieved by rain sensor treatments, in the same experimental field, in previous studies (Cardenas-Lailhacar et al., 2008 and 2010).

From Figures 3 through 6, it can be seen that all SMS replicates and brands applied less water than the comparison treatment (WOS), as a consequence of the SMSs bypassing scheduled irrigation cycles (Table 2). The different replicates from brands ACL, BAS and DYN behaved very similarly through time, resulting in comparable amounts of cumulative irrigation water applied by the end of the experimental period. The range of water savings between the replicates fluctuated by 8, 7, and 10 percentage points for brands ACL, BAS, and DYN, respectively; which make them very consistent and reliable. On the other hand, brand AQU resulted in a wider range of cumulative water applied between replicates, with a variation of 26 percentage points.

The brand that, on average, allowed the least irrigation was ACL, followed by BAS and DYN (Figure 7), with totals of cumulative irrigation of 147, 178, and 181 mm, respectively. The AQU system allowed more irrigation than any other brand, with an average of 255 mm; which resulted in a significant difference ($P<0.05$) with ACL. If AQU is not considered for this analysis, ACL, BAS, and DYN were not significantly different (data not shown). The irrigation water savings compared to WOS averaged 45, 61, 61, and 68% for AQU, BAS, DYN, and ACL respectively. The average water saved by all SMS-based treatments compared to WOS was 59%; which is concordant with previous results (Cardenas-Lailhacar et al., 2008 and 2010).

## Conclusions

Even when RW with an average salinity of 0.75 dS/m was used as the irrigation source, results of the different treatments and brands were consistent with those of the previous studies, when potable water was used to irrigate the turf. The majority of the irrigation cycles bypassed by the SMS-based treatments occurred during the rainy period. Cumulative water savings were lower than those obtained in normal to wet weather conditions, but higher than those previously reported during dry weather conditions. These results verified that the SMSs tested responded properly to differing agro-climatic conditions, and that SMSs might be a useful tool for conserving water on turf irrigated with RW.

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## Acknowledgements

This research was supported by the Pinellas-Anclotte Basin Board of the Southwest Water Management District and the Pinellas County Utilities.

Table1. Treatment codes and descriptions.

| Treatment Codes | Treatment Description or Soil Moisture Sensor Brand | Replicates codes | Set point |
|---|---|---|---|
| Time-Based | | | |
| WOS | Without sensor | | N/A |
| WRS | With rain sensor | | 6 mm |
| DWRS | Deficit with rain sensor | | 6 mm |
| SMS-Based | | | |
| ACL | Acclima | 1-ACL, 2-ACL, 3-ACL | |
| AQU | Aquaspy | 1-AQU, 2-AQU, 3-AQU | |
| BAS | Baseline | 1-BAS, 2-BAS, 3-BAS | |
| DYN | Dynamax | 1-DYN, 2-DYN, 3-DYN | |

**Table 2.** Scheduled irrigation cycles bypassed by treatments, from a total of 42 possible.

| Treatments and Replicates | Total Bypassed (#) | Total Bypassed (%) | Average Bypassed (%) |
|---|---|---|---|
| **Time-based** | | | |
| WOS | 0 | 0 | |
| WRS | 9 | 21 | |
| DWRS | 9 | 21 | |
| **SMS-based** | | | |
| 1-ACL | 29 | 69 | |
| 2-ACL | 25 | 60 | 63 |
| 7-ACL | 26 | 62 | |
| 1-AQU | 19 | 45 | |
| 2-AQU | 23 | 55 | 44 |
| 7-AQU | 13 | 31 | |
| 1-BAS | 27 | 64 | |
| 2-BAS | 23 | 55 | 58 |
| 7-BAS | 23 | 55 | |
| 1-DYN | 23 | 55 | |
| 2-DYN | 26 | 62 | 56 |
| 7-DYN | 22 | 52 | |
| Average of SMS[z]-based | | 55 | |

[z]SMS = soil moisture sensor system.

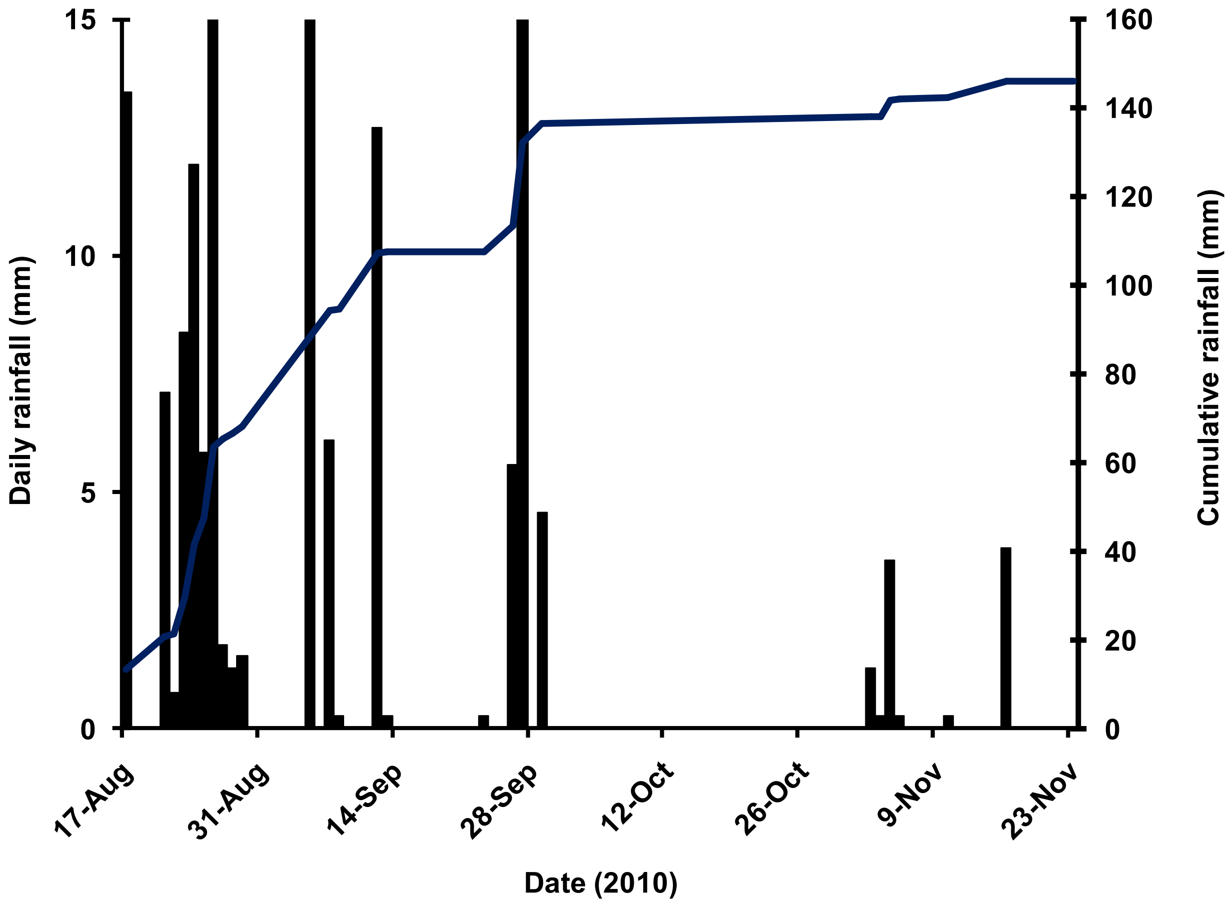


**Figure 1.** Daily and cumulative rainfall, during 17 August through 23 November 2010.

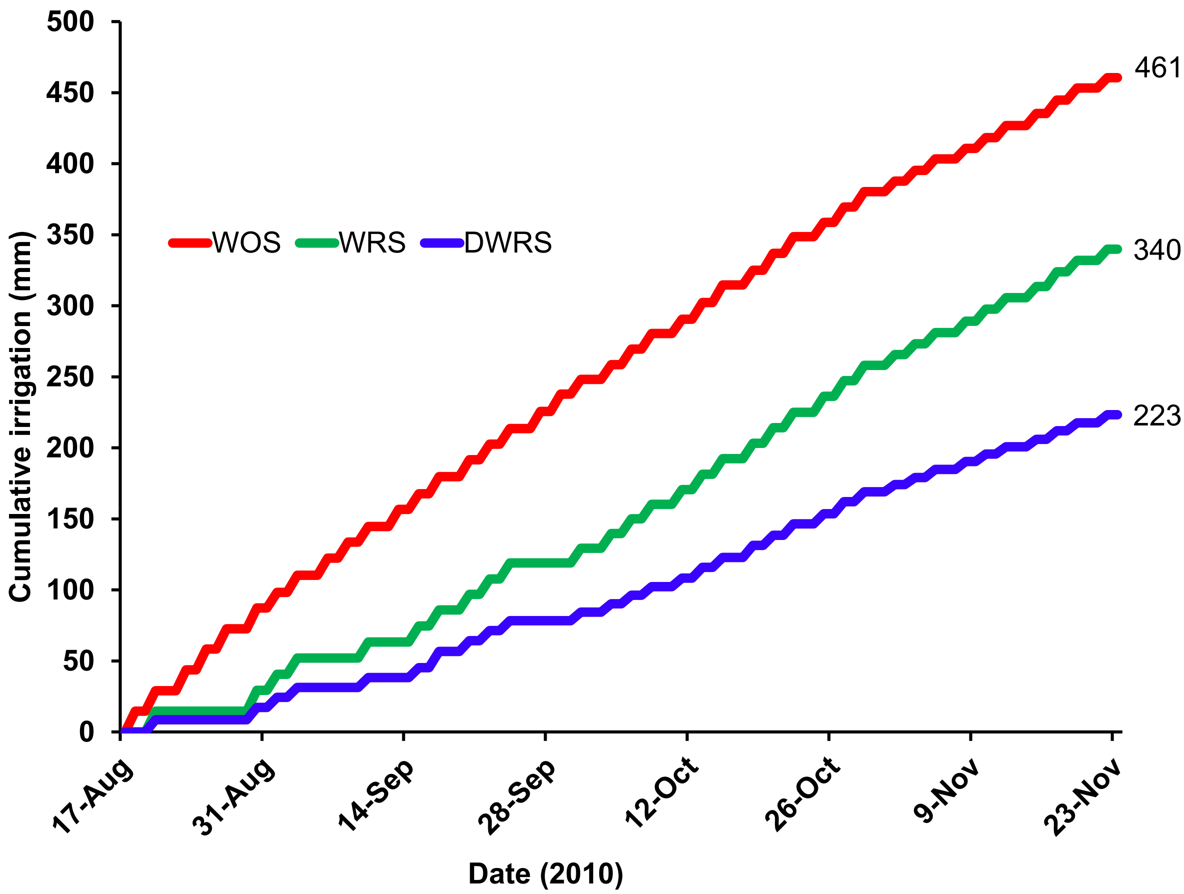


**Figure 2.** Cumulative irrigation applied from 17 August through 23 November 2010 by time-based treatments WOS = without sensor, WRS = with rain sensor, and DWRS = deficit with rain sensor.

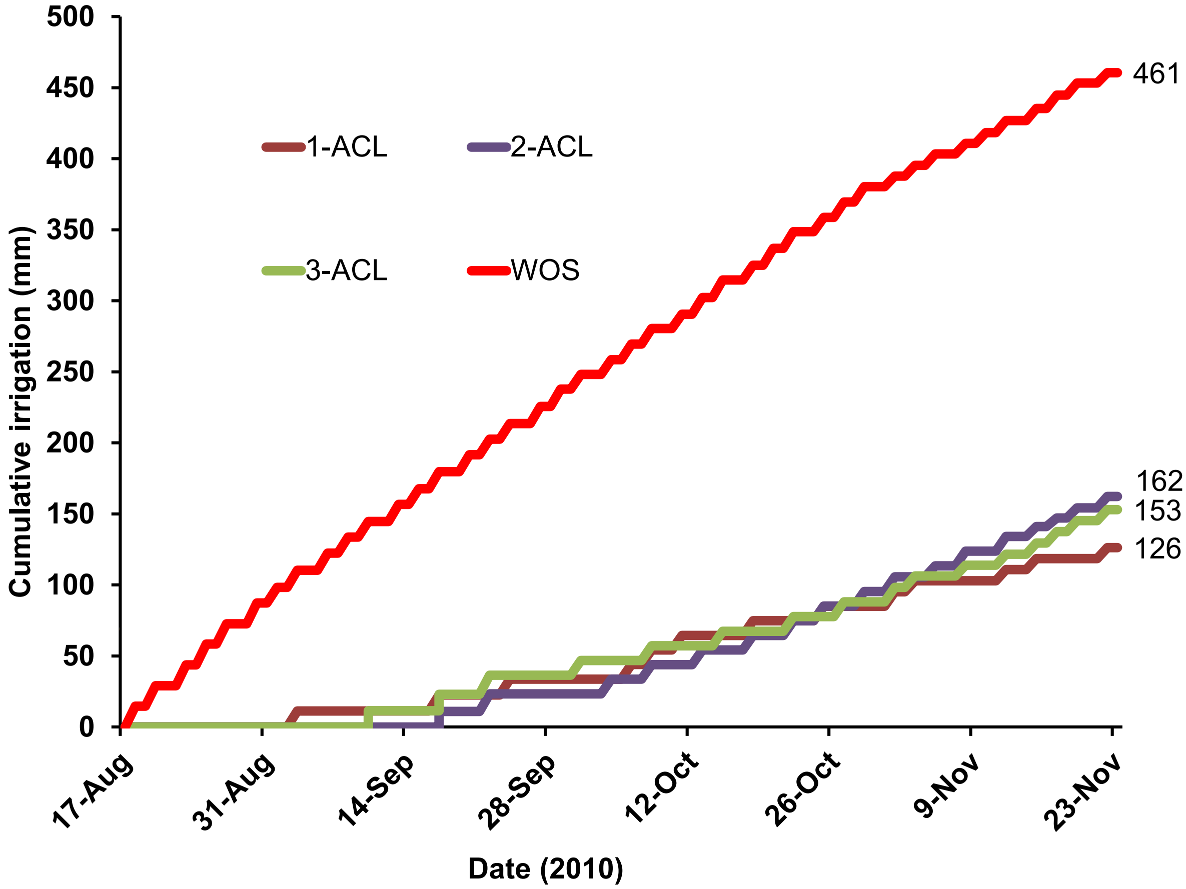


**Figure 3.** Cumulative irrigation applied by replicates of ACL = soil moisture sensors system-based treatment from brand Acclima, compared to WOS = time-based control treatment without sensor, from 17 August through 23 November 2010. (Numbers before -ACL indicate an arbitrary number for the different replicates.)

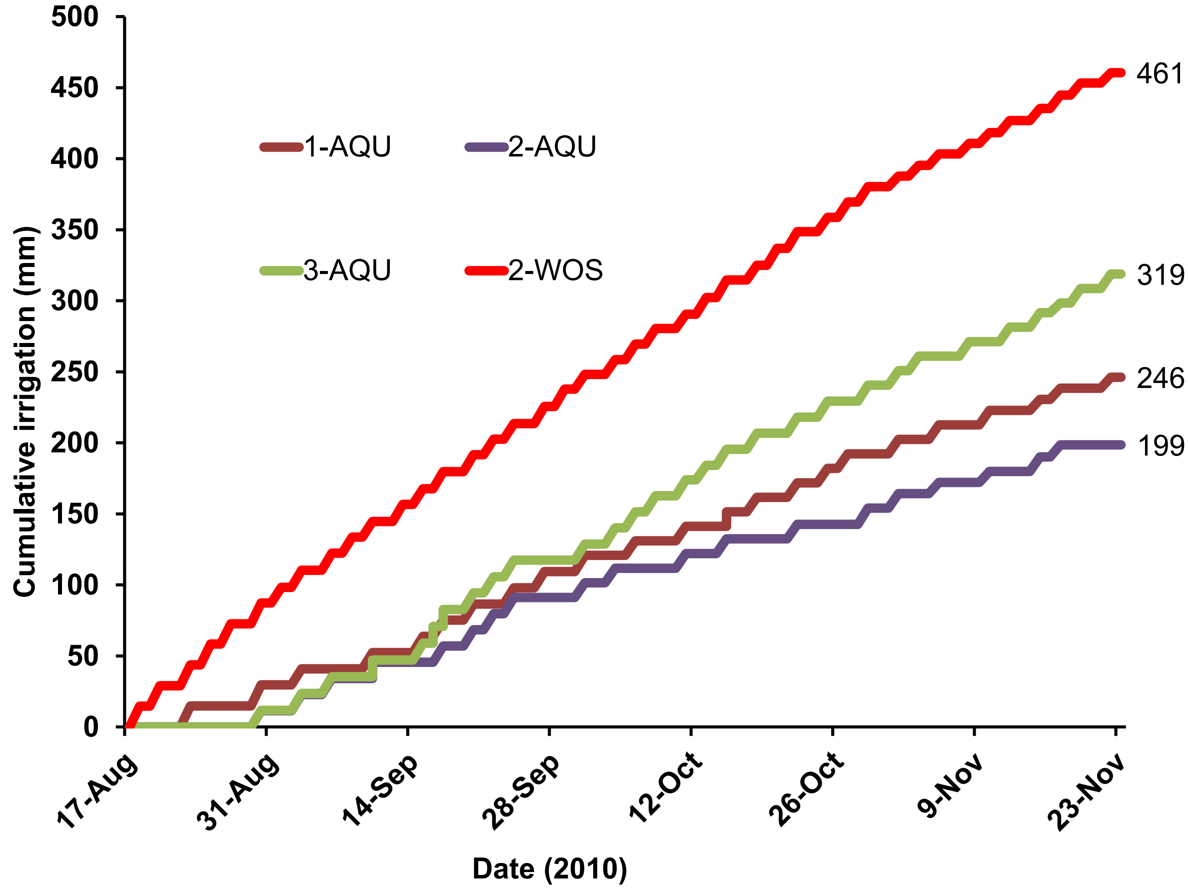


**Figure 4.** Cumulative irrigation applied by replicates of AQU = soil moisture sensors system-based treatment from brand Aquaspy, compared to WOS = time-based control treatment without sensor, from 17 August through 23 November 2010. (Numbers before -AQU indicate an arbitrary number for the different replicates.)

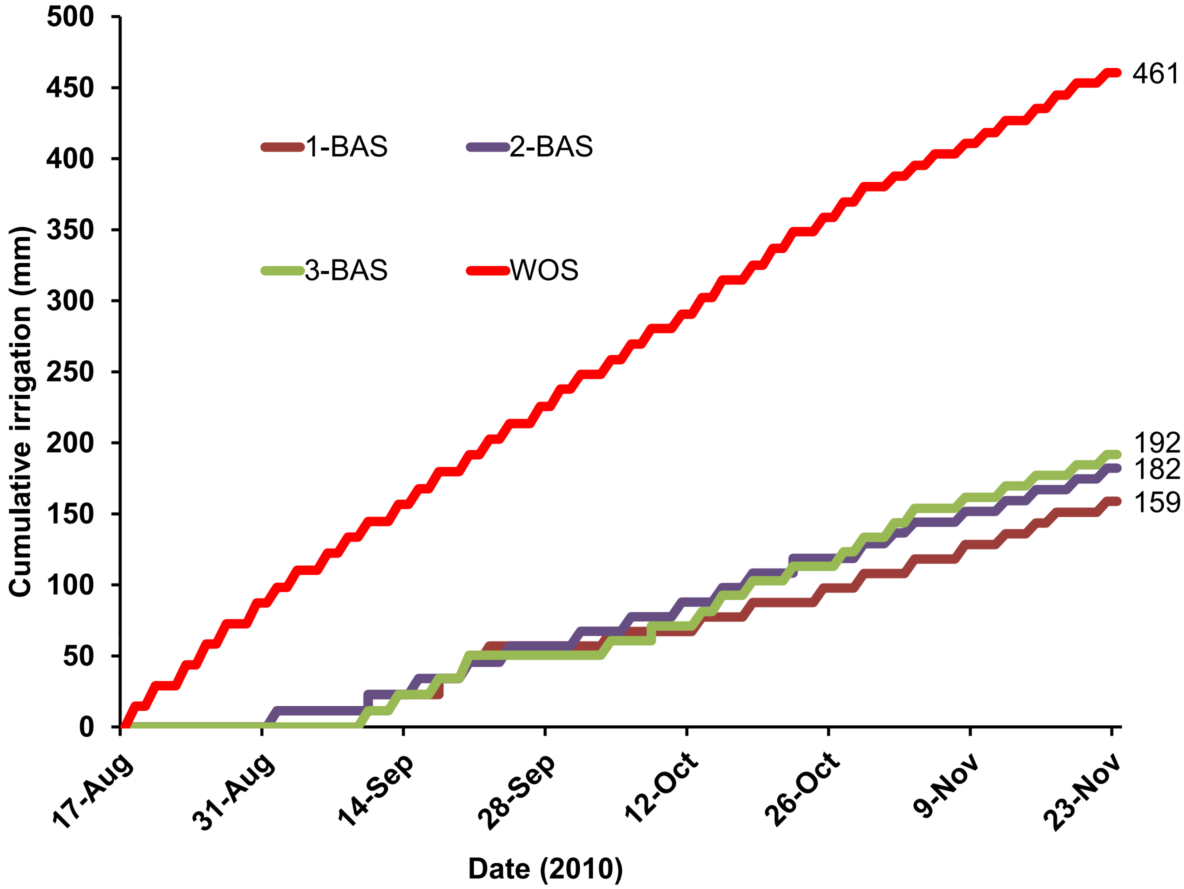


**Figure 5.** Cumulative irrigation applied by replicates of BAS = soil moisture sensors system-based treatment from brand Baseline, compared to WOS = time-based control treatment without sensor, from 17 August through 23 November 2010. (Numbers before -BAS indicate an arbitrary number for the different replicates.)

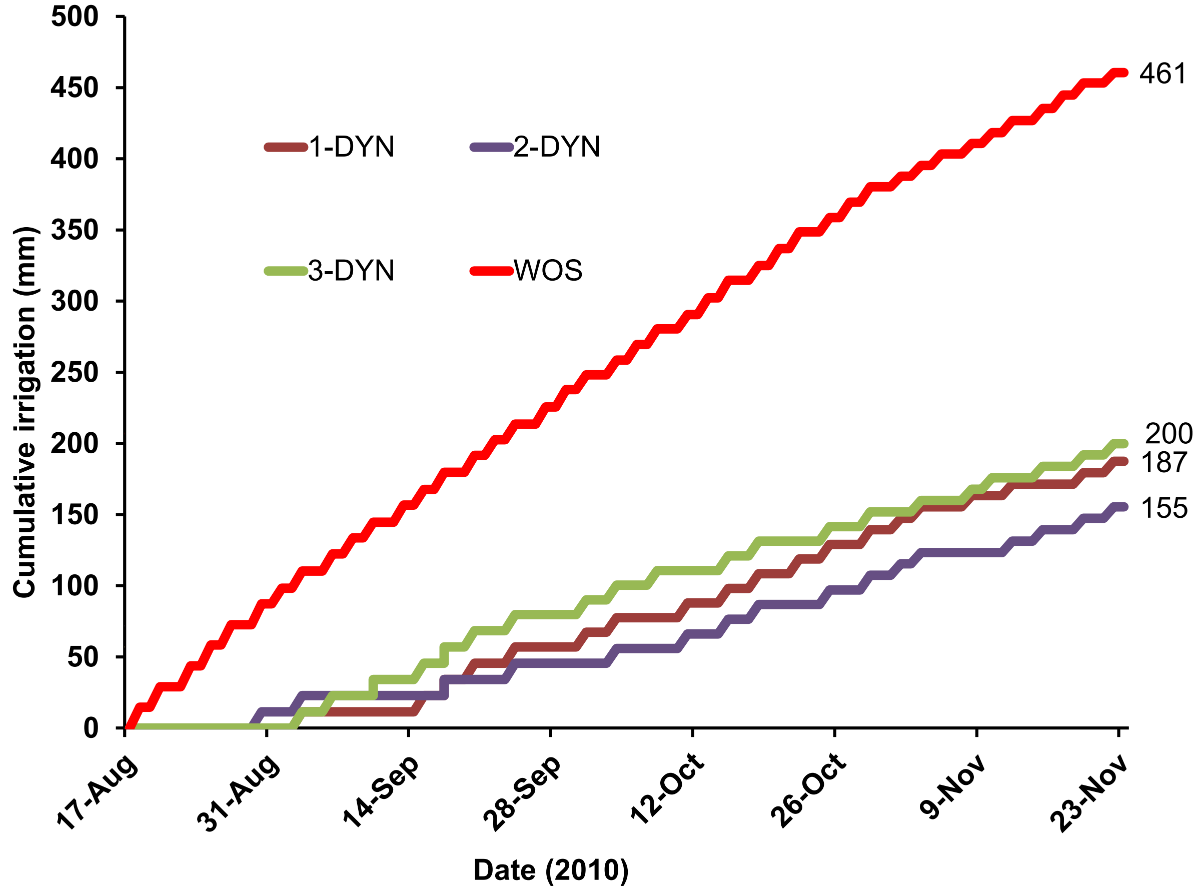


**Figure 6.** Cumulative irrigation applied by replicates of DYN = soil moisture sensors system-based treatment from brand Dynamax, compared to WOS = time-based control treatment without sensor, from 17 August through 23 November 2010. (Numbers before -DYN indicate an arbitrary number for the different replicates.)

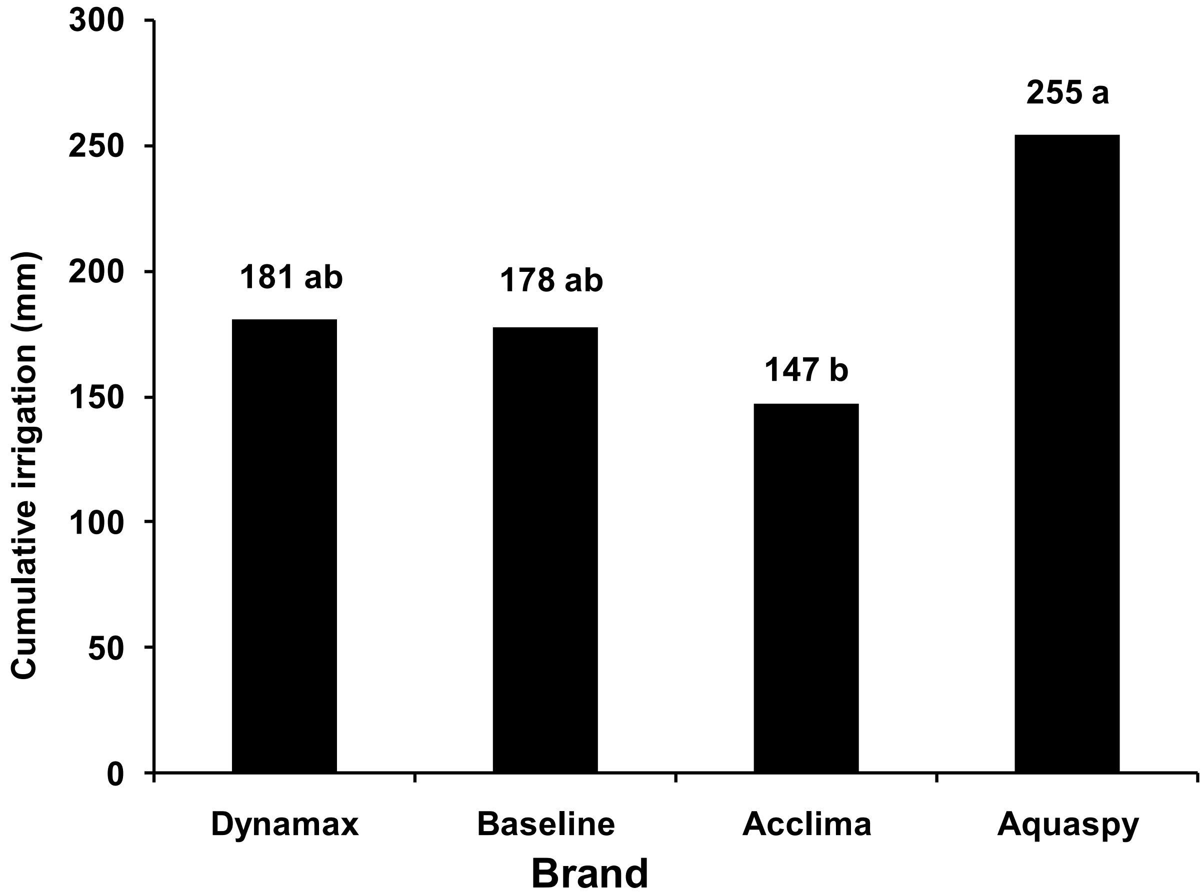


**Figure 7.** Average irrigation depth applied by brand during 17 August through 23 November 2010.